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REGIONAL BEDROCK MINERAL RESOURCE ASSESSMENT OF THE ROSEAU 1° x 2° QUADRANGLE, NORTHERN MINNESOTA

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CONTENTS

FIGURES

[Figures at end of text]

TABLES

[Tables 2–7 repeated on map sheet]

Note: Data expressed in feet in this report (text, p. 6–7, fig. 8, in particular) are from previous work and are retained in the original measurement unit for precision. For conversion to metric, multiply feet by 0.3048.

INTRODUCTION

The U.S. Geological Survey has undertaken a series of mineral resource studies in the Roseau 1°x2° quadrangle of northern Minnesota, which consist of regional geologic mapping, mineral deposit studies, and geophysical and geochemical surveys and analysis. Results of these studies have been used to determine the mineral resource potential for several types of metallic deposits in this region. This pamphlet briefly summarizes the regional geology of the study area, the approach and criteria that were used to assess the metallic mineral resource potential, and the results of that assessment.

The approach used in this assessment consists of the first two steps of the three-step method of mineral resource assessment summarized by Shawe (1981). The first step was to identify the genetic types of deposits that are found, or are likely to exist, within the geologic terranes present in the study area. Permissive genetic deposit types were defined by extrapolation from geologically similar, adjacent terranes in Canada and by inference from terranes elsewhere in the world having a similar geologic history and age.

The second step in the assessment process was to compare, using a consistent framework of features referred to as recognition criteria, the geologic, geochemical, and geophysical features of the permissive genetic deposit types with similar features from tracts identified in the assessment area. The presence or absence of these recognition criteria in a given area provides the basis for both the delineation of an assessment tract and the assessment of its mineral resource potential. The genetic models used in this study were largely based on those presented in Eckstrand (1984a), which include mineral deposits from all major types in the Archean Superior province. All published deposit models were supplemented or updated with the results of recent studies or deposit models (Klein and Day, 1994).

Metallic mineral deposits contained in the immediately adjacent areas of Ontario are typical of those found elsewhere in the Canadian Shield. Numerous mineral prospects and several small, formerly productive mines in the adjacent parts of Ontario are summarized by Klein and others (1995, 1997), based on earlier studies by Poulsen (1984), Beard and Garrat (1976), and Fletcher and Irvine (1954). Similarities in host-rock type, alteration style, ore minerals, structural setting, and stratigraphic relationship of the mineral deposits in the study area with those features in the adjacent area were used to establish principal recognition criteria. Mineral deposit types that are permissive in the study area, based on our extrapolations, are summarized in table 1. Other pertinent resource-related geologic data for this area of northern Minnesota are summarized in Day and others (1990, 1994), Frey and Venzke (1991), Jirsa and Boerboom (1990), Klein (1991, 1994a), Klein and Day (1989), Klein and others (1995), Listerud (1976), Boerboom and others (1989), Martin and others (1988, 1989, 1991), and Ojakangas and others (1977). Geochemical data for this area are summarized in Englebert and Hauk (1991), Frey and Venzke (1991), Klein (1994b), Klein and others (1987, 1988, 1994), and Martin and others (1988, 1989, 1991). The results of a metallic mineral resource assessment in the laterally equivalent rock units of the adjacent International Falls, Minn., 1°x2° quadrangle are presented in Klein and others (1997).

This report uses the definition of the term "mineral resource" that was previously adopted by U.S. Bureau of Mines and U.S. Geological Survey (1980). Because of the small number of nearby mines and well-explored prospects in the study area, and the sparse production and reserve data, only the potential for undiscovered conventional metallic mineral resources has been assessed. Although the number of permissive mineral deposit types is large (table 1), only those deposit types that are hypothetical resources, for example, those that are known in nearby, similar geologic terranes, have been considered. The mineral resource potential for industrial commodities or unconventional "low-grade" resources was not evaluated.

The assessment as presented here is based on the level of knowledge as of August 1997. Because all assessments are time and data dependent, new data and geologic concepts of ore genesis and the stratigraphic and structural framework of the area, as well as economic factors, could significantly alter future mineral resource assessments of the same area.

REGIONAL GEOLOGIC SETTING

The Roseau quadrangle lies within the western extent of the exposed part of the Archean Superior province of the Canadian Shield. The study area encompasses three subprovinces of the Superior province: Wabigoon in the north, Quetico in the south, and Wawa along the southern boundary of the quadrangle (fig. 1). Quaternary glacial deposits cover most of the study area and obscure the Precambrian bedrock geology. However, the regional geologic framework can be pieced together using geologic data from outcrops and drill cores integrated with geophysical information (aeromagnetic and gravity data) and soil geochemical data.

In general, the subprovincial boundaries are delineated by major through-going dextral transpressive fault zones (fig. 1). In the eastern part of the study area, the northeast-striking Rainy Lake–Seine River fault forms the boundary between the Wabigoon and Quetico subprovinces (Ojakangas, 1972; Ojakangas and others, 1977, 1979). The fault is a 0.5–1 km wide zone of intense ductile shear deformation with extensive development of phyllonite, chlorite±biotite schist, and mylonite. Ductile deformation in the fault zone has caused intense flattening and stretching of primary structures. The strong schistosity (or mylonitic fabric) commonly contains quartz and carbonate stringers, lenses, and boudins indicating the presence of metamorphic fluids in the fault zone during deformation. The Rainy Lake–Seine River fault is offset by the Vermilion fault (fig. 1) and continues southwestward as the Four Town fault. The southern terminus of the Wabigoon-

Quetico subprovincial boundary is interpreted from the aeromagnetic data to be transitional between the mafic and felsic volcanic rocks of the Wabigoon subprovince and the garnet-biotite schists of the Quetico subprovince and is interpreted to be the Four Town fault.

Rocks of the Wabigoon subprovince in the area have undergone three major episodes of deformation. The earliest recognized event (D_1) occurred after volcanism and sedimentation (post 2,755 Ma), and took place during or slightly after intrusion of tonalitic, granodioritic, and gabbroic plutons. This episode was associated with deformation that produced recumbent and isoclinal folds (Poulsen and others, 1980; Day and Sims, 1984) and development of an early S_1 foliation. The second major episode (D_2) was associated with the regional Late Archean ductile transpressive deformation. A penetrative cleavage (S_2) forms a S-C mylonitic fabric with the earlier S_1 foliation. Motion along the major faults (or deformation zones) took place at this time. All kinematic indicators reveal that the transpression was dextral. The third episode of deformation (D_3) was an Early Proterozoic event in which brittle motion along the fault zones produced pseudotachylite (Peterman and Day, 1989).

GEOLOGY OF THE WABIGOON SUBPROVINCE

The Wabigoon subprovince (fig. 1) is a greenstone-granite terrane made up of supracrustal sequences (volcanic and associated pyroclastic, epiclastic, and chemical sedimentary rocks) that were invaded by ultramafic, gabbroic, and granitic rocks. In general, the supracrustal sequences have undergone low- to moderate-grade regional metamorphism. These supracrustal rocks were deformed prior to intrusion of large volumes of syn- to post-tectonic granitoids (pre-D_1; Day and others, 1990).

Blackburn and others (1991) noted that the central part of the Wabigoon subprovince (east of the study area) has platform metasedimentary rocks overlying 3.0-Ga granitoid basement. In the western part of the subprovince, which extends into the study area, the pre-intrusive volcanic and sedimentary sequences range from 2,775 to 2,718 Ma. Subsequent syn- to post-D_2 metasedimentary sequences are between 2,695 and 2,686 Ma. One of these latter "Timiskaming-type" epiclastic metasedimentary sequences, the Seine Group, is exposed to the east of the study area in the Rainy Lake area (Day, 1990). However, no such sequences were noted in this study area.

The Late Archean rocks, as well as the major subprovincial bounding faults, are crosscut by the Early Proterozoic 2.1-Ga Kenora-Kabetogama dikes (not shown in fig. 1). The swarm has a minimum strike extent of 310 km and breadth of 270 km (Case and others, 1990). Individual dikes range from 1 m to 100 m wide and can be traced along strike for more than 50 km. The dikes range in composition from gabbro to diorite; they commonly have a fine- to medium-grained texture and characteristically lack tectonic fabric.

GEOLOGY OF THE QUETICO SUBPROVINCE

Rocks of the Quetico subprovince (fig. 1) are poorly exposed in the study area, and, as a consequence, detailed information is limited to a few sparse drill holes. Where exposed immediately east of the study area (Southwick and Ojakangas, 1979; Day and others, 1990; Klein and others, 1997), the Quetico subprovince consists of medium- to high-grade (amphibolite facies), regionally metamorphosed metasedimentary rocks (garnet-biotite schist), gneiss, and granite. The metasedimentary rocks are composed mostly of metagraywacke and metatuff with interlayered amphibolite. The Quetico subprovince is cored by the Vermilion Granitic Complex (Late Archean), a granite-migmatite complex consisting of metasedimentary rocks intruded by tonalite, monzodiorite, and batholithic bodies of the Late Archean Lac La Croix Granite (Southwick and Sims, 1980; Day and Weiblen, 1986).

GEOLOGY OF THE WAWA SUBPROVINCE

The Wawa subprovince (fig. 1) is a granite-greenstone terrane composed of interlayered metavolcanic and metasedimentary rocks that were intruded by granitoid bodies. The contact between rocks of the Quetico and Wawa subprovinces is gradational from the metasedimentary rocks to the north into the layered volcanic and metasedimentary rocks to the south (Jirsa and Boerboom, 1990). The grade of metamorphism decreases from medium grade (amphibolite facies) in the Quetico to low grade (greenschist facies) southward into the Wawa subprovince. The Wawa supracrustal rocks grade into metasedimentary rocks (biotite schist), which have an aeromagnetic signature similar to that of the metasedimentary rocks of the Quetico subprovince to the north (Day and others, 1994).

Recent mapping by Jirsa (1990) and Jirsa and Boerboom (1990) outlined the structural evolution of the area east of Lower Red Lake. Their studies reveal that the supracrustal rocks underwent several periods of deformation. The earliest event (D_1) was associated with large-scale folding (F_1). The second deformation (D_2) produced cleavage, flattening, and local refolding of F_1 folds, and boudinage and folding of D_1 axial planar veins. A later deformation event (D_3) produced localized folding and was associated with movement and deformation along major faults in the area.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

Once appropriate deposit models were selected, tracts that might contain deposits similar to those described by the deposit models were defined on the basis of diagnostic criteria. Recognition

Table 1. *Permissive mineral deposit types in the Roseau 1°x2° quadrangle*

I. Syngenetic-diagenetic mineral deposits
   A. Volcanogenic base- and precious-metal massive sulfide deposits
   B. Algoma-type iron-formation

II. Epigenetic mineral deposits
   A. Archean lode gold deposits

III. Magmatic mineral deposits
   A. Intrusion-hosted deposits
      1. Chromite in ultramafic intrusive rocks
      2. Gabbro-associated deposits
         a. Copper, nickel, and platinum-group elements
         b. Gabbro-hosted titanium and vanadium
      3. Felsic intrusive rocks
         a. Copper and molybdenum porphyry deposits
      4. Alkalic intrusive rocks
         a. Kimberlite-hosted diamonds
         b. Ultramafic copper, uranium
         c. Nephelinitic carbonatite rare-earth elements, uranium, niobium, and tantalum
   B. Volcanic-hosted deposits
      1. Komatiite-hosted nickel, copper, and platinum-group elements

criteria are geologic, geophysical, or geochemical features that suggest a particular mineral deposit type may be present in a given area.

Recognition criteria for deposit models are divided into two types:

1. Diagnostic criteria present in most, or all, of the deposits considered essential for the formation of that deposit type. The presence of these features is a favorable indication that a particular type of deposit may be present in a given area. Conversely, the absence of diagnostic criteria indicates little likelihood for the occurrence of a particular deposit type.

2. Permissive features that are present in some deposits and that, although not essential for deposit formation, may indicate the presence of a particular mineral deposit type.

The delineation of potential metal-bearing domains or assessment tracts was based largely upon two types of diagnostic criteria:

1. The presence of favorable host rocks in the case of syngenetic and magmatic deposits types.

2. The presence of favorable structures in the case of epigenetic gold deposits.

The presence of other diagnostic criteria, such as electrical conductors or magnetic anomalies, geochemical anomalies, coarse-grained felsic volcanic rocks, or chert layers, enhances the potential for massive sulfide deposits in a given area. Extensive chlorite-carbonate alteration, arsenic, antimony, molybdenum, and base-metal anomalies, and multiple episodes of vein formation are considered diagnostic criteria to increase the potential for epigenetic lode gold deposits.

Few permissive criteria were defined because the amount of bedrock information was not sufficiently consistent or detailed. Therefore, the permissive criteria were not used as a primary component of the resource assessment and are only presented as supplemental information on the character of each tract.

Through the application of the above assessment method, the study area was judged to have possible undiscovered resources in five deposit types. These include (1) volcanogenic massive sulfide deposits (table 1, IA), (2) ultramafic- and gabbro-hosted copper, nickel, and platinum-group elements (PGE) (table 1, IIIA, 2a), (3) gabbro-hosted titanium-vanadium deposits (table 1, III, 2b), (4) Archean lode gold deposits (table 1, II, A) and (5) Algoma-type iron-formation (table 1, I, B). The mineral resource potential for other deposit types listed in table 1 was not assessed because analogs are not known to exist in the adjacent parts of the Superior province or sufficient knowledge of geologic, geochemical, or geophysical details is lacking to evaluate them in the study area.

Assessment tracts for the five possible deposit types in the Roseau quadrangle were in large part established from a geologic map (1:250,000) of the area by Day and others (1994). Geochemical information on bedrock samples contained in Klein (1994b), Klein and others (1987, 1988, 1994), and Frey and Venzke (1991) and the results of a soil geochemistry survey by Riddle and others (1992) were also used to evaluate the assessment tracts.

After each assessment tract was geographically defined, an objective score based on the sum of point values for each diagnostic criterion was assigned. In each assessment tract, where a criterion described in the diagnostic criteria was met, a value of 1 was assigned. A tract with the known absence of a criterion was assigned a minus 1 for that criterion. A score of 0 was assigned if the information was not sufficient to establish the presence or absence of a given criterion. The summed score allows an assessment tract to be ranked on the basis of its relative favorability with other tracts for the same deposit type in the study area. Subjective interpretation of these scores was used to establish the probability rank of each assessment tract for each deposit type. The value of these scores of relative favorability is not directly comparable between deposit types. For example, a score of 3 out of a possible 3 for one type of deposit may give it a high resource potential, whereas a score of 3 of a possible 5 for another type of deposit may indicate only a moderate resource potential.

The assignment of resource potential in this study area was accompanied by a qualitative expression of the certainty, which indicates the level of confidence placed on the estimate of resource potential. This value is related directly to such characteristics as the degree of exposure of bedrock or the amount of exploration that has taken place in a given area. We have adopted the convention suggested by Goudarzi (1984) having four levels of certainty ranging from A, which represents the lowest level of confidence, to D, the highest. Level A indicates mineral assessment tracts whose information is insufficient for assessment of a particular commodity. Level B indicates tracts having general geologic, geochemical, and geophysical characteristics that are known well enough to suggest a level of mineral potential, but where several key elements of knowledge needed for mineral assessment are lacking. Level C indicates tracts in which the available information gives a good indication of the mineral resource potential but where a key element of knowledge is missing or of less than ideal quality. Level D indicates tracts whose level and quality of available information clearly define the mineral resource potential. When these confidence levels are referred to in the following sections, level B will be designated as indicating a low degree of certainty, level C as indicating a moderate degree of certainty, and level D as indicating a high degree of certainty. The relation between the level of certainty and the resource potential is illustrated in figure 2.

The assessment tracts and the outline of the Roseau 1°x2° quadrangle are plotted in maps A, B, and C. The tract boundaries and numbers are different for each type of deposit.

VOLCANOGENIC MASSIVE SULFIDE DEPOSITS

Diagnostic criteria were developed for volcanogenic copper-zinc±silver±gold massive sulfide deposits using a volcanic-hosted massive sulfide model adapted from models by Lydon and others (1984), Lydon (1984a, 1984b), Franklin and others (1981), and Franklin (1990). The resource potential for each of the 12 massive sulfide assessment tracts in the study area (map A) was defined on the basis of the diagnostic criteria summarized in table 2. The resource potential for each tract was derived from the subjective interpretation of the assessment tract scores presented in table 3.

Included in Tract I (map A) are all granitoid, gabbro, and ultramafic intrusive rocks in the study area. Volcanogenic massive sulfide deposits are not found in intrusive rocks, and, therefore, the rocks in Tract I are considered to have no potential for massive sulfide deposits.

Tracts II and III (map A) include graywacke-argillite-type metasedimentary rocks of the Quetico subprovince and in the Wabigoon and Wawa subprovinces, respectively. The sedimentary environments in which these rocks were formed do not contain volcanogenic massive sulfide deposits elsewhere in the world. Accordingly, Tracts II and III are considered to have no potential for volcanogenic massive sulfide deposits.

Tract IV (map A) consists predominantly of metasedimentary rocks derived from volcanic sources. These, for the most part, were deposited in a distal environment with respect to volcanic centers. These rocks have a low potential for volcanogenic massive sulfide deposits. However, they have a low potential for massive sulfide in contrast to "no potential" for the graywacke-argillite units defined in Tracts II and III because the metasedimentary rocks of Tract IV were probably deposited in an environment more proximal to the volcanic centers. Distal massive sulfide accumulations may form in this environment or proximal massive sulfide deposits may be transported by large-scale gravity-sliding into this environment, but the occurrence of massive sulfide deposits in rocks of this type is extremely rare in the Superior province. Variation in the degree of confidence between B and C is directly related to the number of drill holes within a tract and the thickness of the glacial cover in the area.

The mafic- to intermediate-composition metavolcanic rocks in Tract V (map A) include those from the Wabigoon subprovince. Samples from this tract contain scattered chert and iron-formation and anomalous base-metal values (Klein, 1994a). Soils that overlie metavolcanic rocks in this tract also have anomalous base-metal values (Carlson and Clark, 1995). Mineral resource potential for volcanogenic massive sulfide deposits is moderate in this tract because of the presence of several diagnostic criteria that are indicators of submarine hydrothermal activity of the type that may form massive sulfide deposits (see table 3). Many of the bedrock geochemical anomalies in this tract are from graphitic rocks that were drilled on the basis of their anomalous electromagnetic properties. These interlayered graphitic rocks have characteristically high background values in base metals and do not necessarily indicate metal enrichments due to hydrothermal activity. The lack of significant amounts of coarse felsic volcanic rocks (those formed proximal to a volcanic vent) (fig. 3) may indicate that vigorous copper- and zinc-bearing hydrothermal systems necessary to generate economic volcanogenic massive sulfide deposits did not develop because these metavolcanic rocks did not form near the most favorable part of the volcanic complex. However, that coarse felsic volcanic rocks are lacking (fig. 3) may result from the lack of comprehensive information on the character of the bedrock and may not preclude the presence of massive sulfide deposits or the possibility that gravity transport may have superimposed massive sulfide bodies upon finer grained, distal volcanic rocks. Classification is dependent upon the recognition of

Table 2. *Diagnostic and permissive criteria for volcanogenic massive sulfide deposits*

Diagnostic criteria:

1. Presence of volcanic rocks.
   Geophysical indicators: irregular aeromagnetic patterns and relative gravity highs.
2. Proximity to felsic volcanic centers characterized by coarse felsic volcaniclastic breccias and fragmental rocks, subvolcanic intrusive rocks.
3. Evidence for hydrothermal fluids associated with massive sulfide deposits.
   a. Exhalite, volcanogenic chert-sulfide horizons, Algoma-type iron-formation, manganese-rich layers.
   b. Hydrothermal alteration such as Mg-, Fe-, and K-enrichment and Na-depletion.
   c. Base-metal and pathfinder-element enrichment (Zn, Cu, ± Se, In, Sb, Sn, or B) as indicated by bedrock and B-horizon soil samples.
   d. Presence of barren, pyrite-rich massive sulfide horizons.
4. Presence of base-metal massive sulfide deposits as indicated by bedded sulfide mineral deposits or stockwork feeder zones, or bedrock electrical conductors.

Permissive criteria:

1. Presence of graphitic sediments.

Table 3. *Resource potential for volcanogenic massive sulfide deposits in the Roseau 1°x2° quadrangle*

Tract No. (map A)	Diagnostic criteria 1	2	3	4	Sum of tract scores	Resource potential	Confidence level
I	0	0	0	0	0	None	D
II	0	0	0	0	0	None	D
III	0	0	0	0	0	None	D
IV	1	0	1[a,b]	0	2	Low	B, C
V	1	0	1[a,b,c]	1	3	Moderate	B, C
VI	1	0	1[c]	0	2	Low	B
VII	1	1	1[a]	0	3	Moderate	B, C
VIII	1	1	1[a,b,c,d]	1	4	High	C
IX	1	1	1[a,b,c,d]	1	4	High	B, C
X	1	1	1[a,b,d]	1	4	High	C
XI	1	0	0	0	1	Low	B
XII	0	1	1[a,b,c,d]	0	2	Low	B

[a]Chert.
[b]Mg or Fe enrichment.
[c]Base-metal anomalies.
[d]Massive sulfide horizons present.

felsic volcanic rocks either as a readily identifiable magnetic unit in aeromagnetic surveys or from drill-hole information. Composition of the volcanic rocks in this region, poorly known because of the scarcity of drill holes and outcrop, is based largely on geophysical discrimination of felsic from mafic volcanic rocks, which locally is uncertain because of the effects of hydrothermal alteration and regional or contact metamorphism. Parts of this mineral assessment tract are given either a low or a moderate degree of confidence, because the level of knowledge of the character of the volcanic rocks is directly related to density of drill holes and the thickness of glacial cover.

Tract VI contains mafic- to intermediate-composition volcanic rocks of the Wabigoon subprovince that are roof pendants in a large granite pluton exposed in outcrops south of Baudette, Minn. This tract also includes an area south of Roseau, Minn., where volcanic rocks of unknown character constitute a roof pendant in a large unexposed granitoid pluton (map A). This tract has low potential because it lacks the significant diagnostic criteria: felsic volcanic rocks and massive sulfide prospects. A broad multielement geochemical anomaly in soils that may be related to base-metal massive sulfide accumulations is generally coincident with this tract (Carlson and Clark, 1995). The significance of this anomaly has not been determined.

Tract VII (map A) is underlain by felsic metavolcanic rocks (**Wfvs**, **Wfv**) in the Birchdale-Indus, Minn., area and by bimodal metavolcanic rocks (**Wmfv**) in the west-central part of the study area (Day and others, 1994). The lithologic units in this tract locally include distinctive coarse felsic volcanic breccia (fig. 3) and locally abundant iron-formation and hydrothermal chert (figs. 4, 5). However, drilling has not encountered significant base-metal enrichment, even where exploration has been relatively intense, for example, drill holes north of Oaks Corner, Minn. (figs. 6, 7; see Klein, 1994a). In the Indus, Minn., area, which is immediately east of the study area, exploration drilling and outcrop sampling of several electrical conductors in these metavolcanic rocks have encountered only pyrite- and pyrrhotite-rich massive sulfide lenses having low base- and precious-metal concentrations (Listerud, 1976). Soil geochemistry from this study in the same area also indicates only low-level anomalies of unknown origin (Carlson and Clark, 1995). Even though the rock units in Tract VII contain appropriate host rocks and indications of hydrothermal activity, the overall character of the volcanic rocks, the lack of base-metal concentrations encountered in bedrock drilling, and the low-level soil geochemical anomalies indicate that the potential of this tract may be rated only as moderate for base-metal-bearing massive sulfide deposits. The area along the western boundary of the study area has not been extensively explored and is covered by thick glacial deposits; its classification is made with less confidence than in the area north of Oaks Corner, Minn. (map A).

Bimodal metavolcanic rocks (**Wmfv**) in the central part of the Wabigoon subprovince in the study area (Day and others, 1994) are included in Tract VIII. This belt of rocks included in the tract (map A) contains five drill holes in which coarse felsic metavolcanic rocks, chert, thin base-metal-bearing massive sulfides, and extensive chloritized rocks have been encountered (figs. 3, and 5–8). The rocks are highly deformed in this area because they lie between two subparallel fault segments (Day and others, 1994). The relatively continuous conductor drilled in holes LW-342-1, LW-342-2, BD-1, BD-2, and BD-3 is the most significant prospect in this belt. Interlayered chert and massive sulfide layers with intercepts of 25 ft and 70 ft were encountered in segments of drill holes BD-2 and LW-342-1, respectively (see Klein, 1994b). Sulfide-rich layers from both of these holes are zinc rich (Klein, 1994a). Results from BD-2 show concentrations ranging from 2,000 to 5,000 parts per million (ppm) in many 4- to 6-ft assay intervals. Assays from LW-346-1 show values of as much as 2,000 ppm zinc in one 4-ft interval. This tract is considered to have high potential for massive sulfide deposits.

An extensive amount of drilling in Tract IX has encountered rocks in 13 drill holes that contain coarse felsic volcanic rocks, iron-formation, chert, and barren and base-metal-rich massive sulfide layers (figs. 3–8), as well as sericite- and chlorite-rich rocks (Klein and Day, 1989). The most significant base-metal deposit was encountered in drill hole BD-N-1 (map A). The results of assays of 5-ft intervals over a 330-ft interval of drill core range from 2,000 to 7,000 ppm zinc and from 200 to 1,100 ppm copper (Klein, 1994a). The mineralized interval is interlayered with porphyritic rhyolite, graphite-rich rocks, and chert and is associated with adjacent intense chlorite, sericite, and silica alteration (see Klein, 1994b). In drill hole B-24-2, a 100-ft interval of interbedded massive sulfide layers (from 2 to 25 ft thick) and rhyolite breccias and tuffs was encountered. Base metals are only enriched in one 0.5-ft interval that assayed 5 percent zinc, 2,900 ppm lead, and less than 25 ppm copper (Klein, 1994a). Because of the abundant diagnostic criteria, Tract IX (map A) has high potential for massive sulfide deposits. The volcanic rocks that are included in the easternmost block of Tract IX may correlate with those in the western part and by analogy have high potential for massive sulfide deposits. A broad soil geochemical anomaly interpreted to reflect buried massive sulfide deposits extends over the area (Carlson and Clark, 1995). However, the eastern part of Tract IX has a low degree of confidence in its classification because of the lack of subsurface data.

In Tract X (map A), seven drill holes intersected chert (brecciated in part) and a pyritic massive sulfide lens interbedded with fine-grained layered tuffs (figs. 5, 8), and subordinate amounts of felsic volcaniclastic rocks. Base-metal concentrations were low in most of the pyritic layers, which range from intercepts of 1 ft to more than 100 ft. Only drill hole FT-21 contains significant zinc concentrations (an 80-ft interval ranging from 175 to 1,080 ppm zinc). Gold concentrations range from 0.1 to 2.75 ppm in scattered assay intervals (2–5 ft) of pyritic massive sulfides and brecciated chert in drill holes FT-7, FT-10, FT-12, and FT-14. Chert intercepts range from 15 ft to 60 ft in thickness (Klein, 1988). Even though base-metal concentrations are low in Tract X (map A), it is considered to have a high potential for base-metal massive sulfide deposits on the basis of strong indications of the presence of massive sulfide bodies.

Tract XI (map A) consists of subsurface metavolcanic rocks in the southeastern part of the study area, in the Wawa subprovince. Significant exploration of these rocks has not taken place. The protoliths for these variably metamorphosed, generally medium grade rocks (Jirsa and Boerboom, 1990) are principally mafic volcanic rocks with a minor component of felsic volcanic rocks. The degree of deformation is moderate to high in this tract, and several northwest-striking fault segments are present. Because most of the volcanic rocks probably are mafic, a low potential for volcanogenic massive sulfide deposits is assigned to this tract. Exploration immediately south of the study area has concentrated on a bimodal mafic to felsic volcanic sequence that is not present in the study area (Jirsa and Boerboom, 1990).

Magnetic iron-formation, included in Tract XII (map A), is considered to have low potential for base-metal massive sulfide deposits. These iron-oxide-rich rocks, although sometimes spatially associated with massive sulfide deposits in this area and elsewhere, do not themselves normally contain economic base-metal accumulations. The presence of iron-rich rocks is one of the diagnostic criteria (see 3a in table 2) for massive sulfide deposits, which indicates the possible presence of submarine hydrothermal vents of the type that may control the emplacement of massive sulfide deposits.

NICKEL-COPPER-PLATINUM GROUP ELEMENT DEPOSITS IN GABBRO AND ULTRAMAFIC ROCKS, AND TITANIUM-VANADIUM IN GABBRO

Favorable host rocks for nickel-copper-PGE deposits in layered mafic-ultramafic rocks and titanium-vanadium in anorthosites, based on the deposit models of Eckstrand (1984b, c) and Gross and Rose (1984), respectively, have been identified in the Roseau 1°x2° quadrangle. Small deposits of titanium associated with the upper part of the nearby Grassy Portage gabbro and the Bad Vermilion anorthosite (both informal units) in the Mine Center area of Ontario (Poulsen, 1984) and nickel-copper deposits in the lower part of the Grassy Portage intrusion, the Dobie intrusion in the Emo area of Ontario (Fletcher and Irvine, 1954), and the recent discovery of Ni-Cu-PGE deposits in magmatic sulfide minerals within a layered mafic-ultramafic body, northeast of Baudette, Minn. (Nuinsco Resources Limited, 1995), are typical of those found elsewhere in Canadian greenstone terranes. Nickel sulfide deposits are associated, worldwide, with olivine-spinifex-bearing komatiites in both stratiform and stratabound accumulations (Lesher, 1989). Although no nickel deposits are known to be associated with komatiitic metavolcanic rocks in the Roseau quadrangle, komatiites are present within greenstone belts in the Wawa subprovince (Williams and others, 1991). The Shebandowan mine in the Wawa subprovince, east of the study area, is the largest Archean nickel-copper deposit in the Superior province. Minor komatiites are known within the western Wabigoon subprovince (Blackburn and others, 1991).

The nickel-copper-PGE potential of the study area has been assessed on the basis of the presence of favorable host rocks (mafic-ultramafic intrusions or komatiites). The identification of komatiites and ultramafic rocks in greenstone belts is usually difficult because of widespread serpentinization of ultramafic rocks during regional metamorphism. Primary textures in these rocks are generally obscured or destroyed during alteration, making it difficult to interpret even the simplest relationships—for example, whether the rocks were intrusive or extrusive. However, ultramafic and mafic rocks are typically enriched in nickel and chromium relative to more magmatically evolved rocks. As a consequence, favorable host rocks in the study area were defined as those rocks with chromium and nickel concentrations greater than 500 ppm (figs. 9, 10). These thresholds will discriminate rocks that are in the compositional range of some high-magnesium basalt and melagabbro and will include all the more magnesian rocks, such as komatiites and basaltic komatiites and their intrusive equivalents, for example, pyroxenite, peridotite, and dunite. The intrusive or extrusive nature of the rocks in most cases could not be determined from textures observed in drill core. However, because both komatiitic nickel-copper deposits and intrusion-hosted gabbroic and ultramafic nickel-copper deposits are associated with high-chromium and high-nickel rocks, this distinction is not necessary for the resource assessment.

The nickel-copper-PGE assessment is dependent on the ability to determine the presence of suitable host rocks, as in other deposit types considered in this assessment. Because most of the area is covered with glacial deposits, the ability to recognize favorable host rocks is mostly restricted to interpretations based on these rocks having a distinctive, consistent, and resolvable magnetic signature. Small intrusive or extrusive ultramafic bodies cannot always be reliably distinguished, based solely on aeromagnetic surveys, because they have undergone varying degrees of serpentinization, chloritic alteration, and metamorphism that may have reduced their magnetic intensity.

The potential for gabbro-anorthosite-hosted titanium-vanadium deposits cannot be accurately assessed in the study area because the compositional variation of most of the buried gabbro bodies is not well known. The sparse subsurface exploration data have not confirmed whether the magmatically evolved rocks (anorthosite) associated with these deposits are present in most of the gabbro bodies. However, any of the gabbro bodies in the study area (Day and others, 1994) that have a high-intensity magnetic signature (Bracken and others, 1989) are considered as a potentially favorable host for titanium-vanadium deposits. These same rocks may host nickel-copper sulfide accumulations in their more mafic lower parts such as that found in the Grassy Portage intrusion (Poulsen, 1984). The diagnostic criteria for nickel-copper-PGE assessment are given in table 4, and the scores for the six assessment tracts are given in table 5.

Granitoid rocks in the Wabigoon subprovince (Day and others, 1994) are included in Tract I (map B). They are not considered to have potential for nickel-copper-PGE deposits because they are unfavorable host rocks (table 5).

Tract II consists of granitoid and metasedimentary rocks in the Wabigoon, Wawa, and Quetico subprovinces. These rocks are considered to have no potential for nickel-copper-PGE deposits because they are unfavorable hosts. These rocks are also apparently not intruded by Archean mafic or ultramafic rocks that could be favorable hosts. The extreme contrast in magnetic properties between gabbroic or ultramafic intrusions and the granitoids and metasedimentary rocks in the Wabigoon, Wawa, and Quetico subprovinces should allow detection of even small gabbro bodies that would otherwise be undetectable in the magnetically highly textured metavolcanic units such as those in the Wabigoon and Wawa subprovinces. Variation in the degree of confidence between B and C is directly related to the number of drill holes in a tract and the thickness of the glacial cover in the area.

Felsic volcanic and volcanic metasedimentary units (Day and others, 1994) in the Wabigoon subprovince are texturally diverse and may contain some mafic or ultramafic volcanic rocks. Distinguishing these from the more felsic host rocks, using the aeromagnetic survey data, may be difficult. These felsic rocks are included in Tract III (map B) and are thought to have low potential (table 5) for nickel-copper-PGE deposits because of their dominantly felsic composition, even though small bodies of rocks with favorable compositions may be unrecognized within these largely felsic units.

Highly altered basaltic komatiite and chlorite- and serpentine-altered ultramafic (in part, probably komatiitic) rocks are inferred to be present locally, based on their distinctive geochemistry, in Tract IV (map B). Concentrations of nickel and chromium greater than 500 ppm in outcrop and drill-core samples of non-quartz-bearing, ferromagnesian mineral-rich rocks are considered to indicate the presence of ultramafic rocks (data from Klein and others, 1987, 1988; Klein, 1994a; Frey and Venzke, 1991). The distribution of these relatively chromium- and nickel-rich rocks is shown in figures 9 and 10. Spatially, these ultramafic rocks are commonly associated with the dominantly mafic volcanic units in the Wabigoon and Wawa suprovinces (Day and others, 1994), and, on that basis, we include these mafic volcanic units in Tract IV (map B). This tract has a moderate potential for nickel-copper-PGE deposits in ultramafic volcanic or intrusive rocks.

Most of the large gabbro bodies in the study area have distinctive magnetic characteristics. These intrusions, defined in Tract V (map B), have a moderate potential for gabbro-hosted nickel-copper-PGE deposits. Included in this tract is the layered gabbro-peridotite body south of Warroad, Minn., which was encountered in several drill holes (see Klein and Day, 1989; Klein and others, 1987). Contacts of this body are defined on the basis of magnetic and gravity data (Bracken and others, 1989; Horton and Chandler, 1988). No nickel sulfide minerals were encountered in limited exploration of this body. Several small gabbro sills containing nickel sulfide minerals were intersected in drill holes R-2-1 and R-2-2 (fig. 10, and map B). These sills do not have a magnetic expression that is detectable by regional aeromagnetic surveys because they contain few magnetic minerals or because they are masked by the adjacent magnetically "noisy" mafic volcanic and bimodal volcanic units (see Klein, 1994b, for graphic lithologic log of R-2-2; Klein, 1994a, for Ni assays). The potential for nickel-copper-PGE deposits in small gabbro bodies of this type is considered to be the same as that of the mafic volcanic and bimodal volcanic units in the Wabigoon and Wawa subprovinces (Tract IV, map B).

Recent exploration in southwestern Ontario has outlined a potential Ni-Cu-PGE deposit in a gabbro-pyroxenite body in the volcanic rocks of the Wabigoon subprovince, about 50 km northeast of Baudette, Minn. (prospect area in the northeastern part of the area of fig. 11) (Blackburn and Hinz, 1996). A 3-m sulfide-rich intercept with 3.3 percent Ni, 2.3 percent Cu, 3.5 g/t Pt, and 7.9 g/t Pd is contained within a body of mafic-ultramafic host rocks that is at least 135 m thick and that has a strike length of 1,200 m (Nuinsco Resources Limited, unpublished company report, June 1996). Proximity of the mineralized rocks to similar rocks southeast of Baudette, Minn., somewhat increases the potential for deposits of this type in the study area even though rocks in the two areas are mapped as different units.

Iron-formation associated with mafic metavolcanic and metasedimentary rocks in the Wabigoon subprovince is included in Tract VI (map B) and is considered to have no potential for nickel-copper-PGE sulfide deposits. Magnetic iron-formation is not generally considered a favorable host for the accumulation of these elements elsewhere, and deposits are not known to be present in them.

ALGOMA-TYPE IRON-FORMATION

In the Wabigoon subprovince in the northeast corner of the study area, a thin unit of magnetic iron-formation, explored by drilling at its west end, can be traced for a distance of more than 30 km by aeromagnetic data (Bracken and others, 1989). Many other thin iron-formations are easily distinguished because of their extremely magnetic character. Several have been intersected in drill holes.

The metasedimentary rocks of the Quetico subprovince (Day and others, 1994) lack known iron-formation and, in the study area, lack the characteristic magnetic anomalies caused by iron-formation, even though the character of the host rock is

Table 4. *Diagnostic criteria for nickel-copper-platinum group element deposits in gabbro and ultramafic rocks in the Roseau 1°x2° quadrangle*

1. Presence of layered gabbro, dunite, peridotite, pyroxenite, anorthosite, and norite intrusions or komatiitic volcanic rocks or subvolcanic sills.
2. Anomalously high concentrations of nickel, copper, ± cobalt, PGE; presence of nickel and (or) copper sulfide or arsenide minerals.

Table 5. *Resource potential for gabbro- and ultramafic-intrusion-associated nickel-copper-platinum group element deposits and komatiite nickel-copper deposits in the Roseau 1°x2° quadrangle*

Tract No. (map B)	Diagnostic criteria 1	2	Sum of tract scores	Resource potential	Confidence level
I	-1	0	-1	None	C
II	-1	0	-1	None	B, C
III	0	0	0	Low	C
IV	1	1	2	Moderate	B
V	1	0	1	Moderate	B, C
VI	-1	0	-1	None	C

permissive. These rocks do not have potential for Algoma-type iron-formation, because iron-formation has not been reported in rocks of this type elsewhere in the subprovince and bedrock in the subprovince lacks the characteristic magnetic anomalies associated with iron-formation found in other parts of the study area. The plutonic rocks of the Wabigoon and Quetico subprovinces do not have potential for iron-formation, except in roof pendants or rafts of country rock, because of their igneous origin.

Iron-formation layers in the study area are less than 10 m thick, based on the results of drilling and by inference from the aeromagnetic data. No substantive amount of structural thickening, which is commonly necessary to produce an economic deposit from thin layers of banded iron-formation, is apparent in the aeromagnetic map (Bracken and others, 1989). The location of the known and inferred Algoma-type iron-formation is summarized in figure 4, based on the geologic map of Day and others (1994). Because the known and inferred thickness of iron-formation layers is thought to be less than that needed for exploitation, the mineral resource potential for iron-formation has not been assessed.

ARCHEAN LOW-SULFIDE GOLD-QUARTZ VEIN DEPOSITS

Diagnostic criteria for Archean low-sulfide gold-quartz vein deposits (table 6) are based on the deposit model of Klein and Day (1994). This model is derived from several models (Thorpe and Franklin, 1984a, b) and reviews on the formation of Archean Au-quartz vein deposits (Hodgson and MacGeehan, 1980; Hodgson, 1989; Roberts, 1987). Twelve tracts were defined, and the resource potential for them is summarized in table 7 and map C.

Tract I consists of metasedimentary rocks of the Quetico subprovince (map C) that (1) are located more than 2 km from known or inferred shear zones, (2) are not sheared, and (3) do not contain anomalous gold concentrations (figs. 11, 12). This tract is considered to have low potential for Archean low-sulfide Au-quartz vein deposits (table 7). The assessment has a moderate degree of confidence because shear zones in these rocks are somewhat difficult to detect if density and magnetic contrasts between units are low. Most of the rock units in the metasedimentary part of the Quetico subprovince have low-intensity magnetic signatures (Bracken and others, 1989), which does not allow the delineation of offsets or abrupt linear terminations of rock units that are normally used, along with magnetic surveys, to identify possible shear zones. Basal till samples in several drill holes near Littlefork, Minn., immediately east of the study area in the adjacent International Falls 1°x2° quadrangle (Klein and others, 1997), contain relatively coarse grained gold from an undetermined source, which suggests that the source of the gold is nearby in the metasedimentary rocks of the Quetico subprovince (Martin and others, 1988).

Tract II (map C) includes plutonic and supracrustal rocks of the Wawa subprovince that are more than 2 km from known or inferred shear zones or isolated intervals of highly deformed rocks in drill holes (fig. 12). These rocks are assigned a low potential for Archean low-sulfide Au-quartz vein deposits (table 7). However, the geologic, geophysical, and geochemical characteristics by which the presence of the diagnostic criteria was determined are poorly known in this tract, and, therefore, the assessment has a low degree of confidence.

Tract III, located along a segment of the Vermilion fault, is in rocks of the Quetico subprovince (map C). Because of the lack of past

Table 6. *Diagnostic and permissive criteria for Archean low-sulfide gold-quartz vein deposits in the Roseau 1°x2° quadrangle*

Diagnostic criteria:

1. Presence of anomalous gold and silver concentrations in drill core or B-horizon soil samples.
2. Proximity to shear zones (<2 km), or presence of structural "breaks," dilatant zones, or highly sheared rock.
3. Evidence of appropriate hydrothermal alteration.
   a. Vein and (or) ribbon quartz.
   b. Carbonate alteration minerals.
   c. Potassic alteration (sericite).
   d. Anomalous boron (exclusive of high abundances typical of sedimentary rocks and massive sulfide deposits).
   e. Anomalous concentrations of As, Se, W, Hg, Sb, Te, Mo, Bi, Zn, and (or) Cu in soil or rock samples.
   f. Disseminated or vein-filling arsenopyrite or pyrite.

Permissive criteria:

1. Presence of chemically favorable host rock, such as iron-formation and iron-rich tholeiitic basalt.
2. Presence of fuchsite or scheelite.

Table 7. *Resource potential for Archean low-sulfide gold-quartz vein deposits in the Roseau 1°x2° quadrangle*

[Superscript letters indicate which type of hydrothermal alteration is present in a given tract. Criterion 3f, presence of disseminated or vein-filling arsenopyrite or pyrite, was not recognized in the present study]

Tract No. (map C)	Diagnostic criteria 1	2	3	Sum of tract scores	Resource potential	Confidence level
I	0	0	0	0	Low	B
II	0	0	0	0	Low	B
III	0	1	0	1	Low	B
IV	0	0	1[d,e]	1	Low	B
V	0	1	0	1	Low	B
VI	0	0	1[e]	1	Low	B
VII	0	1	1[a,b,e]	2	Moderate	B
VIII	0	1	1[a,b,c,d]	2	Moderate	B, C
IX	0*	1	1[d,e]	2	Moderate	B
X	1	1	1[a,b,c,d,e]	3	High	B, C

*Gold present in this tract is related to massive sulfide deposits.
[a]Vein and (or) ribbon quartz.
[b]Carbonate alteration minerals.
[c]Potassic alteration (sericite).
[d]Anomalous boron (exclusive of high abundances typical of sedimentary rocks and massive sulfide deposits).
[e]Anomalous concentrations of As, Se, W, Hg, Sb, Te, Mo, Bi, Zn, and (or) Cu in soil or rock samples.

production of this type, even in well-exposed, adjacent areas in Canada, Tract III has a low potential for Archean low-sulfide Au-quartz vein deposits (table 7). However, in Tract III, the presence of a fracture system of the same age as that which may be gold-bearing elsewhere suggests that rocks in this tract are more favorable for gold deposits than rocks in other parts of the Quetico subprovince. No anomalous gold concentrations are known in bedrock or soils in this tract. The degree of confidence placed in the assessment of Tract III is low because few bedrock samples are available to evaluate for the diagnostic criteria and only one soil geochemistry traverse crosses the structure (see Carlson and Clark, 1995).

Granitoid and supracrustal rocks in the Wabigoon subprovince that are located more than 2 km from known or inferred shear zones are included in Tract IV (map C). These rocks contain isolated drill holes, some of which intersect carbonate and quartz veins (figs. 13, 14). None of the carbonate and quartz veins encountered contain enrichments in gold (fig. 11) or associated elements, nor does the geochemical analysis of overlying soils indicate anomalies thought to indicate lode gold potential (see Carlson and Clark, 1995). The western parts of this tract (map C) have had little exploration drilling. Due to problems with access, the same area was poorly sampled during the soil geochemistry survey (Carlson and Clark, 1995). Rocks in this tract are assigned a low potential for Archean low-sulfide Au-quartz vein deposits. Because of sparse knowledge of the bedrock in most of this tract, the assessment for this tract has a low degree of confidence.

Rocks adjacent to several major known or inferred shear zones in the Wabigoon subprovince are included in Tract V (map C). The bedrock geochemistry and the extent and character of hydrothermal alteration along these segments are poorly known, and most of these tracts are largely unsampled by soil geochemistry (Carlson and Clark, 1995; this report, figs. 11–14). This tract has a low potential for Archean low-sulfide Au-quartz vein deposits and a low degree of confidence in its classification.

Tract VI (map C) is underlain by large granitoid bodies and a subordinate amount of mafic and felsic volcanic rocks. Bedrock in this tract is seen in only a few outcrops and in two shallow bedrock cores. The boundary of the tract is defined by widespread tellurium anomalies in soil samples (Carlson and Clark, 1995). Because tellurium enrichment is commonly associated with Archean low-sulfide Au-quartz vein deposits, these anomalies may reflect hydrothermal activity related to the formation of gold deposits. The tract lacks any definitive indications of shear zones in the aeromagnetic data (Bracken and others, 1989) or in the two bedrock drill holes. However, the lack of contrast in the magnetic properties of these granitoids makes the presence of shear zones difficult to detect. Even though the tellurium soil anomalies may indicate the presence of potential gold-bearing hydrothermal systems, the lack of diagnostic criteria 1 and 2 (table 6: gold enrichment and sheared rocks) requires the tract to be ranked as having low potential for Archean low-sulfide Au-quartz vein deposits. Due to lack of information on the character of its bedrock, the assessment of this tract has a low degree of confidence.

Tract VII (map C) is underlain by deformed rocks near the Four Town and Border faults, northeast-striking structures in the west and central parts of the study area (Day and others, 1994). The tract is considered to have moderate potential for the presence of Archean low-sulfide Au-quartz vein deposits (table 7) on the basis of the presence of these inferred fault zones and anomalous metal concentrations in soil samples (Carlson and Clark, 1995). This classification has a low degree of confidence because of a lack of bedrock data for this tract.

Metavolcanic rocks and granitoid rocks in the Wabigoon subprovince near Birchdale, Minn. (east of the study area), contain low-level gold and base-metal anomalies in several exploration drill holes (figs. 6, 7, 11). A small mineralized shear zone was reported in drill hole MR 86-1, immediately east of the study area near Birchdale (Klein and Day, 1989), although it was not detected in the airborne magnetic survey. Because anomalous gold and zinc concentrations are present in this minor shear zone (see Klein, 1994a, for assays), Tract VIII, in the Birchdale area, has a moderate potential, with moderate confidence, for Archean low-sulfide Au-quartz vein deposits. The classification of moderate potential for the Warroad, Minn., area is based on the presence of quartz and carbonate veins and small shear zones intersected in scattered drill holes. However, because these shear zones are not apparently regional in nature and the sampled drill core intervals lack gold mineralization, this part of Tract VIII has a higher degree of confidence than the area near Birchdale, Minn. (table 7 and map C).

A small wedge-shaped area, underlain mostly by bimodal metavolcanic rocks located between the Border fault and the Vermilion fault in the central part of the study area (Day and others, 1994), is included in Tract IX (map C). The bedrock contains evidence of shearing (fig. 12) and petrographic evidence of hydrothermal alteration (figs. 13, 14). However, the scattered gold anomalies shown in figure 11 may be related to massive sulfide deposits and are not necessarily considered to be indicative of epigenetic gold deposits. Tract IX has been assigned a moderate potential for Archean low-sulfide Au-quartz vein deposits (table 7) with a moderate degree of confidence.

Tract X, composed of highly deformed rocks along parts of the Rainy Lake–Seine River, Baudette, Quetico, and Black River faults (Day and others, 1994), is assigned a high potential for Archean low-sulfide Au-quartz vein deposits because of the coincidence of gold anomalies in bedrock and till samples (fig. 11), structurally favorable shear zones (fig. 12), calcite and quartz veins (figs. 13, 14), and metal anomalies in the thin overburden. Anomalous soil geochemistry (Carlson and Clark, 1995) and several gold anomalies in the nonmagnetic fraction of heavy mineral concentrates from till samples (Martin and others, 1991) may indicate the presence of epigenetic Archean lode gold deposits. These geochemical gold anomalies have been used to partially define the boundaries of this tract. Recent bedrock drilling on gold anomalies found in basal till by the Ontario Geological Survey (Bajc, 1991) have indicated the presence of a gold deposit in southwestern Ontario, northwest of Baudette, Minn. (fig. 11), in felsic volcanic rocks north of the Quetico fault (Blackburn and Hinz, 1996). Initial announcements by Nuinsco Resources Limited indicated substantial amounts of gold contained in this deposit with a preliminary estimate of 55 million tons at 0.075 g/t Au (Nuinsco Resources Limited, 1995). Gold grades range from 0.7 to 3.4 g/t over intercepts of 30–50 m (Anonymous, 1997). Along the Quetico fault and subsidiary structures east of the study area, where they are exposed near Mine Centre, Ontario, gold deposits typically contain less than 350 kg gold (Poulsen, 1984). The small size of these known deposits may be due to the dominance of lateral movement over vertical movement (Sibson, 1989) and the resulting lack of development of subsidiary structures. In Minnesota, some exploration has taken place along parts of these structures included in Tract X (map C).

MISCELLANEOUS DEPOSITS

The Canadian part of the Quetico subprovince, although well exposed, has not produced any metallic resources. However, the metasedimentary belts have received relatively little exploration. Pegmatite-hosted deposits contain rare earth elements, Nb-Ta, Li, U, and Th, at some places in the belt; however, they were not evaluated during this study. Recently, some exploration for Ni, Cu, and PGE in syntectonic mafic and ultramafic bodies in the Quetico subprovince has taken place in Canada. The results of this exploration were not available for this assessment.

SUMMARY AND CONCLUSION

The supracrustal rocks of the Wabigoon and the Wawa subprovinces in the Roseau quadrangle, northern Minnesota, contain several areas of moderate to high potential for volcanogenic Cu-Zn-rich massive sulfide deposits, Archean low-sulfide Au-quartz vein deposits, and Ni-Cu deposits in ultramafic rocks.

High potential for volcanogenic massive sulfide deposits is found in several tracts in the central part of the study area (map A). Tract VIII, located southeast of Baudette, Minn. (map A), contains many drill holes that intersect variably deformed bimodal volcanic rocks. These rocks contain many of the diagnostic criteria that are favorable for volcanogenic massive sulfide deposits (table 3). Drill holes in Tract IX (map A), which is located approximately 40 km southwest of Baudette, Minn., contain several significant intercepts of base-metal-bearing massive sulfide in bimodal volcanic rocks. Near the common corner of Beltrami, Lake of the Woods, and Roseau Counties, evidence of thick massive sulfide intercepts, siliceous exhalites, and explosive felsic volcanic activity is found in several drill holes. These favorable rocks define Tract X (map A).

Some gabbroic rocks and possible isolated occurrences of komatiitic volcanic rocks in the greenstone parts of the Wabigoon and Wawa subprovinces have a moderate potential for magmatic or komatiitic Ni-Cu deposits. Some of these deposits typically contain enrichments in the platinum-group elements. Tract V, in the central part of the area of map B, has a moderate potential for Ni-Cu deposits in a large, poorly explored gabbroic body. The greenstones that make up much of Tract IV may contain komatiitic nickel deposits. Several drill holes in the study area encountered highly deformed or altered rocks of uncertain origin having ultramafic compositions.

Areas of high potential for Archean low-sulfide Au-quartz vein deposits are located in Tract X (map C) along several segments of the Rainy Lake–Seine River fault and the Vermilion fault. In addition, several tracts with moderate and high potential for these deposits, such as Tracts VII, VIII, and IX (map C), underlie large areas of the central part of the Roseau 1°x2° quadrangle.

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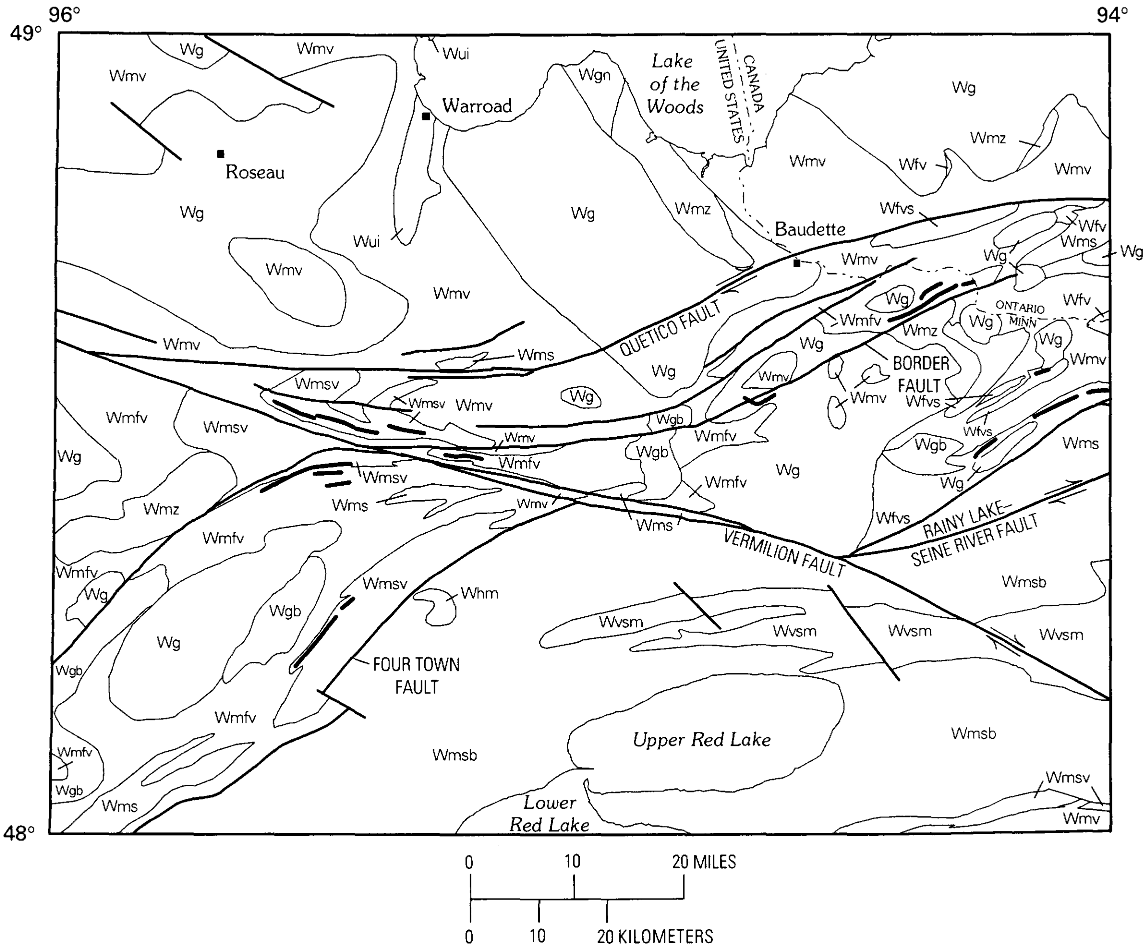


EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
(heavy line)	**Iron-formation**
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**

Contact

Fault—Opposed arrows show relative movement where known

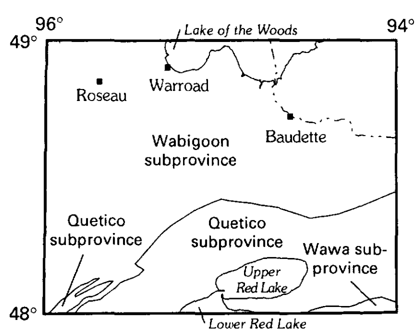


Figure 1. Generalized regional bedrock geologic map.

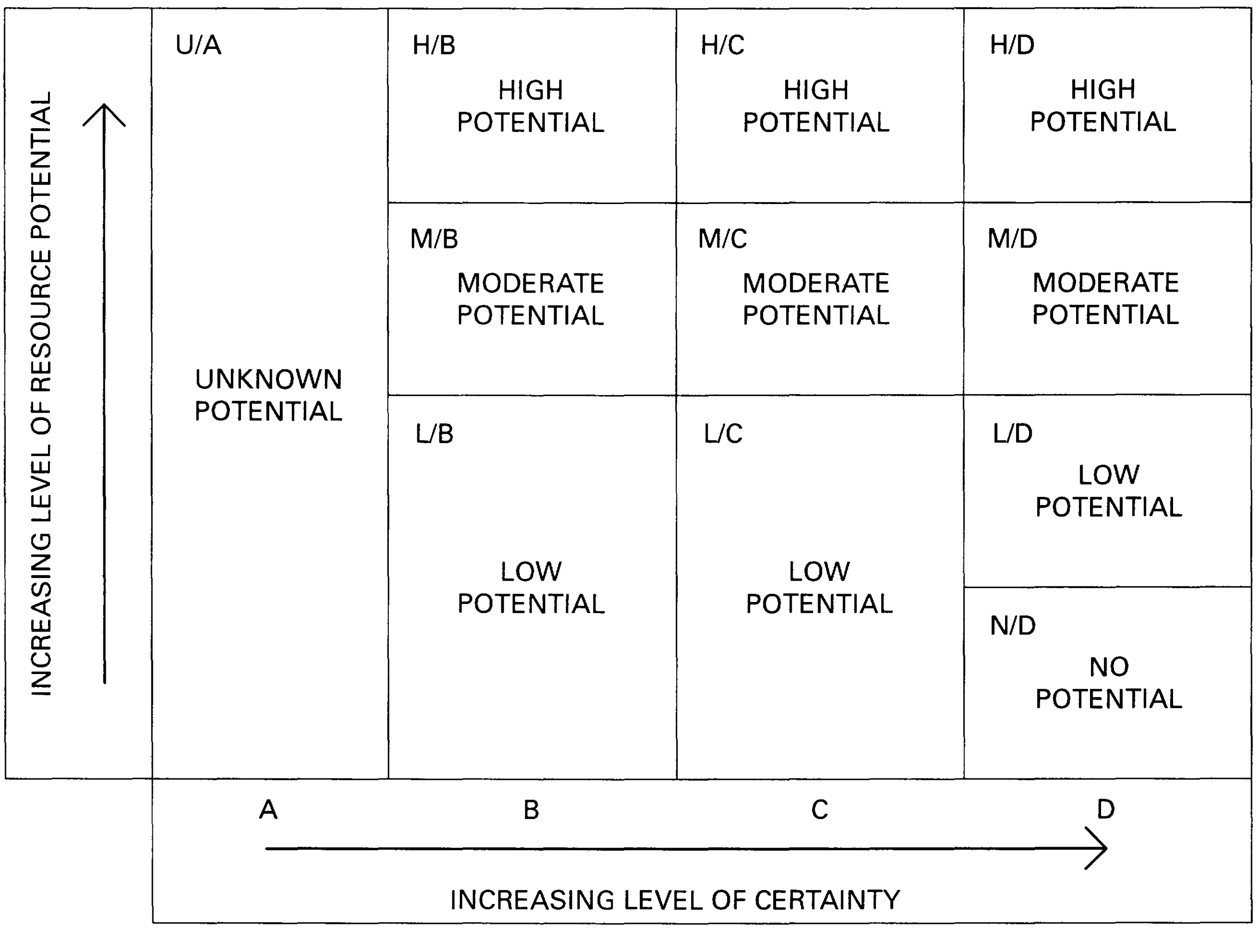
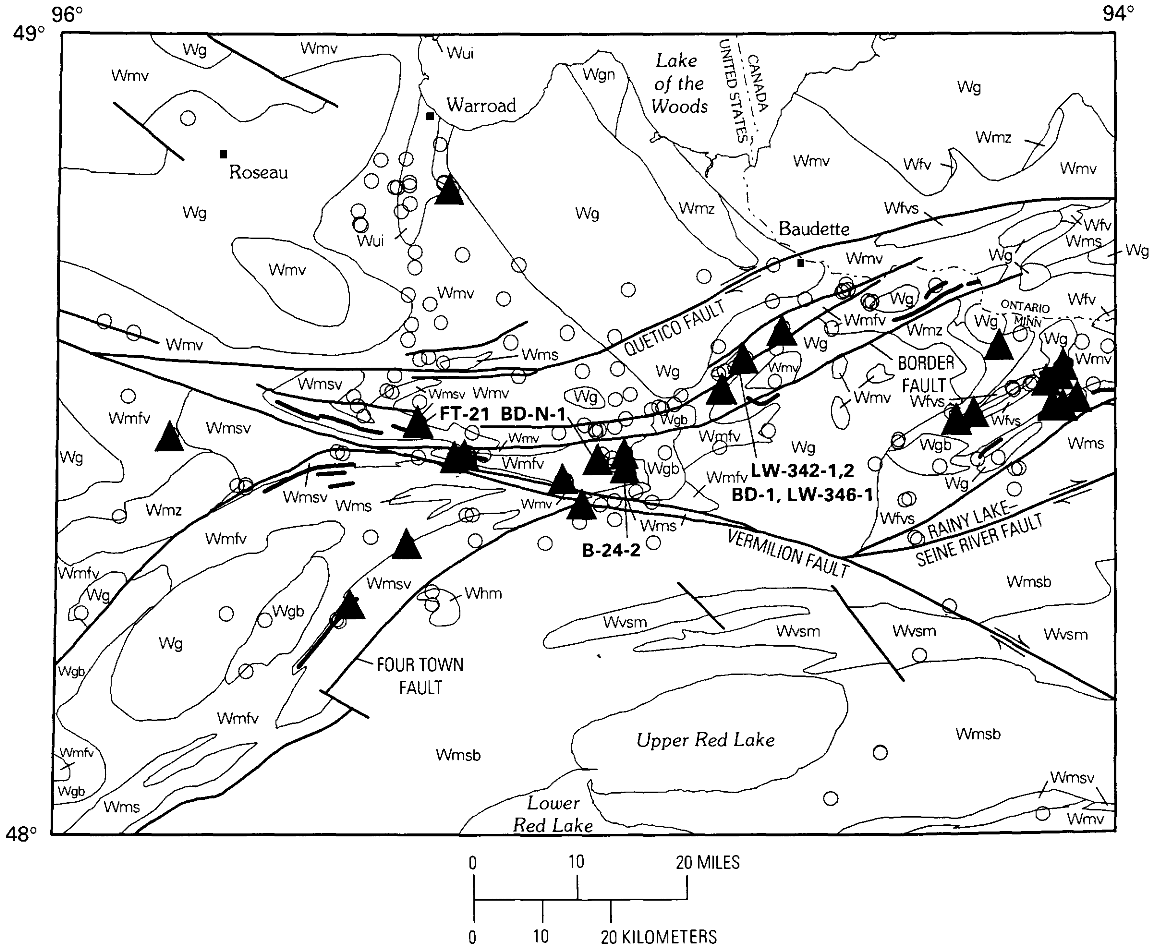


Figure 2. Relation between levels of resource potential and certainty (from Goudarzi, 1984).



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

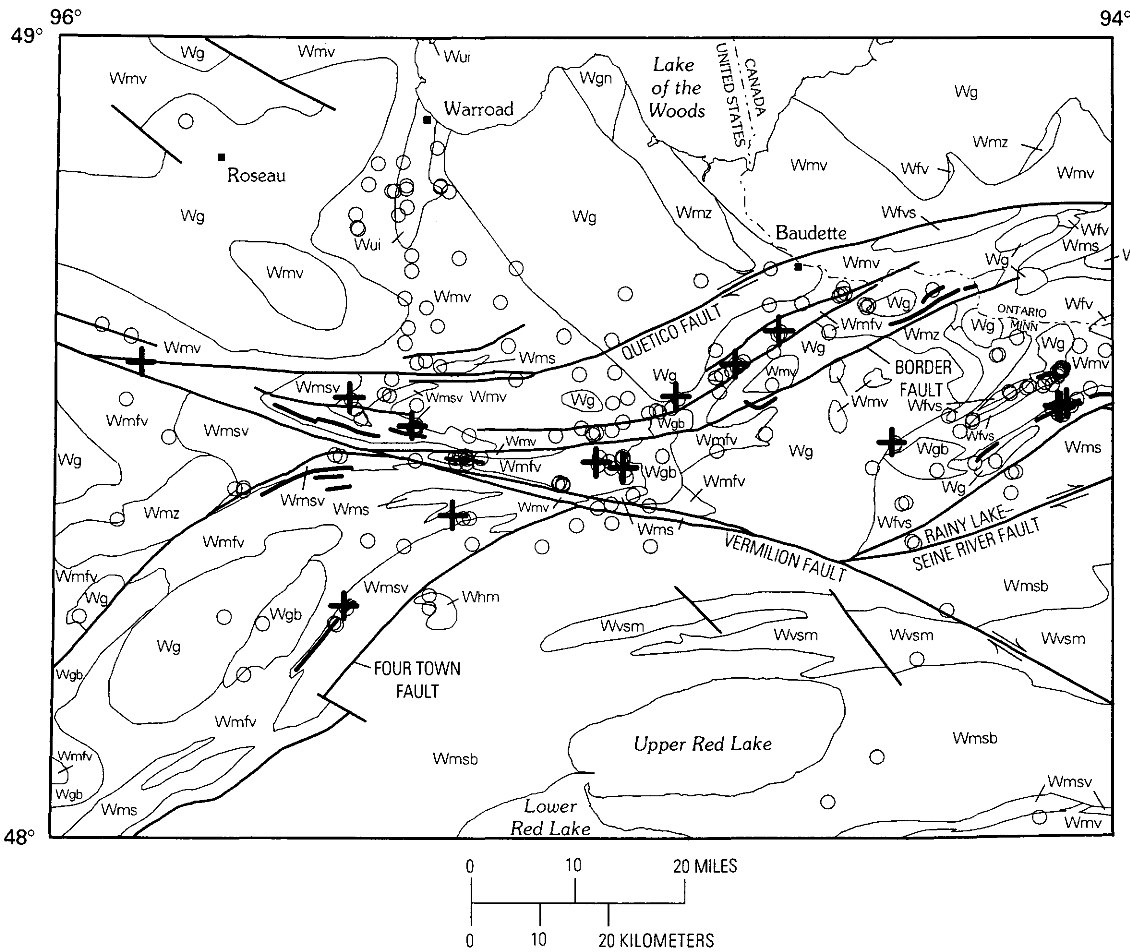
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
○	**Drill hole**
▲	**Drill hole containing coarse-grained felsic volcanic rocks and flows**—Numbered when referred to in text

Figure 3. Generalized geologic map showing distribution of drill holes containing intervals of coarse felsic volcaniclastic breccia and rhyolite flows in bedrock.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
(heavy line)	**Iron-formation**
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

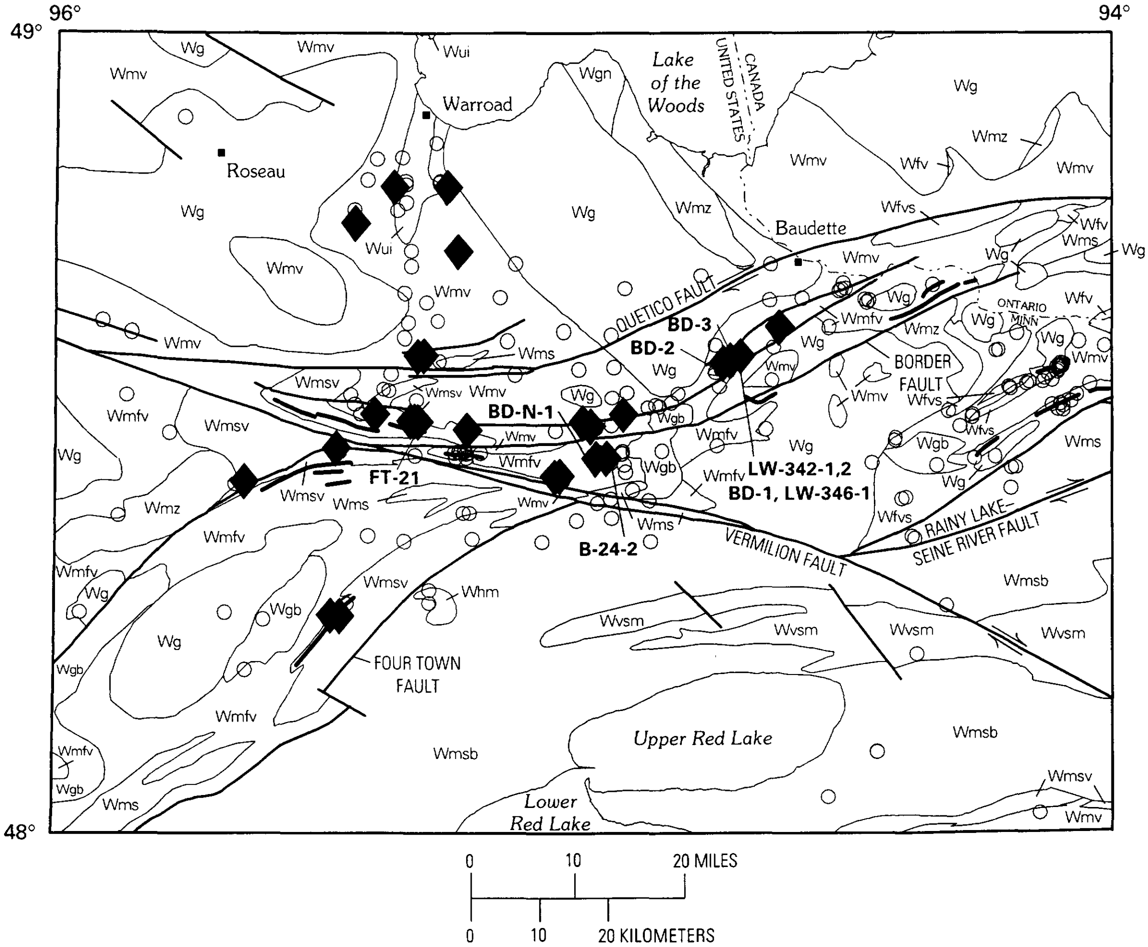
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
———	**Contact**
(fault symbol)	**Fault**—Opposed arrows show relative movement where known
○	**Drill hole**
✚	**Drill hole containing iron-formation**

Figure 4. Generalized geologic map showing distribution of drill holes containing iron-formation and iron-formation layers inferred from aeromagnetic interpretation.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

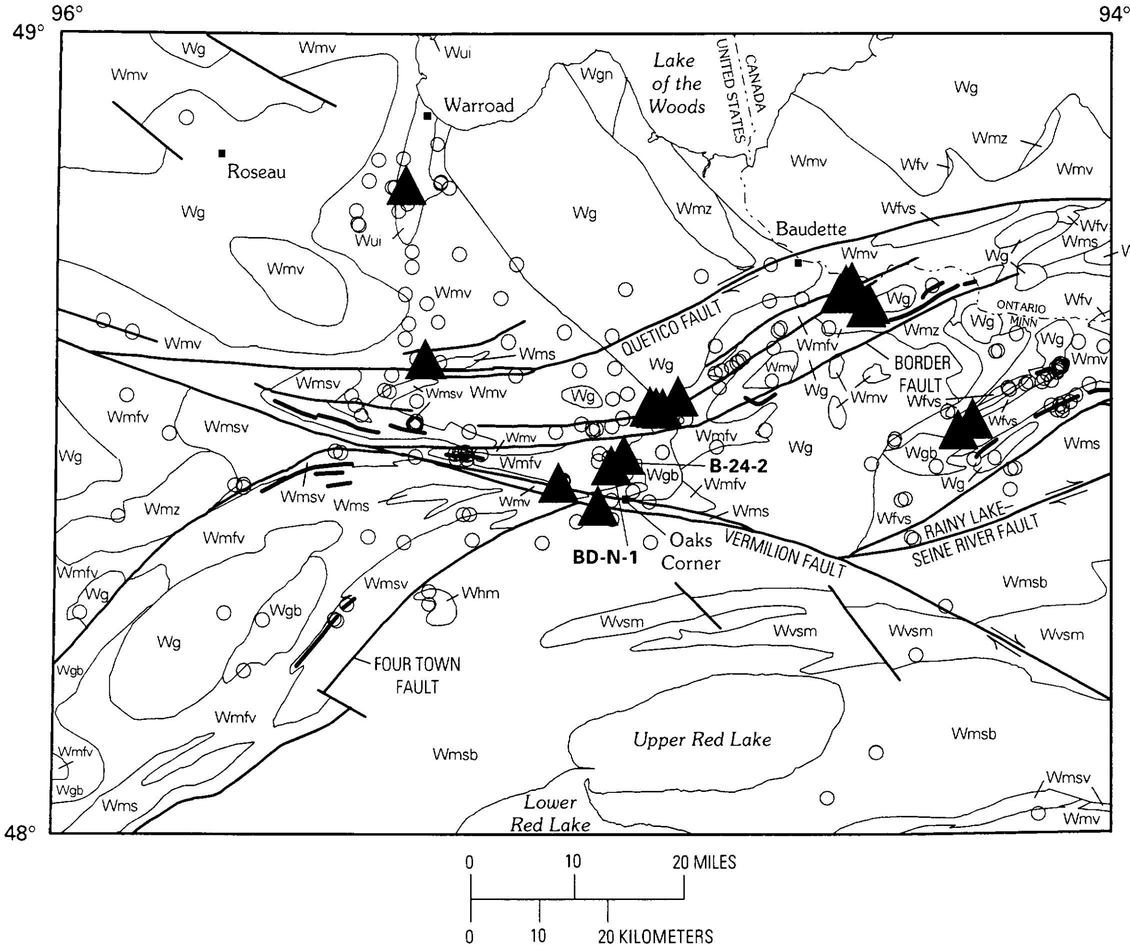
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
	Drill hole
	Drill hole containing hydrothermal chert interval—Numbered when referred to in text

Figure 5. Generalized geologic map showing distribution of drill holes containing hydrothermal chert intervals.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**

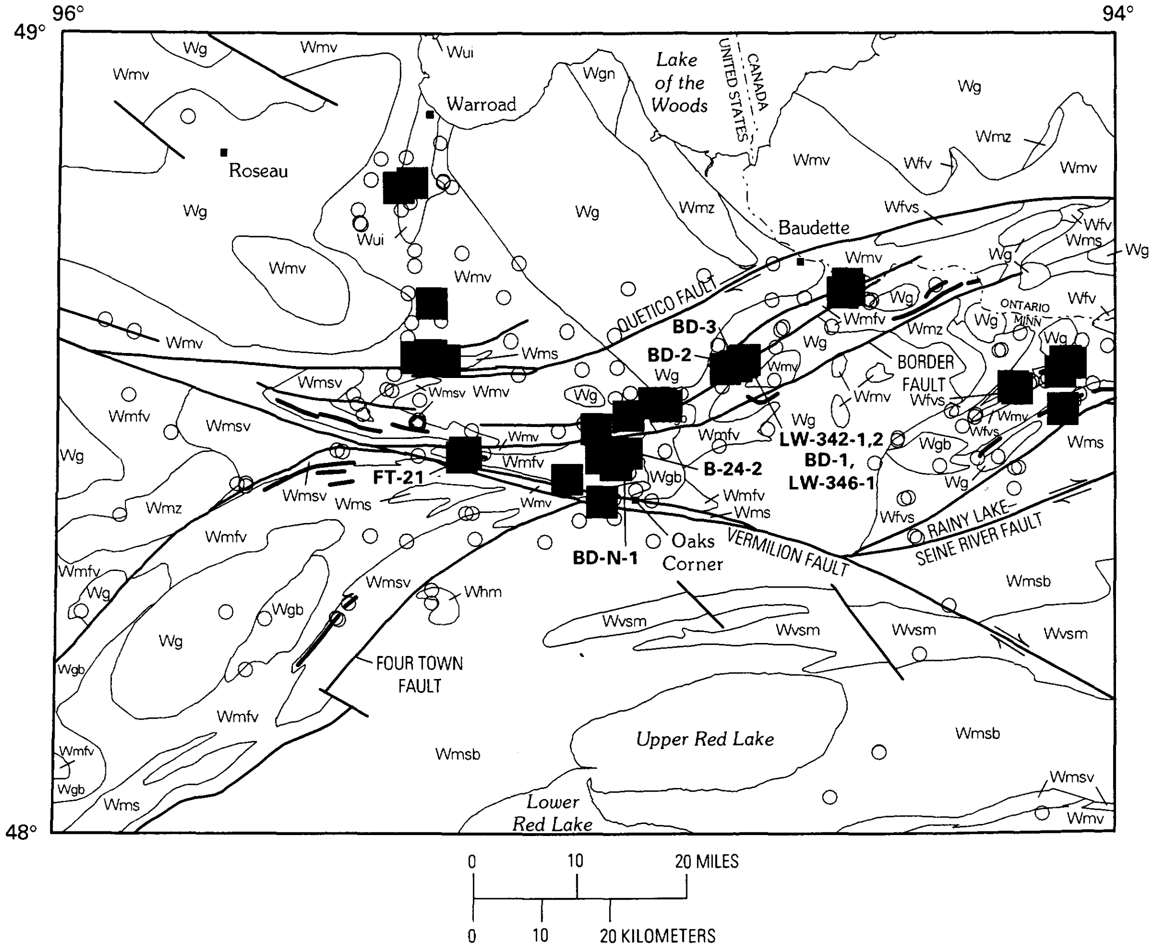
Contact

Fault—Opposed arrows show relative movement where known

Drill hole

Drill hole with average intercept of greater than 500 ppm Cu—Numbered when referred to in text

Figure 6. Generalized geologic map showing distribution of average assay intervals in drill holes having copper concentrations greater than 500 ppm. Average assay = (drill-hole length x assay) / drill intercept length.



EXPLANATION

Late Archean units

Wabigoon subprovince

- Wg — **Granite**
- Wgn — **Granitic gneiss**
- Wmz — **Monzonite**
- Wgb — **Gabbro**
- Wui — **Ultramafic to mafic intrusive rocks**
- Wmsv — **Volcaniclastic and volcanic rocks**
- **Iron-formation**
- Wms — **Biotite schist (metagraywacke)**
- Wfv — **Felsic volcanic rocks**
- Wfvs — **Felsic volcaniclastic rocks**
- Wmfv — **Mafic and felsic volcanic rocks**
- Wmv — **Intermediate to mafic volcanic rocks**

Late Archean units

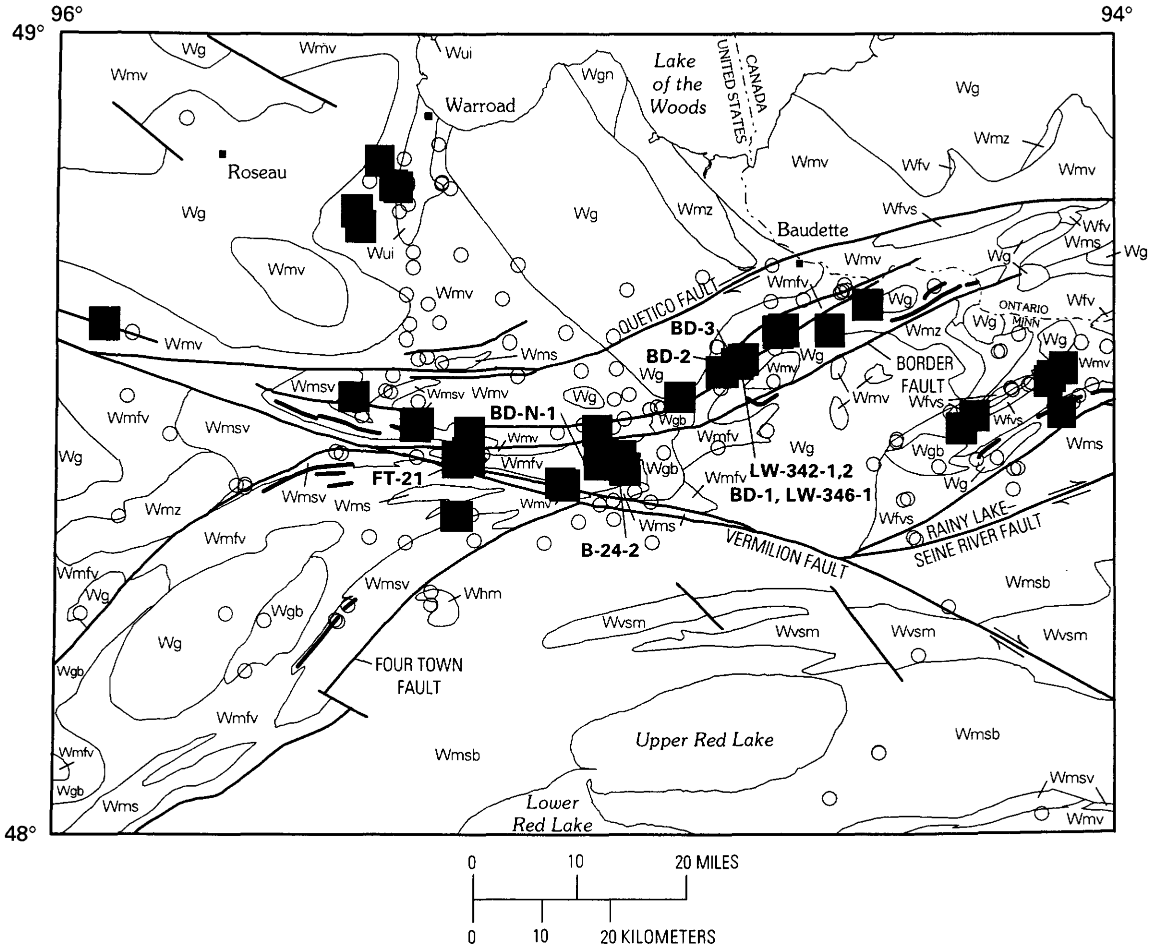
Wawa subprovince

- Wmsv — **Volcaniclastic and volcanic rocks**
- Wmv — **Intermediate to mafic volcanic rocks**

Quetico subprovince

- Whm — **Hornblende monzonite**
- Wvsm — **Schist-rich migmatite**
- Wmsb — **Garnet-biotite schist (metagraywacke)**
- **Contact**
- **Fault**—Opposed arrows show relative movement where known
- **Drill hole**
- **Drill hole with average assay interval greater than 500 ppm Zn**—Numbered when referred to in text

Figure 7. Generalized geologic map showing distribution of average assay intervals in drill holes having zinc concentrations greater than 500 ppm. Average assay = (drill-hole length x assay) / drill intercept length.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
(line symbol)	**Iron-formation**
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**

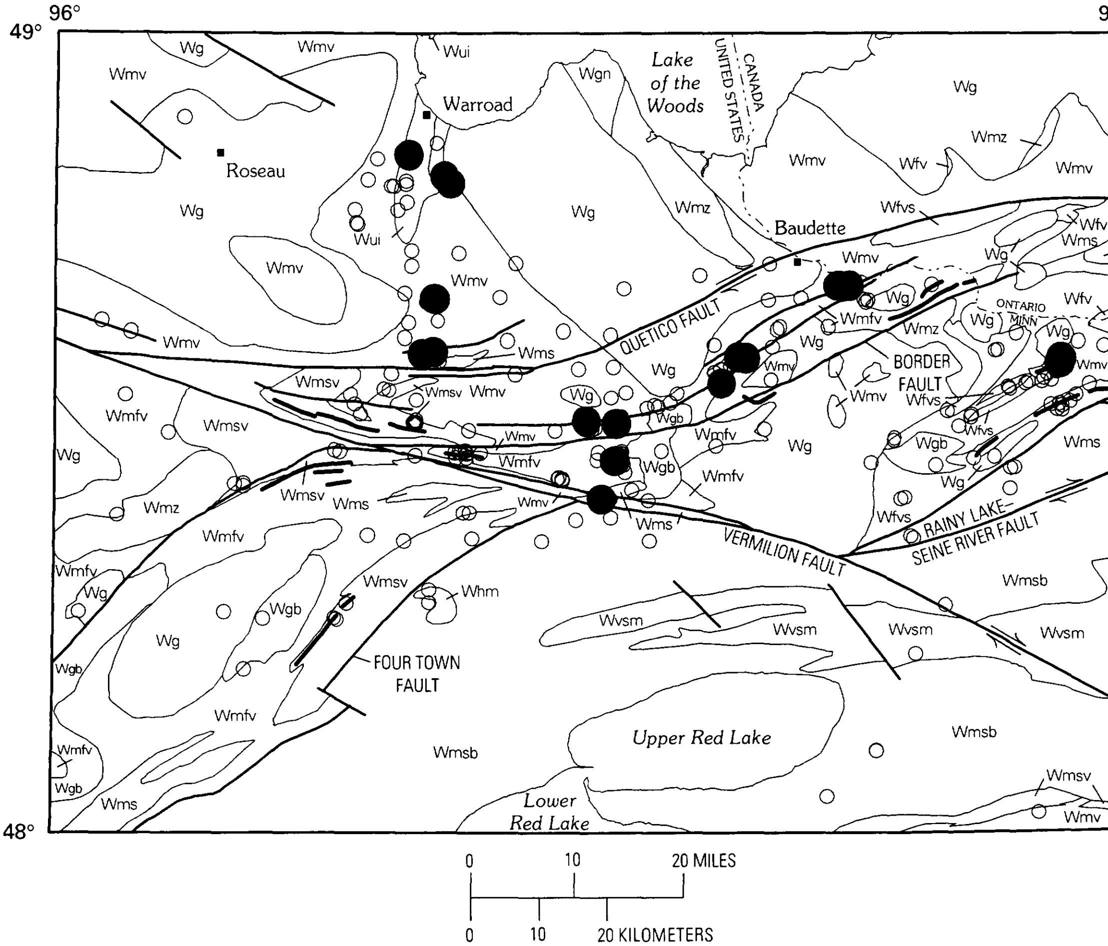
Contact

Fault—Opposed arrows show relative movement where known

Drill hole

Drill hole having a total intercept of more than 2.5 ft of massive sulfide—Numbered when referred to in text

Figure 8. Generalized geologic map showing distribution of drill holes containing massive sulfide intercepts.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

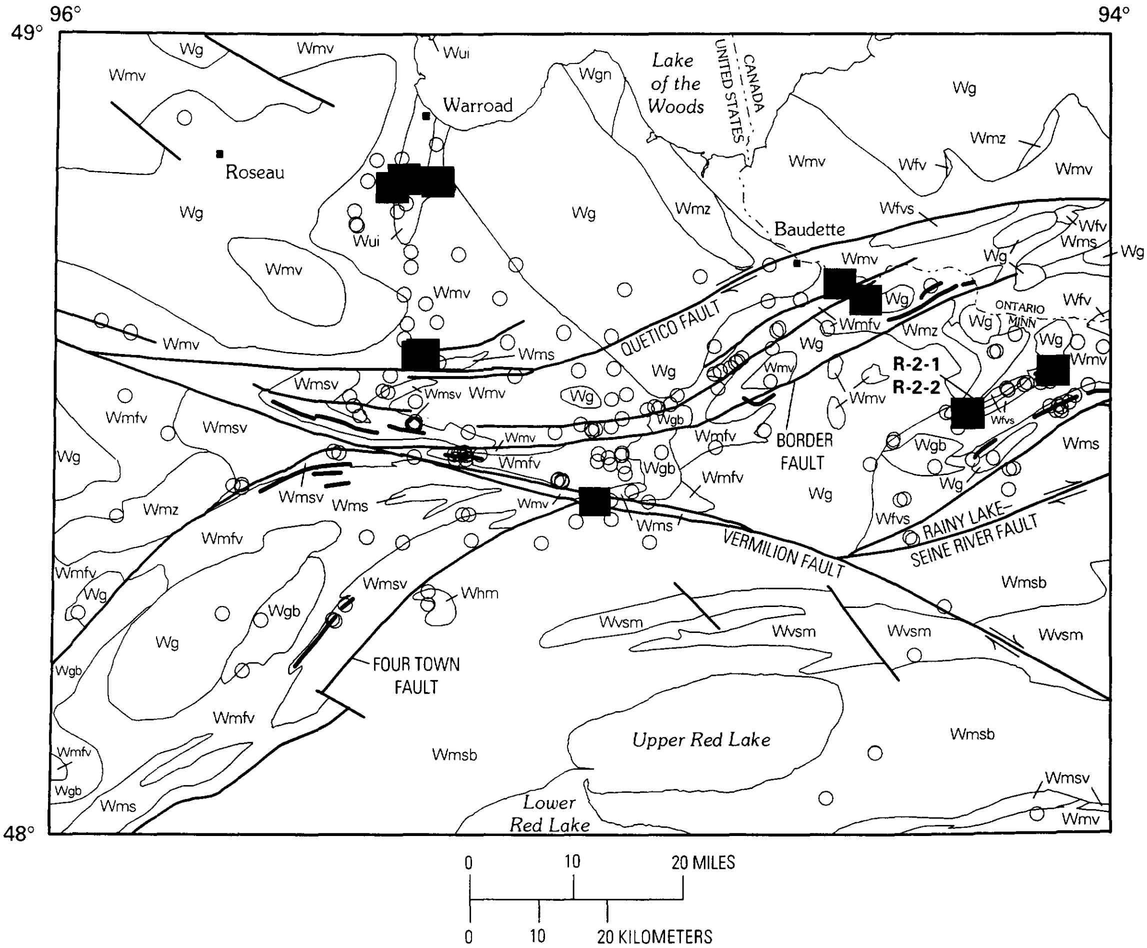
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
○	**Drill hole**
●	**Bedrock samples having greater than 500 ppm Cr**

Figure 9. Generalized geologic map showing distribution of bedrock sample localities having greater than 500 ppm chromium.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg **Granite**

Wgn **Granitic gneiss**

Wmz **Monzonite**

Wgb **Gabbro**

Wui **Ultramafic to mafic intrusive rocks**

Wmsv **Volcaniclastic and volcanic rocks**

Iron-formation

Wms **Biotite schist (metagraywacke)**

Wfv **Felsic volcanic rocks**

Wfvs **Felsic volcaniclastic rocks**

Wmfv **Mafic and felsic volcanic rocks**

Wmv **Intermediate to mafic volcanic rocks**

Late Archean units

Wawa subprovince

Wmsv **Volcaniclastic and volcanic rocks**

Wmv **Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm **Hornblende monzonite**

Wvsm **Schist-rich migmatite**

Wmsb **Garnet-biotite schist (metagraywacke)**

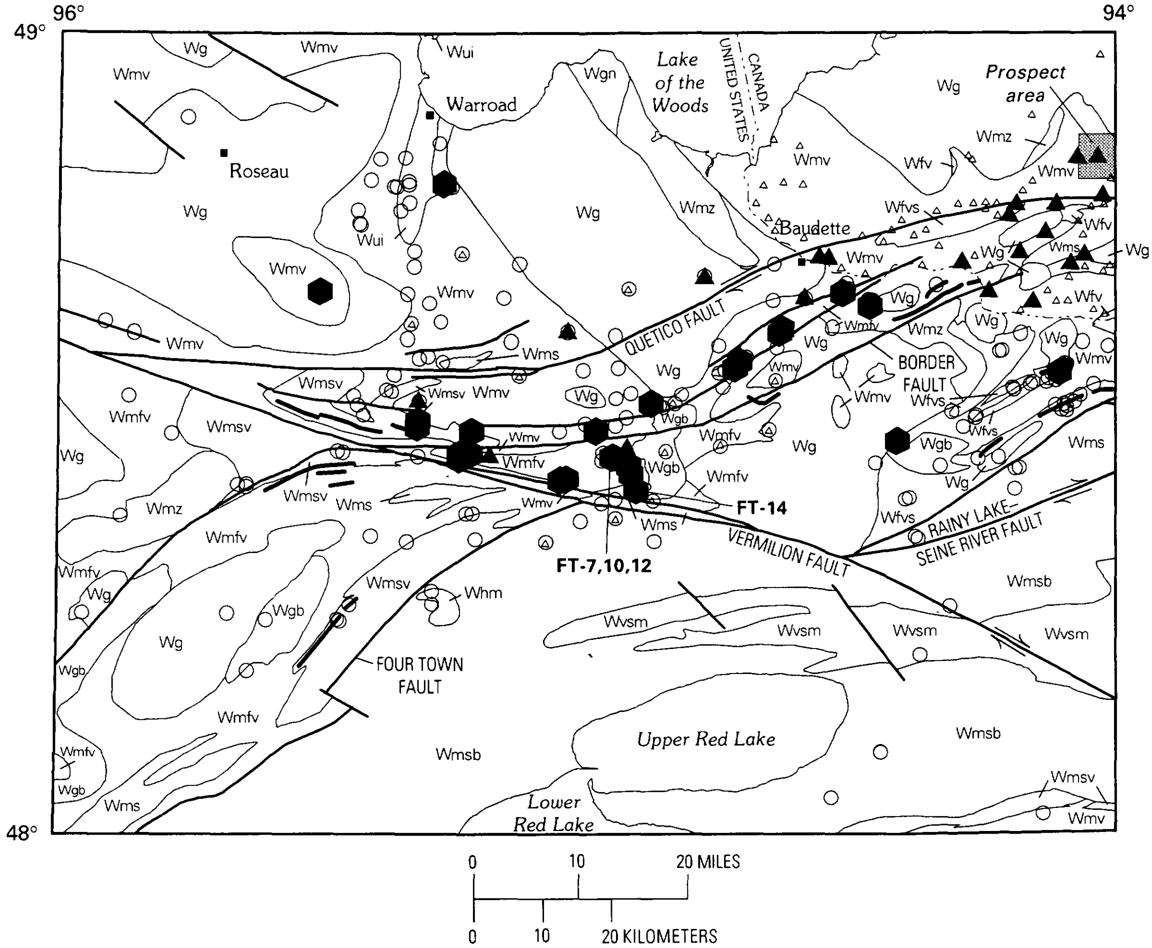
Contact

Fault—Opposed arrows show relative movement where known

Drill hole

Bedrock sample localities having greater than 500 ppm Ni—Numbered when referred to in text

Figure 10. Generalized geologic map showing distribution of bedrock sample localities having greater than 500 ppm nickel.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

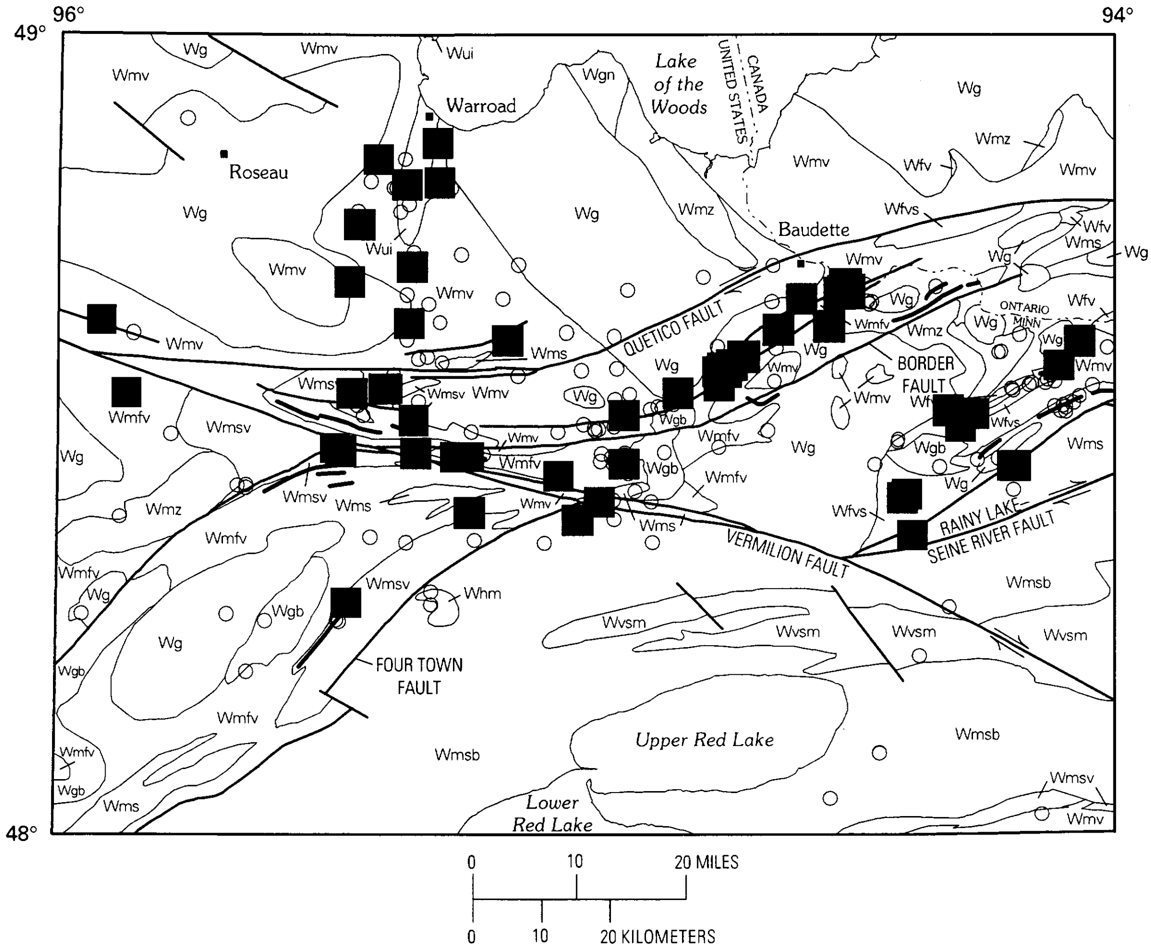
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
	Drill hole
	Drill hole containing assay intercepts greater than 0.1 ppm Au—Numbered when referred to in text
	Till sample
	Till sample containing greater than 400 ppb Au in HMC

Figure 11. Generalized geologic map showing distributions of (1) bedrock sample localities in which drill-hole assays were greater than 0.1 ppm Au and (2) glacial till sample localities in which the nonmagnetic fraction of heavy-mineral concentrates (HMC) contained greater than 400 ppb Au.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Mònzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

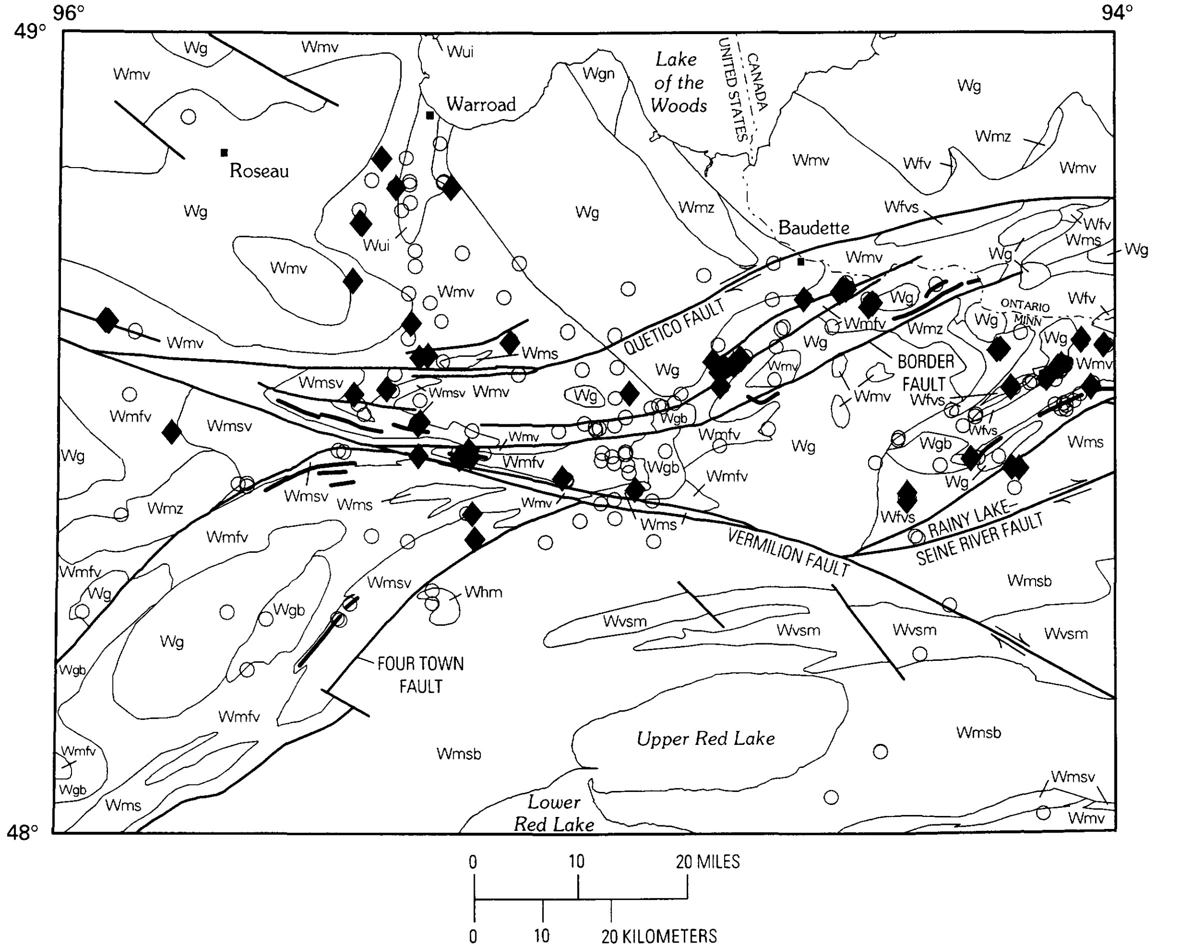
Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
	Drill hole
	Drill hole containing highly deformed rocks

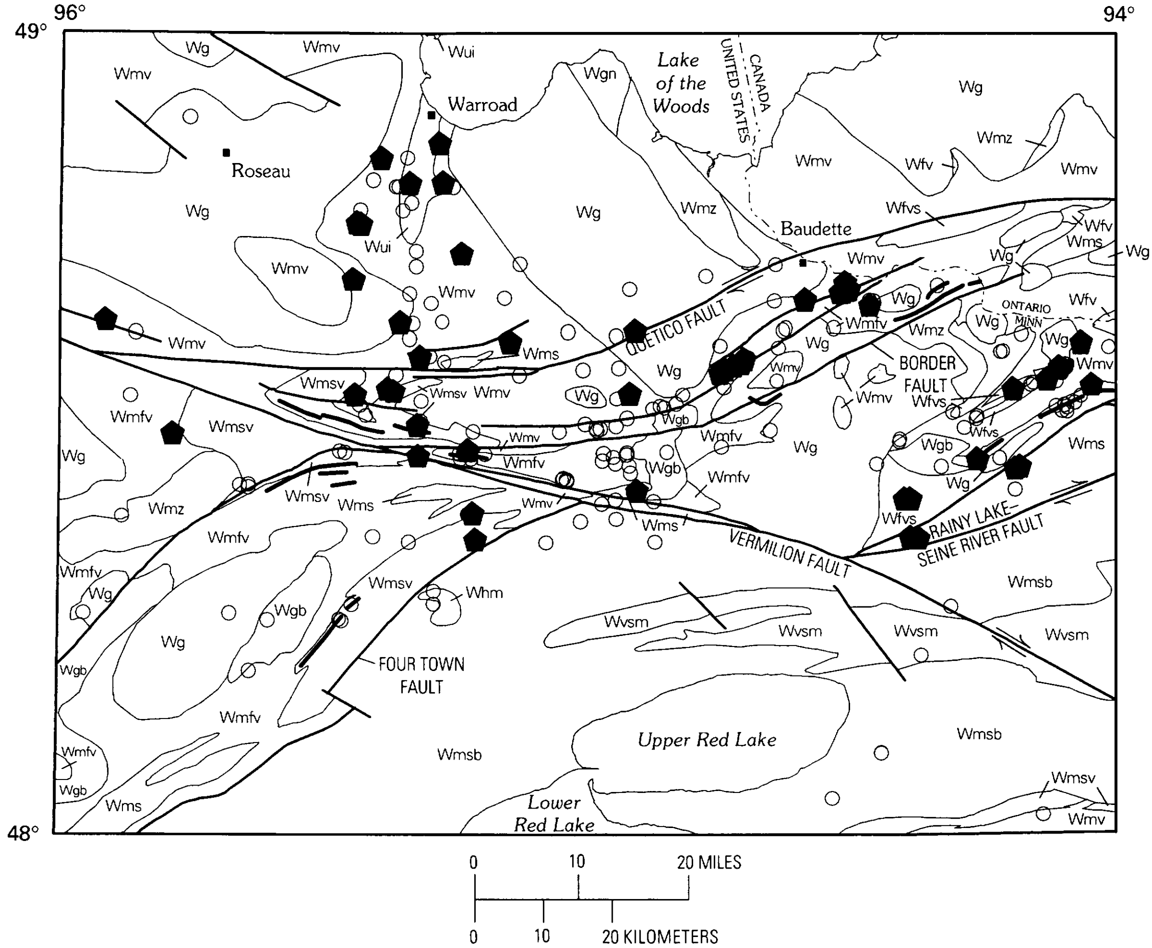
Figure 12. Generalized geologic map showing distribution of highly deformed rocks observed in drill core.



EXPLANATION

	Late Archean units		Late Archean units
	Wabigoon subprovince		**Wawa subprovince**
Wg	Granite	Wmsv	Volcaniclastic and volcanic rocks
Wgn	Granitic gneiss	Wmv	Intermediate to mafic volcanic rocks
Wmz	Monzonite		**Quetico subprovince**
Wgb	Gabbro	Whm	Hornblende monzonite
Wui	Ultramafic to mafic intrusive rocks	Wvsm	Schist-rich migmatite
Wmsv	Volcaniclastic and volcanic rocks	Wmsb	Garnet-biotite schist (metagraywacke)
	Iron-formation		Contact
Wms	Biotite schist (metagraywacke)		Fault—Opposed arrows show relative movement where known
Wfv	Felsic volcanic rocks	○	Drill hole
Wfvs	Felsic volcaniclastic rocks	◆	Drill hole containing substantial amounts of carbonate alteration minerals
Wmfv	Mafic and felsic volcanic rocks		
Wmv	Intermediate to mafic volcanic rocks		

Figure 13. Generalized geologic map showing distribution of bedrock from drill core in which carbonate veins (mostly calcite) were encountered.



EXPLANATION

Late Archean units

Wabigoon subprovince

Wg	**Granite**
Wgn	**Granitic gneiss**
Wmz	**Monzonite**
Wgb	**Gabbro**
Wui	**Ultramafic to mafic intrusive rocks**
Wmsv	**Volcaniclastic and volcanic rocks**
	Iron-formation
Wms	**Biotite schist (metagraywacke)**
Wfv	**Felsic volcanic rocks**
Wfvs	**Felsic volcaniclastic rocks**
Wmfv	**Mafic and felsic volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Late Archean units

Wawa subprovince

Wmsv	**Volcaniclastic and volcanic rocks**
Wmv	**Intermediate to mafic volcanic rocks**

Quetico subprovince

Whm	**Hornblende monzonite**
Wvsm	**Schist-rich migmatite**
Wmsb	**Garnet-biotite schist (metagraywacke)**
	Contact
	Fault—Opposed arrows show relative movement where known
○	**Drill hole**
⬟	**Drill hole containing quartz veins in bedrock**

Figure 14. Generalized geologic map showing distribution of drill holes containing quartz veins in bedrock.

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