A. **Northern Projects** *sponsored or implemented by the Saskatchewan Geological Survey*

The Geological Setting of Mineral Deposits of the Flin Flon–Amisk Lake Area[1]

B.A. Reilly

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In 1989, the Saskatchewan Geological Survey (SGS) initiated a program to remap the western Flin Flon–Amisk Lake area at a minimum of 1:20 000 scale in order to better understand the distribution and controls on gold and base metal deposits in this region. In 1990, this program was incorporated into the Canada-Saskatchewan Partnership Agreement on Mineral Development 1990-1995 as Project Seagull (Reilly *et al.*, in press). In 1991, the Geological Survey of Canada (GSC) initiated the Shield Margin Project of the national mapping program (NATMAP) to provide for geoscience studies in the Flin Flon–Snow Lake–Hanson Lake belt, including extrapolation of the exposed Precambrian Shield rocks under the Phanerozoic cover rocks. This multi-disciplinary approach (with participants primarily from the GSC, SGS, and Manitoba Geological Survey) has enhanced our knowledge of the Shield margin area. This report reviews the geological setting of mineral deposits in the Flin Flon–Amisk Lake area in light of these new perspectives.

1. Regional Geology

The Flin Flon–Amisk Lake area lies within the Flin Flon–Snow Lake greenstone belt (i.e. Flin Flon Domain), which forms a relatively low metamorphic grade component and most southerly exposed part of the Paleproterozoic Trans-Hudson Orogen (Figure 1). The greenstone belt has a transitional boundary to the north and to the east into high-grade gneisses of the Kisseynew Domain, and is in tectonic contact with the Hanson Lake Block to the west. The greenstone belt is unconformably overlain by flat-lying unmetamorphosed Ordovician rocks to the south which include marine sandstones of the Winnipeg Formation and dolomites of the Red River Formation.

The Flin Flon–Snow Lake greenstone belt comprises a diverse suite of volcanic, sedimentary, and intrusive rocks. These rocks have previously been described in terms of two stratigraphic groups: Amisk Group volcanic rocks and Missi Group continental sedimentary rocks (Bruce, 1918). However, the belt is now recognized as an amalgamation of several distinct 1.92 to 1.84 Ga lithotectonic assemblages (Figure 2), referred to as the Amisk Collage (Lucas *et al.*, in press), which are intruded by 1.87 to 1.84 Ga plutons and unconformably overlain by 1.87 to 1.84 Ga volcanic and sedimentary rocks. Five main assemblage types, which are defined as stratified volcanic and/or sedimentary rocks deposited during a discrete interval of time in a common setting, are found in the Flin Flon–Snow Lake greenstone belt: juvenile arc, juvenile ocean floor, oceanic plateau/ocean island basalt, isotopically evolved arc, and Archean crustal slices (Watters *et al.*, 1994; Stern *et al.*, 1995a, b; David and Syme, 1994). Informal assemblages of the Flin Flon–Amisk Lake area, which are subject to further modifications, are shown in Table 1.

2. Volcanogenic Massive Sulphide Deposits

The Flin Flon–Snow Lake greenstone belt is one of the most productive base metal mineral regions in Canada, hosting over two dozen producing and past-producing mines. Production plus reserves in these mines total 109.5 million metric tons of Cu and Zn (Syme and

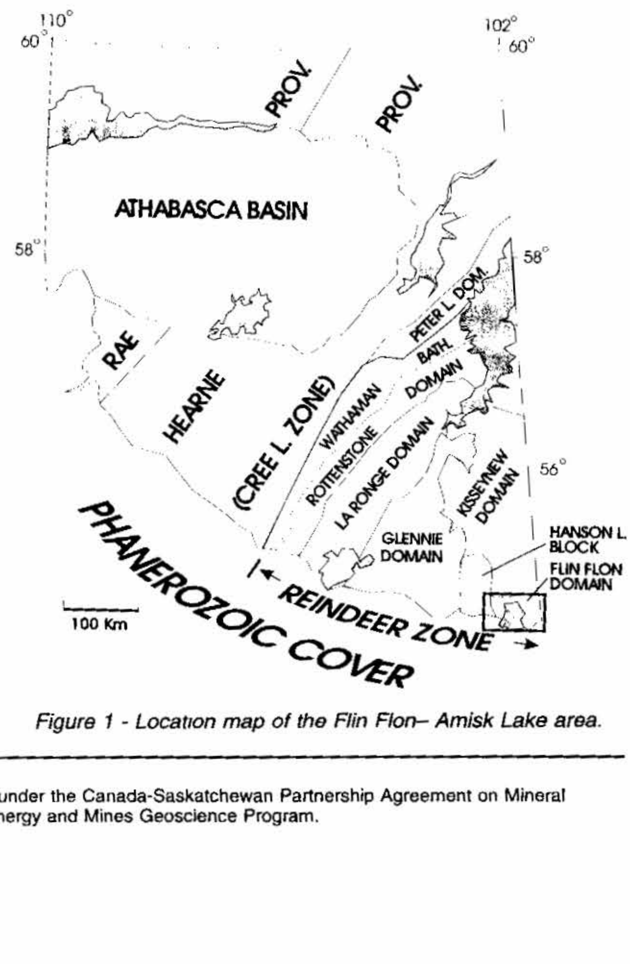

Figure 1 - Location map of the Flin Flon– Amisk Lake area.

(1) Saskatchewan Project F.102 is a continuation of Project A.112 initiated under the Canada-Saskatchewan Partnership Agreement on Mineral Development 1990-95; funding in 1995 was under the Saskatchewan Energy and Mines Geoscience Program.

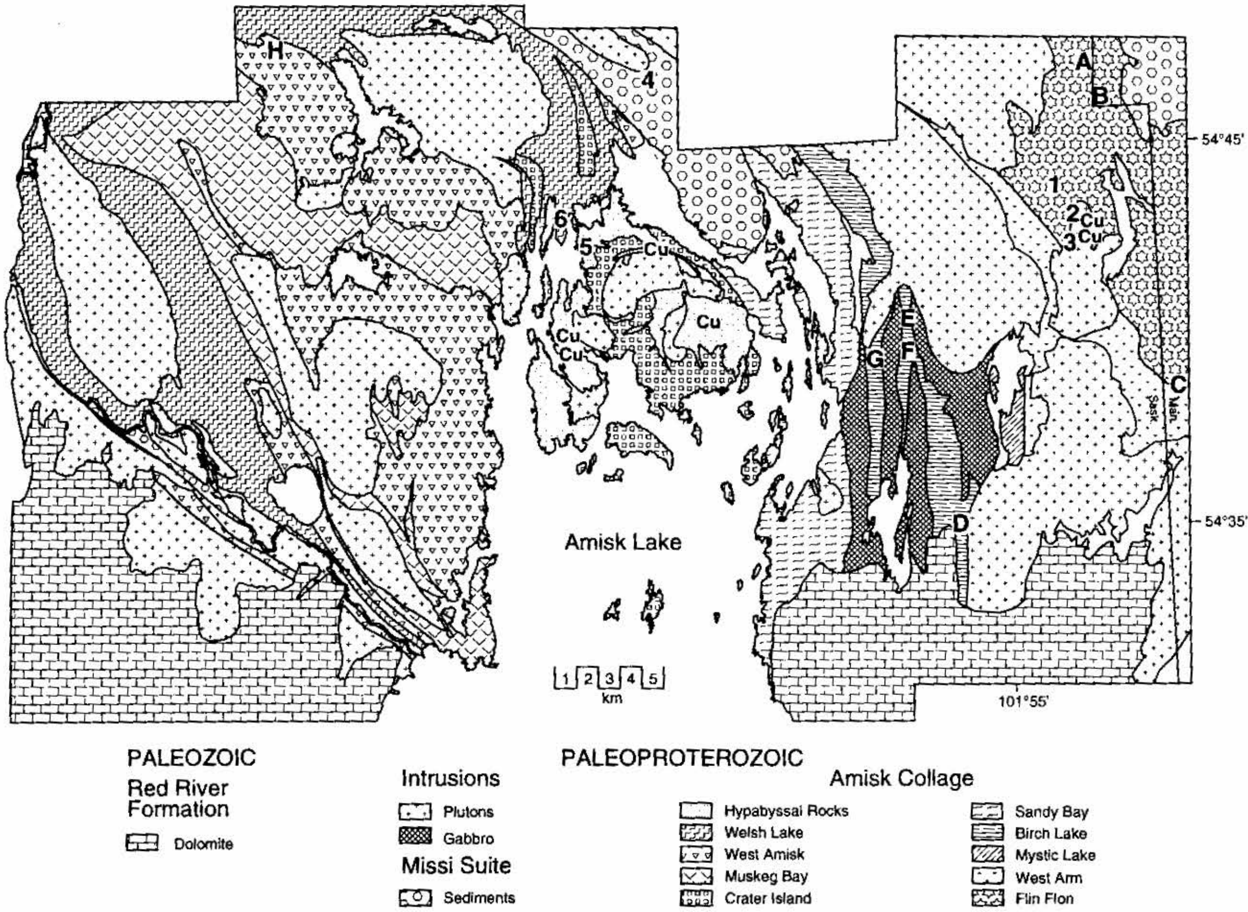

Figure 2 - Lithotectonic assemblages of the Flin Flon–Amisk Lake area. VMS deposits: A=Callinan; B=Flin Flon; C=West Arm; D=Coronation; E=Flexar; F=Birch; G=Konuto Lake; and H=Fon Zone. Gold deposits: 1=Newcor; 2=Rio; 3=Henning-Maloney; 4=Graham; 5=Laural Lake; and 6=Monarch/Prince Albert. Cu=porphyry copper occurrences.

Bailes, 1993). The value of contained base metals per square kilometre of greenstone belt is estimated at six million dollars, approximately three times that of the Abitibi greenstone belt (Franklin, pers. comm., 1994). Base metal mineralization in the region has been reviewed by Sangster (1972), Koo and Mossman (1975), Stauffer *et al.* (1975), Price (1977), Thomas (1990), Coombe (1991), and Syme and Bailes (1993). The deposits are classified as volcanogenic massive sulphide (VMS) deposits.

At Flin Flon–Amisk Lake, two producing mines (Callinan and West Arm), four past-producing mines (Flin Flon, Coronation, Birch, and Flexar), a potential mine (Konuto Lake), and an undeveloped deposit (Fon Zone) are the major deposits found to date. All deposits are hosted by juvenile island arc rocks; however, deposits fall into four distinct categories in terms of rock type/metal association, as follows:

1. tholeiitic basalt-dominant, rhyolite-subordinate Zn-Cu deposits,
2. tholeiitic basalt-dominant Cu-rich deposits,
3. calc-alkaline felsic-dominant Zn±Pb-Cu deposits, and
4. sediment-dominant Cu-Zn deposits.

a) Tholeiitic Basalt-dominant, Rhyolite-subordinate Zn-Cu Deposits

The Flin Flon mine, the largest deposit (62.4 Mt) in the Flin Flon–Snow Lake greenstone belt, and its stratigraphic equivalent, the Callinan mine (2.8 Mt), are hosted by a rhyolite which yields a U-Pb age at 1904 +6/-3 Ma (David *et al.*, 1993) within a predominantly tholeiitic basalt sequence of the Flin Flon lithotectonic assemblage. The South Main basalts in the stratigraphic footwall form a thick sequence of relatively shallow-water (300 to 700 m) pillowed flows and pillow fragment breccias (Syme and Bailes, 1993). A discordant chloritic alteration zone occurs beneath the massive sulphide orebody of pyrite, sphalerite, pyrrhotite, and chalcopyrite which is contained in the mine "rhyolite". The "rhyolite", which at this location is a 200 m thick package of rhyolite flows and breccias, is immediately overlain by a very thin unit of bedded volcaniclastic rocks. Hanging-wall Hidden Lake basalts comprise a

3.3 km thick relatively uniform succession of porphyritic pillowed flows that are compositionally unrelated to the South Main basalts (*ibid.*).

b) Tholeiitic Basalt-dominant Cu-rich Deposits

The Coronation (1.3 Mt), Flexar (0.31 Mt), Birch (0.28 Mt), and Konuto Lake deposits together define a copper-rich trend. At the Coronation Mine, the mineralized zone of pyrite, pyrrhotite, and chalcopyrite is intimately associated with a variably sheared and layered tuffaceous(?) horizon which lies between an amygdaloidal basaltic flow and a stratigraphically overlying massive to pillowed flow (Coombe, 1991). Cordierite-anthophyllite rocks represent a metamorphosed chloritic zone of a large alteration pipe (Whitmore, 1969; Froese, 1969). The geological setting of the Flexar and Birch Lake deposits is very similar. Chlorite schist in the vicinity of the chalcopyrite, pyrrhotite, and pyrite orebodies, possibly represents modified footwall alteration (Coombe, 1991). The Birch Lake deposit is hosted by a thin rhyolite tuff-agglomerate, structurally underlain by pillowed basalt and overlain by andesitic(?) tuff. Massive sulphide mineralization of the Flexar deposit is contained in chlorite schist sandwiched between two andesitic(?) flows.

c) Calc-alkaline Felsic-dominant Zn±Pb-Cu Deposits

The Fon deposit (5.1 Mt) is hosted by a calc-alkaline sequence of dominantly felsic volcanic and volcaniclastic rocks of the West Amisk assemblage which gives a U-Pb zircon age of 1888 ±3 Ma (Heaman *et al.*, 1993). The mineralized zone consists of massive and disseminated pyrrhotite-pyrite-sphalerite-chalcopyrite. Cordierite-anthophyllite-sillimanite, garnet-staurolite-biotite, actinolite-chlorite-biotite, and garnet-anthophyllite rocks proximal to mineralization represents metamorphosed Fe-Mg alteration zones (Schwann, 1992). Silicified and carbonatized felsic-mafic volcanic rocks and sediments envelope the Fon deposit.

d) Sediment-dominant Cu-Zn Deposits

The West Arm mine (1.6 Mt), located approximately 600 m east of the Saskatchewan-Manitoba border, is hosted by pyritic graphitic argillite of the Flin Flon assemblage in tectonic contact with the West Arm assemblage. The structural footwall to the deposit comprises strongly silicified and carbonatized pillowed basalts, pillow fragment breccias, and diorite. These rocks were described previously as dacites because of their bleached white to buff weathered colour which is now attributed to alteration along the West Arm shear zone. No VMS-style footwall alteration is recognized, the orebody likely being structurally controlled and probably not *in situ.* Mineralization consists of chalcopyrite, sphalerite, pyrite, and minor pyrrhotite. The structural hanging wall is found to be silicified and carbonatized basalt and diorite overlain by unaltered and undeformed basaltic flows above the West Arm shear zone.

3. Porphyry-style Mineralization

Porphyry-style copper (-molybdenum-gold) mineralization was first documented on Missi Island of Amisk Lake by Kirkham (1974). Porphyry dykes ranging in composition from rhyolite to andesite (Harper, 1993) and transitional into felsic to intermediate flows and fragmental rocks (Kirkham, 1974) are interpreted as a subvolcanic vent complex (Chute and Ayres, 1977). Copper, molybdenum, and gold mineralization associated with extensive zones of pyritization is found near Cougal Lake in the central part of the island and on the Brain and adjacent properties on the west side of the island. Chute and Ayres (1977) recognized pervasive silicification and sericitization affecting both porphyries and country rocks, and an extensive development of veinlets of quartz, carbonate, chlorite, epidote, hematite or pyrite. Younger, discrete stocks of porphyritic granodiorite, which yield a single-zircon Pb-evaporation age of 1848 ±11 Ma (Ansdell and Kyser, 1991b), intrude the dyke suite on Missi Island.

Porphyry-style mineralization in the Phantom Lake area was recognized by Wallster (1979) and is documented by Pearson *et al.* (1986) and Galley and Franklin (1987, 1989). The Boot Lake–Phantom Lake Intrusive Complex (PLIC) is a high-level zoned calc-alkaline intrusion which ranges in composition from gabbro (oldest) to microcline porphyritic monzogranite (youngest). The PLIC gives a conventional U-Pb zircon age of 1838 ±2 Ma (Heaman *et al.*, 1992). Zones of propylitic and phyllic alteration, with associated copper, tungsten, molybdenum, silver, and gold within the PLIC, are controlled by faults and shears (Galley and Franklin, 1989).

4. Mesothermal Shear Zone-hosted Gold Mineralization

The largest mesothermal shear zone-hosted gold deposits in the area include the Rio Mine, Monarch/Prince Albert Mine, and Graham Mine. Gold is hosted by auriferous veins of quartz±ankerite±chlorite±tourmaline± muscovite occurring in brittle-ductile shear zones which cut all lithological units. Alteration includes silicification, carbonatization, chloritization, sericitization, and overprints regional metamorphic assemblages. The main sulphides associated with the gold, pyrite and arsenopyrite, give rise to extensive gossanous zones. Mineralizing fluids were 300° to 450°C, of low salinity, CO_2-bearing, and derived by ongoing prograde metamorphism at depth (Ansdell and Kyser, 1992). The dominant vein-forming episode is constrained by the $^{40}Ar/^{39}Ar$ method at 1791 ±4 Ma (Fedorowich *et al.*, 1991) and a Rb-Sr isochron age of 1760 ±9 Ma (Ansdell and Kyser, 1992).

5. Epithermal Gold-Silver Mineralization

The Laural Lake Gold-Silver deposit has geological, structural, mineralogical, and fluid characteristics that resemble an epithermal system and distinguish it from other gold occurrences in the area (Walker and McDougall, 1987; Ansdell and Kyser, 1991a). This pre-meta-

Table 1 - A comparison of lithotectonic assemblages of the Flin Flon–Amisk Lake area.

Assemblage	Flin Flon (Creighton section)	West Arm	Mystic Lake	Birch Lake
Dominant Lithology	Mafic volcanics	Mafic volcanics	Tonalite	Mafic volcanics
Volcanic Rock Type	Lava flows > volcaniclastics	Lava flows	N/A	Lava flows > volcaniclastics
Characteristics:	Subaqueous aphyric to feldspar-phyric pillowed to amoeboid flows dominate. Highly amygdaloidal flows. Rhyolite flows and porphyries found locally. Heterolithic mafic volcaniclastics are common.	Subaqueous massive to pillowed flows and pillow breccias. Local feldspar-phyric flows. Synvolcanic gabbroic sills are common. Epidotization is widespread.	Protomylonitic to ultramylonitic medium- to coarse-grained tonalite and minor quartz diorite to gabbro. Variably strained pegmatities and fine-grained to aphinitic felsic and mafic sheets.	Subaqueous massive to feldspar-phyric flows are dominant. Pillowed to pillow breccia flows are subordinate. Minor volcaniclastics and volcanogenic conglomerate. Ubiquitous feldspar, quartz, and epidote net veining. Rare felsic (silicified?) volcaniclastics.
Thickness (approximate)	4000 m	2500 m	1500 m	3000 m
Upper boundary	Tectonic	Tectonic	Tectonic	Tectonic
Lower boundary	Tectonic	Tectonic	Tectonic	Tectonic
Magma Series	Tholeiitic basalts	Tholeiitic basalts	N/A	Tholeiitic basalts
Tectonic Setting	Island arc	Ocean floor	Isotopically evolved arc	Island arc
Age (Ma)	1904 (David et al., 1993)	?	1906 (Heaman et al., 1992) 1920 (Stern and Lucas, 1994)	?
VMS potential	Zn-Cu	low	low	Cu

morphic hydrothermal deposit is hosted by quartz and feldspar-phyric rhyolite and felsic fragmentals near the stratigraphic top of the West Amisk assemblage. These rocks yield a U-Pb zircon age of 1887 ±3 Ma (Heaman *et al.*, 1993). Mineralization consists of irregular veins of quartz-muscovite-pyrite-sphalerite-galena-chalcopyrite-tennantite-electrum-carbonate within a more widespread zone of potassium metasomatism (Ansdell and Kyser, 1991a). Mineralizing fluids were >300°C, saline, CO_2-bearing, and representative of modified seawater (*ibid.*). Gold deposits, such as the Monarch/Prince Albert, are hosted by flanking volcanogenic greywacke-argillite sediments of the Welsh Lake assemblage, and may represent remobilized equivalents of deposits originally formed from epithermal systems (Harper, 1993).

6. Discussion

The relationship between an island arc tectonic setting and VMS mineralization in the Flin Flon–Snow Lake greenstone belt was first proposed by Syme and Bailes (1993). Throughout geological time it holds true that VMS deposits preserved in arcs are an order of magnitude larger than those preserved at spreading centres (Franklin, 1995). Therefore, assemblages of ocean floor and ocean plateau affinities in the belt are deemed to have a lower potential for exploration. Additionally, VMS deposits formed in these settings may have been destroyed through subduction. This is a useful first order exploration guide.

Although the VMS deposits may share a common tectonic setting, they exhibit a wide-range of ore compositions and depositional styles. Their differences may be explained in several ways, however, there is a strong empirical relationship between the deposit type and the dominant lithology of the stratigraphic footwall (Fox, 1976) which is discussed below. Water depth may also play a significant role in controlling metal content (Franklin, 1993). Deposits formed in deep water contain only sphalerite and chalcopyrite whereas those formed in shallow water typically contain recoverable galena. High copper/(copper+zinc) ratios are found in stratigraphically lower zones and lower ratios in the upper zones. Deposits can be further classified on this basis.

Tholeiitic basalt-dominant, rhyolite-subordinate Zn-Cu deposits are classified as typical Noranda-type deposits which exhibit the following characteristics: concordant to semi-concordant, massive iron-rich sulphide bodies, commonly underlain by vein systems constituting stringer ore with chloritic alteration pipes, within volcanic sequences dominated by mafic volcanic rocks, with locally important felsic rocks, and deposited in water depths of more than 500 m (Franklin, 1993). Other examples of this type of deposit in the Flin Flon–Snow Lake greenstone belt are the Anderson and Stall mines of Snow Lake.

The significantly smaller tholeiitic basalt-dominant Cu-rich deposits which share many of the features of the Zn-Cu deposits (except felsic rocks are much less important and often absent) are interpreted as relatively deeper water deposits based on the abundance and small size of the amygdales in the associated pillowed and massive tholeiitic basalt flows. It remains unclear whether the orebodies found within the Birch Lake assemblage are hosted by a single favorable horizon (Price, 1977).

Table 1 (con't) - A comparison of lithotectonic assemblages of the Flin Flon–Amisk Lake area.

Sandy Bay	Crater Island	Muskeg Bay	West Amisk	Welsh Lake
Mafic volcanics	Mafic volcanics	Mafic volcanics	Felsic to intermediate volcanics	Greywacke/argillite
Lava flows	Volcaniclastics = lava flows	Lava flows > volcaniclastics?	Volcaniclastics > lava flows	N/A
Subaqueous aphyric, pillowed flows are dominant. Amygdaloidal flows are subordinate. Massive flows and synvolcanic gabbro intrusions are common. Flow breccias occur locally. Volcaniclastics are rare.	Subaqueous massive to pillowed feldspar-phyric flows dominate. Interflow tuff and lapilli tuff and synvolcanic gabbro intrusions are common. Olivine- and pyroxene-rich flows are rare. Minor highly amygdaloidal subaerial flows. Subaerial volcaniclastics of tuff and lapilli tuff are abundant.	Subaqueous massive to pillowed aphyric flows are dominant. Feldspar-phyric and amygdaloidal flows are found locally. Olivine-normative base and quartz-normative top. Synvolcanic gabbro intrusions are common. Volcaniclastics are rare and found near top.	Subaerial volcaniclastics are dominant. Tuff breccia, lapilli tuff, and tuff are present. Rare subaqueous volcaniclastics. Minor subaqueous flows and flow breccias are typically feldspar± hornblende-phyric. Pillowed flows and amygdales are rare.	Monotonous sequence of very thinly to thinly bedded greywacke and argillite. Bouma sequences present. Local pebble conglomerate and rare polymictic cobble conglomerate.
4000 m	3000 m	2500 m	3000 m	1000-5000 m
Tectonic	Conformably overlain by West Amisk assemblage.	Conformably overlain by West Amisk assemblage.	Conformably overlain by Welsh Lake assemblage.	Tectonic
Tectonic	Unknown	Unknown	Conformably underlain by Crater Island/Muskeg Bay assemblages.	Conformably underlain by West Amisk assemblage.
Tholeiitic basalts	Tholeiitic basalts	Tholeiitic basalts	Calc-alkaline andesites-rhyolites	N/A
Back-arc/oceanic plateau	Island arc	Island arc/back-arc	Island arc	Turbidite basin
?	?	?	1882-1888	1884-1913 detrital zircons (Heaman et al., 1993)
low	Zn-Cu	Zn-Cu	Zn±Pb-Cu	low

Zn±Pb-Cu deposits occur primarily in stratigraphic footwall sequences of dominantly felsic calc-alkaline volcanic rocks, with or without associated sedimentary strata. The deposits are tabular, concordant, massive pyritic bodies, typically underlain by less prominent stringer ore and sericitic alteration pipes (Franklin, 1993). Examples of this type of deposit include the Kuroko deposits of the Hokuroko district of Japan, and Buchans, Newfoundland. The Chisel, Lost, and Ghost mines of Snow Lake, and the Western Nuclear and McIlvenna Bay mines at Hanson Lake are also found in a similar setting.

The sediment-hosted deposits resemble Besshi-type deposits which typically form stratiform lenses and sheetlike accumulations of semi-massive to massive sulphide (±footwall feeder zones) occurring in clastic sedimentary rock and intercalated basalt (Slack, 1993). Examples are the Besshi District, Japan and Windy Craggy, British Columbia. The Cuprus and White Lake mines, located approximately 8 km east of the Saskatchewan/Manitoba border, are found in a similar environment.

At Amisk Lake, the calc-alkaline felsic-intermediate West Amisk assemblage is deposited on the tholeiitic basalt Muskeg Bay/Crater Island assemblages and intruded by porphyritic dykes of the hypabyssal suite. The West Amisk assemblage exhibits variations in erupted products and evidence of mass wastage of a steep-sided cone resulting in a complex stratigraphy typical of a stratovolcano (Cas and Wright, 1987). Such edifices may host vein stockwork porphyry-copper-molybdenum-gold deposits, which are formed during the final consolidation of high-level magma chambers beneath felsic-intermediate stratovolcanoes (Sillitoe, 1973), and shallow level epithermal gold and silver deposits, like the Laural Lake deposit. This geological setting is similar to that observed at Missi Island.

Recognition of porphyry-style mineralization in the Precambrian Shield has increased since the first discoveries in the early 1970s (Kirkham, 1972). This type of deposit is now well documented in some regions of the Precambrian Shield, for example the Archean porphyry Cu-Au±Mo camp in the Dore Lake area of Chibougamau, Quebec (Pilote and Guha, 1995).

The majority of the approximately 50 gold occurrences found in the Flin Flon–Amisk Lake area (Byers and Dahlstrom, 1954; Byers *et al.*, 1965; Coombe, 1984; Pearson *et al.*, 1986; Ansdell and Kyser, 1992) exhibit characteristics akin to epigenetic mesothermal mineralization, similar to shear-hosted lode gold deposits found in the Archean (Colvine *et al.*, 1988). The Flin Flon–Amisk Lake occurrences are generally small and marginally economic. Their small alteration haloes and relatively low gold contents suggest that the fluid flux through these vein systems was probably small in relation to that of the giant Archean deposits. Additionally, shear systems do not represent transcrustal structures like the terrane-bounding faults in Archean greenstone belts (Ansdell and Kyser, 1992).

Excluding the mesothermal gold deposits, mineral deposits of the Flin Flon–Amisk Lake area have been modified by metamorphism and deformation related to the Trans-Hudson Orogeny. A complex history is apparent in these generally low-grade sub-greenschist to lower amphibolite metamorphic rocks. Additionally the distribution of strain is heterogeneous resulting in areas of low strain with relatively undeformed stratigraphic sections and localized areas of high strain with transposed stratigraphy (Figure 3). A summary of the structural and metamorphic events is presented in Figure 4.

Two deformation events, post-dating D1 accretion of distinct lithotectonic assemblages, which give rise to regional fold structures are recognized. North-south shortening (D2) and accompanying regional metamorphism resulted in recumbent folding and westerly trending fold axes. Superimposed east-west shortening (transpression?) (D3) produced northerly trending upright folds under peak metamorphic conditions. In the Amisk Lake area, Type 3 fold interference patterns are observed on a macroscopic scale (Figure 5) and mesoscopic scale (Figure 6). The Laural Lake Au-Ag vein system is folded about a D3 north-trending upright fold (Walker and McDougall, 1987; Harper, 1993); however, structural repetition of the orebodies during D2 folding needs to be tested. In the Flin Flon area, Type 2 to Type 3 fold interference patterns have been documented, and the stratigraphic equivalent of the mine "rhyolite" is found on the west limb of a D3 north-trending fold (Hidden Lake Synform) at Millrock Hill (Thomas, 1994). Folding at this location is shown in Figures 7 and 8. The Flin Flon Mine orebodies plunge parallel to the D3 fold axis and D2/D3 intersection lineations, but the possibility that the orebodies were structurally repeated during D2 folding remains unclear. Gale *et al.* (in press) have attempted to unravel this structural problem in the Flin Flon area.

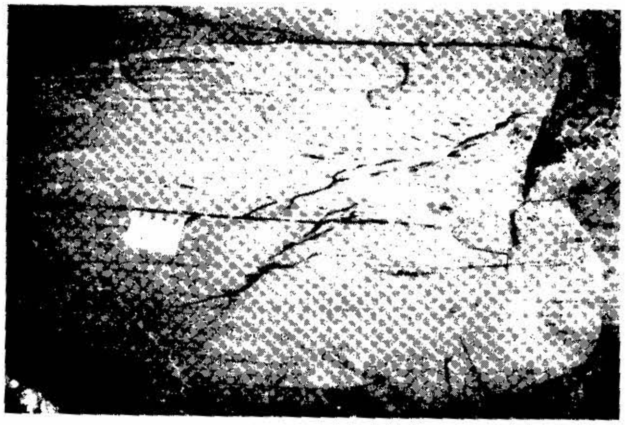

Figure 3 - Transposition of easterly trending bedding into northerly trending orientation in greywacke/argillite of Welsh Lake assemblage.

Shearing and faulting have also played a significant role in modifying the mineral deposits. The West Arm Mine deposit is an example of an orebody controlled by a shear zone, the West Arm shear zone, which marks a tectonic break between an ocean floor assemblage and an island arc assemblage. Like most Besshi-type deposits, it is highly deformed due to the competency contrast between the host argillites and the surrounding basalts. The enveloping basalts are intensely altered exhibiting silicification, which appears to be earlier than the chloriti-

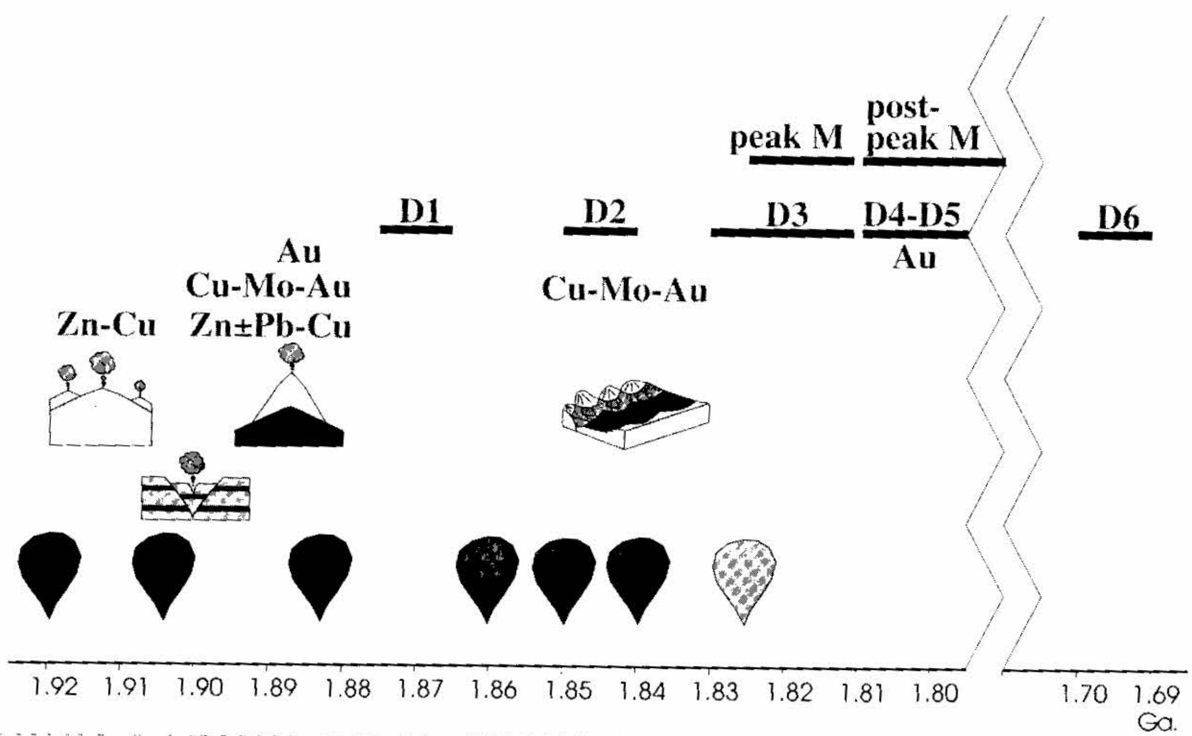

Figure 4 - Geochronology and tectonic summary of the Flin Flon–Amisk Lake area.

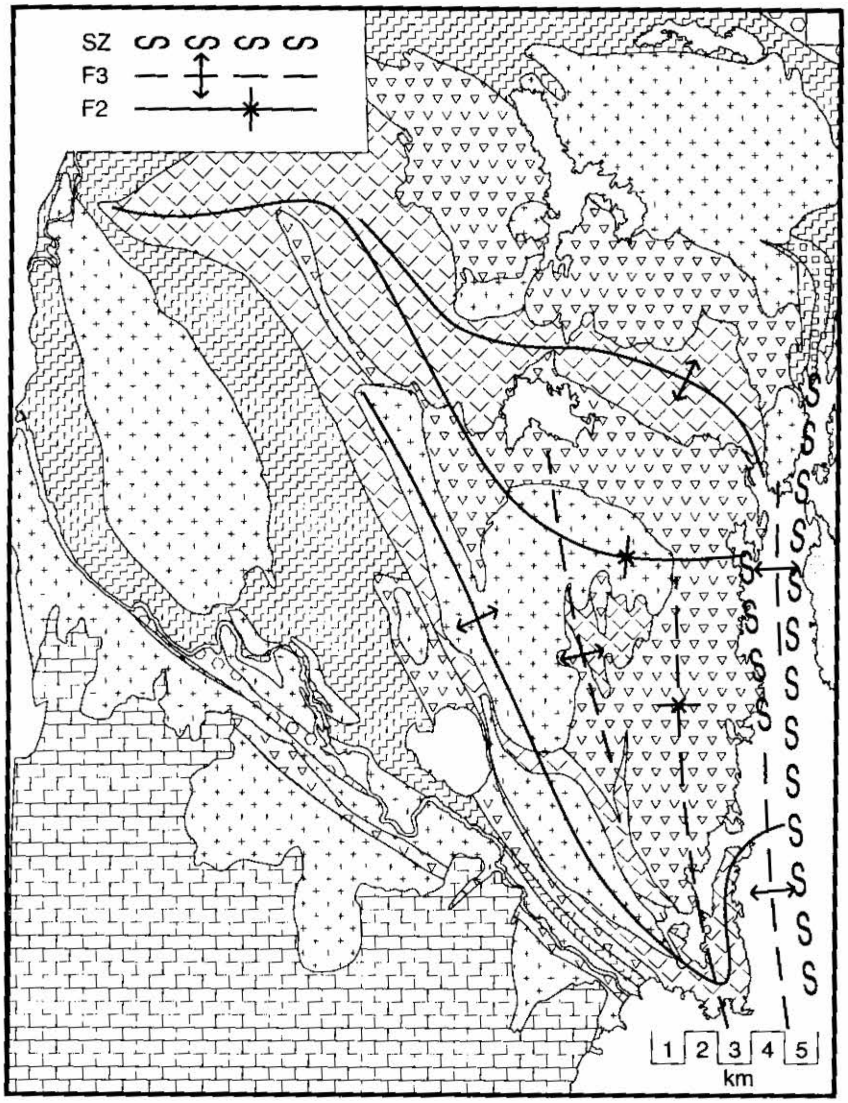

Figure 5 - Type 3 fold interference pattern in West Amisk Lake area.

zation, sericitization, and ankeritization. A strain gradient is observed whereby relatively undeformed amygdaloidal pillow basalts at the margin of the shear zone are transformed into silicified "cherty" mylonites in the centre (Thomas, 1990; Reilly, 1990). The West Arm shear zone was probably active from D1 accretion to D4 which is manifest as discrete brittle-ductile shear zones and associated retrograde metamorphism. The amount of displacement along the structure is unknown, but the orebody plunges parallel to the stretching lineation of the shear zone. The orebody is probably not *in situ*. A complex shearing and faulting history has been recognized in the Flin Flon area where D3 to D4 shears have produced a series of 100 to 400 m wide structural blocks which disrupt the stratigraphy, including the orebody at the Callinan deposit (Thomas, 1994).

Alteration assemblages associated with the mineral deposits in the area are modified during metamorphism. Ayres and Findlay (1976) point out that the wide spread alteration associated with many porphyry deposits, which is one means of identifying such deposits, may have been obscured or transformed during metamorphism. In the case of VMS mineralization, original chloritic zones associated with alteration pipes in the footwall volcanics may be metamorphosed to form cordierite-anthophyllite alteration assemblages. This is documented at the Coronation Mine (Whitmore, 1969; Froese, 1969)

Figure 6 - Type 3 fold interference pattern in interbedded garnet-rich and staurolite-rich metasediments of Welsh Lake assemblage.

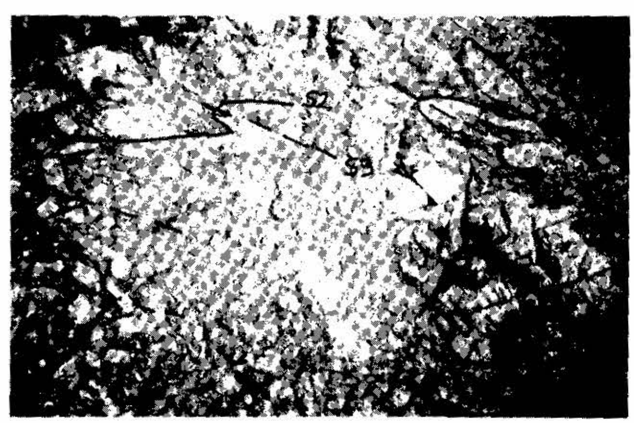

Figure 7 - S2/S3 relationships in amoeboid pillow breccia of South Main basalts at Millrock Hill, Flin Flon area.

Figure 8 - S2/S3 relationships in heterolithic volcanic breccia at Millrock Hill, Flin Flon area.

and in the Attitti Block, which represents the high metamorphic grade equivalent of the Flin Flon–Amisk Lake area (Ashton and Leclair, 1991).

7. Conclusions

1) VMS deposits are associated with juvenile island arc sequences in the Flin Flon–Amisk Lake area.
2) Within the arc systems, the VMS deposits exhibit a wide-range of ore compositions, host lithologies, and depositional styles. Four deposit types are recognized on this basis.
3) The potential for low-grade, high-tonnage porphyry-style Cu mineralization has not been fully evaluated.
4) Epithermal-like gold and porphyry-style Cu mineralization may represent different crustal levels of a stratovolcano.
5) Mesothermal gold mineralization resembles Archean shear-hosted lode gold deposits, however, large economic deposits have not been found.
6) Orebodies and their related alteration assemblages have been modified by metamorphism and deformation during the Trans-Hudson Orogeny.

8. References

Ansdell, K.M. and Kyser T.K. (1991a): The geochemistry and fluid history of the Proterozoic Laurel Lake Au-Ag deposit, Flin Flon greenstone belt; Can. J. Earth Sci., v28, p155-171.

_________ (1991b): Plutonism, deformation, and metamorphism in the Proterozoic Flin Flon greenstone belt, Canada: Limits on timing provided by the single-zircon Pb-evaporation technique; Geology, v19, p518-521.

_________ (1992): Mesothermal gold mineralization in a Proterozoic Greenstone Belt: Western Flin Flon Domain, Saskatchewan, Canada; Econ. Geol., v87, p1496-1524.

Ashton, K.E. and Leclair, A.D. (1991): Revision bedrock geological mapping, Wildnest-Attitti lakes area (parts of NTS 63M-1 and -2); *in* Summary of Investigations 1991, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 91-4, p29-40.

Ayres, L.D. and Finlay, D.J. (1976): Precambrian porphyry copper and molybdenum deposits in Ontario and Saskatchewan; *in* Report of Activities, Part B, Geol. Surv. Can., Pap. 76-1B, p39-41.

Bruce, E.L. (1918): Amisk-Athapapuskow Lake district; Geol. Surv. Can., Mem. 105, 91p.

Byers, A.R. and Dahlstrom, C.D.A. (1954): Geology and mineral deposits of the Amisk Lake–Wildnest Lake area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 14, 169p.

Byers, A.R., Kirkland, S.J.T., and Pearson, W.J. (1965): Geology and mineral deposits of the Flin Flon area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 62, 95p.

Cas, R.A.F. and Wright, J.V. (1987): Volcanic Successions - Modern and Ancient: A Geological Approach to Processes, Products and Successions; Allen and Unwin, London, 529p.

Chute, M.E. and Ayres, L.D. (1977): Missi Island volcanic centre, Saskatchewan; *in* Geol. Surv. Can., Pap. 77-1B, p29-31.

Colvine, A.C., Fyon, J.A., Heather, K.B., Marmont, S., Smith, P.M., and Troop, D.G. (1988): Archean lode gold deposits in Ontario; Ont. Geol. Surv., Misc. Pap. 139, 136p.

Coombe, W. (1984): Gold in Saskatchewan; Sask. Energy Mines, Open File Rep. 84-1, 134p.

_________ (1991): Base metals in Saskatchewan; Sask. Energy Mines, Open File Rep. 91-1, 134p.

David, J., Machado, N., Bailes, A., and Syme, E. (1993): U-Pb geochronology of the Flin Flon–Snow Lake belt: New results; *in* LITHOPROBE Trans-Hudson Orogen Transect, Rep. 34, p84-87.

David, J. and Syme, E. (1994): U-Pb geochronology of late Neoarchean tonalites in the Flin Flon belt, Trans-Hudson Orogen: Surprise at surface; Can. J. Earth Sci., v31, p1785-1790.

Fedorowich, J.S., Stauffer, M.R., and Kerrich, R. (1991): Structural setting and fluid characteristics of the Proterozoic Tartan Lake gold deposit, Trans-Hudson Orogen, northern Manitoba; Econ. Geol., v86, p1434-1467.

Fox, J.S. (1976): Some comments on the volcanic stratigraphy and economic potential of the West Amisk Lake area, Saskatchewan; Sask. Res. Counc., Circ. 9, 30p.

Franklin, J.M. (1993): Volcanic-associated massive sulphide deposits; *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M. (eds.), Mineral Deposit Modeling, Geol. Assoc. Can., Spec. Pap. 40, p315-334.

_________ (1995): Volcanic-associated massive sulphide deposits through time; *in* Precambrian '95, International Conference on Tectonics and Metallogeny of Early/Mid Precambrian Orogenic Belts, Prog. Abstr., p315.

Froese, E. (1969): Metamorphic rocks from the Coronation Mine and surrounding area; *in* Byers, A.R. (ed.), Symposium on the Geology of Coronation Mine, Saskatchewan, Geol. Surv. Can., Pap. 68-5, p55-77.

Gale, D., Lucas, S.B., and Dixon, J. (in press): Structural geology of the Flin Flon area, Manitoba and Saskatchewan; Geol. Surv. Can., Pap. 96-C.

Galley, A.G. and Franklin, J.M. (1987): Geological setting of gold, copper, tungsten, and molybdenum occurrences in the Phantom Lake region; *in* Summary of Investigations 1987, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 87-4, p115-124.

________ (1989): Setting of gold in the Phantom Lake region, Saskatchewan; *in* Investigations by the Geological Survey of Canada in Manitoba and Saskatchewan during the 1984-1989 Mineral Development Agreements, Geol. Surv. Can., Open File 2133, p33-44.

Harper, C.T. (1993): Intrusive and extrusive rocks of the western part of Missi Island, Amisk Lake; *in* Summary of Investigations 1993, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 93-4, p30-39.

Heaman, L.M., Ashton, K.E., Reilly, B.A., Sibbald, T.I.I., Slimmon, W.L., and Thomas, D.J. (1993): 1992-93 U-Pb geochronological investigations in the Trans-Hudson Orogen; *in* Summary of Investigations 1993, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 93-4, p109-111.

Heaman, L.M., Kamo, S.L., Ashton, K.E., Reilly, B.A., Slimmon, W.L., and Thomas, D.J. (1992): U-Pb geochronological investigations in the Trans-Hudson Orogen, Saskatchewan; *in* Summary of Investigations 1992, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 92-4, p120-123.

Kirkham, R.V. (1972): Geology of copper and molybdenum deposits; *in* Report of Activities, Part A, Geol. Surv. Can., Pap. 72-1A, p82-87.

________ (1974): Geology of copper and molybdenum deposits in Canada; *in* Report of Activities, Part A, Geol. Surv. Can., Pap. 74-1A, p377-379.

Koo, J. and Mossman, D.J. (1975): Origin and metamorphism of the Flin Flon stratabound Cu-Zn sulphide deposit, Saskatchewan and Manitoba, Canada; Econ. Geol., v70, p48-62.

Lucas, S.B., Stern, R.A., and Syme, E.C. (in press): Flin Flon greenstone belt: Intraoceanic tectonics and the development of continental crust (1.92-1.84 Ga); Geol. Soc. Amer. Bull.

Pearson, J.G., McDougall, F.H., and Galley, A.G. (1986): Geology and evolution of gold deposits in the Flin Flon–Amisk Lake area, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield, CIM Spec. Vol. 38, p399-411.

Pilote, P. and Guha, J. (1995): Metallogeny of the eastern extremity of the Abitibi Belt; *in* Pilote, P. (ed.), Metallogenic Evolution and Geology of the Chibougamau Area - From Porphyry Cu-Au-Mo to Mesothermal Lode Gold Deposits; Field trip guidebook; Geol. Surv. Can., Open File 3143, p31-44.

Price, D.P. (1977): Geology and economic potential of the Flin Flon–Snow Lake area; Univ. Manit., Cent. Precamb. Stud., Ann. Rep., p52-83.

Reilly, B.A. (1990): Bedrock geological mapping, Mystic–West Arm, Schist lakes area (northwest part of NTS 63K-12); *in* Summary of Investigations 1990, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 90-4, p25-35.

Reilly, B.A., Thomas, D.J., Slimmon, W.L., Ashton, K.E., and Harper, C.T. (in press); Project Seagull: A multi-disciplinary approach to revisional geological bedrock mapping along the Shield Margin in the Flin Flon–Amisk Lake area; *in* Investigations by the Geological Survey of Canada and the Saskatchewan Geological Survey in Saskatchewan during the 1990-1995 Mineral Development Agreement, Geol. Surv. Can., Rep. 3118, Sask Energy Mines, Open File Rep. 95-3.

Sangster, D.F. (1972): Isotopic studies of ore-leads in the Hanson Lake–Flin Flon–Snow Lake mineral belt, Saskatchewan and Manitoba; Can. J. Earth Sci., v9, no5, p500-513.

Schwann, P.L. (1992): The geology of the Fon zinc deposit; *in* Summary of Investigations 1992, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 92-4, p87-91.

Sillitoe, R.H. (1973): The tops and bottoms of porphyry copper deposits, Econ. Geol., v68, p799-815.

Slack, J.F. (1993): Descriptive and grade-tonnage models for Besshi-type massive sulphide deposits; *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M. (eds.), Mineral Deposit Modeling, Geol. Assoc. Can., Spec. Pap. 40, p343-371.

Stauffer, M.R., Mukherjee, A.C., and Koo, J. (1975): The Amisk Group: An Aphebian(?) island arc deposit; Can. J. Earth. Sci., v12, p2021-2035.

Stern, R.A. and Lucas, S.B. (1994): U-Pb zircon age constraints on the early tectonic history of the Flin Flon accretionary collage, Saskatchewan; *in* Radiogenic Age and Isotopic Studies: Report 8, Geol. Surv. Can., Current Research 1995-F, p75-86.

Stern, R.A., Syme, E.C., Bailes, A.H., and Lucas, S.B. (1995a): Paleoproterozoic (1.90-1.86 Ga) arc volcanism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; Contrib. Mineral. Petrol., v119, p117-141.

Stern, R.A., Syme, E.C., and Lucas, S.B. (1995b): Geochemistry of 1.9 Ga MORB- and OIB-like basalts from the Amisk collage, Flin Flon Belt, Canada: Evidence for an intra-oceanic origin; Geochim. et Cosmochim. Acta, v59, p3131-3154.

Syme, E.C. and Bailes, A.H. (1993): Stratigraphic and tectonic setting of Early Proterozoic volcanogenic massive sulphide deposits, Flin Flon, Manitoba; Econ. Geol., v88, p566-589.

Thomas, D.J. (1990): New perspectives on the Amisk Group and regional metallogeny, Douglas-Phantom Lake area, northern Saskatchewan; *in* Summary of Investigations 1990, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 90-4, p13-20.

________ (1994): Stratigraphic and structural complexities of the Flin Flon mine sequence; *in* Summary of Investigations 1994, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 94-4, p3-10.

Walker, T. and McDougall, F. (1987): Geology of the Laurel Lake gold-silver deposit; *in* Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan, Sask. Geol. Soc., Spec. Publ. 8, p44-53.

Wallster, D.E. (1979): Geology reviewed for the Dion Lake region with specific reference to a possible Aphebian porphyry-type copper deposit; unpubl. M.Sc. thesis, Univ. Western Ontario, 141p.

Watters, B.R., Dostal, J., Slimmon, W.L., and Thomas, D.J. (1994): Geochemistry, petrogenesis, and tectonic setting of Early Proterozoic volcanic rocks of the Flin Flon Domain, Saskatchewan (Canada): Oceanic back-arc volcanism; N. Jb. Miner. Mh., H.9, p416-432.

Whitmore, D.R.E. (1969): Geology of the Coronation copper deposit; *in* Byers, A.R. (ed.), Symposium on the Geology of Coronation Mine, Saskatchewan, Geol. Surv. Can., Pap. 68-5, p37-53.