GEOLOGICAL SURVEY OF CANADA

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Gold-related geology in the Kirkland Lake and Timmins camps, Ontario (Field Trip 5)

edited by

K. Hattori
C.J. Hodgson

1991

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GOLD-RELATED GEOLOGY IN THE KIRKLAND LAKE AND TIMMINS CAMPS

[FIELD TRIP 5]

BY

KEIKO HATTORI[1] and C. JAY HODGSON[2]

8TH IAGOD SYMPOSIUM

FIELD TRIP GUIDEBOOK

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1. INTRODUCTION

The Porcupine and Kirkland Lake mining districts represent two of the largest Archean gold camps in North America. The former has produced over 57 million troy ounces (1,800 tonnes) of gold and the latter has yielded more than 24 million oz (750 tonnes) of Au.

The main objectives of this field trip are to examine the geology of the areas, and to evaluate the occurrences of gold in their regional geological settings. Though the tour will primarily focus on the geology and mineralization in the Kirkland Lake-Larder Lake area, the Porcupine camp is described first because it better defines the structural history of the Abitibi belt, and the place of gold ore formation in that history.

2. FIELD TRIP ITINERARY

DAY 1	Monday (Aug. 6,1990)	8:30 AM	Pick up your hard hat, steel-toed boots before leaving Ottawa Lunch stop at Mattawa Check in at Bon Air Motel, Kirkland Lake (tel: 705-567-3241)
DAY 2	Tuesday (Aug. 7, 1990)	AM/PM	Surface tour in the Kirkland Lake-Larder Lake area Visit the Upper Canada mine, Queenston Gold Ltd.
DAY 3	Wednesday (Aug. 8, 1990)	AM:	Underground mine tour at Macassa guided by Mr. G. Nemcsok, Chief Regional Geologist, Lac Minerals Ltd.
		PM:	Examination of cores at the Macassa Mine Surface tour in the area Visit the Matachewan gold camp
DAY 4	Thursday (Aug. 9, 1990)	AM:	Underground mine tour at Ross guided by Mr. R.Calhoun, Chief Exploration Geologist, Preston Mechanical and Electrical Ltd.
		PM:	Open pit of the Ross Mine Visit the Canadian Arrow deposit Drive to Timmins Check in at Bon Air Motel, Timmins (tel: 705-264-1275)
DAY 5	Friday (Aug. 10, 1990)	AM:	Underground mine tour at Dome guided by Mr. Eric Kallio, Chief Mine Geologist, Placer-Dome Ltd.
		PM:	Surface geology in the Dome Mine
Day 6	Saturday (August 11,1990)	AM: 6:00	Leaving Timmins Arrival in Ottawa

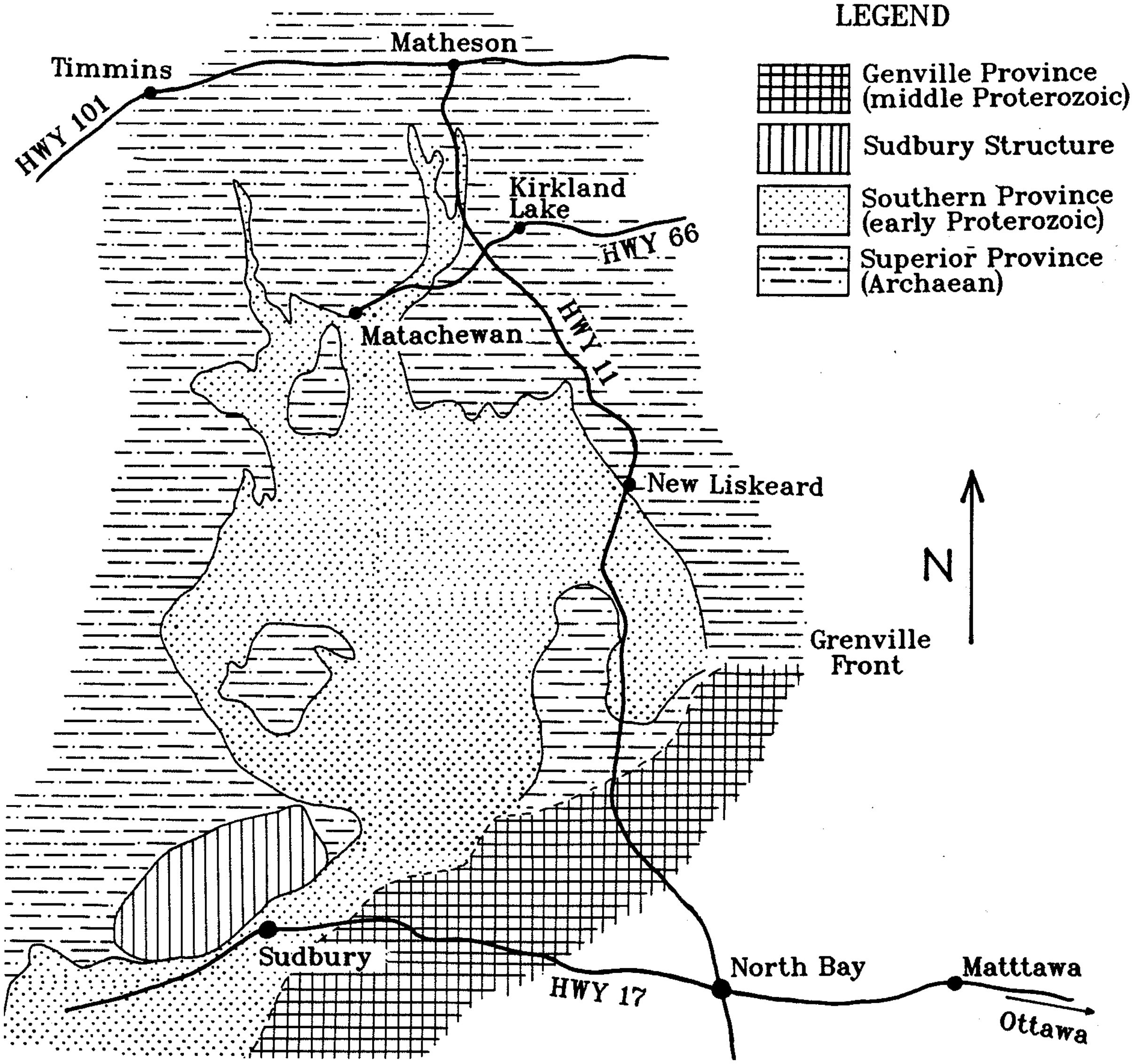

Figure 1. Field trip route map
(For more details, please see the attached Geological Highway Map.)

3. REGIONAL GEOLOGICAL SETTING

3.1 Geology of the Southern Abitibi Belt[1]

The southern Abitibi greenstone belt is bounded by the Proterozoic Southern and Grenville Provinces to the S and E, the Kapuskasing Structural Zone to the W and the Opatica gneiss belt to the N (Fig. 1 and 2). Recent precise age determinations of zircon and titanite indicate that the entire region was formed in a geologically short period in late Archean, 2750 to 2700 Ma (3.1.1 Corfu et al., 1989).

3.1.1 Lithologic Assemblages

The supracrustal rocks of the southern Abitibi greenstone belt are divided into four major lithological assemblages (Fig. 3):

(1) Tholeiites and komatiites of ocean crustal origin;
(2) Calc-alkaline basalts and rhyolites, and related sedimentary rocks of island arc origin;
(3) Quartz-rich clastic sedimentary rocks with interbedded komatiite (?) flows formed on a continental margin and/or as a fore-arc accretionary prism; and
(4) Polymictic conglomerates, sandstones and associated trachytes of uncertain tectonic affiliation.

The subalkalic volcanic rocks appear to belong to two temporally distinct stratigraphic packages, each consisting of a basal unit of ocean crustal rocks (lower unit of komatiites and upper unit of tholeiites; assemblage 1) overlain by a sequence of calc-alkaline island arc rocks (assemblage 2) (Jensen and Langford, 1985). The interpretation of the tectonic environment is based mainly on the comparison of the chemistry with modern analogues (Pearce et al., 1975; Dimroth et al., 1983).

The most widespread of the calc-alkalic assemblages are basalts and interbedded rhyolite and synvolcanic intrusions of the younger stratigraphic package. These rocks have been dated at ~2700 Ma (Corfu et al., 1989), and occupy the core of the Blake River synclinorium, in the central part of the area (Fig. 2). They overlie a sequence of tholeiite and komatiite flows and associated subvolcanic intrusions which have very similar ages (Corfu et al., 1989).

The island arc assemblage of the older stratigraphic package is best exposed S of Timmins. Here, older arc assemblage differs from the younger arc assemblage in that it contains minor amounts of oxide-facies banded iron formation associated with rhyolitic units. The stratigraphic package includes a high proportion of differentiated mafic and ultramafic sills of both tholeiitic and komatiitic affinity (Pyke, 1982). The komatiitic sills have been interpreted as temporal equivalents of the basal komatiitic unit of the younger stratigraphic package (Pyke, 1982).

Assemblage 3 of continental margin and/or for-arc accretionary prism sedimentary rocks (Lajoie and Ludden, 1984) is confined to the Bellecombe terrain in Quebec, S of Noranda. These rocks consist of quartz-rich turbidites with local interbeds of komatiitic basalt (MERQ-OGS, 1983). Rounded zircons with ages up to 300 Ma older than volcanic rocks occur in these sedimentary rocks (Gariepy et al., 1984). The quartz-rich composition and the age of zircons in these sedimentary rocks indicate a dominantly older cratonic source.

The sedimentary rocks of the Abitibi belt, other than those in the Bellecombe terrain, occur mainly within linear belts (Fig. 3). These sedimentary rocks, which lie concordantly on volcanic rocks and consist of greywacke turbidites with minor magnetite-chert banded iron formation, are interpreted as part of Assemblage 1 and/or 2, and may represent a fore-arc prism (Goodwin et al., 1972; Dimroth et al., 1983; Percival and Williams, 1989). Lying unconformably on the concordant sedimentary and volcanic rocks is a younger sedimentary assemblage (Assemblage 4) consisting dominantly of fluviatile sandstones, polymictic conglomerates and minor turbidites (Hyde, 1980). Trachytic tuffs and flows are interbedded and intercalated in the younger assemblage in the Kirkland lake area, but not in the Timmins area. This assemblage is spatially related to

[1] Based on Hodgson et al., in prep.

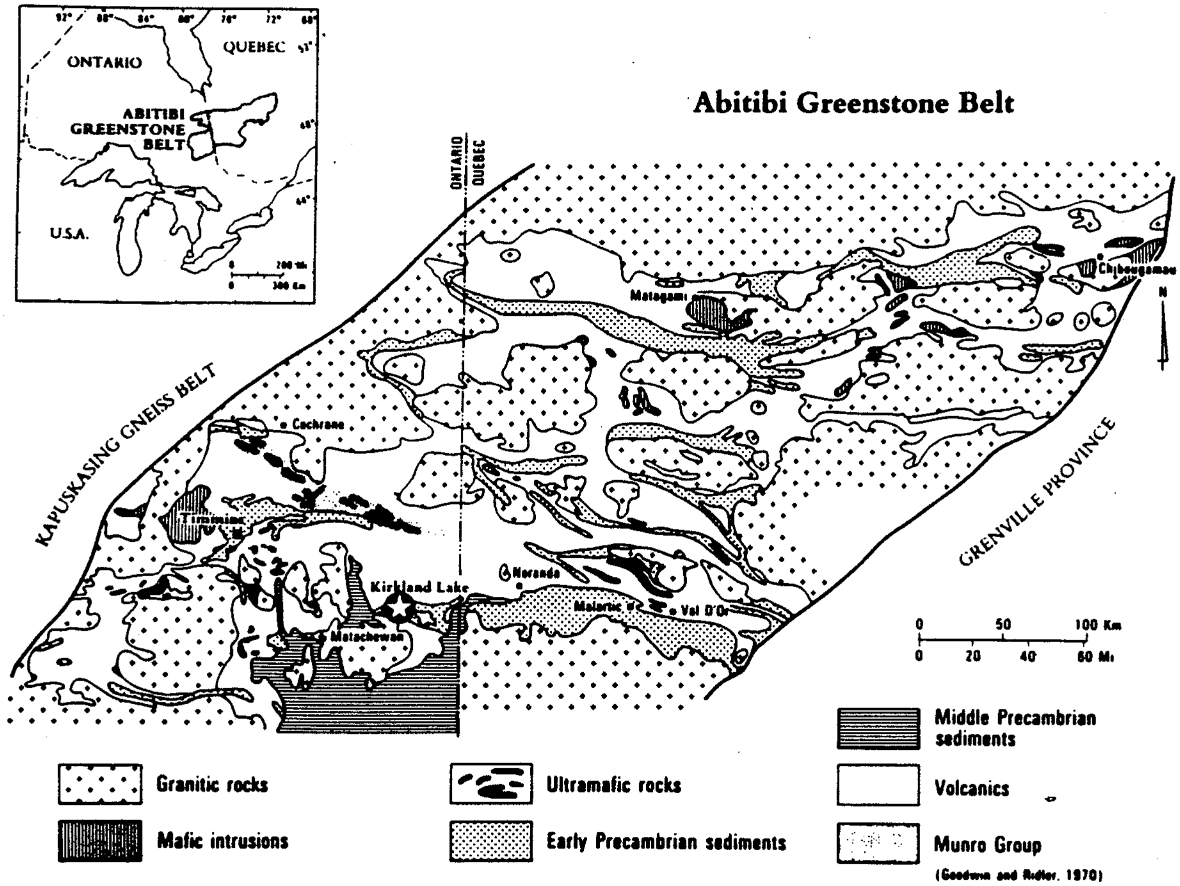

Figure 2 Geology of Abitibi Greenstone Belt (After Goodwin and Ridler, 1970)

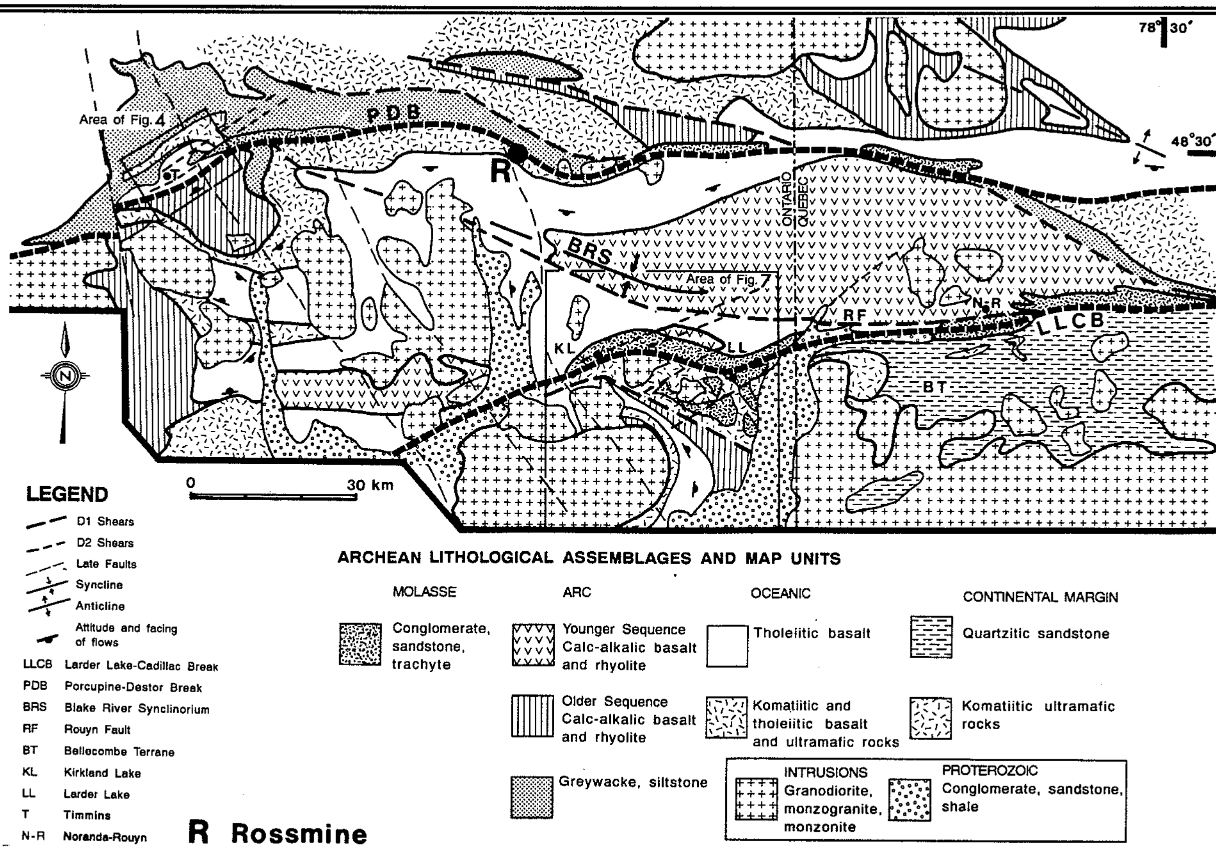

Figure 3 Geology of southern Abitibi Greenstone Belt (after Hodgson and Hamilton, 1989).

the two major faults in the area, and has been variously interpreted as a molasse facies formed in a footwall trough along an oblique-slip reverse fault (Hodgson and Hamilton, 1989), as a transtensional basin facies formed along a wrench fault (Hubert et al., 1984; Colvine et. al., 1984; 1988) and as a rift basin facies formed along a normal fault (Dimroth et al., 1983). It may also represent an intra-arc or back-arc basin related to a later period of subduction.

The origin of Assemblage 4 is of great economic importance since these rocks are almost certainly related genetically to the major structural breaks, in whose proximity (within a few kilometers) occur all major gold deposits. The petrochemistry of the trachytic volcanic rocks and associated intrusive rocks of Assemblage 4, and their relationship to the structural breaks and gold mineralization are discussed in more detail in the section on the geology of the Kirkland Lake-Larder Lake area.

3.1.2 Structural Framework

The southern Abitibi greenstone belt is subdivided into domains of generally coherent, dominantly steeply dipping stratigraphy, which are separated by structural and/or stratigraphic discontinuities (Hubert et al., 1984; Hodgson and Hamilton, 1989). The discontinuities separating the larger-scale domains are narrow continuous zones of high strain variously characterized by well developed schistosity, tight to isoclinal folding of sedimentary or earlier-formed tectonic layering, carbonate alteration zones and quartz veining. These discontinuities are considered shear zones as they commonly truncate stratigraphic contacts. However, in places the dominant deformational style is flattening and pressure solution parallel to the dominant foliation (Hodgson and Hamilton, 1989). The discontinuities were the loci for intrusion of felsic dykes and stocks ("porphyries"), mafic dykes (including lamprophyres), and linear arrays of gold deposits, (Hodgson, 1986; Thomson, 1948). The most continuous of these shear zones are the Larder Lake-Cadillac and the Porcupine-Destor breaks. All major gold deposits in the southern Abitibi belt are within a few kilometers of these two major breaks.

The metamorphism of the Abitibi belt ranges from sub-greenschist to greenschist. Local zones of amphibolite facies are developed near late intrusions and in the Pontiac Group rocks of the Bellecombe terrain, Quebec (Jolly, 1974). There is no evidence of high pressure metamorphism; pressures appear to have been uniformly low, ~ 2 to 3 Kb (Powell et al., 1989)

3.2 GEOLOGY OF TIMMINS AREA

The regional and detailed geology of the Timmins area is presented in Figure 5 and 4, respectively. Stratigraphy is dominated by the presence of two major lithologic units: the Tisdale Group and the Deloro Group (Dunbar, 1948). Younger Timiskaming Group rocks unconformably overlie the Tisdale Group (Table 1).

3.2.1 Deformation history

Mapping suggests the presence of at least five distinct deformational events (D_{on}, D_{ob}, D_{oc}, D_1 and D_2). The geological development of the area (Hodgson et al., in prep.) is outlined in Fig. 6 and summarized, together with age data, in Table 2.

The youngest Archean structures, termed D_2, are NE-trending zones of foliation and shearing. The best developed of these is the lenticular zone of very strongly foliated and altered rocks that host the Hollinger-McIntyre gold deposits (Fig. 4, 5).

In the area between the Hollinger-McIntyre deposit and the Dome fault, D_1 foliation has been rotated in a left-handed sense into the D_2 zone of the Hollinger-McIntyre deposit and into the Dome fault (Fig. 5). As the Dome fault predates D_1, the pattern of rotation near it suggests that the Dome fault was re-activated during the D_2 deformation. D_2 structures in the Timmins area are similar in orientation and style, and are correlatable with D_2 in the Kirkland Lake-Larder Lake area. D_2 structure in the Kirkland Lake-Larder Lake area also show a spatial relationship to gold deposits.

Pre-dating D_2 are D_1 folds and an associated WNW-trending, steeply N-dipping axial planar foliation. This foliation is the earliest recognized penetrative fabric in the rocks. Between the Hollinger-McIntyre and Dome deposit, the D_1 foliation crosses the axial surface of the Porcupine syncline, which is refolded to form the South Tisdale anticline, a D_1 fold (Fig. 4). The Dome fault is also folded where it is intersected by the axial surface of the South Tisdale anticline, and therefore must also pre-date D_1 (Fig. 4).

A pronounced lineation in the D_1 foliation is defined by the elongation of varioles (Pyke, 1982), by

Table 1. Archean Lithologies of the Timmins Area@

Group	Formation	Lithologies
Timiskaming	Intrusives Younger Sediments (Timiskaming Gp.)	(quartz)-feldspar porphyry
Tisdale	Older Sediments (Porcupine Gp.)	greywacke
	Upper Tisdale (Krist Fm.)	calc-alkaline pyroclastics (2698 ± 4 Ma#)
	Middle. Tisdale Fm	Fe-rich tholeiitic basalt; Variolitic flow
	Central Sediments	greywacke
	Lower Tisdale Fm	Komatiite and basaltic komatiite
Deloro	Upper Deloro Fm.	Calc-Alkaline felsic tuff; oxide-sulphide iron formation (2725 Ma*)
	Middle Deloro Fm	Komatiitic and tholeiitic volcanic rocks

: Marmont and Corfu, 1989
* : Nunes and Pyke, 1980
@ : Hodgson et al. (in preparation) modified after Hodgson (1986) and Pyke (1982)

TABLE 2. GEOLOGICAL HISTORY OF THE TIMMINS AREA (AFTER HODGSON ET AL., IN PREP.)

	Vein Formation, >2633 ± 6 Ma* ($^{40}Ar/^{39}/Ar$ mica)
D_2	Intrusion of late tectonic albitite dyke 2673 MA(U/Pb zircon)#
D_1	Initiation of felsic porphyries along faults 2690 Ma (U/Pb zircon)# Oblique-slip reverse faulting ("backthrusts") along Porcupine-Destor and Dome faults Deposition of Timiskaming sediments along Porcupine-Destor Break
D_{oc}	Formation of Porcupine-Destor Break and Dome fault
D_{ob}	Gilles Lake fault, Hollinger anticline
D_{oa}	Thrust imbrication, North Tisdale anticline Porcupine syncline
	Porcupine Group: Greywacke turbidites Tisdale Group: Calc-alkaline volcanism 2698±4 Ma (U/Pb zircon)# Tholeiitic volcanism Komatiitic volcanism

*: Masliwac et al., 1986
#: Corfu et al., 1989

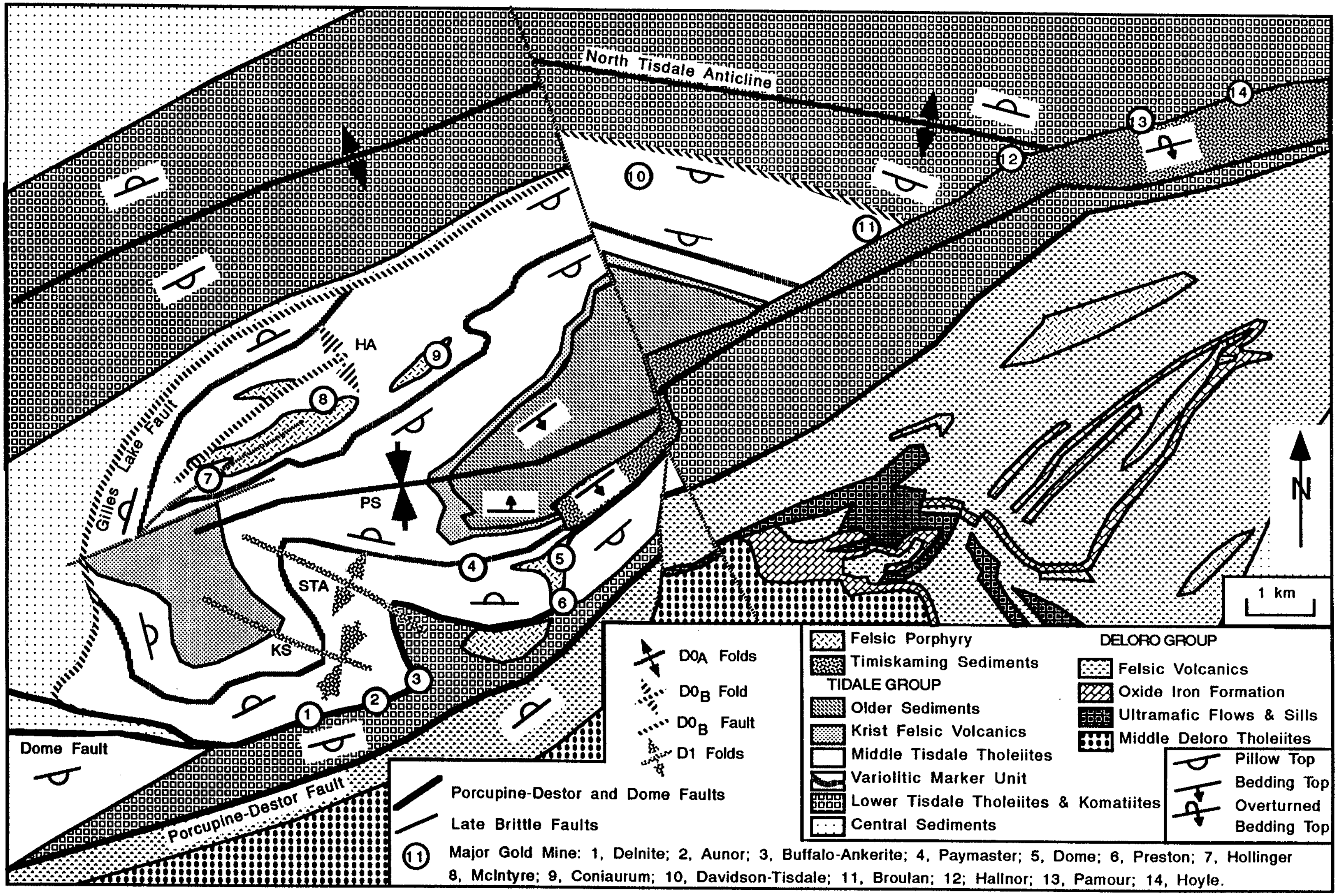

Figure 4 Geology of the Timmins camp showing location of major gold deposits. Compiled from township maps on 1":1000" and 1":1/4 Mile scale published by the Ontario Geological Survey (and its prcursor, the Ontario Deparment of Mines), and including revisions to these maps based on the field work of Piroshco & Kettles (1988) (Hodgson et al., in preparation).

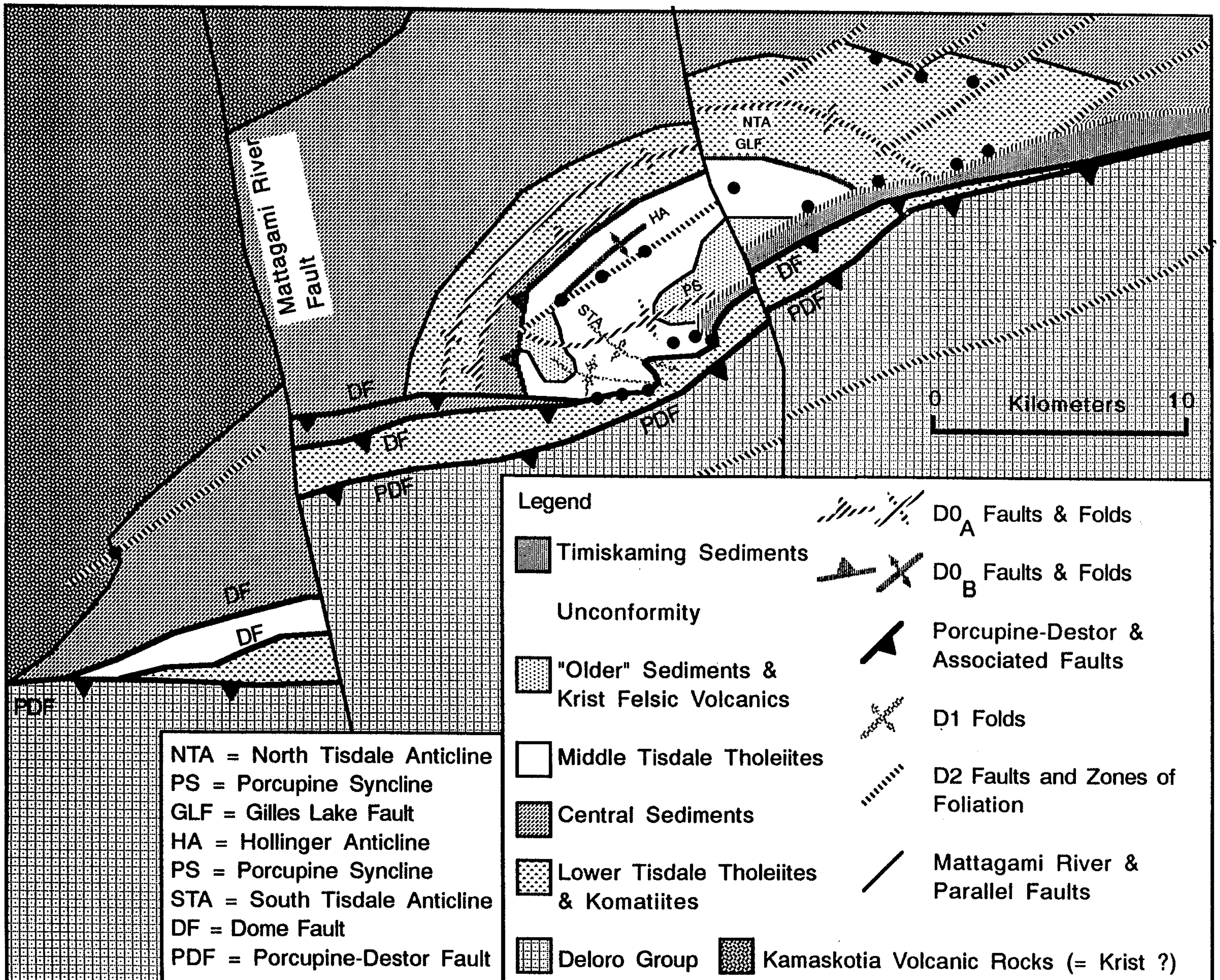

Figure 5 Geology of the Timmins mining camp and surrounding area. Compiled from maps published by the Ontario Geological Survey (and its precursor, the Ontario Department of Mines), including revisions based on interpretation of aeromagnetic maps published by the Ontario Geological Survey (Hodgson et al., in preparation).

the shape of porphyry intrusions at the Hollinger-McIntyre Mine (Fig. 4; Mason and Melnik, 1986) and by the plunge of the ore zones and "Greenstone Nose" at the Dome mine (described in a later section). This lineation plunges ~60° NE and may be the result of superimposed D_1 and D_2 flattening (Piroshco and Kettles, 1988). Because both D_1 and D_2 foliations are developed in the felsic porphyry intrusions in the area, the intrusive event occurred before D_1. By removing the late brittle faults, D_1 folds and D_2 shear zones, a pre-D_1 geology map of the area can be constructed (Fig. 6a)

Pre-dating D_1 is the deformation in which the Dome and Porcupine-Destor faults were formed. Since no pre-D_1 foliations have been identified, different pre-D_1 deformations can only be recognized by the interpretation of map-scale structures. Due to the resulting degree of uncertainty in the interpretation of structural relations, all pre-D_1 structures are termed D_O structures.

The youngest of the pre-D_1 structures, termed D_{oc}, are the synchronous, co-genetic, south dipping Porcupine-Destor 'Break' and the Dome Fault. Deposition of Timiskaming Group rocks was synchronous with the development of these faults and D_{oc}. The preservation of the Timiskaming Group rocks as the north limb of a syncline on the north side of the Dome fault in the Timmins area, and the occurrence of Timiskaming rocks on the north side of the Larder Lake-Cadillac and Porcupine-Destor breaks indicates that the post-Timiskaming movement on these faults was reverse, (S-over-N.)

Intruded into the Dome fault and the Timiskaming Group in the Dome mine area are felsic porphyry bodies whose zircons have been dated by the U/Pb method at 2690 Ma (Corfu et al., 1989). This suggests that the major post-Timiskaming Group movement on the Dome fault occurred before 2690 Ma. The reconstructed geology of the Timmins area before the last movement on the Dome fault is shown in Fig. 6b.

Predating the Dome fault and the major breaks are a series of folds which include the Porcupine syncline, and the North Tisdale and Hollinger anticlines. The Hollinger anticline is the most enigmatic of these folds and has been interpreted in different ways (see review in Hodgson, 1982). The map relationships shown in figure 4 indicate that the Hollinger anticline is a fold in the north limb of the Porcupine syncline, related to a right-handed sense of lateral offset on the Gilles Lake fault. The eastward projection of the Gilles Lake fault is truncated by the unconformity at the base of the Timiskaming Group. These relationships indicate that the Gilles Lake fault and the Hollinger anticline post-date the Porcupine syncline but pre-date the Timiskaming Group. The truncation of the SW end of the Gilles Lake fault by the North Branch of the Dome fault (Fig. 5) clearly establishes the relative age of these structures.

The relationship of the Hollinger anticline and the Porcupine syncline indicates that the pre-D_{Oc} folds and faults were formed in two separate periods; an older deformation resulting in the Porcupine syncline (D_{OA}) and a younger deformation resulting in the Gilles Lake fault and the Hollinger anticline (D_{OB}). If the Central Sediments lie on top of the Lower Tisdale Group, then a N-over-S sense of offset on the Gilles Lake fault would be necessary to bring the Middle Tisdale Group above the level of erosion to the W of Timmins, as well as cut out the Central Sediments along the fault on its eastern end (Fig. 4 and 6b).

The oldest structures recognized in the area are the Porcupine syncline and the North Tisdale anticline (D_{OA}). These have long axial surface traces, and therefore probably an overall gentle plunge, However, the plunge of the eastern part of the Porcupine syncline is moderate due to D_1 refolding (Fig. 4). The relationship of the Central Sediments to the Lower Tisdale Group around the North Tisdale anticline in the pre-D_{OB} reconstruction (Fig. 6c) suggests that the North Tisdale anticline may be associated with a thrust fault.

The timing of gold mineralization in the geological development of the Timmins area remains controversial. The fact that major gold ore bodies occur in the porphyries, some of which were emplaced into the Dome fault, suggests the gold must post-date D_{OC}. In addition, there are gold-bearing veins that appear to cut across D_1/D_2 foliations, and alteration minerals appear to be superimposed on the tectonic fabrics of the D_1 and D_2 deformations. $^{40}Ar/^{39}Ar$ dating of muscovite in veins and vein-related alteration zones indicates ages of 2600-2630 Ma, some 50 Ma after porphyry emplacement (Masliwec et al., 1986; Hanes et al., 1987). The latter suggest that the gold may be very late in the geological development of the area. However, some workers in the area consider the porphyries and gold to be genetically related (Mason and Melnik 1986), and interpret the Ar age to have been re-set as a result of later hydrothermal activity.

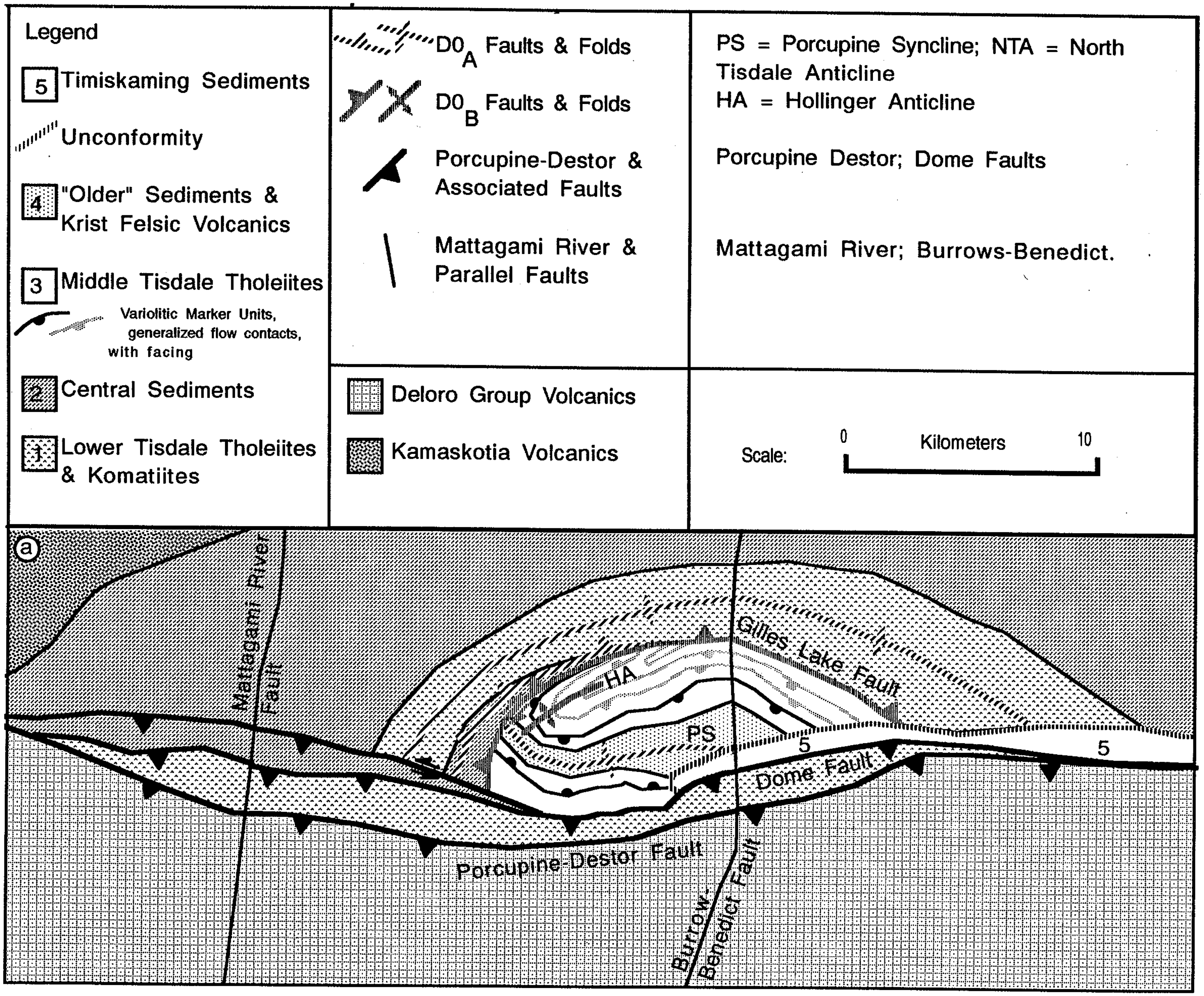

Figure 6a Interpretation of the geological development of the Timmins and surrounding area. Geological reconstruction based on removing the effects of movement on late faults, D2 and D1 folding. Shows geology after D0, but before D1 and D2

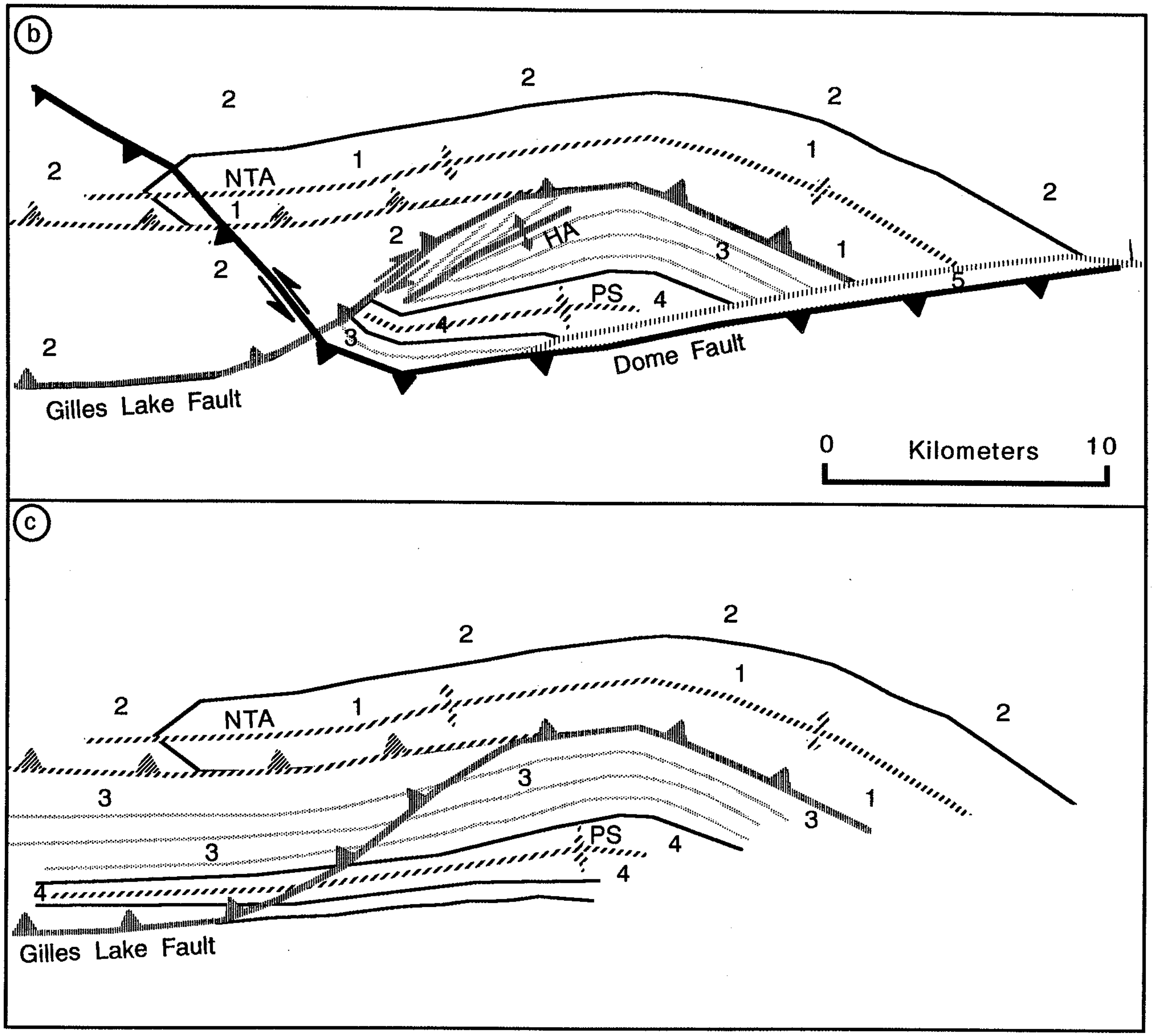

Figure 6 b,c, interpretation of the geological development of the Timmins and surrounding area. 6b., geological reconstruction based on removing the effects of oblique-reverse movement on the Dome fault. Shows geology after DO_A and first part of DO_B; 6c., geological reconstruction based on removing the effects of oblique-reverse movement on the Gilles Lake fault and the associated Hollinger anticline. Shows geology after DO_A (Hodgson et al., in preparation).

3.3 GEOLOGY OF KIRKLAND LAKE-LARDER LAKE AREA

The Kirland Lake-Larder Lake area is on the western end of the Larder Lake-Cadillac 'Break', one of the two major gold-related faults in the southern Abitibi belt (Fig. 3). The area is underlain by the sedimentary and volcanic rocks of the Timiskaming Group, which unconformably overlie older volcanic rocks (Fig. 7, Table 3). The unconformity between the Timiskaming Group and tholeiites of the Kinojevis Group is exposed north of Kirkland Lake and the unconformity with komatiites and tholeiites of the Larder Lake Group is exposed S of Larder Lake. The stratigraphic sequence of the older volcanic rocks is uncertain because many units are in fault contact and because the zircon ages of all Groups are similar, ranging from 2705 to 2701 Ma (Table 3; Marmont and Corfu, 1989; Corfu et al., 1989).

The volcanic rocks of the Timiskaming Group are of particular interest because the Timiskaming Group is closely related spatially, and probably genetically, to the 'Break', which also controls the occurrence of gold deposits in the area. These volcanic rocks are mostly porphyritic trachytes, with feldspar and augite phenocrysts. Other minerals include olivine, augite, plagioclase, phlogopite and minor K-feldspar and hornblende. Pseudoleucite occurs locally (Cooke and Moorehouse, 1969).

The volcanic rocks are nepheline normative to quartz normative. Andesite and calc-alkaline basalt accompany the alkaline rocks, suggesting that the volcanism is related to subduction processes. They show the high alkali/silica ratios (Fig. 8) and typical trace element signature (high Sr, Ba, and LREE and low Ti, Nb and Ta) (Fig. 9) of shoshonites. Major, minor and trace element compositions of these volcanic rocks are identical to other Archean alkaline volcanic rocks located along the major deformational zones in the Superior Province (e.g. Shebandowan and Chibougamau; Hattori, 1989). The chemistry of the volcanic rocks is remarkably similar to that of shoshonites found in present-day arcs (Central Italy, Aeolian arc, Papua New Guinea, Wyoming and Navajo Provinces). Present-day shoshonites show varied enrichment of radiogenic isotopes, probably due to the contamination by crustal or subducting slab materials. Recent Nd- and Sr-isotope data, however, indicate that the shoshonites in the Kirkland Lake area are depleted mantle derivatives and different from those of present-day arcs. Existing geochemical data indicate that the Archean shoshonites formed from a depleted lithospheric mantle which had undergone enrichment of alkalis and other LLIE by mantle metasomatic processes (Hattori and Hart, in prep.). Local crustal thinning along the 'Breaks' may have provided the necessary conduits for the introduction of upper mantle metasomatized magmas. The enrichment of alkali elements may be due to the ascent of fluids derived from the dehydration of subducted material.

The spatial distribution of the Timiskaming volcanic sedimentary rocks along the Larder Lake-Cadillac Break suggests these rocks were deposited in transtentional environments along the 'Break', a reverse fault.

The presence of clasts of equigranular to porphyritic felsic intrusive rocks, identical in appearance to the subvolcanic intrusions, in the conglomerates of the Timiskaming Group indicate the rapid erosion of un roofed intrusive rocks during the deposition of the sediments. Rapid erosion due to tectonic activity is also evidenced from the occurrence of hematitic iron formation clasts in the Timiskaming Group conglomerates. Because there is no obvious source in the surrounding basement sequence, the iron formation was probably formed within the Timiskaming Group, then was eroded and redeposited in the sediments (Hodgson, 1986).

Some syenite and porphyry intrusions were emplaced into the Timiskaming Group after the sediments were tilted into subvertical orientation, and juxtaposed against the older volcanic sequence along the Larder Lake-Cadillac break. These younger rocks, which are superficially similar to intrusions emplaced synchronously with the volcanic rocks, are temporally and structurally equivalent to the quartz-feldspar porphyries of the Timmins area. The late intrusions in the Kirkland Lake area include the Kirkland Lake Intrusive Complex, numerous feldspar porphyry intrusives and lamprophyre dykes (minette and vogesite) that cross cut all Archean lithologies. Sr and Nd isotope data indicate that these post-tectonic (~2680Ma) alkaline rocks where derived from the similar source in the mantle as the earlier volcanic rocks (Fig. 10) (Hattori and Hart, in prep.).

3.3.1 Deformation history

The tectonic structures in the Kirkland Lake-Larder Lake area are similar to those in the Timmins

Table 3. Geological Column for the Kirkland Lake-Larder Lake area[@]

Stratigraphic sequence of Archaean Groups in parentheses are uncertain. The apparent "sequence" in the list is probably due to tectonic imbrication.

Eon	Deform-ation	Group, formation	Lithologies
Cenozoic			Glacial Gravel, sand and clay
Proterozoic (Huronian)		Nipissing Dyke	Diabase (2219 ± 4 Ma*)
		Cobalt Group Gowganda Fm. First Brook Member Coleman Member	 argillite conglomerate, greywacke
		Intrusions	Mattachewan diabase dykes
	D_2 D_1 D_0	Timiskaming	(Quartz-) feldspar prophyry, diorite, shoshonitic and calc-alkaline volc. sub-vol. intrusions (2680 ± 1 Ma#); greywacke; conglomerate **(UNCONFORMITY)**
		(Blake River)	calc-alkaline volcanic; mainly basalt, with minor andesite, rhyolite (2701 ± 2 Ma$)
		(Kinojevis)	Mg-, & Fe-tholeiite, dacite, rhyolite towards the top
		(Larder Lake)	komatiite, basaltic komatiite, Mg-rich tholeiite, intercalation of rhyolite (2705 ± 2 Ma$)
		(Skead)	calc-alkaline volcanics; rhyolite, with minor basalt and andesite (2701 +3 -2 Ma$)
		(Catherine)	Mg- & Fe-tholeiite
		(Wabewawa)	mafic and ultramafic flows
		Pacaud Tuff	andesite, dacite tuff (2747 Ma$)

#; Otto syenite stock (U/Pb zircon; Corfu et al., 1989);
minimum age of syenite porphyry at Macassa (U/Pb zircon; Krogh, pers. comm., 1988); lamprophyre at the Adams Mine (U/Pb titanite; Wyman and Kerrich, 1987)

$ Corfu et al., 1989
* Corfu and Andrews, 1986
@ Hodgson et al. (in preparation), modified from Jensen and Langford (1985)

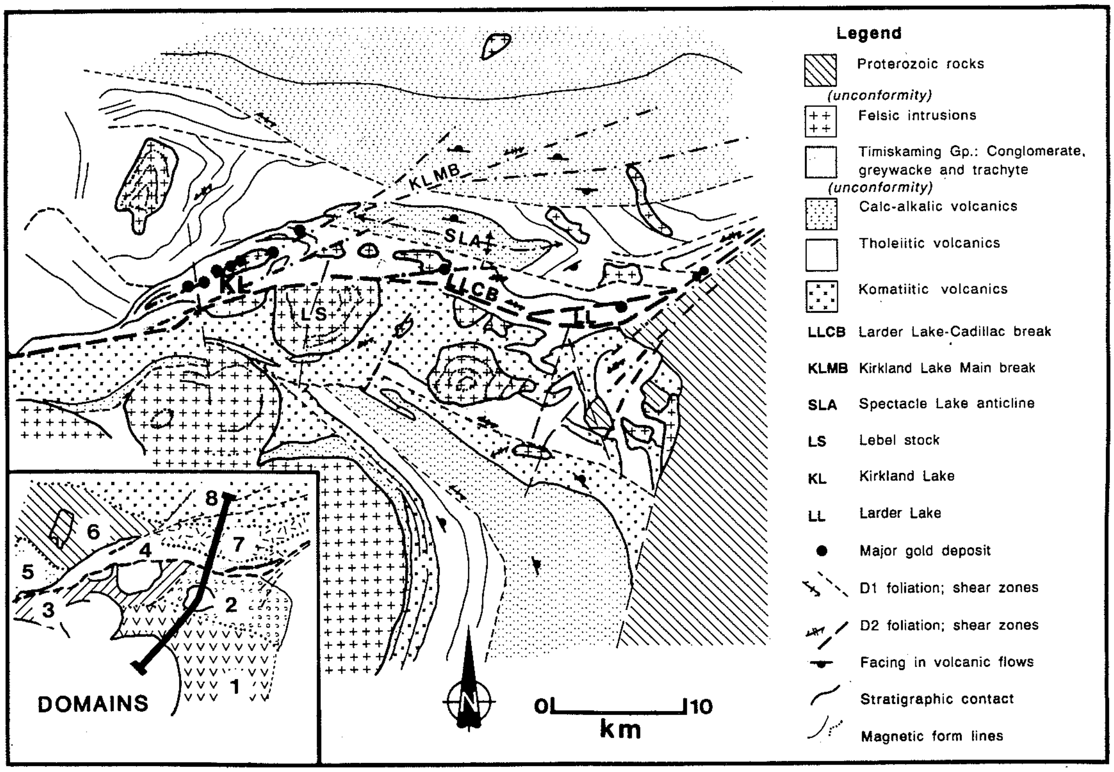

Figure 7 Geology of the Kirkland Lake-Larder Lake area. Based on compilation of 1":1000' township maps published by the Ontario Department of Mines and interpretation of computer-processed aeromagnetic maps. Inset shows domains of coherent stratigraphy and structure. Stratigraphic correlations are uncertain across zones of high strain which separate domains. Heavy line on inset shows approximately line of section of Fig. 8 (Hodgson & Hamilton, 1989).

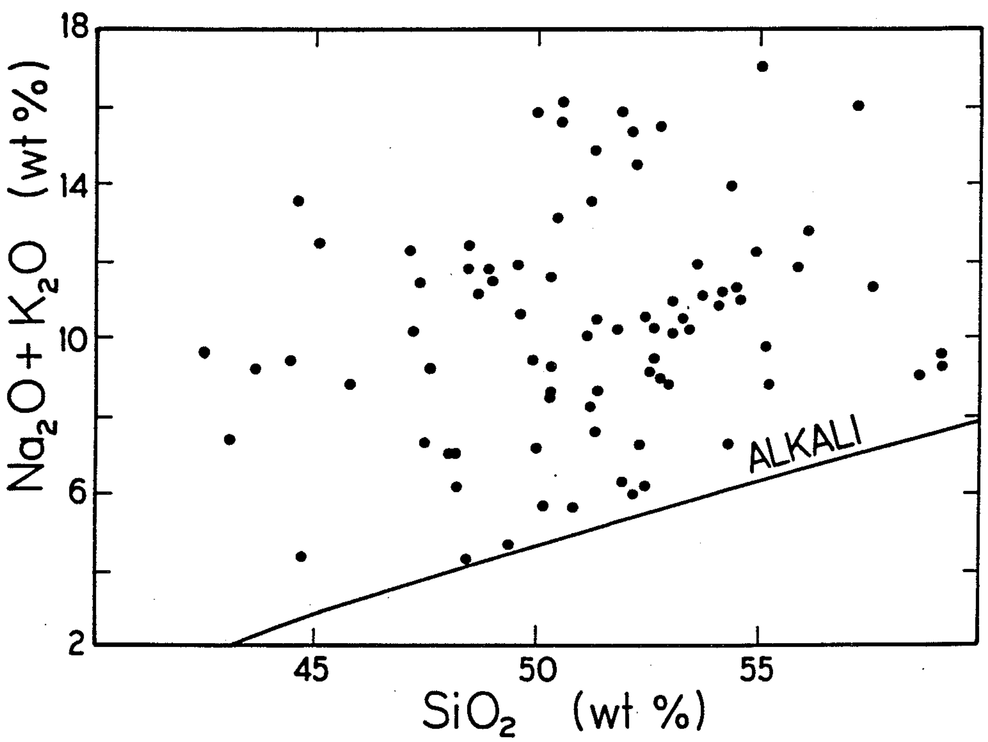

Figure 8 Alkalis-silica plot of the Timiskaming volcanic rocks

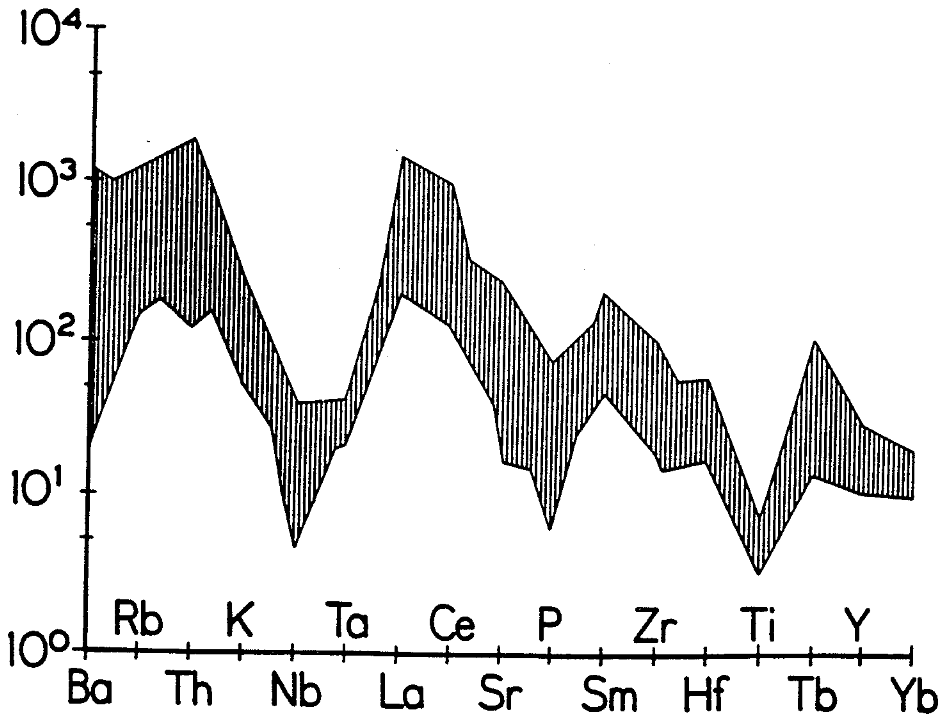

Figure 9 Spider plot of the Timiskaming volcanic rocks (Hattori, 1989).

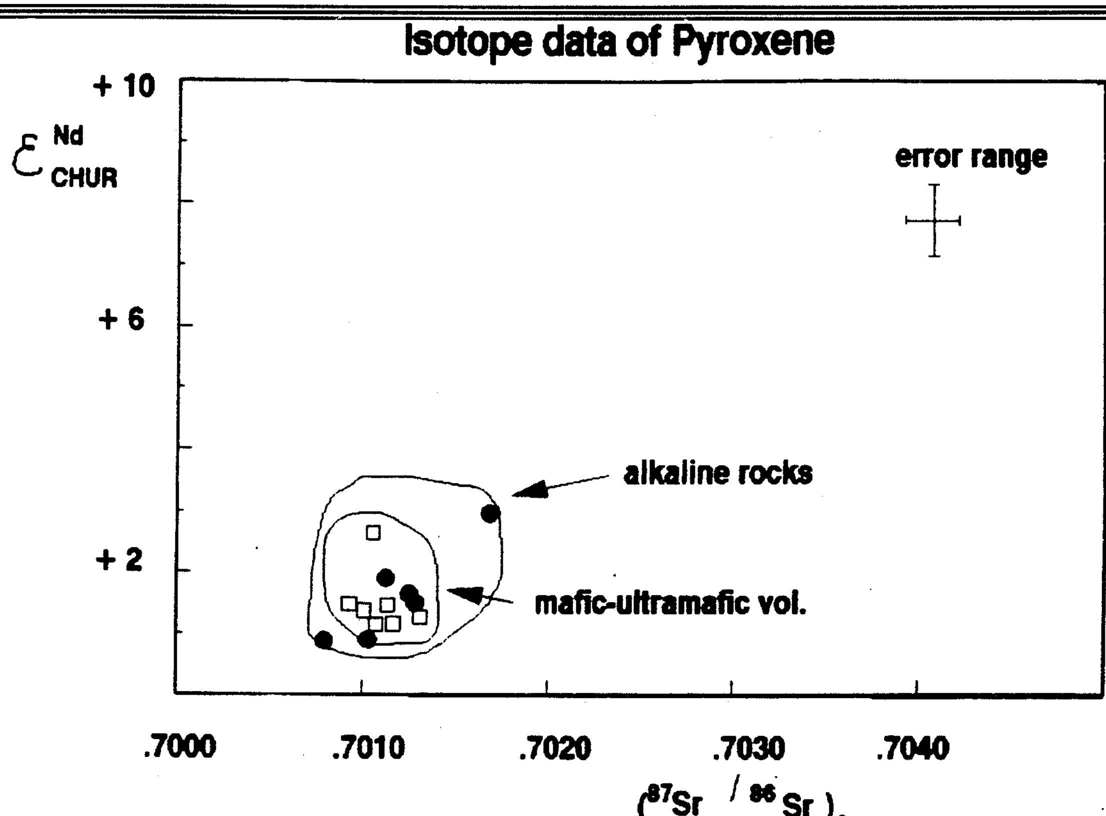

Figure 10 Sr- and Nd- isotope compositions of alkalic magmas of the Timiskaming Group rocks (Hattori and Hart, in prep.)

area, and have been divided into three main groups (D_O, D_1, D_2) on the basis of style, superposition and general orientation (Table 4) (Hodgson and Hamilton, 1989). As in the Timmins area, D_O structures are defined as folds with no associated axial planar foliation, and faults which pre-date folds with associated foliation. Two groups of D_O structures are recognized. The first group includes rare, small scale folds with axial planes inclined to the earliest flattening fabric and large folds indicated by pillow facing reversals in older sedimentary and volcanic sequences W and N of the town of Kirkland Lake (Fig. 7). These folds are tentatively correlated with the D_{OA} structures in the Timmins area (Table 2). The second group is the Larder Lake-Cadillac break and associated structures, correlated with the D_{OC} structures of the Timmins area (Table 2). Here, unlike the Timmins area, pre-cleavage folds have not been identified in the Timiskaming Group, nor have D_{OB} folds and faults been identified.

Reactivation of the Larder Lake-Cadillac break resulted in the rotation of all post-break fabrics in the vicinity of the break which gives the false impression that the break is a post foliation structure. The distribution of the Timiskaming Group rocks along the break and the relationship of the break to the D_{OA} folds indicate that the break post-dates a major period of folding and thrusting (D_{OA}), but pre-date cleavage-forming deformations (D_1). The Timiskaming Group and the break appear to pre-date all of the cleavage-forming deformations in the area, since the earliest recognized cleavage occurs in the Timiskaming Group as well as in older rocks.

The first foliation-forming deformation (D_1) resulted in WNW- to W-trending folds and an associated subvertically to moderately dipping axial planar foliation. In contrast to the Timmins area, the axial planes of many of the large folds and shear zones in the area approximately parallel the D_1 foliation. An example is the Spectacle Lake anticline (Fig. 7). Similar fold structures, such as the Rouyn Lake syncline (Fig. 1 in Hubert et al., 1984) have long axial surface traces, > 25 km, indicating that the plunge of these folds is subhorizontal. The limbs of these large folds are locally truncated by D_1- parallel shear zones. For example, both the N and S limbs of the Spectacle Lake anticline are truncated by faults which parallel the D_1 foliation (Fig. 7). The Larder Lake-Cadillac break also truncates some of these folds and faults. In fact, the fault truncating the S limb of the Spectacle Lake anticline is truncated by the break between Larder Lake and Ontario-Quebec border (Fig. 7). This relationship indicates that the folds pre-date the break, which would make these faults and folds D_O structures that had axial planar cleavage developed when they were reactivated and tightened in the subsequent D_1 deformation. The rotation of the D_1 foliation and associated small-scale folds into the 'Break' indicates that the 'Break' was also reactivated during D_1. It is likely that D_O and D_1 represent various stages of one continuous deformation. The elongated clasts in conglomerates indicate that the sense of translation was generally dip-slip on the shears during the D_O and D_1 stages of deformation.

D_2 structures in the area include folds with an axial planar foliation, a steeply-plunging lineation, and a set of shear zone with an WSW to SW-strike. The D_2

TABLE 4. SUMMARY OF TECTONIC EVENTS IN KIRKLAND LAKE-LARDER LAKE AREA (HODGSON ET.AL., IN PREP).

N-trending foliation with multiple sets of strain-slip cleavages and crenulation lineation	
D_2	folds with an axial planar foliation steeply-plunging lineation a set of shear zones with WSW to SW strike
D_1	WNW- to W-trending folds and associated axial planar foliation
D_0	Larder Lake-Cadillac break and subsidiary structures Sedimentation and volcanism of Timiskaming Group Major folds (e.g., Spectacle Lake Anticline)

foliation is less penetrative than the D_1 foliation and it is domainal in distribution. Various degrees of structural overprinting are observed, including: dome-and-basin fold interference patterns in Heast Township S of Larder Lake (Hodgson and Hamilton, 1989); rotation of D_O and D_1 structures into D2 orientations in the area between Larder Lake and the Quebec-Ontario Border; and the complete obliteration of bedding and D_1 by intense development of the D_2 foliation in a 500 m wide zone along the break NE of Larder Lake. Major gold deposits are all hosted by shear zones which parallel, and contain D_2 cleavages, and occur within a few km of the Larder Lake-Cadillac 'Break'. Although this suggests that the gold deposits post-dated D_2, it is also possible that the mineralization was emplaced during D_O into parts of D_O structures that were later superimposed by D_2 structures. If this interpretation is correct, the post-D_2 veins in the area would be ascribed to "remobilization".

Superimposed on the above structures are a group of late minor structures, which do not significantly affect map patterns. These structures include N-S trending foliation zones and multiple sets of strain-slip cleavages, and related crenulation lineations. Based on mapping by Thomson (1943), Abraham (1950), Lawton (1959), Jensen and Langford (1985), and Hodgson and Hamilton (1989), a schematic NE-SW cross-section through the Larder-Lake area can be constructed (Fig. 11). In this cross section the Round Lake batholith, a composite tonalite-granodiorite body S of Kirkland Lake, is interpreted as basement exposed by thrusting or by fold interference. The overlying supracrustal rocks are stacked on shallowly N dipping, S verging, W- to WNW-trending thrust and folds (Hodgson and Hamilton, 1989). The configuration displayed in Fig. 11 may account for the anomalous stratigraphic thickness reported in the area, ~40 km (Jensen and Langford, 1985).

This stacked supracrustal stratigraphy is truncated by the Larder Lake-Cadillac break and associated NE-trending D_2 shears which splay from the break. These faults dip steeply S. Based on the offset of stratigraphy, the break is interpreted as an oblique thrusts with S over N translation.

3.4 GEOTECTONIC AND METALLOGENETIC MODEL OF THE SOUTHERN ABITIBI BELT

Many different models have been proposed for the evolution of the Abitibi Greenstone Belts. These range from "sagduction" (Jensen and Langford, 1985), to wrench fault tectonics (Hubert et al., 1984) to Himalayan-type collisional tectonics (Hodgson and Hamilton, 1989). The geological development of the area outlined above is consistent with the schematic model shown in Fig. 12 and the relationships among rock formation, deformation events and mineralization shown in Fig. 13. This model is presented here to provide a basis for discussion during the field trip, and should not be considered as being unequivocal.

The calc-alkaline volcanic rocks of the Abitibi belt are interpreted as having formed in an oceanic island arc plate tectonic setting, above a N-dipping subduction zone. The arc was located outboard of a continental mass now represented by the Opatica Belt (the genesis belt which bounds the Abitibi belt to the north), and was built on komatiitic to tholeiitic ocean crust previously formed at an accreting plate margin. (Fig. 12A). As plate consumption progressed, a southern continental mass, now represented by the Bellecombe terrain, migrated northwards and eventually collided with the arc. Collision resulted in the arc sequence and the oceanic rocks of the down-going slab being stacked on imbricate thrusts, and the development of a zone of crustal thickening (Fig. 12B) The initiation of imbrication of ocean crustal rocks, however, could well have started before the collision. Similar imbricated zones are associated with many active arcs without a history of collision orogeny. An example is the southern part of the central American arc, which contains a fore-arc zone of imbricated oceanic rocks. The folds and faults of D_{OA} and D_{OB} formed at this time.

The last increments of crustal thickening were effected by reverse movement along relatively steeply S-dipping faults and/or major breaks which cut the earlier imbricate thrusts. (Fig. 12C). These faults and/or major breaks represent D_{OC} Structures. Immature sediments of the Timiskaming Group were deposited in linear troughs developed along the breaks and continuous movement of the breaks caused folding and faulting of these rocks. The development of transtensional zones in local extensional bends along the faults resulted in crustal thinning and the formation of mantle conduits. The partial melting and metasomatism of mantle material through the addition of water from dehydrating underplated oceanic crust may have resulted in

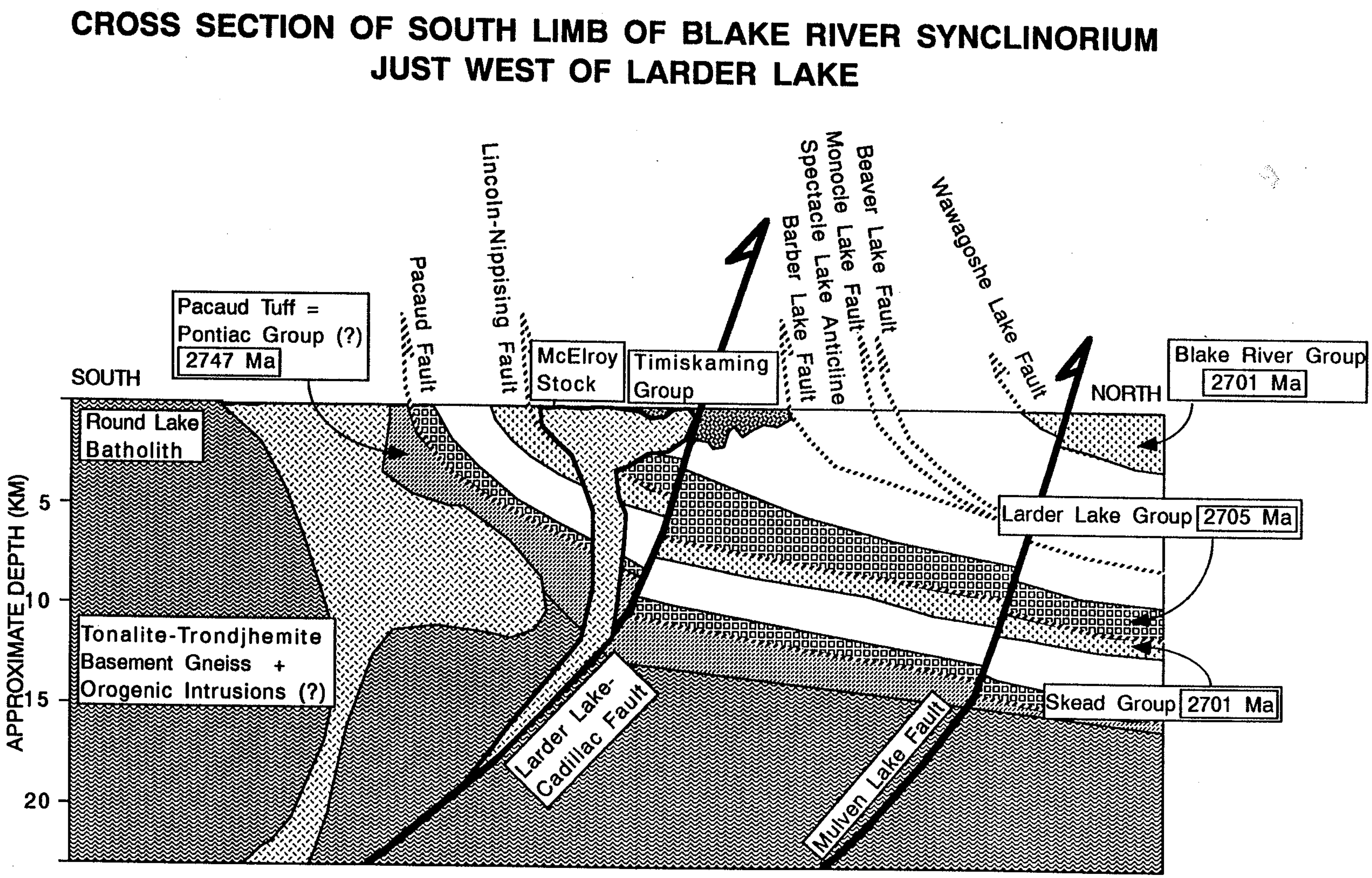

Figure 11 Diagrammatic NNE-SSW geological cross section across the Kirkland Lake-Larder Lake area (see inset on Fig. 7 for location.) Based on map shown in Fig. 7, new seismic reflection on data (Jackson et al., in press and U-Pb dating in area) (Corfu et al., 1989) (Hodgson et, al. in preparation.)

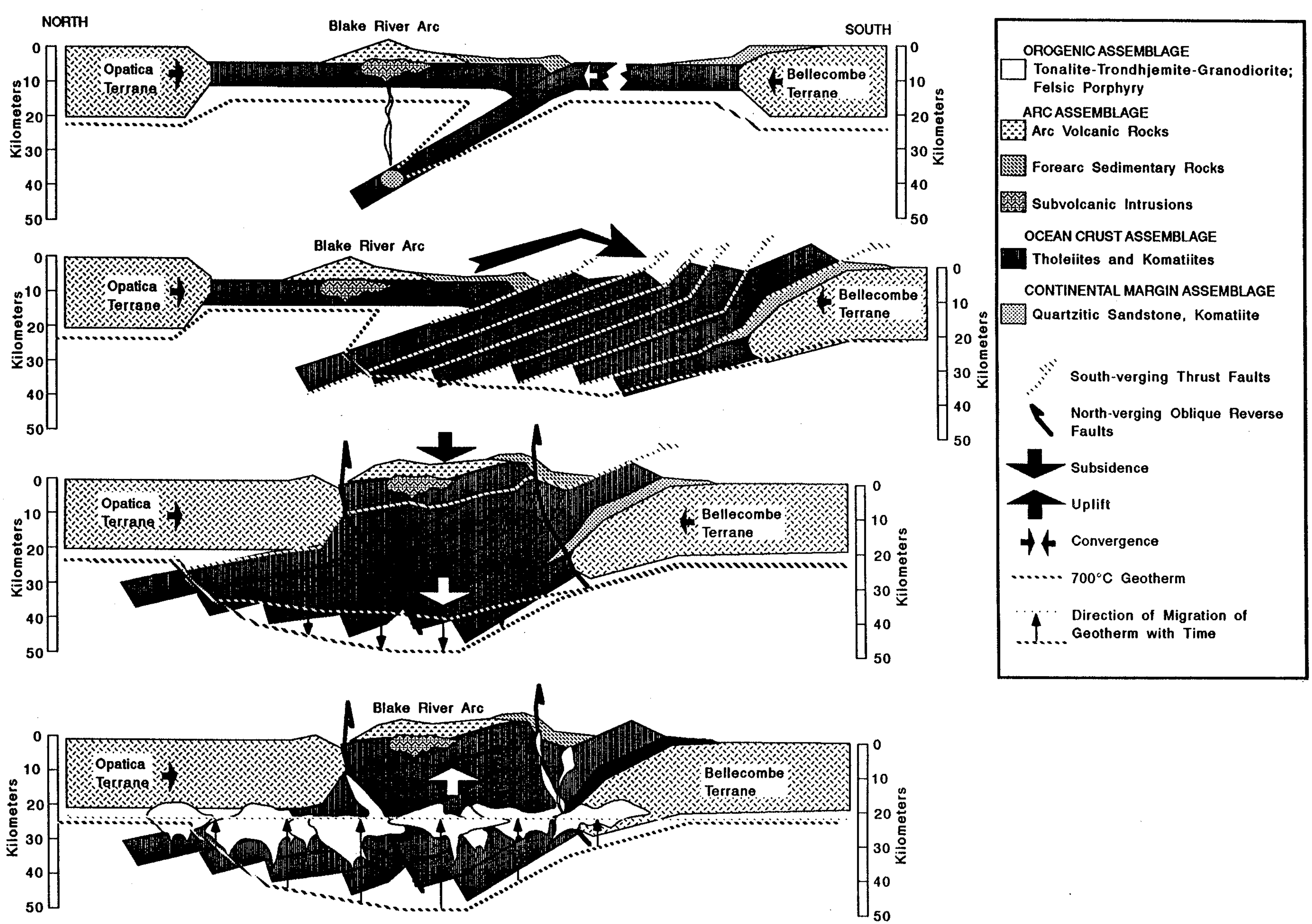

Figure 12 Model for the geological evolution of the Abitibi Greenstone belt (Hodgson et al., in prep.)

COLLISION MODEL FOR ARCHEAN GOLD

SEDIMENTS + VOLCANICS	STRUCTURES	INTRUSIONS + MINERALIZATION		TIME
ACCRETING AND CONSUMING PLATE MARGIN VOLCANISM; ARC AND CONTINENTAL MARGIN SEDIMENTATION AND VOLCANISM	SYNVOLCANIC FAULTS	SUBVOLCANIC INTRUSIONS; MASSIVE SULFIDE MINERALIZATION		2700Ma
FOREARC SEDIMENTS, SOME MOLASSE?	IMBRICATE THRUSTS, CAUSING CRUSTAL THICKENING	NONE?		
SYNTECTONIC MOLASSE SEDIMENTS; SOME TRACHYTIC VOLCANICS ASSOCIATED WITH "BREAKS"	OBLIQUE-REVERSE FAULTS (THE "BREAKS")	MELTING AT BASE OF THICKENED CRUSTAL PRISM BEGINNING OF "PORPHYRY" INTRUSIVE ACTIVITY	THERMAL RE-EQUILIBRATION: TEMPERATURE INCREASE AT DEPTH →	2690-2670Ma
	UPLIFT AND DILATION	EMPLACEMENT OF TTG MAGMA INTO MID-CRUST		
		CONTINUED HEATING AT DEPTH CAUSING GENERATION OF AU FLUIDS; EMPLACEMENT OF AU FLUIDS IN DILATANCY CAUSED BY UPLIFT		2630Ma → 2580Ma

Figure 13 Collision model for Archean gold mineralization of Southern Abitibi belt (Hodgson et al., in preparation).

mantle upwelling.

As tectonism was rapid, relative to the rate of heat conduction, geotherms were depressed and neither pervasive metamorphic re-crystallization nor metamorphic tectonite fabrics seem to have developed in associated D_O structures.

Once the rapid tectonic thickening had ended, the crustal prism started to equilibrate thermally. It is proposed that the magmatic, metamorphic and hydrothermal effects which followed D_O were the result of the thermal equilibration of the base of the thickened crustal prism (Fig. 12D). These effects were focussed along the breaks because it is these relatively steep structures which penetrated to depth where magmas were generated and where metamorphic dehydration reactions were occurring. Alternatively, the supply of mantle derived magmas may have heated the thickened crusts, causing partial melting and dehydration reactions. In either case, the D_1 and D_2 deformations were localized along the same broad zone because the penetrative strain represented by these deformations required metamorphic re-crystallization, which in turn required fluids, and the heat transported from depth by these fluids and by magmas.

4. GOLD DEPOSITS

4.1 Kirkland Lake Gold Camp

4.1.1 Mining History

Gold at Kirkland Lake was first discovered by W.H.Wright in 1911 on what became the Wright-Hargreaves Mine. In the following year, another discovery was made on the site which was later developed as the Toburn Mine, The Toburn discovery created a great prospecting rush in the area. Production at Toburn started in 1913. Since then, gold recovered from the camp has amounted to 710 tonnes (23 million ounces) from 7 mines (Table 5). They are the Macassa, Kirkland Lake Gold, Teck Hughes, Lake Shore, Wright Hargreaves, Sylvanite and Toburn (Fig.14). At present, only the Macassa Mine is still operating.

TABLE 5. GOLD AND SILVER PRODUCTION FROM SELECTED MINES IN THE KIRKLAND LAKE-LARDER LAKE AREA.@

MINE	GOLD (10^3 oz)	SILVER (10^3 oz)	GOLD GRADE (oz/ton)
Kirkland Lake	1,173	130	0.37
Kerr Addison	9,652	532	0.28
Lake Shore	8,499	1,955	0.51
Macassa	2,355	385	0.44
Sylvanite	1,667	338	0.33
Teck-Hughes	3,689	502	0.38
Toburn	571	135	0.48
Upper Canada	1,398	590	0.30
Wright-Hargreaves	4,818	854	0.49

@ Bertoni (1983)
Mines along the Kirkland Lake Main Break located in Fig. 14

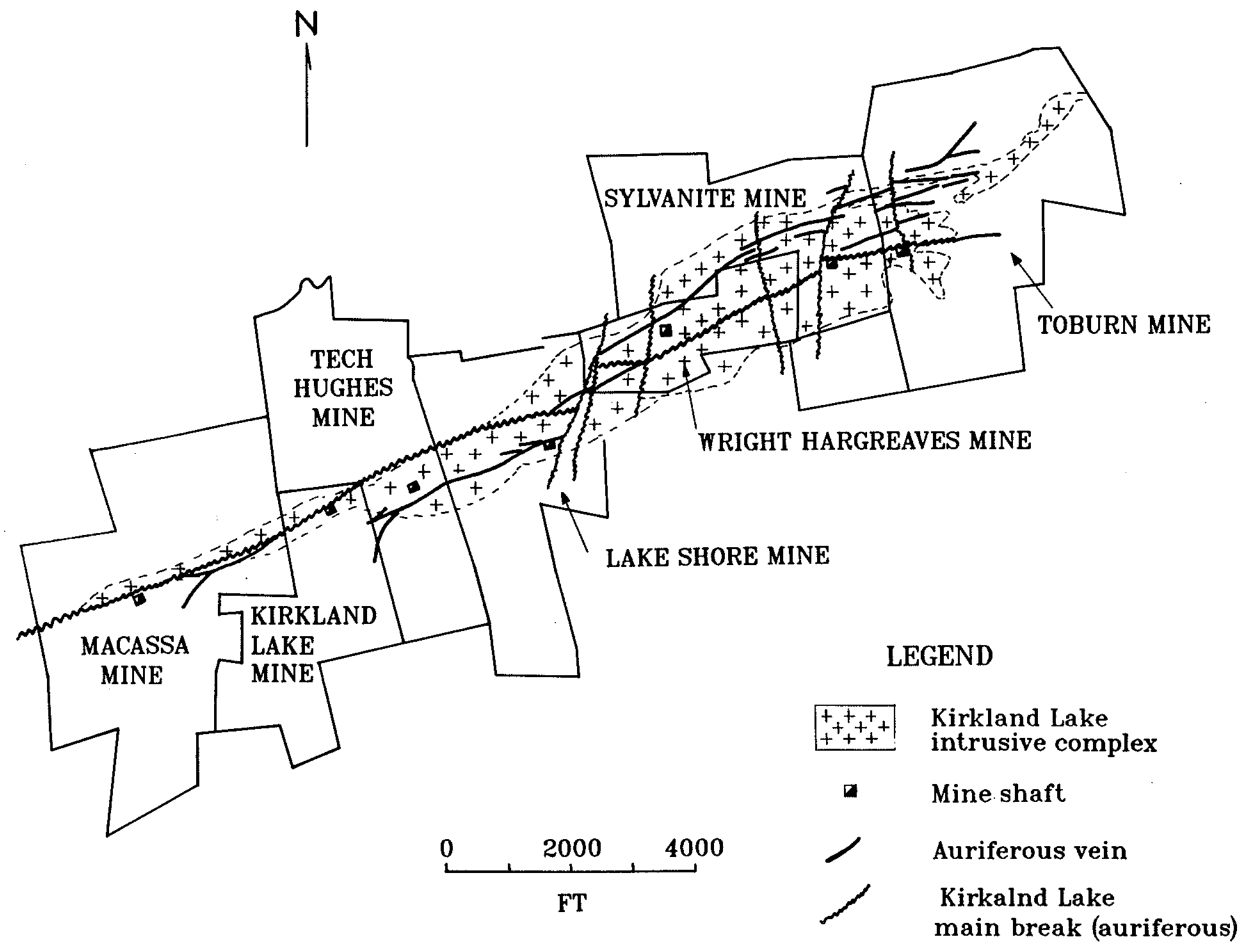

Figure 14 Vein system and mines in the Kirkland area (Ploeger and Crocket, 1982).

4.1.2 Lithologies

The most important rocks in the area are the composite intrusions of the Kirkland Lake Igneous Complex, which controls the distribution of veins and hosts the majority of the gold (Fig. 14). The Igneous Complex intruded Timiskaming Group rocks after the entire assemblage was tilted to a subvertical orientation. The emplacement occurred along a fault which is roughly parallel to the strike of the sediments (60 to 80 °) and dips steeply to the S near the surface and flattens at depths greater than 4000'. This fault appears to be a reverse fault (Thomson et al., 1950) and a splay off the Larder Lake-Cadillac break. It is classified as a D_o structure, and is analogous to the Dome fault in the Timmins area. Following the emplacement of the Kirkland Lake Igneous Complex, the fault was re-activated, forming the present Kirkland Lake Main Break and associated subsidiary faults. These faults host most of the auriferous veins in the camp.

At Macassa, the Kirkland Lake Main Break offsets the Igneous Complex by about 1500'. In the central part of the camp, offset is less. Following the vein formation, subsequent movement produced fault gouge along both the Kirkland Lake Main Break and adjacent to veins, and it also offset the auriferous veins.

In the Kirkland Lake area, the alkalic intrusive complex displays many mineralogically and texturally distinct phases. Four units are recognized (Thomson et al., 1950; Kerrich and Watson, 1984): augite syenite, (felsic) syenite, feldspar porphyry, and quartz-feldspar porphyry. The porphyry units occur in the central and northern part of the complex and they are the host rock for gold at the Lake Shore Mine, the largest past-producer in the camp. Augite syenite hosts most of the ore at Macassa Mine. Syenite units are alkalic and nepheline normative.

Augite Syenite: This grey black to olive black coloured unit has a granular textures with distinct augite phenocrysts. Mineralogically it consists predominantly of augite and K-feldspar, with minor Ti-magnetite, biotite, hornblende, apatite and titanite.

Felsic Syenite: This rock is grey to pink in colour and consists primarily of K-feldspar with minor augite and biotite. The gradational contact relationships and continuous chemical differences between the augite syenite and felsic syenite suggests that the felsic syenite is a differentiate of the augite syenite.

Feldspar Porphyry: The porphyry unit is sub-alkalic and predominately quartz normative. The modal compositions plot in the quartz monzonite field of a Streckeisen diagram (Hicks and Hattori, 1988). This unit consists of at least four phases; plagioclase-biotite porphyry, plagioclase-hornblende-biotite porphyry, quartz-plagioclase-K-felspar porphyry, and biotite porphyry (Hicks and Hattori, 1988). While plagioclase is the dominant phenocryst mineral in the porphyry, K-feldspars are usually larger, (~15mm,) than plagioclase. K-feldspar-bearing feldspar porhyry is called "bi-modal porphyry" in the camp. The occurrence of titanite enclosed in plagioclase together with hornblende suggests the parent magma was oxidized. The feldsapr porphyr unit contains small miarolitic cavities, up to 5 mm, suggesting a relatively high crustal level of emplacement and/or high water pressure of the magma (Hicks and Hattori, 1988). The porphyries have a characteristic deuteric alteration, as a result of the magmas having high partial pressure of water (Hattori and Levesque, 1989).

Major and minor element analyses indicate that the earlier syenite units are identical to the volcanic rocks of the Timiskaming Group. The latter suggests that the two are co-magmatic even though the volcanism and the intrusion of the Kirkland Lake Igneous Complex are temporally separated by a major deformation event in which the Timiskaming Group was tilted to a subvertical orientation. Sr- and Nd-isotope study of pyroxene remnants indicate that the magmas were directly derived from depleted mantle source which had undergone extreme enrichment of LLIE by mantle metasomatic processes (Hattori and Hart, in prep.). Younger porphyry units intruding the syenite units in the Kirkland Lake Intrusive Complex were, however, formed from different source magmas under high water pressure. It appears that these rocks were formed at least partly from a crustal source (Hattori and Levesque, 1989). Multiple zircon ages, ranging from 2680 to 2700 Ma, (Krogh, pers. comm, 1988) also support the view that the porphyry intrusions incorporated older crustal materials.

4.1.3 Alteration

The Kirkland Lake camp was not only the center of igneous activity, as described above, but also the focus of a variety of hydrothermal activity. The rocks in the area have undergone several stages of overprinting hydrothermal alteration. Alteration in the Kirkland Lake gold camp has been classified into three types (Table

6). The earliest alteration (Type 1) took place immediately after magma solidification and is best developed in the porphyry units. This alteration, typically displayed by many hydrous felsic intrusives, is cryptic and only observable under the microscope. Hematitization and titanization suggest the hydrothermal fluids were oxidixing, which in turn reflects the oxidized nature of the parent magmas.

TABLE 6. HYDROTHERMAL ALTERATION IN THE KIRKLAND LAKE GOLD CAMP (Hicks and Hattori 1988; Hattori and Levesque, 1989).

Type	Style	Mineralogy and Chemistry
Type 1	Pervasive* related to intrusion especially in porphyries	titanite after Ti-magnetite hematite rim on magnetite minor biotitization
Type 2	Pervasive,	Green phlogopite rich in Cr, Ba, F,Sr; Oxides rich in Zn, Cr; Sulphates rich in Sr, Ba. Enrichment of Ba,Sr in K-feldspar minor carbonate
Type 3	Vein related	enrichment of K^+ (K-fledspar sericite) carbonate, quartz, pyrite, removal of Mg

*"Pervasive" means the alteration is neither controlled by fractures nor by veins.

All intrusive bodies at Kirkland Lake have undergone second stage hydrothermal alteration. (Type 2, Table 6). This is also a cryptic alteration and is not controlled by fractures. It appears that the alteration may have taken place after the cooling of the intrusions, as evidenced from the occurrence of phlogopite replacing chloritized mafic minerals. Alteration is characterized by the enrichment of Ba, and Sr in orthoclase and sulphates and the formation of Cr-bearing phlogopite and oxides. The alteration products and chemistry of the minerals are very similar to those found in, and adjacent to, lamprophyre dykes in the area Type 2 alteration is especially prevalent near the vicinity of the Kirkland Lake Main Break and is thought to have been caused by fluids ascending the Break. The preservation of barite-celestine mixtures within the phlogopite suggests the temperature of Type 2 alteration was over 450°C (Hattori, 1989).

Following Type-2 pervasive alteration, the rocks near the Kirkland Lake Main Break experienced Type 3-fracture controlled and/or vein-related alteration. This sequence of alteration is best documented by the occurrence of mica and Fe-minerals (Table 6 and 7). The occurrence of fuchsite surrounded by Cr-free mica adjacent to the ore at the Lake Shore mine indicates that the introduction of Cr occured prior to vein development. (Hicks and Hattori, 1988).

The vein-related alteration was also oxidizing. Because the Fe content of the porphyry unit is far less than that of the augite syenite unit, the effect of oxidizing vein fluids was more profound on the porphyry unit. Fe^{2+} in augite syenite was oxidized to magnetite, but only a minor quantity of magnetite was in turn oxidized to hematite. In the porphyry unit, however Fe^{2+} in magnetite is changed to hematite, producing a brick-red colouration. Close to the vein, the introduction of S from the vein fluids produced pyrite from hematite or magnetite. Other notable changes associated with this alteration type is the replacement of K-feldspar phenocrysts in the porphyry unit by sericite. In the synite unit, which has a higher alkali content, K-feldspar is stable in vein envelopes (Hattori and Levesque, 1989).

TABLE 7. WALLROCK ALTERATION RELATED TO AURIFEROUS VEINS IN THE KIRKLAND LAKE GOLD CAMP (after Hicks and Hattori, 1988; Hattori and Levesque, 1989)

Porphyry

	close to veins	far from veins	unaltered/least altered
Appearance	buff creamy green straw	brick red orange red	
Textures	fine foliation obliterate porphyritic texture	porphyritic	porphyritic
Mineralogy	sericite fuchsite quartz pyrite ankerite	K-feldspar albite phlogopite hematite (pyrite only in veinlets) minor ankerite	K-felspar albite biotite, chlorite partially chloritized horblende magnetite with hematite rim

Augite Syenite

	close to veins	far from veins	unaltered/least altered
Appearance		brownish feld cloudy fuzzy rim of augite	cleavage of augite and feld black, grey black
Textures	primary tex. totally obliterated	phenocrysts smaller	
Mineralogy	secondary K-feldspar pyrite carbonates	recryst felds albite second magnetite (low Ti) hematite recryst. biot. carbonates	perthite augite Ti-magnetite biotite

Though carbonate is ubiquitous in the Kirkland Lake gold camp, carbonatization appears less conspicuous here than in other gold camps.

Carbonate contents in the wall rocks rarely exceeds 10%. Carbon isotopic compositions of carbonates are consistent within the Main Ore Zone, (~-3 $^{\circ}/_{oo}$) and are in accordance with ore fluids being supplied from a large reservoir at depth (Hattori, unpublished data). These values are, however, distinctly different from those of ankerite-siderite along the Larder Lake Break (~-4.5 $^{\circ}/_{oo}$, S of the Kirkland Lake Main Break) and those of ankerite from the BAZ zone on the north side of the Main Break near the unconformity with the Kinojevis Group (-1.5 $^{\circ}/_{oo}$), (Fig. 15). Variable carbon isotopic compositions suggest inhomogeneous crustal sources of CO_2.

4.1.4 Vein Mineralization

Gold occurs primarily in quartz veins along the Kirkland Lake Main Break, and numerous parallel and branching veins in the Kirkland Lake Intrusive Complex. (Fig. 14) The Main Vein is exposed on the surface and it is continuous to at least 8000' below the surface. Several auriferous veins run parallel to the Main Break, such as the Narrows Break (no. 3 zone at Lake Shore), and

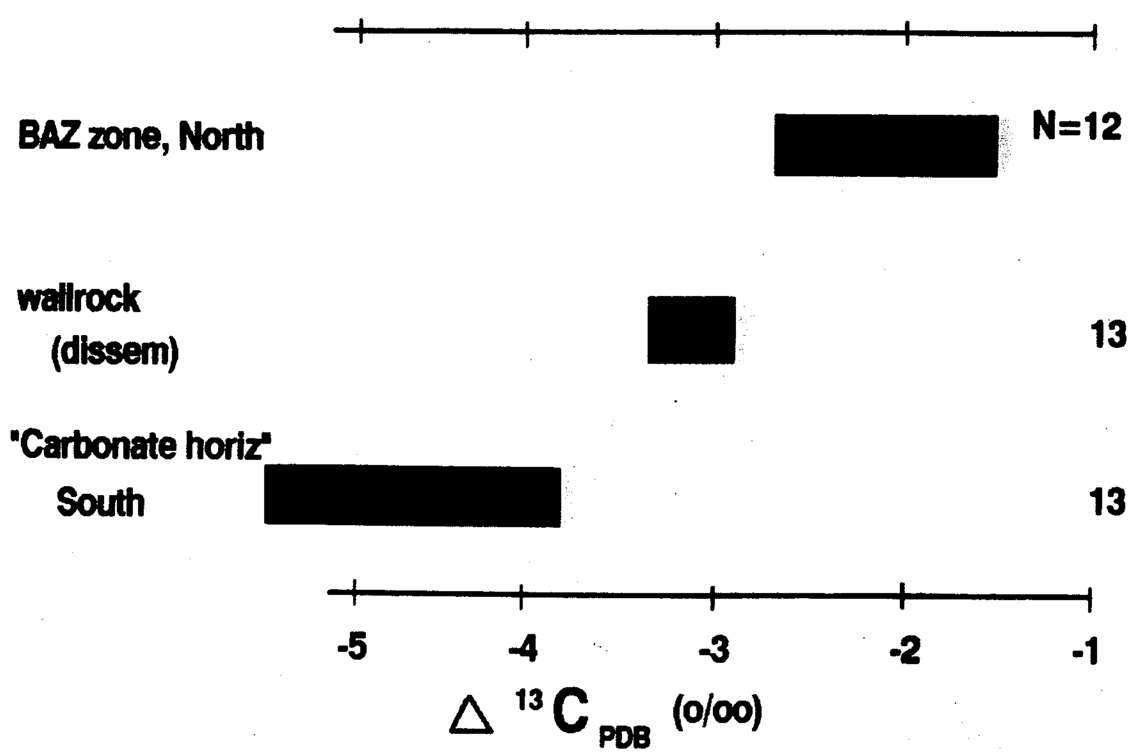

Figure 15 Carbon isotope compositions of carbonates in the Kirkland Lake Area (K. Hattori, unpublished data).

the Brown Altered Zone (Fig. 14). These veins are not as continuous as the Main Vein and their grades are not as consistent as those in the Main Break. A prominent vein parallel to the Main Vein on the S side is called S Vein at Lake Shore.

Many tension fractures occur between the Main Vein (North Vein) and S Vein at Lake Shore. These veins are less continuous than those in the shear Zones, and they commonly show pinch and swell. The deformation of the vein minerals and veins themselves are less profound than in the Main Break.

Veins along the Kirkland Lake Main Break display complex textures due to continuous hydrothermal activity and recurrent movement of the fault. The development of chlorite fault gouge ("mud seam") on both sides of the main vein suggests movement of the fault after the lapse of major hydrothermal activity.

The veins, which may be classified into a number of types according to their morphologies, include single fissure veins, sheeted veinlets zones with many parallel quartz stringers, stockwork zones and vein breccias zones.

Most fragments in quartz veins are angular to subangular blocks of the host intrusive rock. However, brecciated fragments of basalts are not uncommon in some parts of the Main Vein. These fragments were apparently brought to the site from far below the intrusive body since there is no exposure of basalts in the immediate vicinity of the mines.

Vein formation apparently started with the precipitation of quartz. The early quartz displays abundant evidence of ductile deformation, pressure solution, and re-crystallization. Preliminary fluid inclusion examination indicates that the initial stage of vein formation took place at temperatures above 340°C (Hattori and Levesque, 1989). The re-crystallized quartz was then fractured. The fractures were filled with a variety of minerals reflecting the temporal change of hydrothermal fluids. In the early stage, "moly" slip, a mixture of mostly molybdenite and graphite, was developed. Because these minerals are ductile, they commonly show slickensides due to slipping along the fractures. Other fractures were filled mainly by pyrite, quartz and ankerite. Very minor amounts of chalcopyrite and other base metal sulphides accompanied the pyrite. This was followed by the introduction of gold and tellurides. The occurrence of gold and tellurides within euhedral pyrite grains suggests that continuous hydrothermal activity caused re-crystallization of pyrite. However, since most gold and tellurides occur in fractures, the introduction of precious metals into their present sites was late in the history of hydrothermal activity. In grab samples, the typical observable relationship includes early quartz (usually with a greasy appearance) being cut by numerous veinlets of sulphides (dark seams), molybdenite ("moly-slip"-shiny seams), and quartz-carbonate-sulphate (clear).

The veins are also cut by stringers of quartz and carbonates (Mn-calcite, calcite) that may be accompanied by specular hematite veinlets. Based on fluid inclusion filling temperatures, these late cross-cutting veins formed at relativelatively high temperatures (>280°C, Hattori and Levesque, 1989).

Gold occurs mainly as native gold, and in minor quantities of tellurides, (mostly as calaverite $AuTe_2$). Petzite (Ag_3AuTe_2) also carries gold, but its occurrence is rare in the camp. The occurrence of gold is closely associated with that of telluride minerals such as coloradoite (HgTe) and altaite (PbTe). A rare occurrence of melonite (NiTe) is reported from the central part of the camp (Thomson et al., 1950). Underground, the characteristic blue-greenish tarnish of altaite is common in high grade zones.

SURFACE TOUR OF THE KIRKLAND LAKE CAMP (Fig. 16, 17)

The surface tour will examine the typical lithologies in the area and the Kirkland Lake Break.

Ample opportunity to observe gold veins hosted by augite syenite will be available during the tour of the Macassa Mine (Day 3).

STOP 1. Otto syenite stock intruded by several lamprophyre dykes on HWY. 11. (Fig. 18)

The Otto stock, ~ 10 km across, is one of a series of late- to post-kinematic alkalic intrusions emplaced in the Kirkland Lake-Larder Lake area. Like other stocks, the Otto stock is a composite intrusion containing several mineralogically and texturally

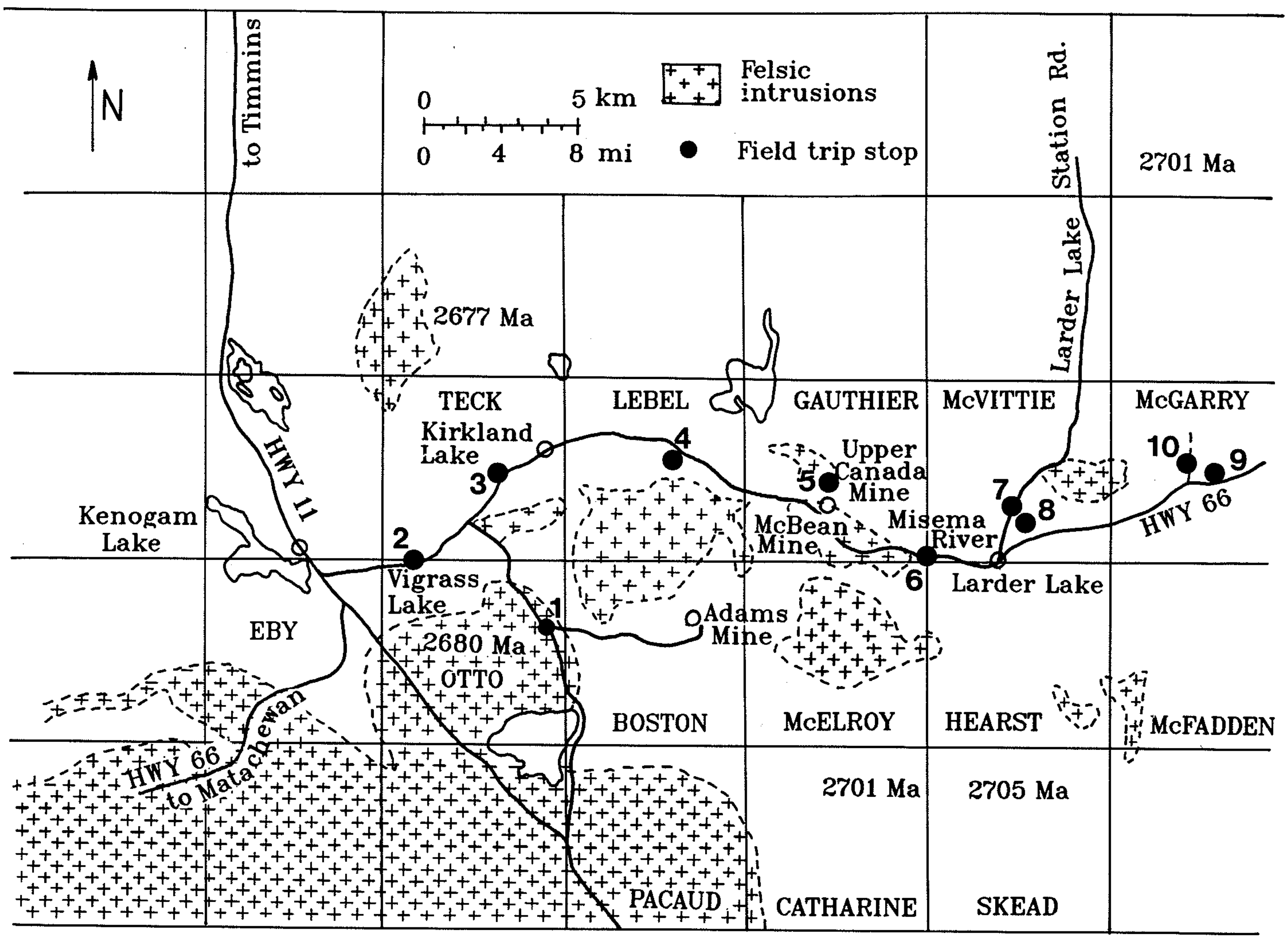

Figure 16 Location of stops (numbered) in the Larder Lake-Virgineatown area

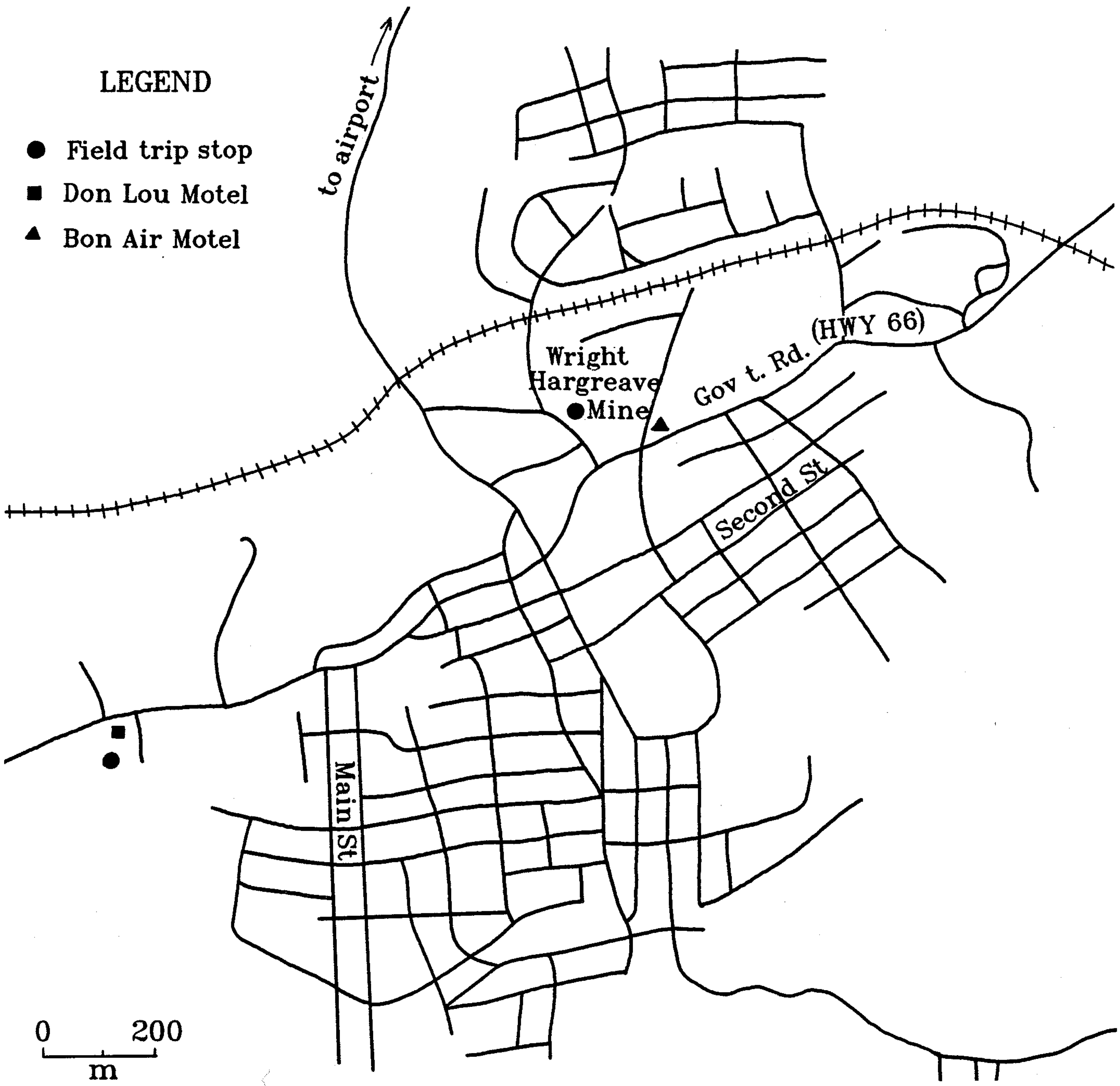

Figure 17 Location of stops in the town of Kirkland Lake

distinct phases (Fig. 18). U/Pb zircon age of the intrusion is 2680 ± 1 Ma (Corfu et al., 1989).

The Otto stock is intruded by numerous calc-alkaline lamprophyre dykes (minette and vogesite). They are abundant along the stock contact zone. Minette consists mostly of biotite and augite with minor K-feldspar and carbonates. Vogesite contains biotite, hornblende, augite, K-feldspar and carbonates. The dykes in this outcrop are very typical of lamprophyre dykes in the area. Lamprophyre titanites give an age similar to the Otto stock, within the error range of the dating method.

STOP 2: Vigrass Lake outcrop- Keewatin and Timiskaming contact. (Fig. 19)

The outcrops located 1.6 km W of Swastika on HWY 66, show many rock types and structural relations typical of the Southern Abitibi belt (Fig. 19). Here NW-striking, W-facing greywackes of the Timiskaming Group are in contact with NW-striking, W-facing komatiites and Mg-tholeiites of the Larder Lake Group across the EW-trending Larder Lake-Cadillac Break. The break is largely covered by the road, but is exposed in one outcrop on the N side of the road.

The volcanic rocks and sedimentary rocks are cut by quartz syenite intrusions. Near the intersection of the road and the power line, a body of syenite lies across the break. Prominent carbonatization occurs in mafic and ultramafic rocks, but is weak in the Timiskaming sedimentary rocks near the intrusion. Carbonate locally occurs as light coloured pods within the dark coloured serpentinized ultramafic unit. In places, the carbonate contains Cr-mica (fuchsite), giving it a green colour.

STOP 3: Teck Hughes mine property at Don Lou Motel (Fig. 20)

In the outcrop W of the parking lot, augite syenite intrudes trachyte tuff and is is in turn intruded by a syenite porphyry dyke. To the S, the upper section of the tuff is exposed on the top of the hill behind the Don Lou Motel. The tuff is unconformably overlain by typical Timiskaming Group

polymictic conglomerate (Fig. 20). Characteristics features of the conglomerate include the polymictic nature of the clasts and the presence of red jasper pebbles derived from banded iron formation.

Production figures from the Teck-Huges Mine are found in Table 5.

STOP 4: Trachytic tuffs and sedimentary rocks of the Timiskaming Group at the junction of the railway and HWY 66 past King Kirkland.

This outcrop shows well bedded trachyte tuff and fine grained sedimentary rocks, and the relationships among the bedding, D_1 and D_2 cleavages.

Stop 5: L ore zone of the Upper Canada Mine, Queenston Gold Mine Ltg., near Dobie, in the central Gauthier Township.

The Large stripped area shows one of the mineralized zones of the Upper Canada Mine (Fig. 21). The mine produced over 1 million oz of gold.

The property is underlain by the Timiskaming Group rocks, which are composed of a variety of alkaline volcanic flows, breccias, pyroclastic rocks and intercalated sedimentary rocks. They are intruded by syenites and feldspar porphyries. The rocks in the property are foliated to 070° and the intensely sheared 1 km wide subvertical zone of is called the Upper Canada Break. The rocks in the Break are sericitized and dolomitized and locally tourmalinized and silicified.

Gold mineralization at the main L ore body is restricted to quartz-carbonate veins and strongly carbonatized adjacent wallrocks in the core of the Upper Canada Break. All orebodies are tabular with a subvertical dip and parallel the dominant foliation (Toogood, unpub. data). Other minerals include sphalerite, galena, tennantite, hematite, magnetite, altaite and scheelite. The deposit is relatively silver rich with silver/gold ratios at the mill of 0.42

STOP 6: Larder Lake-Cadillac Break at the Misema River

The break here consists of a highly deformed green carbonate-rich schist zone which is well exposed beside the Misema River bridge on the north side of Highway 66, 2.5 km W of Larder.

On the S side of the highway (just inside the forest), spinifex texture and poorly developed

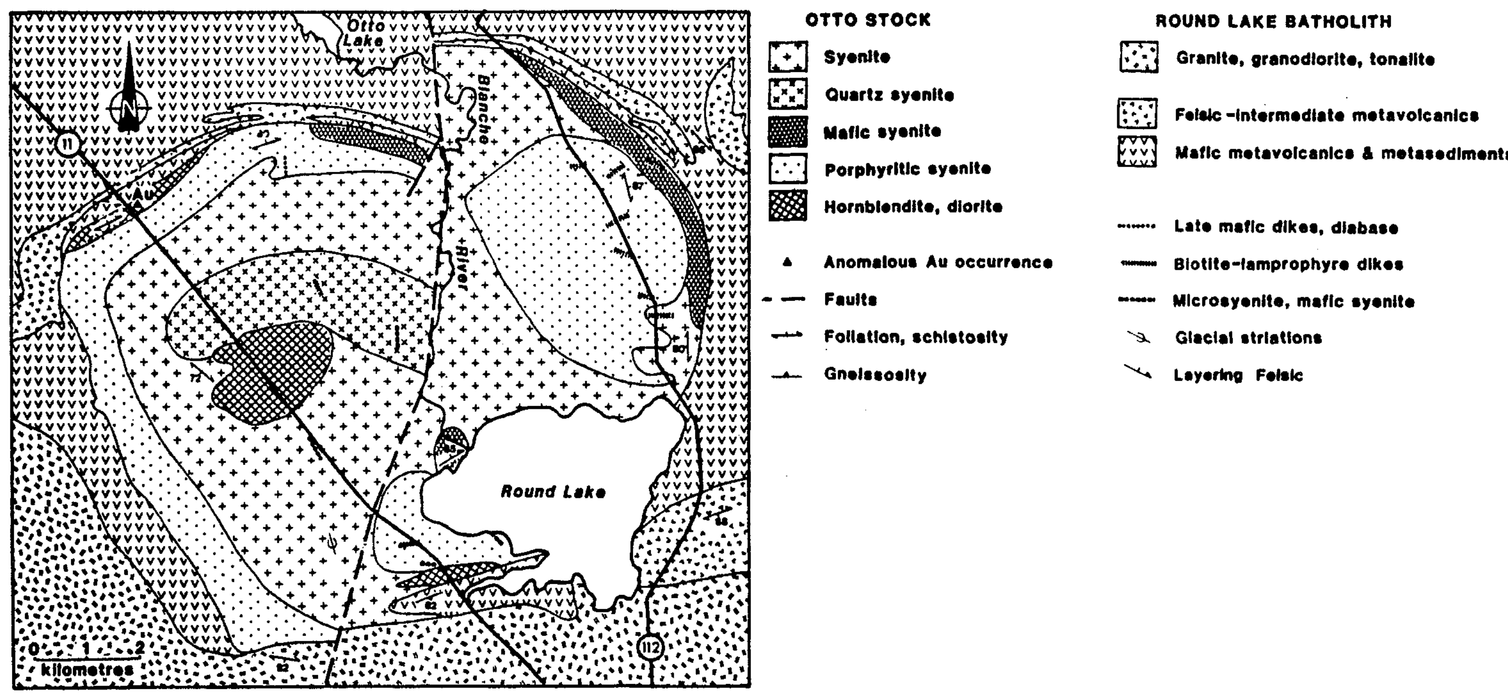

Figure 18 Generalized geology of the Otto stock (after Smith and Sutcliffe, 1988).

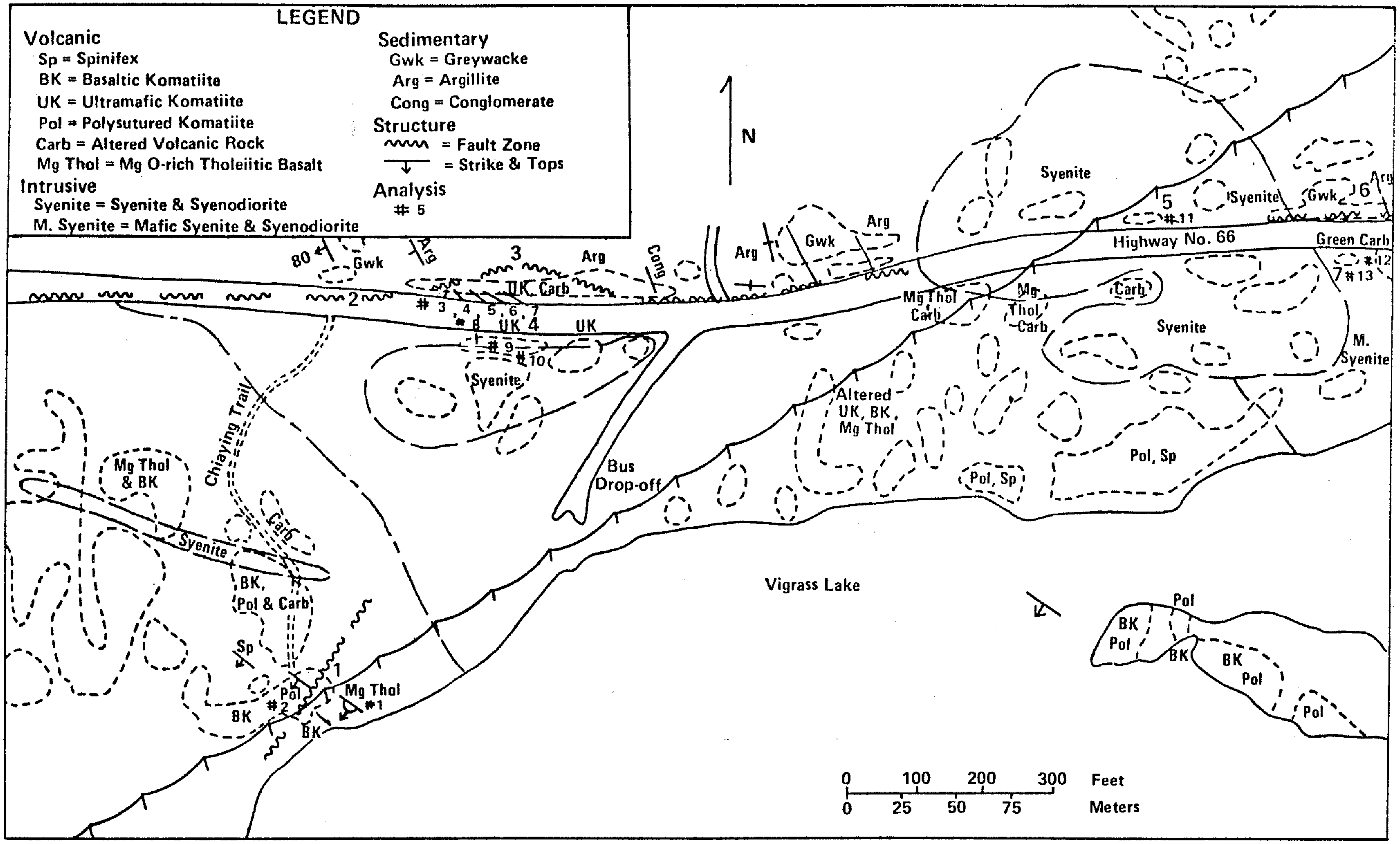

Figure 19 Surface geological map showing outcrop distribution at Vigrass Lake (after Jensen, 1978)

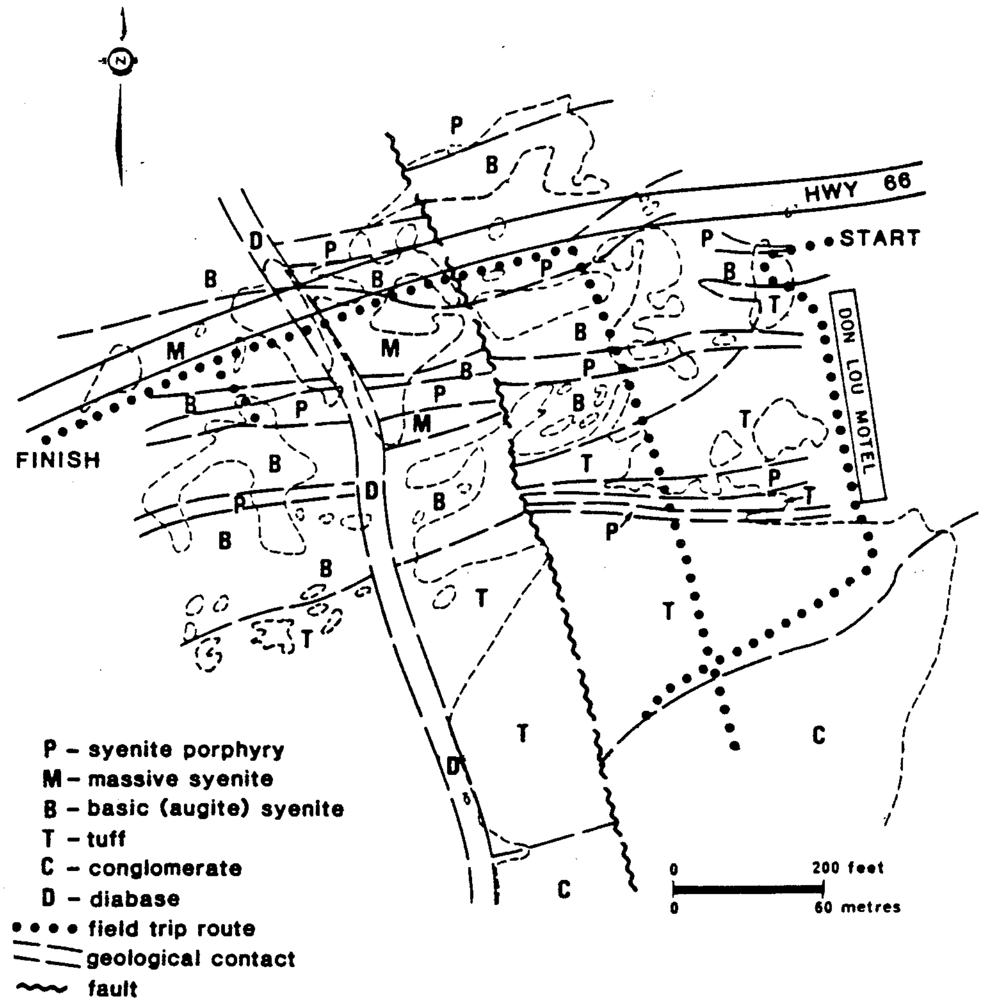

Figure 20 Surface Geology of the Teck-Hughes (after Ploeger, 1986).

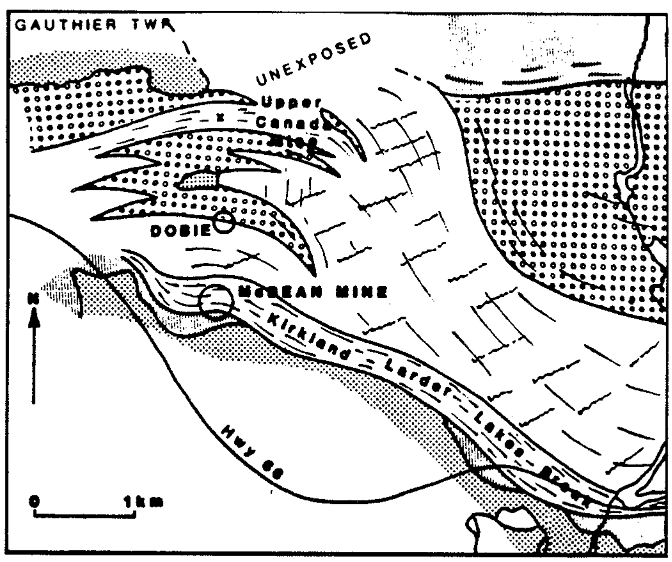

Figure 21 Schematic geological map of southeastern Gauthier Township (after Toogood 1986). Ornamentation: stippled - syenites; hatchured - Pre-Timiskaming mafic volcanic rocks; circles - trachytes; straight lines - first foliation; wavey lines - second foliation.

polysuturing of the komatiitic lavas can be observed.

STOP 7: Auriferous vein on Larder Lake Station Road near Highway 66.

Zone of variably developed D_2 cleavage superimposed on D_1, with auriferous quartz-tourmaline veins emplaced parallel to D_2. This NE-trending part of the Larder Lake Break is dominantly a zone of D_2 flattening and left-handed lateral slip.

STOP 8: Omega Mine crown pillar

The ore is well exposed on the Larder Lake Station road past the railway tracks. This outcrop displays typical auriferous pyrite quartz veinlet mineralization in a thin slice of carbonatized komatiites. The komatiites occur along the Larder Lake-Cadillac break between the Kerr Addison mine and the Misema River.

STOP 9: Larder Lake-Cadillac Break.

The Break is exposed in numerous Timiskaming Group road cuts. Thick-bedded arkosic sandstones strike at a high angle on the north side of the highway. Komatiites of the Larder Lake Group are altered to carbonate rocks in the highway outcrop, while less carbonatized komatiites are exposed in the ditch on the S side of the highway.

STOP 10: Small road north along the E side of the Kerr Addison mine townsite

The outcrop displays NE-striking turbidites of the Timiskaming Group. These rocks form a fault-bounded panel in contact with the thick-bedded sediments to the SE (Stop 9)and trachyte to the NW. (Stop 11). The Kerr Addison mine has been described by Kishida and Kerrich (1987).

STOP 11: Trachyte of the Timiskaming Group

The trachytes are observed by following the trail on the W side of the road to the high outcrops. These appear to be in fault contact with the turbidites. (Stop 10)

OPTIONAL STOPS

Optional Stop: Tower Gold Mines Limited "Kirkland Commodore" gold occurrence.

Optional Stop: McBean Mine Open Pit, Gauthier Township, South of Dobie

The mine (formerly known as the Queenston Mine) had reserves of 500,000 tons of ore at 5.0 g/t Au to a depth of 85 m with a cutoff grade of 3.4 g/t (Toogood, 1986). The deposit occurs within the Kirkland Lake-Larder Lake Break which coincides with the southern contact of the Timiskaming Group. The orientation of the Break changes from 90° to 120° in the eastern part of the township, then changes back to ~70° just W of the mine (Fig.21).

The Timiskaming Group rocks in the area are mostly graded argillites and minor conglomerates. Trachytic tuff and flows are intercalated with the sediments north of the mine and in the eastern portion of Gauthier Township. Tholeiitic basalts and gabbros of the Larder Lake Group occur S and W of the mine (Fig.21). Gold mineralization is associated with syenite intrusions. The syenite bodies, as well as the volcanic and sedimentary host rocks, are intensely deformed and altered.

Auriferous quartz veins are prominent in syenite because of the brittle response of syenite to the deformation. Veins in the host sediments and basalts are less obvious because of the ductile response of these rocks to the deformation.

In the 50 m wide ore zone at the pit, two subvertical foliations are prominent and they intersect at an angle of 20 to 30°. In places, the intersects of the foliations produce a steeply plunging lineation. Shear parallel foliation (C-fabric) with a flattening foliation (S-fabric) parallel to the strain ellipsoid extension axis, indicates right lateral strike slip movement in the shear zone.

Optional Stop: Wright-Hargreaves gold mine site in front of the BDR Drug Mart building near the ball fields, 110 m north on Tweedsmuir Road from Highway 66.

This locality marks the first gold discovery in the Kirkland Lake area.

In the outcrop between the parking lot and the road, syenite porphyry hosts an auriferous quartz vein. The vein display a high degree of brecciation and is bordered by a 10 to 30 cm wide intense alteration zone.

Optional Stop: Timiskaming Group volcanic and sedimentary rocks along the railway track, S of Kenogami, 4 km W of the town of Swastika.

The rock types found in this ~ 200 m section along the railroad track are medium grained greywacke, polymictic conglomerate, trachyte and, in the S end of the outcrop, syenitic dykes. The greywacke displays primary sedimentary textures, graded bedding, cross bedding (E side of the outcrop), and scouring, indicating that top is towards the S. The strike of the bedding is 055° with dips of 80 to 85°. The conglomerate contains clasts of diverse origin, including; mafic volcanic rocks, red jasper, trachyte, and spherulitic volcanics.

Below the conglomerate and greywacke units, is a porphyritic trachyte pink containing pink, up to 2cm long, K-feldspar phenocrysts, up 2 cm long.

The Timiskaming rocks are intruded by a felsic dyke in the north end of the outcrop.

Optional Stop: Timiskaming Group volcanic rocks at Crystal Lake

The stop is 1.9 km W of the intersection to the Crystal Lake. The alkalic rocks are reddish grey porphyries. They are more mafic than most trachyte in the area (~53 wt.% SiO_2) and are nepheline normative (>10 %).

Optional Stop: Kenogami Lake rock cuts

This stop allows observation of the tholeiitic basalts of the Kinojevis Group north of the Timiskaming Group and the unconformity between Proterozoic and Archaean rocks.

Tillite and arkosic greywacke of the Huronian Gowganda formation (early Proterozoic age) unconformably overlie Mg-rich tholeiitic basalt of the Kinojevis Group. The Mg-rich basalt consists of massive flows, pillows and pillow-breccias mixed with hyaloclastite. Approximately 2.5 km north of this outcrop, dark green to black magnetic Fe-rich tholeiitic basalts of the Kinojevis Group are well exposed.

Optional Stop: Fluviatile Timiskaming Group sediments at Chaput Hughes on HWY. 66.

The large outcrop on the north side of HWY 66 at Chaput Hughes displays textures and compositions typical of Timiskaming Group conglomerates. Cross-bedding, the presence of pebble trains and many other sedimentary features of fluviatile conglomerate are observable in this outcrop. Note the presence of distinctive red jasper clasts, derived from banded iron formations, and pink felsic porphyry clasts.

Optional Stop: Trachyte tuff with gold mineralization

Trachyte tuff hosts gold mineralization 11 km E of the Ontario Northland Railway crossing at the E edge of Kirkland Lake. The tuff is brownish pink due to fine disseminations of hematite and K-feldspar and the oxidation of pyrite.

Optional Stop: Komatiite and alternating rhyolitic tuff of the Larder Lake Group.

These outcrops, situated along HWY 624 in Skead Township, consist of Larder Lake Group komatiite flows, with pyroxene spinifex textures, intercalated with rhyolitic tuff containing large quartz phenocrysts. The tuff is inter-layered with conglomerate containing clasts of spinifex textured ultramafic rocks.

Optional Stop: The exposure of Kerr Addison ore.

In a rock cut along the south side of HWY 66, on top of the hill W of Kearns, typical "flow-type" ore is exposed. The auriferous rock is intensely sheared and highly carbonatized and shows well developed fine foliation, which resembles "flow" texture.

4.1.6 Macassa Mine

The Macassa is the most westerly of the 7 mines located along the Kirkland Lake Main break (Fig. 14). The development of the Macassa mine began in 1931, when arrangements were made to drive westward from the adjoining Kirkland Minerals property on their 2475' level. Subsequent discovery of ore along the Kirkland Lake Main Break and in subsidiary veins in hanging wall rocks prompted shaft sinking. Since then, two additional winzes have been put down with the present depth at 6875'. Current active workings begin at the 2300' level and extend down to the 6450' level (Nemcsok, 1988).

Mineralization at the Macassa Mine

The Kirkland Lake Main Break, with

accompanying zones of mylonitized and brecciated wallrocks and chloritized mud gouge, traverses the entire length of the Macassa property. The strike of the Main Break on the property averages 65° and it dips 80° to the S to about the 3475' Level, then it gradually flattens to 50°. Flattening, splitting, and connecting of breaks produced a complex vein system at Macassa. The Main break is accompanied by several parallel veins (Figures 22 and 23). Among these, the 04 break is by far the most important. During the last 25 years, the 04 break, between the 4500 and 6500' level, produced most of the Macassa ores. (Nemcsok, 1988). The Main vein splits into N and S veins below the 4125' level and the South vein combines with one of the parallel veins (Fig. 23).

Vein morphology is dependent, on the nature of the hosting faults and on post-ore movement of the faults. A single fissure vein-type with brecciated fragment of the host rocks is common along the Main Break. However, a scattered breccia type is more common in the western part of the property. In extreme cases, the ore zones widen up to 30' over intervals of a few hundred feet and the wallrocks are highly brecciated so that the contact between the vein and wallrock is not discernable.

Several post-ore faults displace the mineralized vein system. The "Boundary Fault" and Tegren Cross Fault are the major ones on the Macassa property. The Tegren Cross fault, which strikes 16° and dips steeply E, is a major post-ore fault displaces the mineralized veins vertically ~300' (W over E) and horizontally ~200' (W side S) (Nemcsok, 1988). The presence of vuggy calcite and chalcopyrite mineralization along these faults and red hematitic alteration in wallrocks suggest that hydrothermal activity was apparently continuous during post-ore fault movement.

4.2 MATACHEWAN GOLD CAMP

The Matachewan camp is located along the western extension of the Larder Lake-Cadillac Break. Proterozoic sedimentary rocks underlie the area between Matachewan and Kirkland Lake (Fig. 24).

4.2.1 Regional Geology

The Archean supracrustal rocks in the Matachewan area consist mainly of tholeiitic basalt and andesite flows with minor iron formation and interflow sedimentary rocks. These are unconformably overlain by alkaline volcanic rocks and sedimentary rocks of the Timiskaming Group (Thomson, 1946). The Timiskaming Group rocks occur as lenses along the Larder Lake-Cadillac Break. The geology and structure of the Matachewan area is shown in Figure 24.

4.2.2 Mineralization

The Matachewan camp has produced over 1 million oz (31 tonnes) of gold and 170,000 oz (5.3 tonnes) of silver between 1934 and 1956 (Sinclair, 1982). Most of the gold mineralization mined was of low-grade. In the Matachewan camp gold occurs in narrow quartz stringers and as disseminations with pyrite within, and near, monzonitic to syenitic intrusions.

The spatial occurrence, mineralogy and alteration of the ore in the Matachewan camp is similar to that of the Kirkland Lake gold camp. The ores are mostly hosted in late- to post-kinematic monzonitic intrusions, which were emplaced near the Larder Lake-Cadillac break. The wall rock alteration consists of hematitization, sericitization and minor carbonatization. The metallic mineralogy of Matachewan veins is similar to that of Kirkland Lake, but with enhanced tellurides.

The host intrusions are commonly porphyritic with large oscillatory zoned plagioclase phenocrysts, suggesting emplacement along a tectonically active zone. The altered varieties display red colouration due to intense hematitic and K-feldspar alteration. Mineralized basalts near the intrusions (e.g., Matachewan Consolidated Mine), are commonly brecciated ("ore breccia") and show a buff greenish colouration due to the formation of fuchsite and carbonate (Derry et al., 1948).

4.2.3 Young-Davidson Mine

The deposit, located in the SE part of Powell Township, is confined to a syenite body that has been intruded along the southern contact between Timiskaming-type sedimentary rocks and older mafic volcanic rocks. (Fig. 25, 26) The syenite body consists of hornblende-bearing, porphyritic syenite and foliated syenite. Proterozoic Cobalt Group sedimentary rocks overlie the Archean rocks 300 ft S of the Open pit.

As previously mentioned, the mineralized portions of the syenite are brick-red due to intense K-feldspar and fine grained hematite alteration. Pyrite is ubiquitous near the mineralization. Less altered rocks

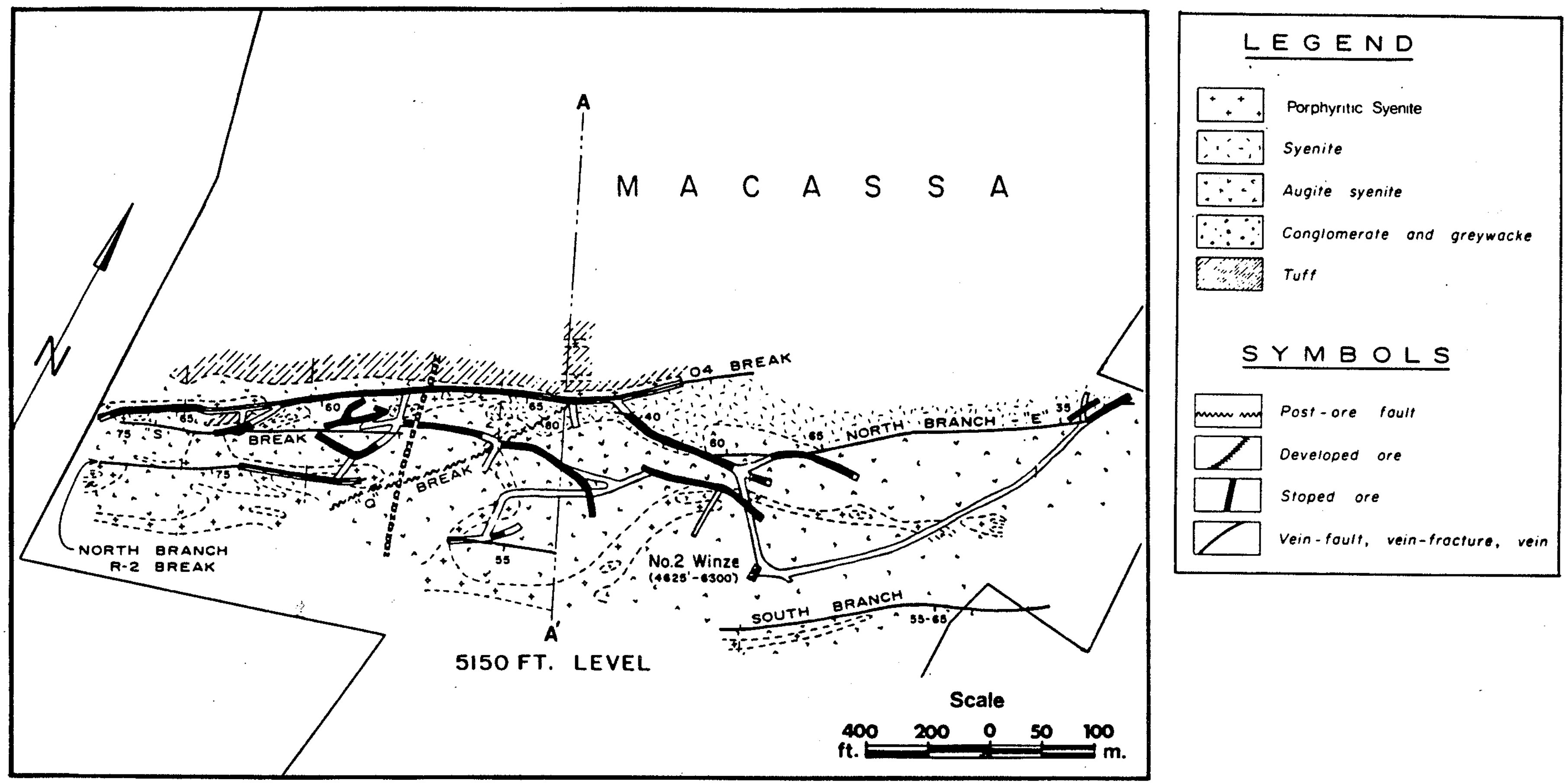

Figure 22 Plan view of auriferious veins, Macassa Mine, Kirkland Lake. Geological plan of 5150 foot level illustrating relationship between the '04 and Main Breaks, S and R-Z Breaks (after Charlewood, 1964).

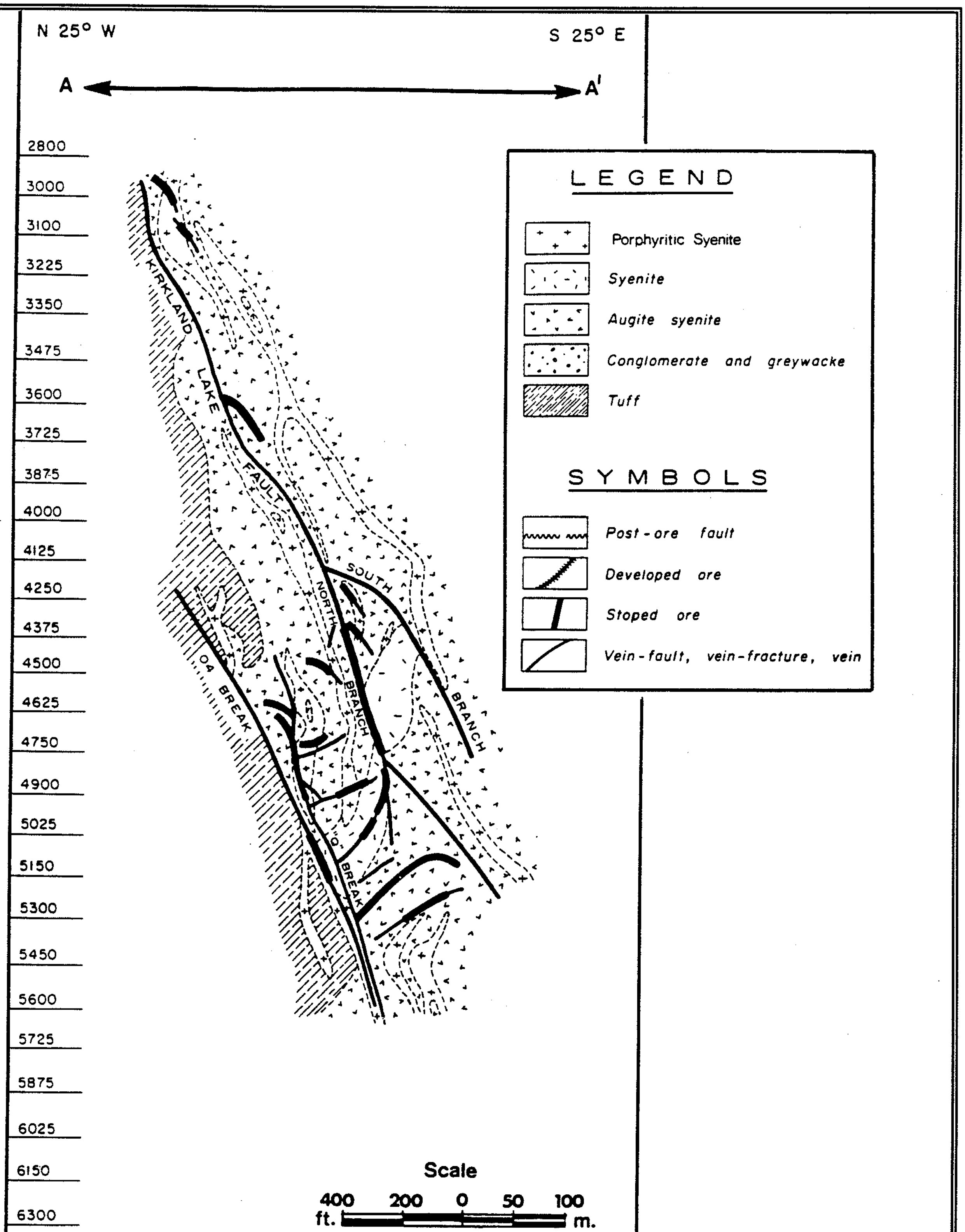

Figure 23 Vertical section of the Kirkland Lake Main Break (after Charlewood, 1964).

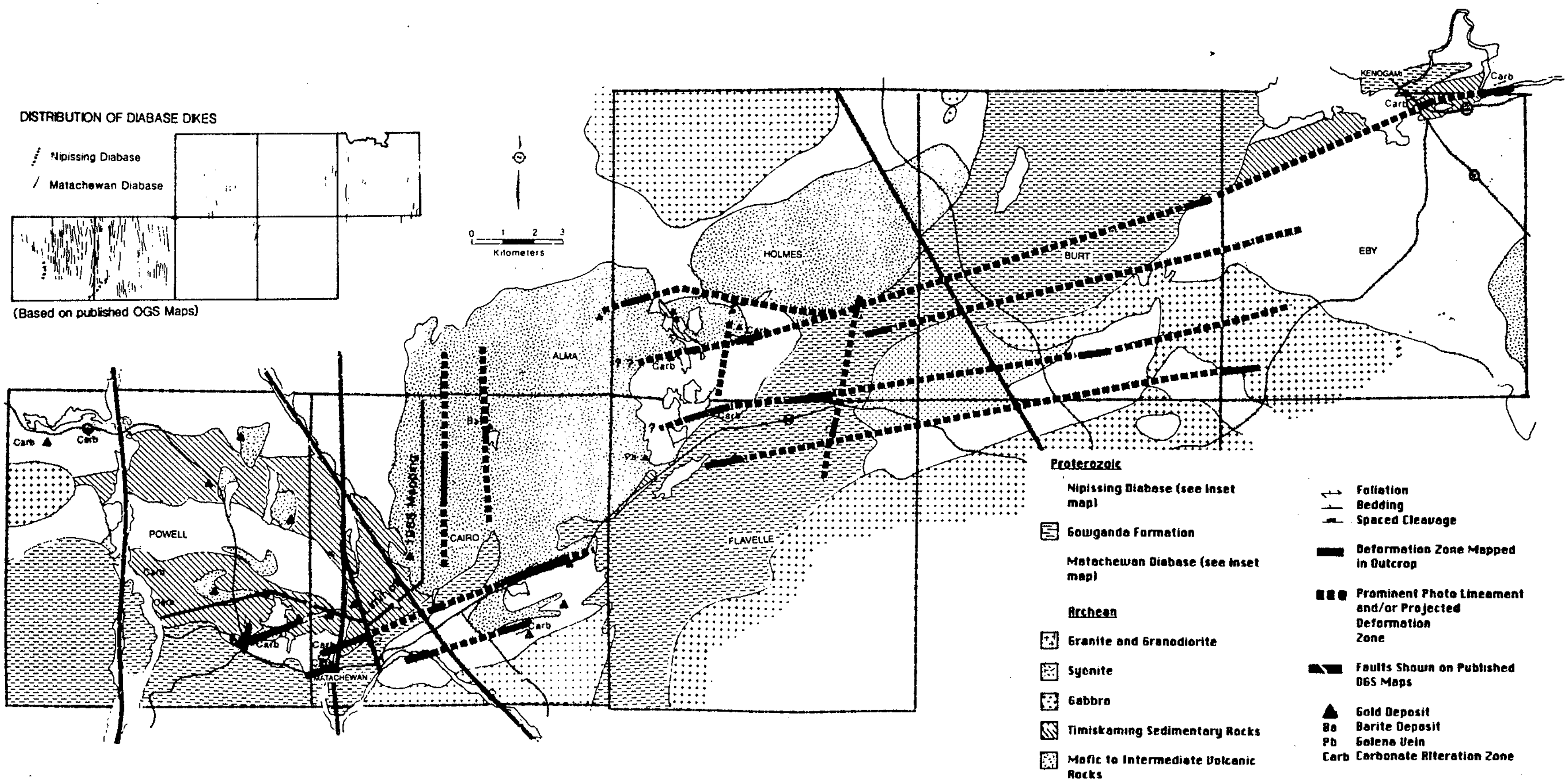

Figure 24 Geology of area between Matachewan and Kirkland Lake (Powell et al., 1989).

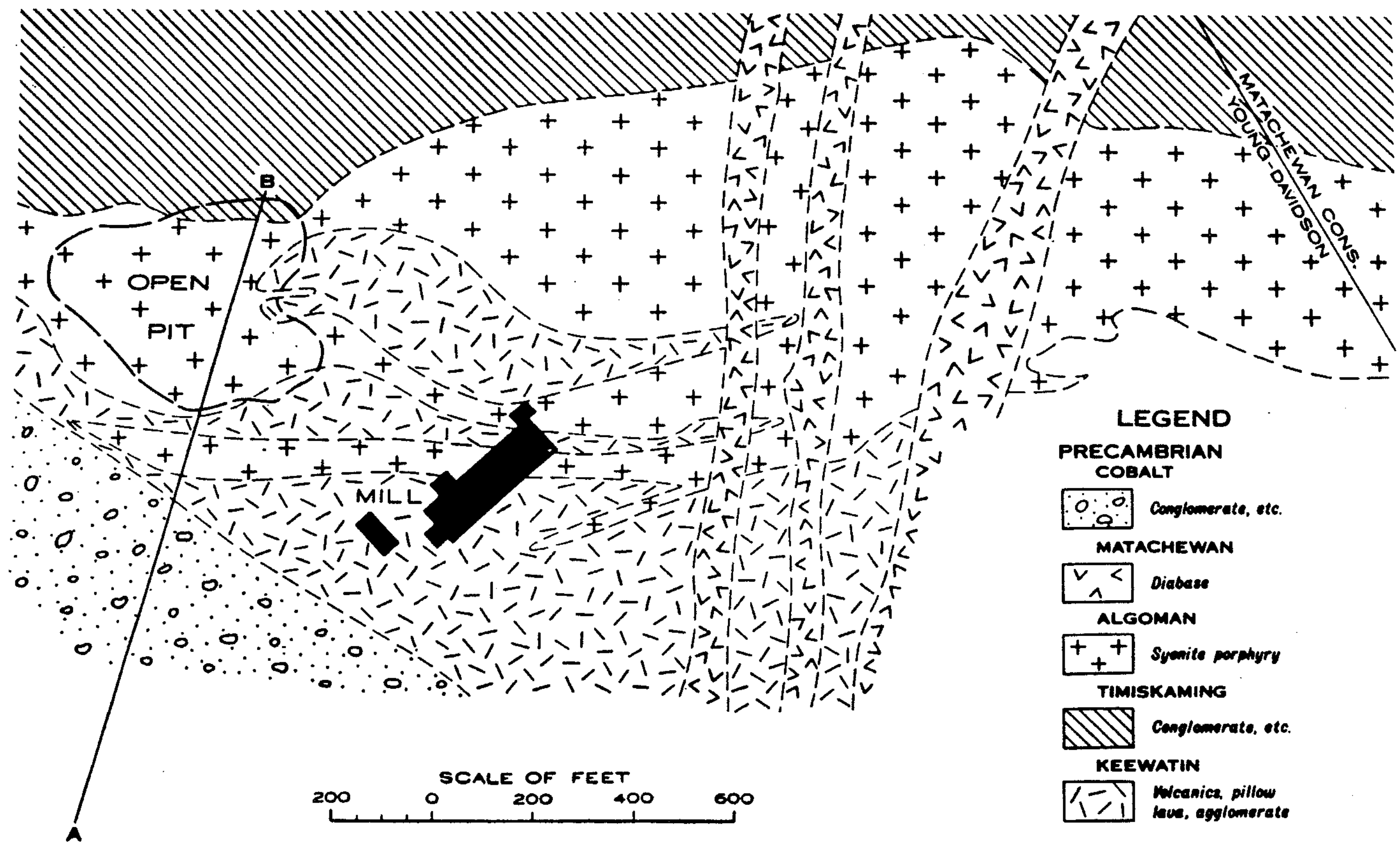

Figure 25 Surface geology of the Young-Davidson Mine, Matachewan (after Lovell, 1967).

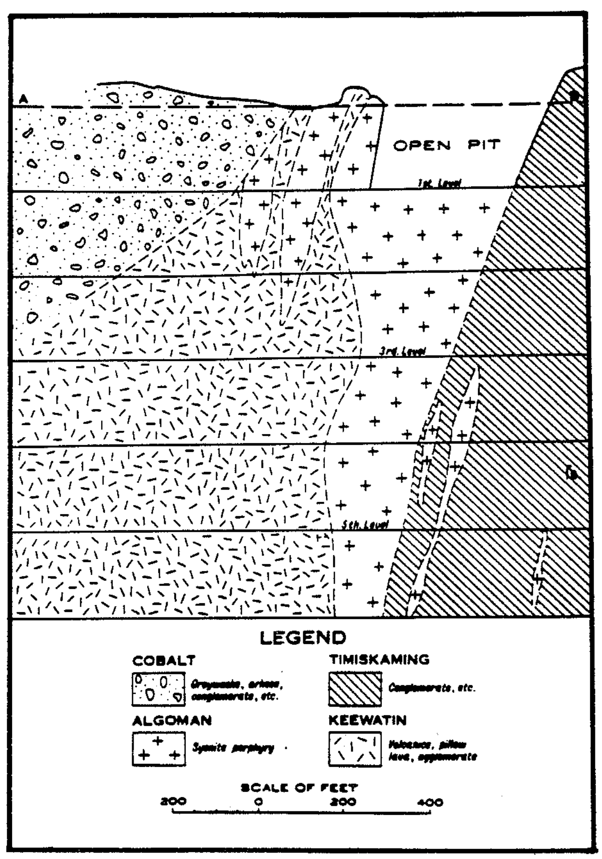

Figure 26 Vertical section of the Young-Davidson Mine, Matachewan (after Lovell, 1967).

retain a gray colour and plagioclase phenocrysts.

The ore body in the syenite has a tapering cone shape extending downward from the open pit (Fig. 26). Locally, small syenite plugs, mainly E of the open pit, also contain economic grades of mineralization.

4.3 ROSS MINE, HISLOP TOWNSHIP

4.3.1 Mining History

The mine is located near the SE corner of Hislop Township, ~96 km NW of Kirkland Lake (Fig. 3, 27).

The initial discovery of gold in the Hislop area dates back to 1905. After relatively little exploration in the 1910's and 20's, ore grade gold was found at the present site of the Ross Mine in 1933, and shaft-sinking commenced in 1934. Since 1935, the mine has produced ~900,000 oz of gold and 1,330,000 oz of silver from ores averaging 0.169 oz/t Au and 0.283 oz/t Ag. The current mine workings extend from the 150' level down to below the 3400' level, and are serviced by a three-compartment shaft.

4.3.2 Geology

The geology of the area is not well understood because of poor exposure, the intense hydrothermal alteration, deformation and the presence of numerous intrusions. Many syenitic stocks and lamprophyre dykes occur along the Hislop fault and the Porcupine-Destor Break. Representative maps of the mineralization are shown in figures 28-31.

Host rocks to the mineralization include tuff breccias and flows of andesitic compositions that belong to the uppermost part of the Stoughton-Roquemaure Group, and younger syenitic intrusions, (Prest, 1957; Akande, 1982). Recently, Troop (1985) has argued that the andesites are actually intensely altered and silicified basaltic rocks of the Kinojevis Group and that fragmentation is due to tectonic brecciation.

SW of the Ross mine (S border of the Hislop Township) and W of the Hislop Fault, trachyte and conglomerate of the Timiskaming Group occur (Fig. 27) (Prest, 1957). Some of the altered rocks on the mine property are also believed to belong to the Timiskaming Group (Troop, 1986).

The major, minor and trace element compositions and mineralogy of relatively unaltered trachyte from the area are identical to those of the Kirkland Lake area (Hattori, unpub. data). This suggests that the tectonic setting of the Ross mine area was similar to that of the Kirkland Lake area.

Lithologies present in the Ross mine area are shown in Table 8.

4.3.3 Mineralization

Mineralization at the Ross Mines is spatially related to the NWN-trending Hislop Fault (Fig. 28). Based on their morphology, auriferous quartz-carbonate veins are classified into three types (Table 9; Akande, 1982; Troop, 1986); (1) stringer ores, (2) breccia ores, and (3) vein ores.

Stringer ore is economically the most significant ore type at the Ross mine, and consists of sheeted quartz veins and veinlets. Ore zones are roughly cylindrical to ellipsoidal in shape and dip subvertically (75 to 90°; Fig. 28, 29). Stringer ore grades are not high (0.1 oz/t Au) but are very consistent. The No. 2 vein, exposed in the open pit, is a typical example of this ore type (Fig. 31).

Breccia ores consist of irregular shaped fragments of ore and host rock in a finer grained rock flour matrix of chloritized altered host volcanic rocks. Apparently brittle failure resulted in brecciation subsequent to veining. The breccia ores are common in the upper parts of the vein system and are usually high grade (0.3 oz/t Au).

Vein ore (Narrow vein ore) consists of simple quartz-carbonate-sulphide veins. Breccia ores may have formed by brecciation of this type of ore. This type of ore includes the No.3, 4, 5, 6, 7, 8, 9, 14, 15, 16, 17 and 19 veins. (Fig. 30).

The composite level plan of the ore bodies in Fig. 29 shows the upward expanding, grossly funnel shape of the ore bodies.

Gold occurs as the native metal and as tellurides. Base metal contents in the Ross ores are high compared with other Archean gold deposits, and some ore resembles a base metal vein with high Cu and low Au. Coarse chalcopyrite, bornite and tetrahedrite are very common in the Ross ore. In addition, the ores contain coarse pyrite, sphalerite,
galena, tennantite ((Cu, Fe)$_{12}$ As_4S_{13}), pearceite

TABLE 8. Lithologies in the Ross Mine area, Hislop Township@

Eon	Group	Lithology
Cenozoic		peat glacial till, silt and clay
Proterozoic	intrusions	Matachewan diabase dykes
Archean	intrusions	lamprophyre, quartz-feldspar porphyry, syenite granite, peridotite, gabbro, diabase
	Timiskaming	conglomerate, greywacke trachytic volcanics
	Kinojevis	Mg- & Fe-tholeiite, andesite, dacite and rhyolite flows and tuffs
	Stoughton-Roquemaure	Komatiite basaltic komatiite tholeiitic basalt minor calc-alkaline rhyolitic tuff ioron formation (2714 $\pm$ 2 Ma*)

@ Troop (1985)
* Corfu et al. (1989)

Table 9: Ore vein types of the Ross Mine (after Akanle, 1982; Troop, 1986)

Type	Characteristics/Mineralogy	example in mine
Stringer	Sheeted quartz-carbonate veins, and veinlets, consistant grade	No. 2/2B veins
Breccia	brecciated vein fragments in "milled" host rocks grade high in both Au and Ag	No. 10/12 and No. 13/14 vein(s)
Narrow vein ore	Ag-Au-Pb-Zn pinch and swell, gn, sph, tenn, proustite	No. 14 vein

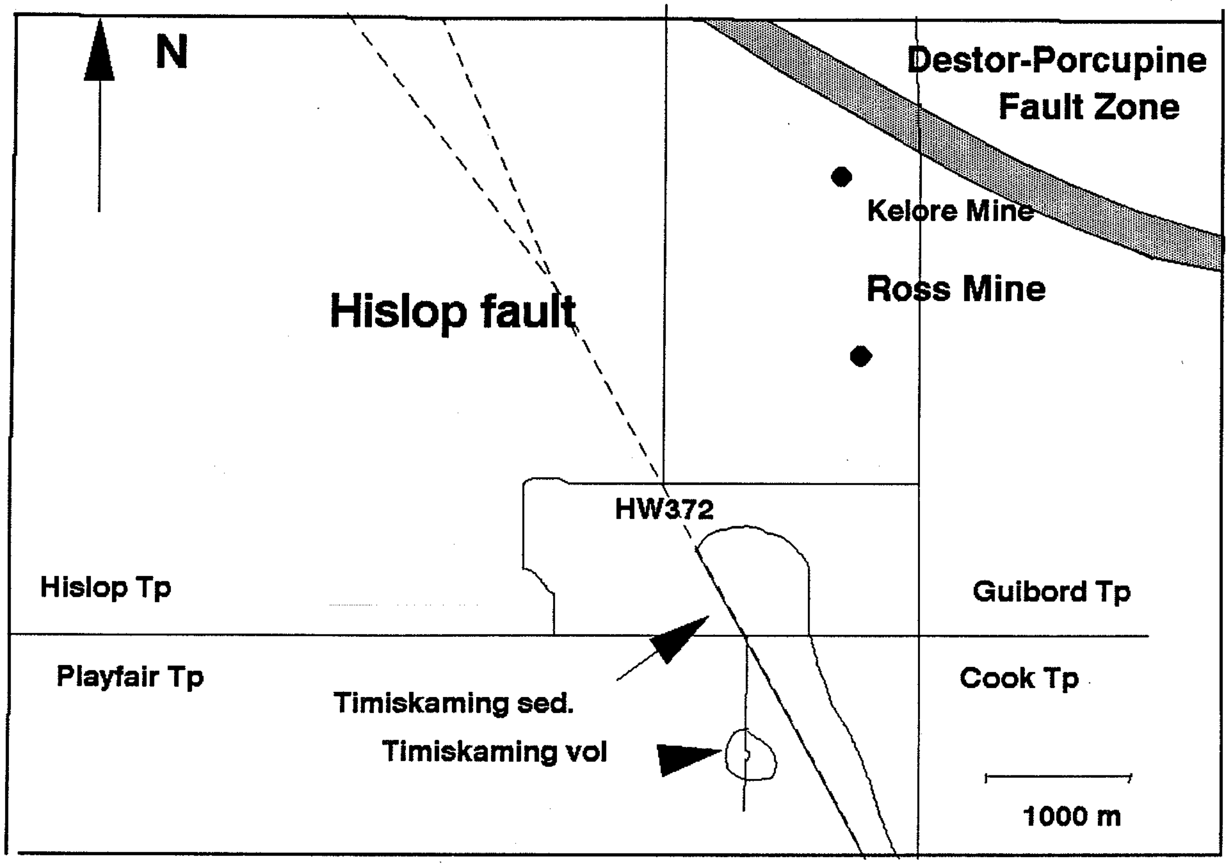

Figure 27 Location of Ross mines and the distribution of Timiskaming rocks (Troop, 1986).

($Ag_{16}As_2S_{11}$), and proustite (Ag_3AsS_3). Though some gold grains are associated with base metal sulphides, base metal-rich portions of veins are not necessarily high in gold.

The host rocks near the veins are heavily carbonatized and sericitized. They are commonly yellowish-green to light apple-green on fresh surfaces, but weather yellowish brown due to presence of ankerite.

Very characteristic alteration at the Ross Mine is the occurrence of pink anhydrite. Anhydrite may form wide lenses and veinlets in the vicinity of veins. Lack of anhydrite in the area immediately adjacent to ore suggests that anhydrite formed earlier and was subsequently dissolved during gold ore deposition. Reddish alteration due to hematite dust in the wall rocks and the common occurrence of specular hematite in the ore zones may be the result of oxidation of wallrock ferrous iron due to the dissolution of anhydrite.

Field Trip (Ross Mine)

In the morning, R. Calhoun, Chief mine and exploration geologist, will lead an underground tour of the Ross mine. Please remember to bring the hard hat and steel-toed boots supplied to you at Ottawa.

In the afternoon, we will examine the open pit, which exposes the No.2 vein system. (Fig. 31). The pit displays the relationship between the host rocks and the mineralization and the strong deformation and intense alteration.

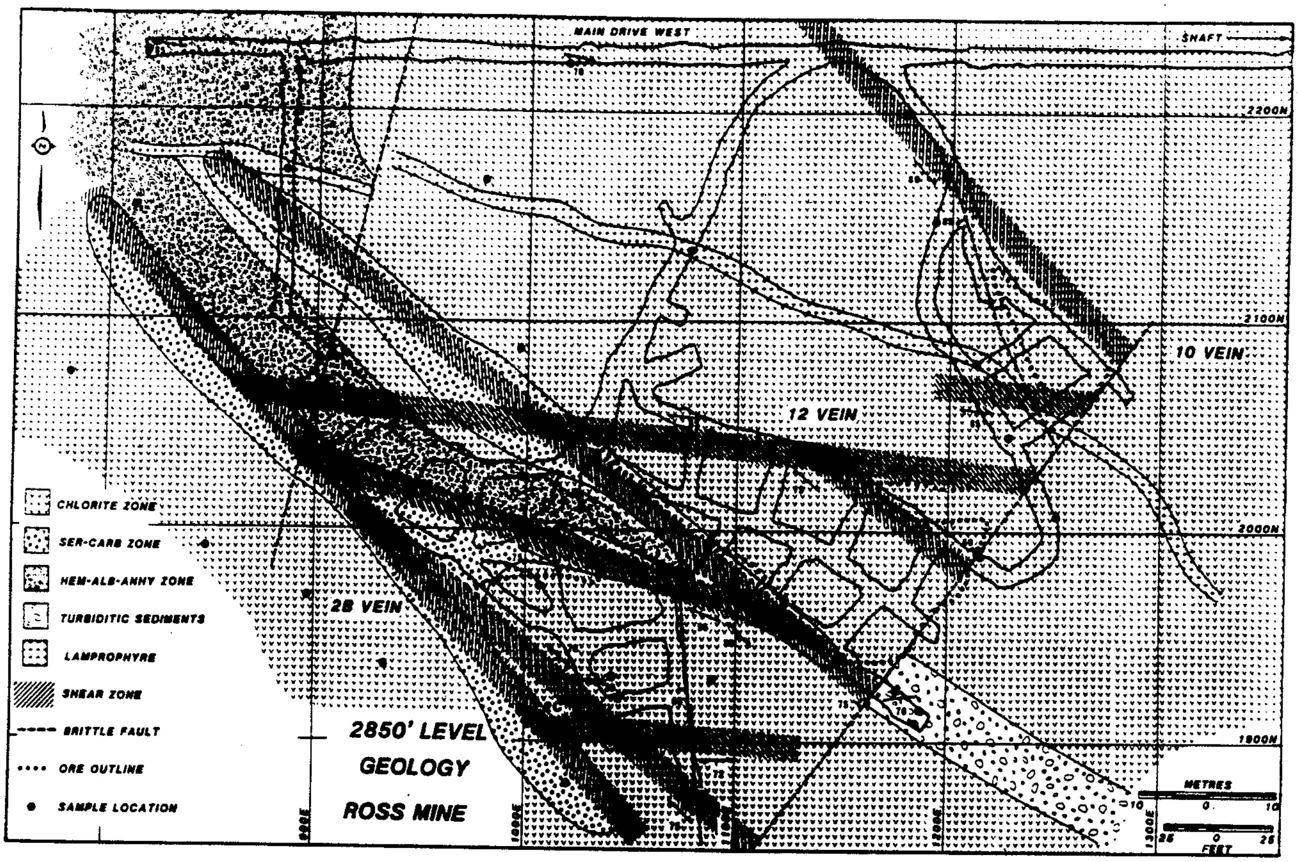

Figure 28 Plan geology of the 2850' level at the Ross mine. Includes the 2B, 10 and 12 vein systems (after Troop, 1986).

Description of the Open Pit (Fig. 31)

The host rock is highly carbonatized and sericitized. The protolith has been interpreted as a mafic volcanic rock, which has undergone brecciation (Troop, 1986) or as a felsic pyroclastic unit (Jones, 1948).

NW-trending cleavage occurs throughout the pit and parallels the auriferous quartz stringers.

4.4 DOME MINE, PORCUPINE CAMP

4.4.1 Mining History

The history of the mine dates back to 1909 when a party of prospectors, headed by John S. Wilson, discovered a spectacular showing of gold on a dome-shaped outcrop of quartz situated approximately two miles SW of the shore of Porcupine Lake. Subsequent prospecting around the "Dome" outcrop resulted in the staking of all adjacent land and the discovery of the Hollinger-McIntyre and other deposits in the Porcupine camp.

Mining at Dome commenced in 1911. Since then, the Mine has been in continuous production and has produced in excess of 11.5 million oz (360 tonnes) of gold and 2.0 million oz (62 tonnes) of silver from 39 million tonnes of ore (Rogers, 1988).

4.4.2 Geological Setting

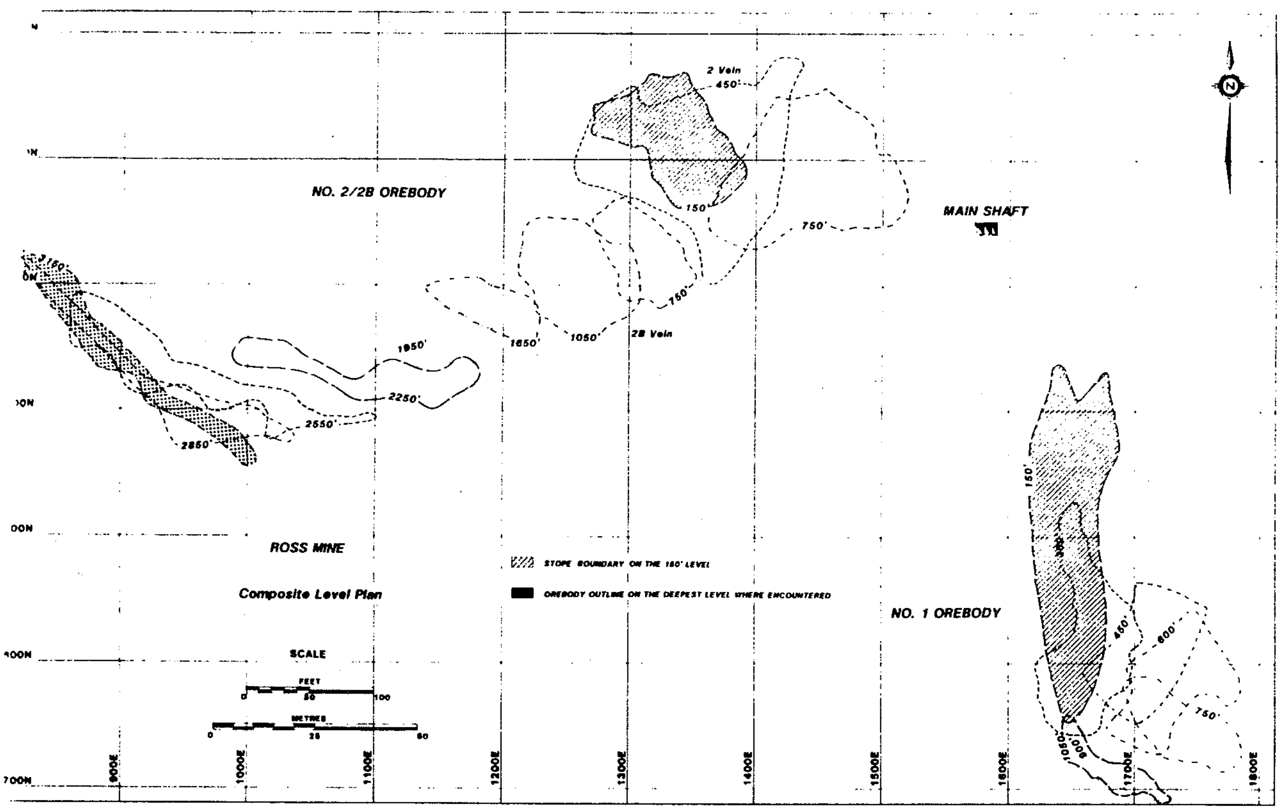

Figure 29 Composite level plan for No. 2/2 /b and No. 1 ore bodies at the Ross mine (after Troop, 1985).

The mine occurs on the S limb of the Porcupine syncline where the volcanic rocks of the Tisdale Group and the unconformably overlying Timiskaming Group sedimentary rocks are in contact, across the Dome fault, with a sequence of S-facing flows termed the South Greenstones (Fig. 4).

The zones of mineralization in the Dome mine and in the past producing Preston and Paymaster mines, are localized in the vicinity of a group of felsic quartz-feldspar porphyry intrusions emplaced near a major bend in the Dome fault (Figs. 4 and 32).

In the mine area, the Dome fault trends NE when it forms the contact between Timiskaming and South Greenstone rocks then strikes NS as it cuts the stratigraphy below the Timiskaming-Tisdale Group unconformity, and finally trends EW when it parallels the stratigraphy of the Tisdale Group. The Timiskaming-Tisdale unconformity also bends from its regional NE trend, to a NS trend where the fault cuts it. This NS-trending segment of the unconformity is termed the "Greenstone Nose". In the Dome mine, the Dome fault corresponds to what is termed the "porphyry and highly altered zone" (Figs. 32, 33).

In the Porcupine camp, the Dome fault is a locus of porphyry intrusions, hydrothermal alteration and gold mineralization. The Buffalo-Ankerite, Aunor, and Delnite mines to the W of the Dome mine are all associated with this structure (Fig. 4). The Dome fault appears to be a branch of the Porcupine-Destor Break, which like the Larder Lake-Cadillac Break is a regional-scale structural discontinuity. The Porcupine-Destor Break is exposed 1,200 m S of the Dome mine, where it appears as a well defined talc-chlorite alteration zone.

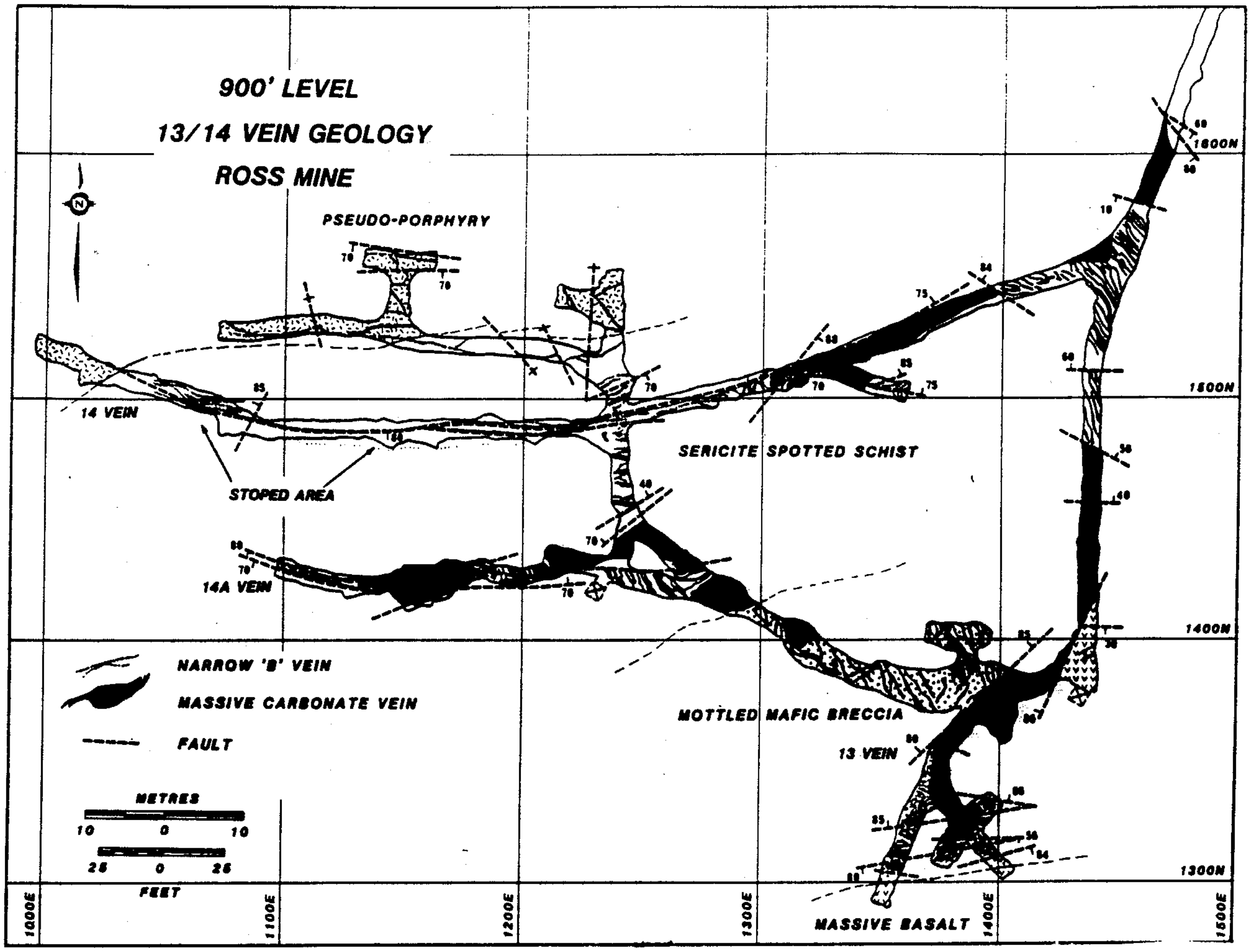

Figure 30 Plan map of the 13/14 vein system on the 900' level, Ross mine (after Troop, 1986).

4.4.3 Mine Rock Units

At the Dome mine, the steeply north dipping Middle and Upper Formations of the Tisdale Group are exposed. The Upper Tisdale Formation, also known as the Krist Formation, is a feldspar porphyry volcaniclastic unit that is overlain concordantly by the sedimentary rocks of the Porcupine Group. The Tisdale and Porcupine Group are unconformally overlain by the Timiskaming Group. No ore occurs in the Krist Formation.

The Middle Tisdale Formation consists of massive, flow breccia and pillowed tholeiitic lavas. Some flows are variolitic. Commonly a thin layer of dark argillite/basalt hyaloclastite occurs between the flows. Many individual flows, especially variolitic flows, have a distinctive texture, which allows them to be traced both within the mine and throughout the camp. A major source of ore in the mine is the "ankerite veins". These veins are generally stratiform and are localized in interflow sediments in the Middle Tisdale Formation. Locally, however, they cut across flow boundaries and penetrate a short distance across the unconformity into

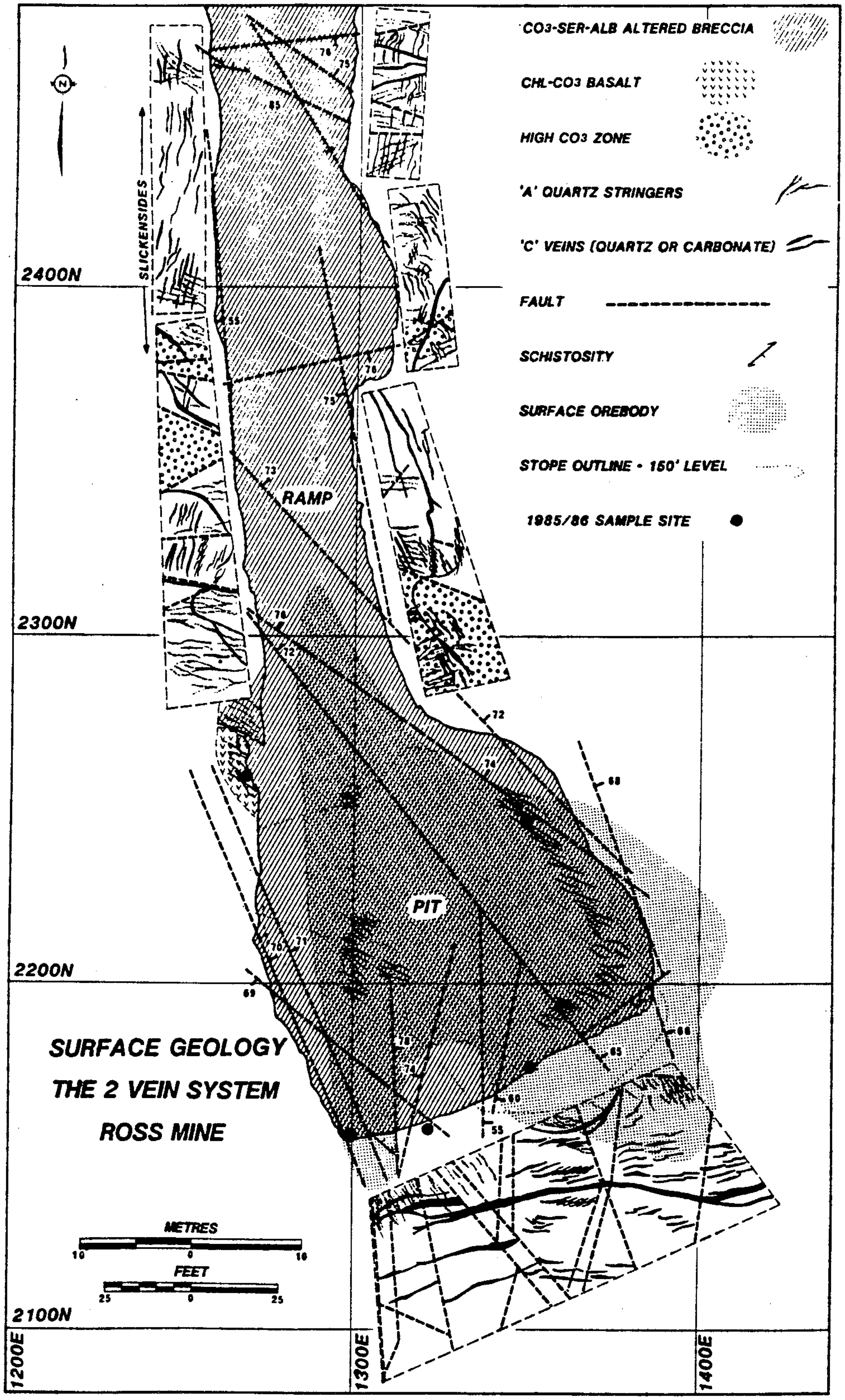

Figure 31 Surface geology of the open pit at the Ross mine. Detailed plan and section of the surface geology of the Ross mine open pit floor, ramp and walls. This is the uppermost exposure of the No. 2 vein system, (Troop, 1985).

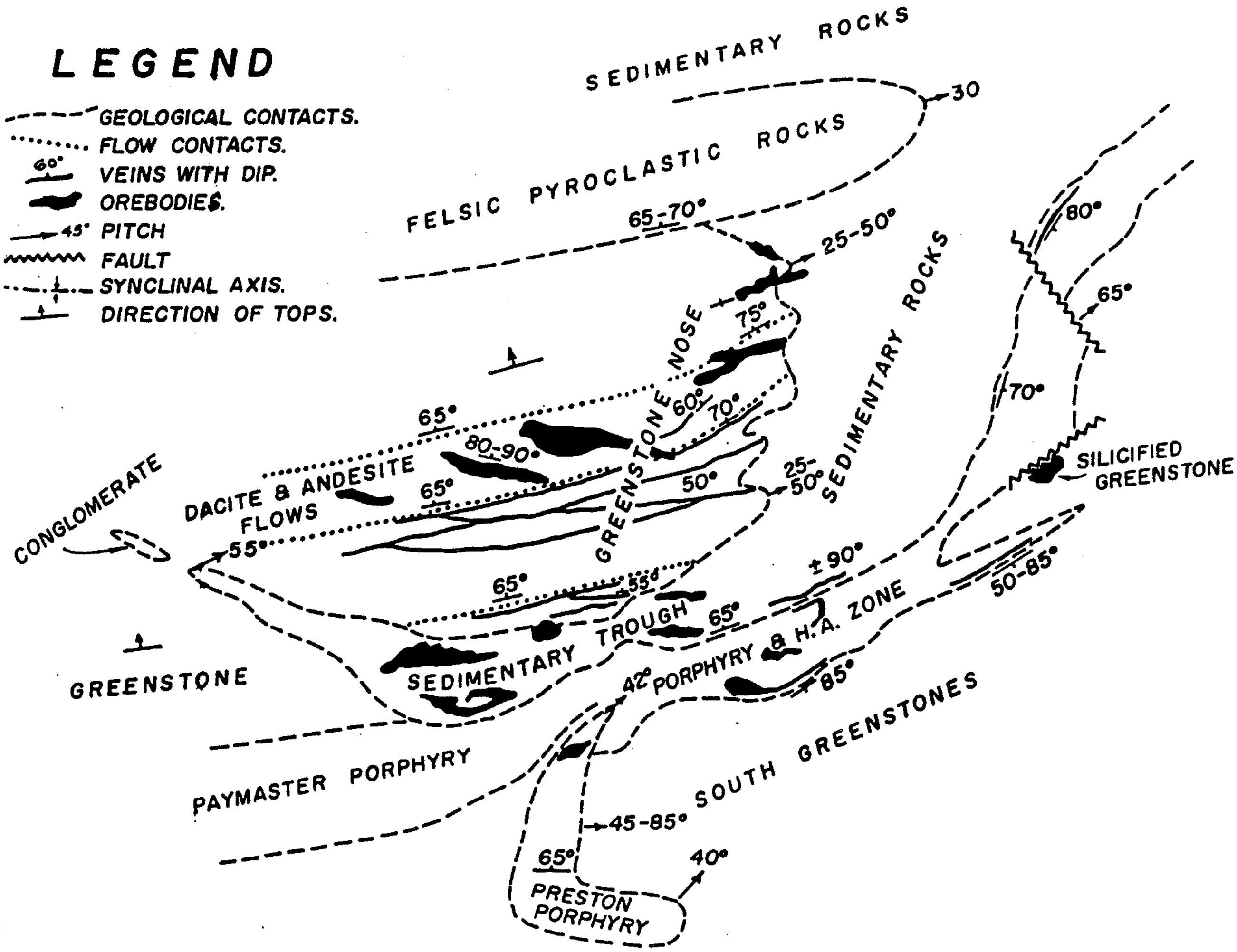

Figure 32 Generalized geology plan at Dome (Rogers, 1988).

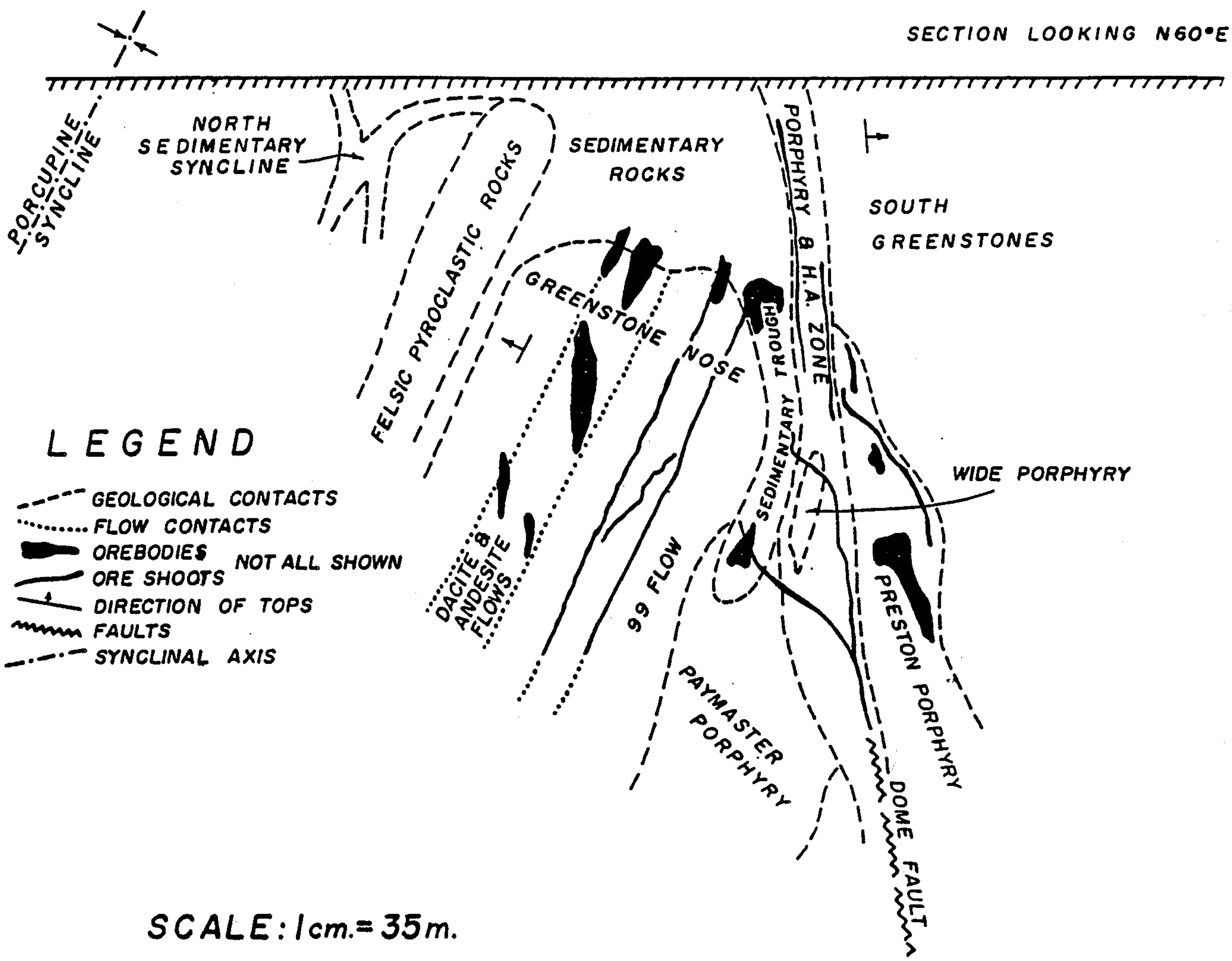

Figure 33 Diagrammatic section of geology and ore zone at Dome (looking N60^{0}E) (Rogers, 1988).

the Timiskaming Group rocks. In a series of flow units known as the "Dome Dacite", irregular zones of en-echelon veinlets and disseminated mineralization are preferentially developed. These flows, though resembling dacite, are actually intensely carbonatized and silicified basalts.

Timiskaming Group: In the mine area this unit consists of a basal polymictic conglomerate that is overlain by greywacke turbidites. Some irregular ore bodies, consisting of highly altered and pyritized conglomerate, are localized at the base of the Timiskaming Group. As mentioned above, stratiform ankerite veins in the Middle Tisdale formation commonly penetrate a short distance into the Timiskaming Group.

South Greenstones: These are a sequence of tholeiitic to komatiitic massive to pillowed flows which both dip and face south. Pyke (1982) suggested that these rocks are actually a fault wedge of Lower Tisdale Formation volcanics. A highly carbonatized unit termed "Carbonate Rock" is probably a carbonatized ultramafic komatiite that belongs to the South Greenstone sequence. This unit hosts quartz-fuchsite veins, which are a major source of ore at the Dome mine.

Porphyries: Two major bodies of quartz-feldspar

porphyry, the Preston and Paymaster porphyries, have been identified in the mine sequence. These bodies, and many smaller dykes, were intruded along the Dome fault; however, emplacement also seems to be controlled by faults which cut flow contacts at a low angle in the Middle Tisdale Formation. Irregular zones of stockwork mineralization are developed both within the porphyries and along the highly altered contact zones of the porphyries. ("Porphyry and Highly Altered Zone" - Figs. 32, 33).

"Sedimentary Trough": This unit was originally thought to represent an infold of Timiskaming conglomerates. Recently however, it has been re-interpreted as a lens of intrusive breccia (Piroshco and Kettles, 1988). Similar breccia dykes in spatial association with the porphyry intrusions have been recognized elsewhere in the camp (Piroshco and Hodgson, 1988). Approximately half of the ore mined at Dome is hosted by this unit. The "trough" is approximately 300 m long, 30-130 wide, and extends 2500 m down plunge. Mineralization consists of individual veins to complex stringer zones and occurs over the entire vertical extent of the "trough". In some areas, the stringer zones are minable across the entire width of the "trough".

4.4.3 Mineralization and alteration

Minerology of the veins and associated altered zones includes: quartz, ankerite, sericite, albite, chlorite and pyrite. Locally tourmaline and green muscovite (fuchsite) are abundant. Gold occurs primarily as native gold and in several gold-bearing tellurides. The auriferous tellurides however, are present in very minor amounts. Other reported tellurides include altaite (PbTe), petzite(Ag_3AuTe_2) and tellurobismuthite (Bi_2Te_3). Sulphides are common in all ore types and usually average 2 to 3 %. Pyrite and pyrrhotite are the dominant sulphides with minor chalcopyrite, sphalerite and galena. Scheelite is found in minor quantities, predominantly in association with the porphyry ores. Arsenopyrite, though rare, is found as sparse disseminations in silicified mafic volcanic rocks.

The alteration in the Dome mine, typical of greenstone-hosted gold deposits, consists of zoned facies of progressive cabonatization. The zone of most intense alteration is bleached, and is characterized by the presence of ankerite-quartz-sericite (and/or) albite-pyrite. Around this zone is an unbleached chlorite-rich zone in which the dominant carbonate is calcite. The least altered rock may contain actinolite and epidote. The degree of carbonatization appears to have depended on the Ca^{2+} + Mg^{2+} + Fe^{2+} content of the protolith, being high in ultramafic rocks, intermediate in mafic rocks and lowest in felsic and sedimentary rocks.

Classification of Mineralization Types (modified after Rogers, 1988): (Table 10)

Type 1. Long narrow foliation-parallel veins in schist.

1a. Ankerite veins in Middle Tisdale Formation.

This vein Sub-Type consists of banded carbonate with variable amounts of fine cherty silica, and cross-cutting "ladders" of quartz. Veins are 10 cm to 2 m wide and 200 to 500 m long. Vertical extent averages about 150 to 200 m, but veins range up to 1000 m.

1b. Quartz-tourmaline veins in "Highly Altered (H. A.) Zone" (Dome fault).

These veins are sulfide poor, and consist of quartz with septa of tourmaline oriented parallel to the

Table 10 Classification of the Ore Types at Dome (after Rogers, 1988)

TYPE 1 Long narrow foliation - parallel veins	
a. Ankerite veins	in "Greenstone Nose"
b. Quartz-tourmaline veins	in the "Highly Altered Zone"
c. Quartz-fuchsite veins	in "Carbonate Rock"

TYPE 2 Lenticular or Irregular veinlets	
a. En-echelon	in Dome Dacite with Py$\pm$Po
b. Stockwork	in "Sedimentary Trough"
	in Porphyries
	in Timiskaming conglomerate

TYPE 3 Disseminated mineralization, consisting of Py$\pm$Po with little quartz.

TYPE 4 Silicified Zones	in the "South Greenstones"

vein walls. Veins are about 200 m long and 2 to 4 m wide. In some areas, sulphidic stockworks in the vein walls extend stoping widths to 10 m

1c. Quartz-fuchsite veins in "Carbonate Rock".

This vein Sub-Type is sulphide poor and consists of white quartz with green mica orientated parallel to the vein walls. The main quartz-fuchsite vein is 500 m long, averages 3 m wide and extends from the 6th to the 17th level, a vertical distance of about 550 m. Three ore shoots occur in the vein on the 12th level, each about 100 m long.

Type 2: Lenticular or irregular veinlets in altered massive rocks or schist.

2a. En-echelon This sub-type of mineralization consists of 20 % en-echelon veinlets set in a matrix of carbonatized volcanic rock, ("Dome Dacite") with pyrite ± pyrrhotite forming 5 to 7 % of the ore.

2b. Stockwork veinlets in bleached and altered rock. This mineralization comprises ore bodies found in the "Sedimentary Trough", Timiskaming conglomerate and porphyry and highly Altered Zones".

Type 3. Disseminated mineralization, consisting of pyrite ± pyrrhotite with little or no vein material.

Type 4: Silicified zones in the South Greenstones.

Ore body systems:

A number of spatially distinct ore body systems occur in the mine, each characterized by certain types of mineralization. All ore body systems and most individual ore bodies rake 60^0E parallel to the Greenstone Nose and the porphyry intrusions (Figs. 32, 33, 34)

Ankerite Vein Systems:

Two ankeritic vein systems can be distinguished, (MAIN & WEST) each consisting of subparallel veins (Sub-Type 1a mineralization), mainly localized along flow contacts, in the Middle Tisdale Formation. The E end of the Main Ankerite Zone coincides approximately with the Tisdale Timiskaming unconformity and the W end is a gradational line (across which the veins thin and decrease in grade) that plunges E, parallel to the Greenstone Nose. The W Zone lies 500 m W of the Main Zone, and plunges parallel to it. (Fig. 34).

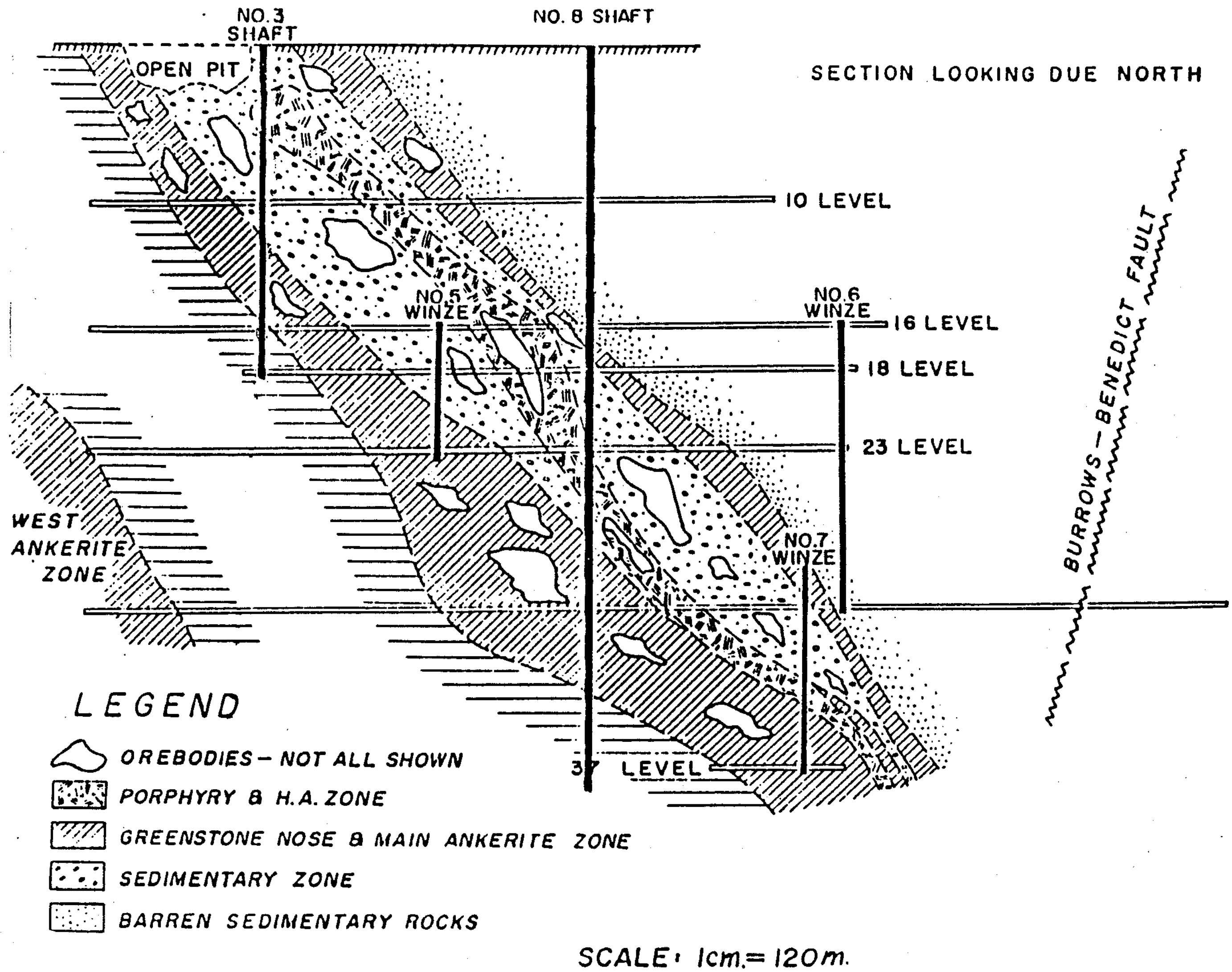

Figure 34 Longitudinal section showing relationship of ore zones at Dome (Rogers, 1988).

Dacite Ore bodies:

This ore system consists predominantly of Sub-Type 2a mineralization and is localized in the massive flows of the "Dome Dacite" sequence. The richest of these ore bodies are within 500 m of the Tisdale-Timiskaming unconformity, and they generally tend to decrease in grade, number and size towards the west.

"Sedimentary Trough" Ore bodies:

These consist of a range of mineralization types, from Type 1 to Type 2b.

Conglomerate Ore bodies in the Basal Timiskaming: These consist predominantly of Type 3 mineralization.

Porphyry Ore bodies:

These consist of sub-Type 2b-stockwork mineralization.

Ore bodies in the "Highly Altered Zone" (Dome fault):

Several Sub-types of mineralization comprise these ore bodies, the most important being quartz-tourmaline mineralization (Sub-Type 1b). However, Type 3 mineralization forms ore bodies in the fuchsite-rich rocks of this unit. Also associated with the latter ore zones are quartz-fuchsite veins, (Sub-Type 1c mineralization) which occur at the contact of the highly altered zone with the Timiskaming Group sedimentary rocks.

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