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Ontario Geological Survey Open File Report 6158

The Timmins-Porcupine Gold Camp, Northern Ontario: The Anatomy of an Archaean Greenstone Belt and its Gold Mineralization: Discover Abitibi Initiative

## ONTARIO GEOLOGICAL SURVEY

Open File Report 6158

The Timmins-Porcupine Gold Camp, Northern Ontario: The Anatomy of an Archaean Greenstone Belt and its Gold Mineralization: Discover Abitibi Initiative
by
R. Bateman, J.A. Ayer, B. Dubé and M.A. Hamilton

2005

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Discover Abitibi
A project of innovation, cooperation and revitalization
Découvrons l' Abitibi
Un projet d' innovation, de coopération et de renouvellement

## Discover Abitibi Initiative

The Discover Abitibi Initiative is a regional, cluster economic development project based on geoscientific investigations of the western Abitibi greenstone belt. The initiative, centred on the Kirkland Lake and Timmins mining camps, will complete 19 projects developed and directed by the local stakeholders. FedNor, Northern Ontario Heritage Fund Corporation, municipalities and private sector investors have provided the funding for the initiative.

Initiative Découvrons l'Abitibi
L'initiative Découvrons l'Abitibi est un project de développment économique régional dans une grappe d'industries, projet fondé sur des études géoscientifiques de la ceinture de roches vertes de l'Abitibi occidental. Cette initiative, centrée sur les zones minières de Kirkland Lake et de Timmins, mènera à bien 19 projets élaborés et dirigés par des intervenants locaux. FedNor, la Société de gestion du Fonds du patrimoine du Nord de l'Ontario, municipalités et des investisseurs du secteur privé ont fourni les fonds de cette initiative.


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#### Abstract

Mapping of foliations in the Timmins-Porcupine gold camp, in the Abitibi greenstone subprovince of northern Ontario, has systematically identified 3 foliations in Tisdale and Porcupine assemblage rocks, 2 of these in younger Timiskaming assemblage sediments, plus 2 minor late crenulations. Previously, a maximum of 2 important foliations had been recognized, both post-Timiskaming. While pre-Timiskaming folding has long been recognized in Tisdale assemblage rocks, no foliations had been attributed to these events. Penetrative foliation in all rocks is still attributed to post-Timiskaming deformation. The new data and interpretations refine the structural history of the gold camp by more precisely defining the generations, timings and effects of deformation phases. Examination of diamond drill core through 3 profiles across the Porcupine-Destor deformation zone has also given new timing and kinematic data.

Initial deformation was a regional uplift-extension event, producing a low-angle unconformity between Tisdale and Porcupine assemblages, with partial excision of upper Tisdale stratigraphy. An early D2 dip-slip, south-over-north thrusting event imbricated a set of south-over-north thrust sheets. These root into the Porcupine-Destor deformation zone. The opening of the Timmins Timiskaming basin is interpreted in terms of syntectonic opening of a transtensional basin in the curvilinear trace of the Porcupine-Destor deformation zone. The Dome fault may represent the normal-faulted margin of a halfgraben. D3 folds along the northern flank of the Porcupine-Destor deformation zone can be interpreted as a set of en echelon folds resulting from left-lateral strike-slip movement along this zone continuing from before to after Timiskaming sedimentation. The S4 foliation formed during right-lateral strike-slip movement and folding of S3 foliation. Intense constrictional strain deformed D4 lineations, and may be related to right-lateral movement, making a compressional jog in the trace of the Porcupine-Destor deformation zone of the previously dilatational jog that hosts Timiskaming assemblage sediments. These D3-D4 phases represent an overall transpressional regime.


There were several phases of gold mineralization in the Timmins-Porcupine gold camp. Goldbearing ankerite clasts in Timiskaming assemblage conglomerate attest to early mineralization. Gold mineralization in early ankerite veins at Dome and McIntyre mines may predate Timiskaming sedimentation. However, the important gold-depositional phases postdate Timiskaming sedimentation, as S2 foliation is overprinted by alteration. S3 foliation crosscuts early ankerite veining and alteration and some quartz veining, as at Vedron. Sequences of quartz-carbonate-tourmaline-gold veins (HollingerMcIntyre, Hoyle Pond, Dome, Aunor-Delnite mines) also formed within Timiskaming assemblage and adjacent Tisdale assemblage rocks (Hollinger-McIntyre mine). These gold deposits developed largely as oblique-slip and extensional vein arrays formed during north-south shortening and local strike-slip faulting. Younger deposits (Pamour mine) formed with dip-slip faulting, and are weakly deformed in late D4. They have all been post-dated by constrictional strain and minor veining that was probably not associated with much additional gold.

A protracted history of orogenesis and gold mineralization demonstrates a long-lived or multi-phase gold-bearing hydrothermal system, and indicates a plumbing system geometrically stable enough, and for long enough, to feed gold into a relatively small volume throughout a period of transpressional deformation. This work also suggests that Timiskaming assemblage sediments may be more widespread than previously believed, and so the area of interest for exploration expands into areas previously not considered very prospective.

# The Timmins-Porcupine Gold Camp, Northern Ontario: The Anatomy of an Archaean Greenstone Belt and its Gold Mineralization: Discover Abitibi Initiative 

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2005
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## Introduction

The Timmins-Porcupine gold camp of northern Ontario is one of the most important gold camps hosted in Archaean greenstone belts in the world, together with Kalgoorlie (southwestern Australia). The Timmins-Kirkland Lake region of the Abitibi greenstone belt also contains major $\mathrm{Cu}-\mathrm{Zn}$ and $\mathrm{Ni}-\mathrm{Cu}-\mathrm{PGE}$ mineralization. Most of these deposits were found by prospecting or investigating near-surface geophysical anomalies. Although data on the geology of the Abitibi greenstone belt is good at the mine and regional scales, the understanding of the geology at the sub-regional and district scales is less clear, because of complex stratigraphic variations and complex metamorphic and structural overprints.

The next generation of deposits may be found beneath the extensive overburden that covers much of the Abitibi greenstone belt. Thus, future exploration will require more detailed understanding of the geological characteristics of the existing deposits, the stratigraphic and structural architecture of the region, and will rely on geophysical and geochemical techniques, tested by diamond drilling. The Greenstone Architecture Project was one of 19 projects of the Discover Abitibi Initiative, managed by the Timmins Economic Development Corporation. The project was focussed on improving knowledge of the stratigraphy, volcanology, geochemistry, metamorphic petrology, and structural geology of selected mineralized and barren areas. The objective was to better understand the geological architecture of the belt, to increase knowledge of the complex interactions of stratigraphic, lithological, structural, alteration, geochemical, and metamorphic controls on the localization and genesis of $\mathrm{Cu}-\mathrm{Zn}$, Ni-Cu-PGE and Au deposits, and to aid in the development of new concepts for discovering deposits. This contribution presents results of Discover Abitibi Initiative research in the Timmins-Porcupine gold camp, and has focussed on transects through the Pamour-Hoyle Pond and Dome-Buffalo, Ankerite-Hollinger-McIntyre mines areas. This work around Timmins has been greatly aided by cooperation with the Porcupine Joint Venture, which manages current mining operations at the Hoyle Pond, Dome and Pamour mines in the Timmins area. The Porcupine Joint Venture has provided a wide variety of confidential data that has been used in this project. Some interpretations presented here are partly based on data, confidential to the corporate owners of the data, which themselves cannot be reported.

The first geological report preceded discovery (Parks 1900). Gold was discovered in 1909 by J.S. Wilson (Dome mine) and B. Hollinger and A. Gillies (Hollinger mine). Dome mine has been one of the largest producers in this camp, and has been in continuous production since the earliest days. The earliest reports and maps were published at this time (Burrows 1911, 1912, 1915, 1924). Early work was consolidated in a benchmark report (Ferguson et al. 1968). Since then, a great diversity of research projects have been carried out on the Timmins camp, making this one of the best-studied gold camps and the largest Archaean greenstone deposit in the Canadian Superior Province.

## General Geology of the Abitibi Subprovince

The Timmins-Porcupine gold camp lies within the Abitibi Subprovince (Figure 1), Superior Archaean craton of eastern Canada. A particularly important recent contribution (Ayer et al. 2002) to Abitibi tectonics and consequently Timmins stratigraphy describes the stratigraphic constitution of the southern Abitibi Subprovince in terms of autochthonous volcanic construction comprising 9 supracrustal assemblages, rather than an amalgamation of numerous allochthonous terranes (Dimroth et al. 1983; Jackson 1994; Daigneault, Mueller and Chown 2002). In this autochthonous model, there is a repetition of similar volcano-sedimentary successions throughout the Abitibi and spanning $75 \mathrm{Ma}(2750-2675 \mathrm{Ma}$ ). Each assemblage is laterally extensive, stacked, with conformable, unconformable or disconformable
contacts (Figures 1, 2). The Timmins-Porcupine gold camp lies on the northern flank of the PorcupineDestor deformation zone (Figure 1). This deformation zone, and the Larder Lake-Cadillac deformation zone, are the most important deformation zones within the Abitibi Subprovince in terms of both structural effect and gold production.


Figure 1. Map of the Abitibi Subprovince showing the distribution of assemblages (Ayer et al. 2002). The box around Timmins shows this study's field area.

## TIMMINS AREA LITHOLOGY, STRATIGRAPHY AND GEOCHRONOLOGY

A variety of division names have been used for the supracrustal assemblages of the Timmins district (Figures 1, 3), but the scheme of lithologies and geochronological data used here (Ayer et al. 2002; Ayer, Ketchum and Trowell 2002; Ayer et al. 2003) is summarized in Table 1, together with the subdivisions of the Timiskaming and Porcupine assemblages (Born 1995) and the Tisdale assemblage (Mason and Melnik 1986).


Figure 2. Timeline for the evolution of southern Abitibi greenstone belt including the volcanic and sedimentary assemblages, intrusions, deformation, metamorphism and mineralization episodes. Geochronological data are from several sources (Ayer, Trowell and Josey 2004; Corfu 1993; Mortensen 1993; Powell, Carmichael and Hodgson 1995; Bleeker, Parrish and SagerKinsman 1999; Davis et al. 2000; Heather 2001; Ayer et al. 2002; Ayer, Ketchum and Trowell 2002; Ayer et al. 2003; Dubé et al. 2004; Ayer et al. 2005).

Table 1. Tectonostratigraphic, lithological and geochronological summary for rocks of the Timmins gold camp.

| Assemblage | Formation | Flow | Lithology |
| :---: | :---: | :---: | :---: |
|  | Dykes |  | Pamour porphyry $2677 \pm 1 \mathrm{Ma}$; albitites $2673 \pm 6 /-2 \mathrm{Ma}$ and $2676 \pm 2 \mathrm{Ma}$ (Corfu et al. 1989; Ayer et al. 2005) |
| Albitites cut quartz-feldspar porphyries (Mason and Melnik 1986) and Timiskaming assemblage (Ayer et al. 2005) |  |  |  |
| Timiskaming | Three Nations |  | Interbedded sandstone, pebbly sandstone, conglomerate, shale; 2669 $\pm 1 \mathrm{Ma}$ (Bleeker, Parrish and Sager-Kinsman 1999) |
|  | Dome |  | Greywacke, sandstone, conglomerate Post 2679 Ma (Ayer et al. 2003) |
| angular unconformity |  |  |  |
| Porcupine | Beatty |  | Sandstone, greywacke, shale |
|  | Krist |  | Felsic volcaniclastic breccia, heterolithic tuff, shale $\sim 2690 \mathrm{Ma}$ (Bleeker 1999; Ayer et al. 2003; Bateman et al. 2004) |
|  | graphitic phyllite |  | Carbonaceous shale, typically well deformed |
| disconformity (and shear zone?) |  |  |  |
|  | Dykes |  | Quartz-feldspar porphyries $\sim 2690 \mathrm{Ma}$ (Corfu et al. 1989) |
| intrusive into Tisdale Formation, not known within Porcupine or Timiskaming at Timmins |  |  |  |
| Tisdale | Gold Centre | V11 | Massive and pillowed lava |
|  | Vipond | V10 | Massive and variolitic lavas |
|  |  | V9 | Carbonaceous shale |
|  |  | V8 | Variolitic and pillowed lavas |
|  |  | V7 | Carbonaceous shale |
|  |  | 99 | Massive lava, ankerite-sericite alteration $2707 \pm 3 \mathrm{Ma}$ (Ayer et al. 2002) |
|  | Central | C17 | Carbonaceous shale |
|  |  | C16 | Amygdaloidal lava |
|  |  | C15 | Pillow lava, flow breccia |
|  |  | C14 | Massive lava |
|  |  | C12 | Variolitic lava |
|  |  | 55 | Massive lava |
|  |  | 95 | Massive, amygdaloidal, variolitic, pillowed, hyaloclastic lavas, carbonaceous shale |
|  | Northern | 63 | Massive, amygdaloidal, polygonal jointed lava, carbonaceous shale |
|  |  | 51 | Massive, amygdaloidal lava |
|  | Hersey Lake |  | Mafic and komatiitic lavas |
| unconformable contact (Ayer et al. 2004) and Porcupine-Destor deformation zone |  |  |  |
| $\begin{aligned} & \hline \text { Deloro } 2724 \text { - } \\ & 2730 \mathrm{Ma} \\ & \text { (Ayer et al. } \\ & 2002 \text { ) } \\ & \hline \end{aligned}$ |  |  | Mafic and ultramafic lavas |
|  |  |  | Iron formation |
|  |  |  | Felsic volcanics and volcaniclastic rocks |
| disconformity (Ayer et al. 2002) |  |  |  |

A detailed report of the geochronological work done for the Greenstone Architecture Project is reported elsewhere (Ayer et al. 2005), but a summary of the new results on samples from the Timmins area are reported below. The oldest assemblage within the camp is the Deloro assemblage. It consists predominantly of pillowed calc-alkaline mafic volcanic rocks with lesser amounts of intermediate to felsic volcanics and iron formations. It occurs within the central part of the Shaw antiformal structure, south of the Porcupine-Destor deformation zone (Figure 3). A new geochronological sample from felsic volcanics immediately underlying the iron formations in northeastern Shaw Township have yielded zircons with an age of 2727 Ma confirming the presence of the Deloro assemblage in this area (Ayer et al. 2005). Geochronological analysis was carried out on a felsic volcanic sample intercalated with komatiites south of the Porcupine-Destor deformation zone (PDDZ) in Deloro Township (Figure 3, location 1). From this sample, data for 5 single-grain zircon fractions regress to yield an upper intercept age of
$2724.1 \pm 3.7 \mathrm{Ma}$ (this and all following age errors quoted at $2 \sigma$ level of uncertainty). Although this result is consistent with a Deloro age, the sample also contains a subpopulation of less well preserved rounded and pitted zircons (as yet unanalysed), suggesting sedimentary recycling or transport. This indicates that the sample is likely epiclastic and may be part of the Deloro tectonically interleaved with Tisdale assemblage komatiites, or be part of the Tisdale assemblage with the above analysed zircons possibly being xenocrysts derived from either erosion or entrainment of underlying Deloro assemblage material.

The Tisdale assemblage overlies the Deloro assemblage with a disconformity which may locally be an angular unconformity (Ayer et al. 2004). It occurs around the margin of the Shaw antiformal structure and north of the PDDZ, where the lowermost horizon of the Tisdale assemblage consists of komatiites and basaltic komatiites of the Hersey Lake formation ( $\sim 600 \mathrm{~m}$ thick). These are dark green to black rocks in flows $1-4 \mathrm{~m}$ thick, massive, with chilled margins, spinifex textures in upper parts, and common polysuturing. They comprise serpentine, tremolite, chlorite, talc, carbonate, and some relict olivine, plus chromite and magnetite. Tisdale komatiites are mostly Al-undepleted komatiites derived late in an evolving mantle plume, with minor crustal contamination (Lahaye et al. 2001; Sproule et al. 2002). The upper Tisdale assemblage consists of the Central formation ( 450 m thick), the Vipond formation (200-300 m ) and the Gold Centre formation ( 800 m ). These formations are comprised of a variety of essentially tholeiitic lavas together with subordinate ultramafic lavas, and minor carbonaceous shale interflow sediments. Basalts are variously pillowed ( $1-2<5 \mathrm{~m}$ ), massive or hyaloclastic in flows $10-150 \mathrm{~m}$ thick. Petrographically, they consist of actinolite-tremolite, plagioclase, trace quartz, and titanite. The more $\mathrm{Fe}-$ rich tholeiites are darker in colour, contain magnetite and more pleochroic actinolite and higher contents of quartz. Some Vipond formation Fe-rich lavas are very distinctive in their intensely variolitic texture $(<3 \mathrm{~cm})$, and these serve as marker horizons, and are a feature of well-mineralized rocks (Jones 1992). Tisdale lavas are similar in Th-Nb-LREE to ocean plateau or ocean island basalts erupted above a plume in a subduction zone (Kerrich, Polat et al. 1999). Crustal contamination of these rocks has been ruled out by some workers (Fan and Kerrich 1997; Kerrich, Wyman et al. 1999; Ayer et al. 2003). Published geochronology from the Tisdale has given an age of $2707 \pm 3 \mathrm{Ma}$ from the 99 Flow of the Vipond formation west of the Dome mine in Tisdale Township, and an age of $2708 \pm 2$ Ma from the southeastern margin of the Shaw antiformal structure in Langmuir Township (Ayer et al. 2002).

The base of the Porcupine assemblage varies from disconformable to an angular disconformity (Buffam 1948). At the base is a discontinuous horizon of carbonaceous sedimentary rocks (up to 100 m ), separating the underlying Tisdale assemblage mafic lavas from the Krist formation. The Krist formation is a calc-alkaline pyroclastic deposit, locally up to 500 m in thickness, with an age ranging from 2690 to 2688 Ma (Ayer, Ketchum and Trowell 2002; Ayer et al. 2003). It is poorly sorted and bedded, with angular clasts of 1 to 25 cm across, consisting of feldspar ( $\pm$ sparse quartz)-phyric rhyodacite, chert, and minor but ubiquitous fuchsite-bearing chips of ultramafic rock. The fine-grained matrix to the clasts is also feldspar-bearing. Greywackes, siltstone and mudstone ( $\sim 1000 \mathrm{~m}$ ) overlie the Krist pyroclastic formation, in places unconformably (Ferguson et al. 1968). Elsewhere the Krist formation is absent and the greywackes of the Beatty formation (Porcupine assemblage) directly overlie Tisdale assemblage lavas with an unconformable or faulted contact. The sediments are fine- to medium-grained, well-bedded or laminated arkosic-lithic turbidites with scour and flute marks and crossbedding. Lithic fragments are principally volcanics in an extremely fine-grained quartz-feldspar-sericite matrix.

The Hoyle formation is an extensive part of the Porcupine assemblage lying to the east, north and west of the Timmins camp (see Figure 1). The youngest zircon derived from volcaniclastic arenites within the Hoyle formation south of the Kidd Creek mine provides a maximum age for deposition of $2684.7 \pm$ 6.3 Ma (Bleeker, Parrish and Sager-Kinsman 1999). Analysis of detrital zircons from sandstones in Mountjoy Township (Figure 3, location 2) yielded ages ranging from about 2705 Ma to $2691.3 \pm 1.5 \mathrm{Ma}$, the latter indicating a maximum depositional age of the unit (Bleeker 1999). A third Hoyle formation sandstone sample was collected from diamond drill core intersecting the septum of Porcupine
sedimentary rocks northeast of the McIntyre mine in central Tisdale Township (Figure 3, location 3). Four single zircon grains have been analyzed - 2 were large, slightly elongate colourless subhedral prisms, which gave concordant ages at $2690.9 \pm 2.5$ and $2699.4 \pm 3.8 \mathrm{Ma}$. One was a smaller brown prism that is slightly discordant $(0.8 \%)$ at $2692.3 \pm 1.4 \mathrm{Ma}$, while the fourth was a small elongate prism or needle, concordant at $2695.8 \pm 2.8 \mathrm{Ma}$. Hence, the maximum age of deposition for this sample is constrained to be $<2690.9 \pm 2.5 \mathrm{Ma}$. A fourth Hoyle formation sandstone sample was collected from diamond drill core in Hoyle Township (Figure 3, location 4). This sample yielded detrital zircons IDTIMS (isotope dilution-thermal ionization mass spectrometry) ages of ca. $2725 \mathrm{Ma}, 2713 \mathrm{Ma}, 2711 \mathrm{Ma}$, $2704 \mathrm{Ma}, 2690.4 \mathrm{Ma}$, and 2688.2 Ma. SHRIMP (sensitive high-resolution ion microprobe) data on a larger group of detrital zircons from the same sample indicate an older grain at ca. 2756 Ma but with the bulk of the zircon detritus having ages clustering near 2690 Ma .

The Beatty formation is located in the core of the Porcupine syncline. A sample of Beatty formation sandstone immediately underlying the Timiskaming angular unconformity in Tisdale Township (Figure 3, location 5) contains detrital zircons with ID-TIMS ages of ca. $2726 \mathrm{Ma}, 2720 \mathrm{Ma}, 2708 \mathrm{Ma}, 2692 \mathrm{Ma}$, and 2687 Ma . By comparison, SHRIMP data on a larger group of detrital grains from this sample indicate zircon ages ranging from about 2760 Ma to 2680 Ma , with the bulk of the youngest zircon detritus ages clustering near 2690 Ma . The combined geochronological data from the Porcupine sandstone samples indicates that the Hoyle and Beatty formations are correlative and that detritus constituting these sedimentary units was derived from a source region (or regions) of diverse ages, and included material derived from all older Abitibi assemblages and/or their intrusive equivalents. The results thus confirm a period of significant uplift, erosion and unconformity occurred leading up to deposition of the Porcupine assemblage (see Figure 2).

Overlying the Porcupine assemblage with angular unconformity (Ferguson et al. 1968) is the Timiskaming assemblage ( $\sim 900 \mathrm{~m}$ thick). In the Dome formation, basal conglomerate of up to 50 m contains abundant angular mafic and ultramafic rock clasts, among other rock types, from the underlying Tisdale rocks. The Dome formation contains 2 other cobble conglomerate horizons. Greywacke consist of alternating shale $(5-20 \mathrm{~cm})$ and sandstone $(10-50 \mathrm{~cm})$. P. Born (Ayer et al. 1999) interprets the lower Dome formation as a sequence of turbiditic fan sediments. Two samples from the Dome formation at the Dome mine were analysed using the ID-TIMS method (Ayer et al. 2003): wacke from the basal part of the Dome formation in the Greenstone Nose (Figure 3, location 6) contains detrital zircons with ages ranging from 2710 Ma to $2679 \pm 4 \mathrm{Ma}$, whereas conglomerate in the "sedimentary trough" yielded a broader spectrum of detrital zircon ages ranging from 2814 Ma to $2674 \pm 2$ Ma. Less precise but more comprehensive SHRIMP results from these 2 samples reveal bimodal age distributions with a significant pre-Abitibi population ranging in age from 2820 to 2780 Ma and an Abitibi-aged population ranging from 2730 Ma to approximately 2660 Ma .

Stratigraphically overlying the Dome formation, the Three Nations formation consist of quartz-lithic sandstones, with angular grains, in festoon-crossbedded beds on the scale of $25-100 \mathrm{~cm}$. Conglomerate beds contain rounded clasts ( 1 to 25 cm ) of siltstone, felsic volcanics, ultramafic rock, and vein quartz. The Three Nations formation is interpreted as deltaic-fluvial deposits (Ayer et al. 1999) with mixed felsiclesser mafic provenance (Feng and Kerrich 1990). Detrital zircons from the upper part of the Three Nations formation provide a maximum depositional age of 2669 Ma (Bleeker, Parrish and Sager-Kinsman 1999; Ayer et al. 2003). As-yet unassigned Timiskaming assemblage-aged sedimentary units with maximum depositional ages of 2674 Ma occur as tectonically interleaved slivers within Tisdale assemblage volcanics proximal to the Porcupine-Destor deformation zone at the Buffalo Ankerite and Naybob mines (Ayer et al. 2003). In addition, recent diamond drilling by the Porcupine Joint Venture has indicated the presence of more extensive Timiskaming assemblage units further to the west in Ogden Township consisting of jasper-bearing conglomerate, sandstone and siltstone in faulted contact with ultramafic volcanics to the south.


Figure 3. A generalized map of the Timmins-Porcupine gold camp, covering Tisdale, Deloro, Mountjoy, Ogden, Whitney and Hoyle townships. Location of cross-sections in Figures 13, 14, 24 are shown as straight broken lines. This map is a summary of the 2 maps in the back pocket of this report, geochronology and previous work (Carlson 1967; Ferguson et al. 1968; Piroschco and Kettles 1991; Brisbin 1997; Berger 1998; Hall and Smith 2002).

Timiskaming-aged units also occur south of where they have been previously indicated in Whitney Township. For example, a sample of sandstone interbedded with conglomerate from a unit previously considered to be part of the Porcupine assemblage (Figure 3, location 7) contains detrital zircons with IDTIMS ages of $2726 \mathrm{Ma}, 2723 \mathrm{Ma}, 2692 \mathrm{Ma}, 2689.9 \pm 1.2 \mathrm{Ma}$ and 2690 Ma . SHRIMP data from a larger population of detrital zircons from the same sample show that the zircons define a spectrum of ages between approximately 2750 and 2670 Ma . The younger ages indicate that the unit is likely part of the Timiskaming assemblage and thus extends the known distribution of this assemblage further to the south in Whitney Township.

Porphyry stocks (up to 1200 by 400 m ) and dyke swarms intrude the Tisdale assemblage lavas, but are not known to intrude Porcupine or Timiskaming assemblage sediments (Holmes 1944; Brisbin 1997; Bateman et al. 2004): dykes are truncated at the Timiskaming unconformity surface; porphyry clasts occur in the overlying conglomerates; and so these porphyry bodies are typically older (2691-2687 Ma) than the ages given for the overlying sediments. The porphyries consist of plagioclase ( $30-60 \%, 1-5 \mathrm{~mm}$ ) and quartz $(5 \%, 1-5 \mathrm{~mm})$ phenocrysts in a fine groundmass of feldspar and quartz with sericite and chlorite in foliation, plus carbonate, leucoxene, apatite and actinolite (Pyke 1982). Geochemically, the porphyries are identical to the Krist pyroclastics (unpublished Porcupine Joint Venture data). Geochronological work was carried out on 2 felsic units found within the south volcanic package at the Hoyle Pond mine (Figure 3, location 8): a quartz porphyritic sericite schist and a quartz-albite porphyry (QFP) (Dinel and Fowler 2004). In contrast to the quartz feldspar porphyries, the quartz porphyritic sericite schist is strongly foliated and sericitized and appears to be conformable with the adjacent mafic and ultramafic volcanic units over 200 m (horizontal and vertical). Because of its conformable relationship and embayed quartz phenocrysts, a dissolution texture common in volcanic rocks, the unit was sampled to attempt to date the Tisdale stratigraphy in the mine area. Four single-grain zircon analyses from this unit define a primary age of crystallization of $2687.6 \pm 2.2 \mathrm{Ma}$. This age is within error of most of the other porphyry intrusion ages in the Timmins camp (MacDonald, Piercey and Hamilton 2005). On the basis of this new geochronological data, the unit is best interpreted as a quartz porphyritic intrusion emplaced into the Tisdale assemblage volcanic units. The other quartz-feldspar porphyry is trachytic in texture, composed of quartz and albite phenocrysts with a preferential alignment in a groundmass of microlites. The dominant tectonic fabric is S2 and it appears to have been intruded into a dilation zone during D2 (E. Dinel, personal communication, 2004). The best age estimate for this porphyry is provided by 3 concordant and near-concordant single-zircon analyses, which yield a weighted mean age of $2684.4 \pm$ 1.9 Ma. Minor inheritance is indicated at about 2695 Ma . The crystallization age of the quartzfeldspar porphyry is slightly younger than, but within the error of, most of the early porphyries in the Timmins gold camp (MacDonald, Piercey and Hamilton 2005), which suggests that its age of emplacement may in fact provide an absolute constraint on the timing of D2, which is considered to be pre-Timiskaming assemblage (see "Metamorphism, Structure, Tectonics" section, below).

The Pamour porphyry is a recently recognized intrusion southwest of Pamour mine. The intrusion is not exposed at surface, but recent diamond drilling by the Porcupine Joint Venture indicate it is an elongate body up to several hundred metres in length (MacDonald, Piercey and Hamilton 2005). It consists of 1-5 mm quartz-feldspar porphyritic crystals, with accessory biotite-chlorite-pyrite. Clots of mafic minerals occur, up to 1 cm long. It truncates foliation in the host ultramafic rocks of the PorcupineDestor deformation zone. The foliation in the porphyry is defined by flakes of mafic minerals, by foliation within the clots, and by the shape orientation of the clots. This foliation lies at an angle to that in the host rocks, and may be an igneous foliation. These relationships also suggest that foliation development postdates major movement (D2 - see below) on the Porcupine-Destor deformation zone. Conventional ID-TIMS zircon dating of the Pamour porphyry is complicated by the combined effects of inheritance and Pb -loss. At present, the best constraint on the age of intrusion is provided by a near-concordant, single grain analysis at $2677.5 \pm 2.0 \mathrm{Ma}$. Additional zircon analyses at 2690 Ma and 2703 Ma clearly define xenocryst ages. The age of intrusion is apparently younger than most other porphyries in the camp (see above) and its age constrains D2 as occurring before this time.

Albitite dykes (Ferguson et al. 1968), up to maximum dimensions of $5 \times 1000 \mathrm{~m}$, are known from underground at the Hollinger and McIntyre mines. The dykes consist largely of feldspar, with very minor quartz, biotite/chlorite, plus sericite, carbonate, amphiboles, tourmaline and epidote. Albitite dykes are crosscut by gold-bearing veins and alteration in Hollinger-McIntyre mine (Burrows et al. 1993). Zircons from this dyke yielded an age of $2673+6 /-2 \mathrm{Ma}$ (Corfu et al. 1989). Three additional single-grain fractions were analysed from this sample (SM85-60) to better constrain its age. One shows definite signs of inheritance with a $\mathrm{Pb}^{207} / \mathrm{Pb}^{206}$ age of $2694.4 \pm 1.8 \mathrm{Ma}$; however two others are concordant and overlapping and alone would suggest an age of $2672.7 \pm 1.2 \mathrm{Ma}$. These points are identical to the most precise earlier analyses, which all together give an age of $2672.8 \pm 1.1 \mathrm{Ma}$. This dyke age gives a maximum age for vein quartz gold mineralization at the Hollinger-McIntyre mines. Albitite dykes were also observed in diamond drill core intruding the Timiskaming assemblage conglomerates and ultramafic volcanic rocks proximal to the Porcupine-Destor deformation zone in Whitney township (E. Barr, personal communication, 2004). An 8 m wide dyke cutting ultramafic volcanics in this area (Figure 3, location 9) was sampled for precise U-Pb geochronology. Four abraded zircon fractions from this transgressive unit yield a tightly collinear regression with a concordia upper intercept age of $2677.0 \pm 2.2$ Ma , interpreted to represent the primary age of crystallization of the albitite dyke. This age is within error of the McIntyre albitite dyke and the Pamour porphyry, indicating that post D2 magmatism is more widespread in the Timmins camp than was previously recognized.

TTG (trondhjemite-tonalite-granodiorite) granitoid plutonism, in particular tonalite, in the Abitibi Subprovince is associated with all mafic-ultramafic volcanic episodes and with all deformation periods (Chown, Harrap and Mouksil 2002). Granitoids are closely related to felsic volcanism, and may form subvolcanic complexes. Chown, Harrap and Mouksil (2002) related this granitoid plutonism to extensional phases of subduction- and plume-related tectonics. The Kenogamissi Batholith lies southwest of the camp (see Figure 1) and is a multiphased body consisting of foliated to gneissic synvolcanic hornblende- and biotite-tonalite ranging in age from 2745 to 2713 Ma, moderately to weakly foliated syntectonic biotite- and hornblende-granodiorite and hornblende-diorite ranging from 2700 to 2680 Ma , and massive biotite-granite with an age of ca. 2670 Ma (Heather and van Breeman 1994; Bleeker, Parrish and Sager-Kinsman 1999; Becker and Benn 2003). The Adams pluton (Pyke 1982) consists of weakly foliated granodiorite with an age of $2685 \pm 3 \mathrm{Ma}$ intruded into Tisdale assemblage rocks southwest of the Shaw antiform. Bob's Lake granodiorite is a fine- to medium-grained, locally foliated pink to light grey granodiorite.

Post-Archaean rocks in the Timmins area include the Proterozoic diabase dyke suites. The Matachewan dykes strike north-northwest, the Abitibi dyke set strikes east-northeast, and other strike sets are discussed in some detail elsewhere (Pyke 1982). The north or north-northwest dykes consist of quartzand olivine-bearing variants with plagioclase phenocrysts, dated at $2454 \pm 2 \mathrm{Ma}$ (Heaman 1988). The east-northeast Abitibi set consist of 2 large olivine diabase dykes dated at $1140.6 \pm 2 \mathrm{Ma}$ (Krogh et al. 1987): these are very similar to another set of less common northwest-trending dykes.

## METAMORPHISM, STRUCTURE, TECTONICS

Metamorphism is recorded in all Archaean rocks, and reached lower to middle greenschist grade (only local biotite) in the Timmins area (Thompson 2003). Occurrences of biotite may be attributable to contact metamorphism around porphyry intrusions and/or to potassic metasomatism associated with gold mineralization. An estimate of the age of metamorphism is between 2677 and 2643 Ma , based on overprinting relationships (Powell, Carmichael and Hodgson 1995). Much younger ages (Powell et al. 1995) of 2421,2543 and 2578 Ma suggest multiple and very young metamorphic events. While the multiple foliations recorded in the Timmins area (described and discussed below) require multiple episodes of metamorphism, sufficient data to date have not been acquired to allow assignment of different
grades to different structural/foliation/mineral growth stages and hence to define a P-T trend through a significant period of time. Pressures of metamorphism of $\sim 200 \mathrm{MPa}$ measured on both sides of the Porcupine-Destor deformation zone (Powell, Carmichael and Hodgson 1995) set a limit to vertical offset along this shear zone.

Deformation history in the Abitibi Subprovince and the Timmins area specifically remains a subject for controversy. Regional deformation episodes have been identified based on overprinting relationships of folds and faults with the earliest compressional regime constrained by cessation of Blake River assemblage volcanism at 2696 Ma and onset of the deposition of the Porcupine assemblage at 2690 Ma , synchronous with emplacement of a suite of syn-tectonic granitic plutons (Corfu 1993; Bleeker 1999; Heather 2001; Ayer et al. 2002). These early folds are commonly refolded and transposed by later deformation events and it is therefore often difficult to determine their original orientation. A series of folds and 1 or 2 foliations have been identified (Ferguson et al. 1968; Piroschco and Kettles 1991). The Porcupine syncline (traditionally no related foliation) has been recognized as being early, predating both the Timiskaming unconformity and the foliations in Timiskaming assemblage rocks (Burrows 1915; Hodgson 1983). Folds predating the Porcupine syncline, also traditionally with no foliation, are implied (Hodgson 1983; Piroschco and Kettles 1991), but not discussed in unambiguous terms. These 2 early fold sets dominate the map-scale geometries of the Timmins area. Two foliations have been noted (Brisbin 1997) but they are not attributed to distinct fold sets. In addition to the foliations, an extremely strong lineation (extreme prolate strain in pillow lavas and vesicles, in Krist clasts, and in Timiskaming pebbles) plunges moderately to the east. This is best developed in the western half of the area, along the north side Porcupine-Destor deformation zone. The Dome fault cuts the southern margin of the Timiskaming assemblage trough. Late northwest (right lateral) and northeast (left lateral) trending faults crosscut the sequence and all folds and foliations and earlier faults. It has been proposed that the presence of auriferous clasts within the basal Timiskaming conglomerate proves the existence of pre-Timiskaming gold concentrations (Gray and Hutchinson 2001), whereas others have proposed a magmatic hydrothermal intrusion-related model for gold mineralization in the Timmins district (Mason and Melnik 1986; Brisbin 1997). However, overall, mineralization has generally been recognized as occurring late in this history (Hodgson 1983; Hodgson, Hamilton and Piroschco 1990; Piroschco and Kettles 1991; Robert and Poulsen 1997).

Movement along the Porcupine-Destor deformation zone within the Duparquet Basin (Québec) is constrained to $2700-2680 \mathrm{Ma}$ (Mueller et al. 1996), with a change at 2690 Ma (about Porcupine assemblage age) from thrusting to right-lateral transpression. Thrusting was along a shallowly northdipping zone (Hodgson 1983; Calvert and Ludden 1999; Daigneault, Mueller and Chown 2002). Leftlateral strike-slip motion has also been described (Hodgson 1983). These structural histories are broadly similar in kinematics. Along the Larder Lake-Cadillac deformation zone (see Figure 3), deformation started with coaxial shortening with south-over-north thrusting on a south-dipping (Wilkinson, Cruden and Krogh 1999), or north-over-south movement on a north-dipping (Wilkinson, Cruden and Krogh 1999; Neumayr, Hagemann and Couture 2000) surface. Dip-slip movement is followed by left- and then rightlateral non-coaxial strain, and ages for strike-slip movement along the Larder Lake-Cadillac deformation zone - post-2675 Ma and post-2669 Ma, respectively (Wilkinson, Cruden and Krogh 1999) - are younger than those for the Porcupine-Destor deformation zone. In the Timmins area, the abundance of higher stratigraphic units in the northern block suggests south block up. In detail, the Porcupine-Destor deformation zone has not been adequately identified, located, defined or described in the Timmins camp. Past work has not described any strain gradient across this zone, and in fact the most obvious gradient is along strike.

Tectonically, discussion has been dominated by the "oceanic island arc subduction zone" model (Jackson and Fyon 1991; Kerrich, Wyman et al. 1999; Wyman and Kerrich 2002; Ayer et al. 2002; Wyman, Kerrich and Polat 2002). This depends on the presence of oceanic crust beneath the mafic
volcanic centres. In contrast, juvenile crustal material detected in geochemical and geochronological studies (Lahaye et al. 2001; Thurston 2002; Sproule et al. 2002) and seismic data (Calvert and Ludden 1999) indicates a continental substrate to some of these volcanics, and hence gives strong support to the model of (para)autochthonous terrane development (Thurston 2002; Ayer et al. 2002).

## GOLD MINERALIZATION IN THE TIMMINS-PORCUPINE CAMP

Two recent reviews have given good overviews of gold mineralization in the Abitibi Subprovince (Robert and Poulsen 1997; Hagemann and Cassidy 2000). The Timmins-Porcupine gold camp is one of the great gold camps of the world, with total historic plus modern production and resources totalling 2350 tonnes of gold (Rhys 2003). In addition to the major mines (Dome, Pamour and Hollinger-McIntyre), there are numerous other deposits over 35 km of strike including Hoyle Pond and Aunor-Delnite mines, which have produced nearly 140 tonnes or 4.5 M oz of gold (Rhys 2003). Geologically, the gold deposits of the Timmins camp can be divided into several categories according to relationships between vein parageneses, metal inventory, proximity to the Porcupine-Destor deformation zone, host rock (Timiskaming sediments, Tisdale basalts, felsic porphyry intrusive stocks), geometry and kinematics of vein opening, and chronology of the mineralization relative to the different phases or increments of deformations.

The McIntyre Cu-Au-Ag-Mo porphyry-style ore body hosted by the Pearl Lake porphyry at depth in the McIntyre mine, and the entire Hollinger-McIntyre deposit, have been interpreted as a porphyry-type hydrothermal system with a porphyry Cu -Mo stockwork surrounded by a peripheral zone of auriferous quartz-carbonate veins (Mason and Melnik 1986). Spatially, it is closely related to quartz-feldspar porphyry intrusive rocks. The Hollinger mine consists of extensional quartz-ankerite vein arrays centred on tholeiites and felsic porphyries. Alteration haloes consist of zoned chlorite-calcite-sericite to ankerite (Burrows et al. 1993). Pyrite within host rocks is the main sulphide, and minor components include scheelite, albite, tourmaline, and Ag, W, As, Te, Bi. Mineralization is spatially related to the Pearl Lake porphyry and to the Hollinger Main Fault, which is a high-strain zone of lineation and constrictional strain development with no identified offsets. Fluids for the Hollinger and McIntyre mines were similar (Spooner et al. 1987). Pressure of mineralization were interpreted at $100-260 \mathrm{MPa}$, depending on the occurrence of phase immiscibility (Spooner et al. 1987; Hagemann and Brown 1996). Despite the spatial relationships between gold mineralization and the intrusive centre, presence of auriferous quartzcarbonate veins that cut the 2673 Ma albitite dike at the McIntyre mine (Marmont and Corfu 1989) clearly indicate that the mineralization is much younger than the 2690 Ma porphyry and postdates albitite magmatism. Recent radiometric dating of mineralization at $2672 \pm 7 \mathrm{Ma}$ (Bateman et al. 2004) indicate that there is about a $20 \mathrm{M} . \mathrm{y}$. (minimum) time gap between the quartz-feldspar porphyries ( $\sim 2690 \mathrm{Ma}$ ) and mineralization. Alteration consists of sericite-chalcopyrite-pyrite-albite-hematite-anhydrite-Ag-Cu-Mo$\mathrm{Te} . \mathrm{Cu}-\mathrm{Au}$ mineralization is cut by main-stage quartz veins, so there was a protracted period of mineralization, but there is disagreement on whether McIntyre is pretectonic (Robert and Poulsen 1997) or syntectonic (Rhys 2003).

The Dome mine is the second largest deposit of the district. Different styles of mineralization are exploited at Dome including 1) concordant ankerite interflow veins cut by gold-bearing extensional quartz veins and confined within Fe -tholeiitic basalt, and 2) carbonate and quartz-fuchsite-tourmaline veins hosted by a variety of rock types: basaltic and komatiitic rocks of the Tisdale Group, sediments of the Timiskaming Group, and the altered Preston and Paymaster quartz-feldspar porphyries (Rogers 1986; Proudlove and Hutchinson 1989; Moritz and Crocket 1990). The deposit is centred on the folded Timiskaming unconformity and it is next to the Dome fault. Syntectonic veins (Moritz and Crocket 1990) consist of quartz-ankerite (+fuchsite in ultramafic rocks), some in extensional arrays, some conformable and some discordant (Proudlove and Hutchinson 1989). Disseminated pyrite and pyrrhotite are the
principal sulphides. Elemental enrichment includes Ag, Zn , B. Mineralization post-dated Timiskaming sedimentation at $2670 \pm 10 \mathrm{Ma}$ (Bateman et al. 2004). At Dome, there has been argument over the role of a component of syngenetic mineralization (Proudlove and Hutchinson 1989).

Pamour mine is the principle example of gold mineralization type that extends along the Timiskaming assemblage unconformity in the Timmins-Porcupine gold camp. It consists of quartz-ankerite-albite vein arrays that are hosted mainly in Timiskaming conglomerates, and to a lesser extent in underlying Tisdale (ultra)mafic lavas. Mineralization consists of shear-related east-west-striking sets of fault-fill veins, and sheeted east-dipping extensional arrays (Duff 1986; Aitken 1990). Sericite alteration is relatively weak. Disseminated pyrite, pyrrhotite, sphalerite and arsenopyrite are the sulphide minerals. Metals include Ag, Zn , As, Pb . Mineralization post-dated Timiskaming sedimentation at 2673 Ma (Ayer et al. 2003).

## Lithogeochemistry and Basalt Stratigraphy

In order to help define the stratigraphy and to use it to resolve structural complexities and timing relationships, a set of discriminants (elemental abundance and ratios) have been determined for the various Tisdale assemblage basalt rock units (Table 2) based on geochemical binary plots derived from the Discover Abitibi Initiative sampling (Appendix 1). $\mathrm{TiO}_{2}, \mathrm{Zr}, \mathrm{V}, \mathrm{Ni}$ and Cr proved to be the most useful, similar to Kalgoorlie (Bateman, Costa et al. 2001). These discriminants are also similar to those used by the Porcupine Joint Venture (confidential data) in a modern, large and comprehensive ( 62 elements) data set that includes all Tisdale volcanic rocks (basalts and ultramafic), intrusive rocks (porphyry and albitite dykes) and sedimentary rocks (Timiskaming and Porcupine assemblages). These data enormously expand on early data (Fan and Kerrich 1997).

Discover Abitibi Initiative analytical work distinguished 3 subgroups within the Central formation, and 2 within the Hersey Lake formation. Porcupine Joint Venture work did not identify these subgroups, but did distinguish 2 subgroups in the Gold Centre formation and 2 subgroups in the Vipond formation (V vs. $\mathrm{TiO}_{2}$ : Figure 4). Figure 4 shows variation of $\mathrm{TiO}_{2}$ vs. V. Subgroups of Hersey Lake and Central formations form 2 relatively distinct arrays with slightly different slopes. This bimodality is less obvious on other diagrams (Figure 5: $\mathrm{TiO}_{2}$ vs. Zr ). The third Central formation group is an isolated cluster in $\mathrm{TiO}_{2}-\mathrm{Zr}$ (Figure 5), but otherwise is broadly coincident with the trends for both the other 2 Central formation subgroups and Hersey Lake subgroups (Figures 4 and 5). In $\mathrm{TiO}_{2}-\mathrm{V}$, Gold Centre, Vipond and Central formation subgroups form distinct arrays, and only Central and Hersey Lake formations are collinear. On a $\mathrm{Al}_{2} \mathrm{O}_{3}-\mathrm{Fe}_{\text {total }}-\mathrm{MgO}$ ternary diagram (not shown), Central formation rocks plot as Mg tholeiites, and Gold Centre and Vipond formations plot as Fe tholeiites. None are calc-alkaline basalts. They have generally higher Zr and $\mathrm{TiO}_{2}$ than Hersey Lake-Central formations, and on Figures 5 and 6 plot on inflections in the Hersey Lake-Central formation trend. In Ni-Cr, the 2 subgroups of Hersey Lake formation (Figure 7) and the corresponding 2 Central formation subgroups (Figure 8) are not distinguishable, and form an array up to high values for both elements. The third Central formation subgroup, Vipond and Gold Centre are all restricted to lower and diminishing Cr -Ni values (in that order).
Table 2. Geochemical criteria used to discriminate between the formations of the Tisdale assemblage volcanic rocks. These discriminants are based on Discover Abitibi Initiative geochemical data and on unpublished work of Porcupine Joint Venture and PlacerDome (CLA). Primitive mantle (p.m.) is used for normalization of trace elements (Sun and McDonough 1989).

|  | Ni | Cr | $\mathrm{Cr} / \mathrm{Ni}$ | V | Y | Zr | $\mathrm{V} / \mathrm{TiO}_{2}$ | $\mathrm{V} / \mathrm{Zr}$ | $\mathrm{Zr} / \mathrm{TiO}_{2}$ | V/Y | $\mathrm{Fe} t / \mathrm{MgO}$ | $\mathrm{Th} / \mathrm{TiO}_{2}$ | Th | Ce |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Timiskaming assemblage Porcupine assemblage | Argillite-greywacke sediments of Timiskaming and Porcupine assemblages are not distinguished |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Krist formation |  |  |  |  |  |  |  |  |  |  |  | $<8$ | <5 | $<40$ |
| Tisdale assemblage | Ni | Cr | $\mathrm{Cr} / \mathrm{Ni}$ | V | Y | Zr | $\mathrm{V} / \mathrm{TiO}_{2}$ | V/Zr | $\mathrm{Zr} / \mathrm{TiO}_{2}$ | V/Y | Fet/MgO | REE | normalized trace elements | anomalies |
| Gold Centre 2 groups | <125 | <250 | 1-4 | $<150$ | >30 | >125 | 20; 80 | <1 | 100-150 | <3 | $\begin{aligned} & >3 ; \\ & \mathrm{MgO}<5 \% \end{aligned}$ | flat REE @ 40-50 times chondrite | 10-15 times p.m.; flat | $\mathrm{Ni}, \mathrm{Cr}$ very depleted; mostly negative Eu anomalies |
| Vipond <br> 2 groups | 10-150 | <250 | 1-4 | $<150$ | <25 | <150 | 150; 250 | 1-4 | 50-300 | $\begin{aligned} & 3- \\ & 10 \end{aligned}$ | $\begin{aligned} & >2 ; \\ & \mathrm{MgO}<7 \% \end{aligned}$ | flat REE @ 15-30 times chondrite | 3-10 times <br> p.m.; flat | $\mathrm{Ni}, \mathrm{Cr}$ very depleted; negative $\mathrm{P}, \mathrm{Ti}, \mathrm{Nb}$; mostly negative Eu anomalies |
| Central <br> 3 groups | 25-250 | <400 | 1-4 | >150 | $\begin{aligned} & 10- \\ & 30 \end{aligned}$ | <100 | $>250$ | >4 | $\begin{aligned} & 40 ; 75 ; \\ & 60 \end{aligned}$ | >10 | $\begin{aligned} & 1-3 ; \\ & \mathrm{MgO}>3 \% \end{aligned}$ | flat REE @ 720 times chondrite; one group with positive slope in HREE to 10-15 | 1-10 times p.m.; flat | $\mathrm{Ni}, \mathrm{Cr}$ depleted; negative $\mathrm{Ti}, \mathrm{P}, \mathrm{Nb}$; mostly negative but some positive Eu anomalies |
| Hersey Lake 3 groups | >250 | >700 | $<4$ | $<225$ | $<15$ | <50 | >250 | $\begin{aligned} & 10 ; \\ & 6.5 \\ & 4.5 \end{aligned}$ | $\begin{aligned} & 40 ; 55 ; \\ & 65 \end{aligned}$ | >10 | $\begin{aligned} & 4 ; \\ & \mathrm{MgO}>5 \% \end{aligned}$ | flat REE @ 27 times chondrite; depleted LREE | $\begin{aligned} & 1-5 \text { (p.m.) } \\ & \text { flat } \end{aligned}$ | Negative P; some negative Eu anomalies |



Figure 4. Plot of V vs. $\mathrm{TiO}_{2}$ for Tisdale assemblage mafic and ultramafic lavas. Lines mark off arrays of Gold Centre and Vipond formation, based on discriminants in Table 2. Numbers refer to subgroups defined by trace element discriminant work. Other Ontario Geological Survey data included (Pressacco 1999).


Figure 5. Plot of Zr vs. $\mathrm{TiO}_{2}$ for Tisdale assemblage mafic and ultramafic lavas. Numbers refer to subgroups defined by trace element discriminant work. Some data from Ontario Geological Survey data (Pressacco 1999).


Figure 6. Plot of V vs. Zr for Tisdale assemblage mafic and ultramafic lavas. Numbers after formation name refer to subgroups defined by trace element discriminant work. Some data from Ontario Geological Survey data (Pressacco 1999).


Figure 7. Plot of Cr vs. Ni for Central formation (Tisdale assemblage) mafic lavas and Hersey Lake ultramafic lava subgroups. Numbers after formation name refer to subgroups defined by trace element discriminant work. Some data from Ontario Geological Survey data (Pressacco 1999).


Figure 8. Plot of Cr vs. Ni for Gold Centre, Vipond and Central formation (Tisdale assemblage) mafic lavas and their subgroups. Numbers after formation name refer to subgroups defined by trace element discriminant work. Some data from Ontario Geological Survey data (Pressacco 1999). This is an enlargement of part of Figure 7.

In rare earth elements (Figure 9), a distinctive feature is evident among the subgroup 3 samples of the Central formation rocks. Most groups (Gold Centre formation, Vipond formation, Central formation subgroups 1 and 2) show flat patterns with modest Eu anomalies (positive and negative) and very slight LREE depletion. The Hersey Lake komatiites show marked LREE depletion.

Central formation subgroup 3, however, show quite unique patterns, most notably in HREE enrichment (Figure 9), with a positive slope in Gd to Lu . This, together with moderately elevated MgO (to $12 \mathrm{wt} \%$ ), Ni (to 376 ppm ), Cr (to 760 ppm ), high $\mathrm{Al}_{2} \mathrm{O}_{3}$ (up to $19.38 \mathrm{wt} \%$ ), low $\mathrm{TiO}_{2}$ (below 0.62 wt $\%$ ), low Zr (below 46 ppm ), and negative Nb (normalized) and V (normalized) anomalies indicate that these rocks are boninitic in affinity (Kerrich, Wyman et al. 1999). Few boninitic rocks have been recognized in Archaean greenstone belts (Manikyamba et al. 2005). Their interpretation of this identification is that these magmas were the product of plume-subduction zone interaction.

The multi-element plot of Figure 10 shows generally flat trends at enrichments between 1 and 10 times primitive mantle. Notable are weak and variable, yet discernible, negative anomalies in Nb and Ti , and above all in P , suggesting a weak crustal input into these lavas. Nd isotope data (Ayer et al. 2002; Sproule et al. 2003) are interpreted to indicate a lack of significant crustal contamination. Nd model ages are very close to their eruption ages, indicating that any contaminant had separated from the mantle just before ( $<250 \mathrm{Ma}$ ) incorporation in the volcanics. Ba shows moderately strong enrichment, as do the few data for Rb , and this is most likely in large measure an affect of alteration accompanying gold mineralization. However, these are not the elements that are most enriched: W, K, Ag, As, $\mathrm{Sb}, \mathrm{Li}$ and $\mathrm{CO}_{2}$ show the most intense increases that can be attributed to alteration (Figure 11).


Figure 9. Plot of rare earth elements in selected samples of the Tisdale assemblage mafic lavas and their subgroups. Normalized to chondrite (Sun and McDonough 1989).


Figure 10. Plot of trace elements in samples of the Tisdale assemblage mafic lavas and their subgroups. Normalized to primitive mantle (Sun and McDonough 1989).


Figure 11. Plot of trace elements including those typically enriched around gold mineralization in samples of the Tisdale assemblage mafic lavas and their subgroups. Normalized to primitive mantle (Sun and McDonough 1989).

Thus, 2 major groupings of Tisdale mafic lavas can be made: [1] 2 subgroups of both Central and Hersey Lake formation form 2 slightly different collinear arrays; [2] the third Central formation subgroup appears to be more closely related to the Vipond and Gold Centre formations, which are themselves divided into distinct, non-collinear arrays. The subgroups in Hersey Lake komatiites are defined by sampling in drill core, and these subgroups alternate along the core, indicating that the subgroups coexisted spatially and are purely geochemical groups and do not represent stratigraphic-time units. For the other subgroup, the data do not permit distinctions between simple geochemical or stratigraphic groupings. On Figure 12, basalts in close spatial association with Hersey Lake komatiites are shown as magnesian basalts, although geochemically they appear as Group 3 of the Central formation (see Figures $4,5,6,8)$.

On the basis of lithogeochemistry, the Gold Centre, Vipond and Central formations do appear to be true stratigraphic units since they display systematic map patterns. The geochemical work reported here is the basis of the formation divisions shown for Timmins on Figure 12 and Map P. 3555 (back pocket). However, geochemical groupings as formations are not entirely mutually exclusive. Geochemically, Hersey Lake komatiite and Central formation rocks are closely related and commonly collinear on discrimination diagrams. While the Central formation (as defined geochemically) is largely restricted to the lowest horizon of the Tisdale assemblage, Vipond and Gold Centre geochemical groups are geochemically quite distinct but are interleaved. The boundaries drawn on Map P. 3555 separate zones dominated by one group or the other, rather than delimit "geochemically pure" zones. At the top of the stratigraphic pile of Tisdale assemblage basalts, immediately below the graphitic phyllites at the base of the Porcupine assemblage are basalts that show a geochemical affinity to Central or Vipond formations. This occurs all around both the Porcupine syncline and the Kayorum syncline, rather than Gold Centre geochemical-type basalts that might be expected from the established stratigraphic column (see Table 1). Gold Centre formation rocks are never immediately adjacent to the contact. This means either that there is an unrecognized geochemical group at the top of the Tisdale assemblage that may warrant formation
status, or that an anticlinal crest (presumptively of D2 age), exposing deeper stratigraphic levels, that is not indicated by any structural data parallels the Porcupine assemblage contact.

This uppermost geochemical group disappears to the northeastern part of Figure 12 with Vipond and Central formations occurring adjacent to the Porcupine assemblage contact. Similarly, to the north around the North Tisdale anticline, Central formation rocks are in direct contact with the sediments of the Porcupine assemblage. This implies that the upper parts of the Tisdale assemblage has been excised at the base of the Porcupine assemblage, and that the base of the Porcupine assemblage may be either an unconformity, a major fault, or both.

## Structure of the Timmins-Porcupine Gold Camp

Over the years, considerable work on the structure of Timmins has been done, yet a clear understanding of which phase of deformation is responsible for which structures remains elusive. The idea that the Timiskaming assemblage, itself folded, postdates the Porcupine syncline and other early folding was adopted early (Ferguson et al. 1968; Roberts 1981). Reasons for these difficulties in interpretation are that foliation has not hitherto been recognized as part of the earlier phases of folding (Ferguson et al. 1968; Brisbin 1997), and that systematic variations in bedding dips cannot be defined in the pillow basalts because flattening accompanying foliation forms the observable layering. This fact prevents the use of bedding-foliation vergences in identifying such features as antiformal synclines. Moreover, folding episodes cannot be discriminated on the scale of outcrops. Figure 3 shows a general geology map of the study area, and maps P. 3555 and P.3547-Revised (back pocket) show fuller details.

One major innovation of the work reported here is the recognition and systematic mapping of S2 foliation restricted to the Tisdale assemblage, in addition to the previously recognized S3 and S4 foliations found in the Timiskaming assemblage. While D1 is a recognized deformation event, it is interpreted here as an extensional event and no S 1 foliation has been ascribed to it. In general, as described below, D2 and post-Timiskaming D3, D4 and constrictional strain occur in the Tisdale and Porcupine assemblages, whereas S3 and S4 foliation are the principal fabrics found in the Timiskaming assemblage. The foliations tend to occur in pairs (S2-S3, and S3-S4), and S4 is only locally recognized in Tisdale assemblage rocks adjacent to the Porcupine-Destor deformation zone. The criteria used to distinguish the foliations are: [1] S4 foliation has a regular orientation striking west or west-southwest nearly parallel to the strike of bedding in Timiskaming assemblage sediments; [2] locally within the Tisdale assemblage basalts, a foliation with typical S4 orientation crosscuts S2 and S3; [3] the foliation enumerated S3 has a regular strike generally west to northwest, distinct from S4, and parallel to the axial surfaces of parts of the Porcupine syncline, and oblique to the Timiskaming unconformity; [4] within S3 crenulations, a foliation enumerated S2 is recognized within Tisdale and Porcupine assemblages, and this is in places parallel to the North Tisdale anticline axial surface that has been refolded by F3 folds; and [5] Tisdale assemblage rocks show S2 trends and basalt pillow facings together with formation distribution that are interpreted as F2 folds refolded by the F3 Porcupine syncline (Map P.3555). These distinctions are central to this study and underpin the structural interpretations. Another innovation is a reinterpretation of pre-Timiskaming deformation: here, D1 is interpreted as extensional-uplift, and D2 a fold-and-thrust event. The large-scale Porcupine syncline is not interpreted as the result of 2 preTimiskaming folding events, but as a result of overprinting of a pre-Timiskaming folding event by a postTimiskaming folding event.


Legend


Figure 12. Map of the Timmins camp area, the same as in Map P. 3555 (back pocket), with the locations of Discover Abitibi Initiative geochemical samples classified by $\mathrm{TiO}_{2}-\mathrm{Zr}-\mathrm{V}-\mathrm{Ni}-\mathrm{Cr}$ into Tisdale assemblage basalt formations. The stratigraphic subdivisions are based on these plus a large number of geochemical samples that are confidential and are not shown here. This figure is a summary of the 2 maps in the back pocket of this report, and previous work (Carlson 1967; Ferguson et al. 1968; Piroschco and Kettles 1991; Berger 1998; Hall and Smith 2002). A larger, full-colour version of this figure is included in the back pocket of this report.

## UPLIFT, EXTENSION AND EXCISION OF STRATIGRAPHY D1

On a regional scale, there is evidence for deformation predating deposition of the Porcupine assemblage. Regional deformation episodes have been identified based on overprinting relationships of folds and faults with the earliest compressional regime constrained by cessation of Blake River assemblage volcanism at 2696 Ma and onset of the deposition of the Porcupine assemblage at 2690 Ma , synchronous with emplacement of a suite of syn-tectonic granitic plutons (see Figure 2). In the Timmins camp, there is an age difference of about 15 Ma between cessation of Tisdale assemblage volcanism and deposition of the overlying Porcupine assemblage (see Table 1). The base of the Porcupine assemblage has been interpreted as an unconformity or disconformity on a regional scale (Bleeker, Parrish and Sager-Kinsman 1999) and this is clearly supported by the new geochronological data presented in the Timmins area stratigraphy and lithology section. The Porcupine-Tisdale contact may be better interpreted in terms of uplift and extension, with or without folding. There is the possibility of a folding event predating the deposition of Porcupine assemblage rocks, to wit the interpretation above (from basalt geochemistry) suggesting that an anticline within Tisdale assemblage volcanics has been truncated at the base of the Porcupine assemblage.

There is local evidence for a deformation only affecting Tisdale assemblage rocks and an unconformity predating the Porcupine assemblage. Along the southern margin of the North Tisdale anticline, there is an abbreviated Tisdale assemblage section, with a very narrow sequence of basalts north of a narrow septum of Porcupine assemblage sediments (see Figures 1, 3, Map P.3555). Geochemically ( $\mathrm{TiO}_{2}, \mathrm{Zr}, \mathrm{V}, \mathrm{Ni}, \mathrm{Cr}$ - see "Lithogeochemistry and Basalt Stratigraphy" section above), these basalts can all be defined as Central formation (see Figures 4, 5, 6, 7, 8), particularly further east around Pamour mine where there is greater density of sampling. Thus, it appears that both the Vipond and Gold Centre formations are missing. The northern contact of the sediment septum is not exposed or available for examination in drill core, and may be either a fault or an intact stratigraphic contact. This contact is folded by F2 and F3, and hence dates from a very early stage.

Further east, the contact between Tisdale assemblage volcanics and Porcupine assemblage rocks in the vicinity of Hoyle Pond mine is also a shear zone (Bateman, Ayer and Dubé 2003) marking a zone of excised stratigraphy, where the trends of the mafic-ultramafic volcanic units are also truncated against this contact (Map P.3547-Revised). The volcanic-sediment contacts are characteristically marked by several metres of graphitic schists (Map P.3547-Revised), which are typically strongly deformed and foliated (Photo 1). This zone of graphitic schist lies on both the northern and southern sides of the Hoyle Pond mafic-ultramafic belt. In the vicinity of Owl Creek, the zone of graphitic schist diverges from the mafic-sediment contact where the contact rolls over to a more flat-lying orientation: the graphitic schists continue in a steeply dipping zone entirely within the sedimentary rocks. This indicates that this shearing episode post-dated the juxtaposition - D1 along the North Tisdale anticline - of the 2 rock packages (volcanic and sedimentary). Most drill core is not oriented, so it is not possible to determine foliation orientation or to interpret kinematic microstructures. These graphitic shears most likely are late (D4?) overprints of these early D1 (extensional?) structures.


Photo 1. Graphitic phyllite with intense foliation and deformed pyrite lenses lie along the contact at the base of the Krist formation volcaniclastic and Tisdale assemblage basalts in the Kayorum syncline. This may mark the locus of early faulting. Drill hole KAY99-09, 647 m (Moneta Mines Inc.).

South of Porcupine-Destor deformation zone, along a powerline traverse across the Deloro-TisdalePorcupine assemblage contacts south of Timmins, there is also an abbreviated interval of basalts lying between ultramafic spinifex-textured lavas (assumed to be the Hersey Lake komatiite of the Tisdale assemblage) and felsic volcaniclastic rocks of the Krist formation. Thus, there is a significant interval of Tisdale assemblage rocks missing along both the northern and southern flanks of the Porcupine gold camp, with a thick succession in the middle. This may be interpreted in several ways: [1] in these northern and southern areas, the upper Tisdale assemblage basalts were never erupted, and the central basin of thicker basalt sequence may have been flanked by syn-volcanic faults; [2] there was a more or less uniform sequence of basalts, but some were structurally excised before F2 folding. This may have been caused by extensional faulting, which, given the apparent symmetry, implies north-south extension along east-west-striking faults. The base of the Krist formation is marked by several metres of deformed graphitic phyllite in both the Kayorum and Porcupine synclines, which has been subsequently folded in all folding events. This contact may represent a shear zone with significant displacement in some areas, but in the Kayorum syncline the Gold Centre formation of the uppermost Tisdale assemblage basalts has been identified geochemically; or [3] in some cases such as around Hoyle Pond-Owl Creek properties, late faulting may have contributed, at least in part, to the excision of stratigraphy. This may have been in D3 or D4, during deformation accompanying gold mineralization.

Along the base of the Krist formation in the Porcupine syncline, an unconformity has been identified (Buffam 1948) on the basis of locally truncated folds. Around the northern flank of the Porcupine syncline, the geochemical classification of Tisdale assemblage basalts (Map P.3555) indicates that, further east, progressively lower stratigraphic level basalts are exposed along the Tisdale-Krist contact. This implies that the contact (unconformity or fault) progressively cuts down section further east, but above all cuts down section in the north and probably the south. Given the inferences of D2 thrusting discussed below, reconstruction of thrust slices suggests that the contact between Tisdale and Porcupine assemblages cuts down section toward the north, because the thrust slice with the most complete Tisdale stratigraphic section may have been derived from furthest south. The Tisdale-Krist contact is marked on Map P. 3555 as an extensional fault and unconformity attributed to D1 uplift and extension.

## DEFORMATION D2

D2 is the earliest folding phase that can be identified in the field. F2 folding is most clearly defined in the North Tisdale anticline that strikes from the northwestern part of the gold camp eastward to the north of the Pamour open pit. The trends of layering of mafic and ultramafic lavas at Pamour are well defined by abundant drilling data in 3 dimensions. In plan view, opposed facings in pillows over a wide area (Map P.3547-Revised) indicate an anticlinal fold closure, and this fold closure is also well defined in cross sectional view (Figure 13). F2 folds consists of north-dipping recumbent isoclinal folds that plunge eastward at a shallow angle. The axial surface dips to the north-northeast at $40^{\circ}$, but is somewhat irregular in dip, presumably due to later folding. In cross-section at Pamour mine, the drilling data is sufficient to demonstrate the mafic-ultramafic stratigraphy in the North Tisdale anticline is truncated against the contact with the Porcupine assemblage sediments to the north (Figure 13) along the northern flank of the eastern end of the North Tisdale anticline.


Figure 13. Cross-section through the eastern continuation of the North Tisdale anticline, to the north of the Pamour open pit. Location of section shown in Figure 3. The section shows the recumbent F2 anticlinal hinge with the Timiskaming unconformity to the south (left) and a shear zone contact truncating Tisdale assemblage volcanics and juxtaposing them against Porcupine assemblage sediments to the north (right).

North and northwest of Timmins, the S2 foliation parallels the axial surface of the F2 North Tisdale anticline. This fold is defined by outward facing of basalt pillows and by the trends of distinctive units, which are best shown by aeromagnetic images. This F2 fold plunges west and southwest, with a moderately to steeply south-dipping axial surface. The ultramafic stratigraphy north of Timmins is best defined by aeromagnetic data and is truncated against the contacts with the sediments further north (Map
P.3555; Figure 14). This may be interpreted as a hanging-wall syncline related to the Fifth Avenue thrust (discussed below). On the scale of the entire gold camp, this North Tisdale-Pamour fold is a doubly plunging non-cylindrical anticline.

A syncline-anticline pair of folds have been defined in the large, central block of Tisdale assemblage basalts by pillow facings in the basalts and by S 2 trends (Map P.3555). The syncline is well defined by facing of pillows and by stratigraphy. It lies immediately to the south of the septum of Porcupine assemblage sediments to the north, and may be correlated with the Kayorum syncline (Map P.3555). The southwestern end of this syncline is not well defined, and may be truncated against the fault marking the northern edge of the main southern trend of Hersey Lake komatiites. S2 trends closely parallel the contact between the Tisdale assemblage and Porcupine assemblage rocks. Similarly, an F2 anticline, refolded around the F3 components of the Porcupine syncline, is defined by pillow facings and lies parallel to, and to the southeast of the F2 syncline. It is referred to as the Central Tisdale Anticline, but it does not closely correspond with the previously defined Central Tisdale anticline (Ferguson et al. 1968). Northwest of Timmins, the ultramafic stratigraphy is best defined by aeromagnetic data, and is truncated against the contacts with the sediments further north (Map P.3555).This may also be interpreted as a hanging-wall syncline related to the Fifth Avenue thrust.

On a previous map (Ferguson et al. 1968) the Porcupine assemblage sediment septum along the south flank of the North Tisdale anticline was shown within a synclinal closure, but facing is uniformly southward within both the sediments and the adjacent basalts, showing that it is not a fold. For stratigraphic reasons - incomplete stratigraphic sequence - a fault must be inferred. Two cross sections have been drawn across the southern contact of this septum, using drill hole data, and the sections show both south- and north-dipping contacts (Figure 14). Along the southern contact of this septum of Porcupine assemblage sediments with the Tisdale assemblage volcanics to the south are horizons of deformed graphitic schists (Photo 2). This contact is best interpreted as a D2 thrust fault zone, here termed the Fifth Avenue thrust (Figures 3, 14). It probably extends into Whitney Township across the Burrows-Benedict fault, but has not been identified, as the sediment septum does not appear to extend to the east.

Three other D2 thrust faults are inferred. The North Tisdale anticline is interpreted as a hanging-wall anticline, with the corresponding thrust surface along its northern contact, herein named the North Tisdale thrust. This fold and thrust extends into Whitney Township, immediately north of Pamour mine. The thrust follows along the northern contact of the North Tisdale anticline in Whitney Township at Pamour and dips to the north, with truncated volcanic stratigraphy abutting Porcupine assemblage sediments (see Figure 13). A third D2 thrust is interpreted along the northern contact of the belt of Tisdale assemblage volcanics in southern Hoyle Township that contain the Hoyle Pond mine. This fault also truncates the stratigraphy internal to this belt of volcanic rocks (Map P.3547-Revised), which extends west into northernmost Tisdale Township. The wide belt of Porcupine assemblage sediments along the WhitneyHoyle townships boundary (Map P.3547-Revised) dips and faces southward, except for a narrow selvedge at the southern flank, immediately below the North Tisdale thrust. A fourth D2 thrust fault marks the boundary between Central formation basalts and Hersey Lake ultramafic rocks north of the Porcupine-Destor deformation zone (Map P.3555; Figure 3). The Central Tisdale anticline here strikes nearly north-south (not readily distinguishable from the D3 South Tisdale anticline - see "Deformation D3", below), and appears to be truncated by this fault. The fault is a locus of intense ankerite alteration, and has been folded in D3. It also appears to be truncated by the Fifth Avenue thrust to the west, and so it appears to have been formed slightly earlier in D2 during imbrication of a series of thrust slices. No Porcupine assemblage sediments are involved at the present level of exposure, unlike the more northerly thrusts, and no anticline has been defined in the ultramafic rocks south of this fault.

SE end of section at
476050
5369050
SE $120^{\circ}$
SE $120^{\circ}$


Figure 14. Two cross-sections through the D2 Fifth Avenue thrust, constructed from diamond drill hole profiles. Location of section shown in Figure 3. Locations and dips of the fault in each profile are well constrained, so the variable dip of the fault is correct.


Photo 2. Graphitic phyllite, intense foliation, deformed pyrite lenses (A) and later brittle fractures and veins mark the southern contact (B) of a belt of Porcupine assemblage sediments and an extensive belt of Tisdale assemblage basalts. This probably marks the locus of D2 thrusting. Drill hole TGP002, 647 m (Timginn Property) near Timmins railway station.

These 3 basalt-sediment contacts along the northern edges of (ultra)mafic volcanic rocks may be 3 imbricate D2 thrusts, with a hanging-wall anticline defined in one. The southernmost contact (see Figure 14) has been informally referred to as the Fifth Avenue thrust due to its location in Timmins city. Here, the thrust is marked in drill core by a narrow (less than 1 m : Photo 2 ) of highly deformed and foliated sulphidic graphitic schist. The geometries of truncated volcanic stratigraphy implies south-over-north D2 thrusting, which is most probably rooted in the Porcupine-Destor deformation zone. The thrusts appear to dip both north and south, and it is assumed here that these variable dips are the result of later deformation. The Fifth Avenue thrust and others disappear below the Timiskaming assemblage rocks. Based on relative chronology, D2 folding and thrusting dates from some time between the end of Porcupine assemblage deposition (ca 2685 Ma ) and the beginning of Timiskaming assemblage deposition after 2679 Ma (Bleeker, Parrish and Sager-Kinsman 1999; Ayer et al. 2003).

Since the F2 North Tisdale anticline affects Porcupine assemblage rocks, it is to be expected that rocks within the Porcupine syncline should also exhibit F2 folds. Outcrop and facing data are sparse amongst the Beatty formation sediments of the Porcupine syncline, but F2 folding can be inferred by a line of symmetry that strikes east-northeast parallel to the flank of the Porcupine syncline (seen on the large-scale on Map P.3555, back pocket), yet at an angle to the trend of the crosscutting S3 foliation, dividing east- (inward) dipping, south-dipping and north-dipping beds. This is interpreted as an F2 syncline, refolded in F3. Thus, the Porcupine syncline is mainly an F2 syncline, parallel to F2 folding in the Tisdale assemblage basalts to the north. A stereoplot (Figure 15) of S2 foliations shows the wide range of orientations, reflecting subsequent deformation. The calculated beta axis is close to the constrictional lineation (see below).


Figure 15. Stereoplot of poles to S 2 foliations, mainly from Tisdale Township. Average $\mathrm{S} 2 \mathrm{dips} 84^{\circ}$, strike (RHR) $075^{\circ}$.

An inferred D2 anticline south of the Porcupine-Destor deformation zone is shown in the southwestern corner of Map P.3547-Revised. Its axial trace is undulatory, strikes east-west, and dips north at a moderate angle. It is cut at its eastern end by a fault that terminates against the PorcupineDestor deformation zone, and at the western end by a fault that also terminates against a faulted contact. Hence the fold is early. The rocks involved in the fold include chemical sediments (iron formation and chert), and most likely belong to upper parts of the Deloro assemblage. A fault to the north of this anticline has been named the Whitney thrust (Piroschco and Kettles 1991), and hence the implication is south-over-north movement, toward the Porcupine-Destor deformation zone. No further data is available to better interpret these faults. It may be a pre-Tisdale structure, or part of the thrusts described above.

## DEFORMATION D3

The trends of S3 are relatively regular within the Tisdale assemblage basalts (Map P.3555), with an average strike of $281^{\circ}$ and a dip of $77^{\circ}$ to the northeast (Figure 16). This is the main foliation that is recognized in the Timmins camp, forming the obvious, spaced to near-penetrative foliation in the basalts, and a penetrative fabric that is folded in D4 crenulations in Timiskaming assemblage rocks. Hence, D3 deformation postdates Timiskaming sedimentation. Further to the north, the strike of S3 foliation swings slightly to a more westerly trend. Trends become much more irregular in the vicinity of the Timiskaming trough where D4 deformation is more intense, and is responsible for folding of S3 by F4 folds. This S3 foliation is axial plane to both the South Tisdale anticline (Photo 3) and to subordinate F3 folds overprinting the mainly F2 Porcupine syncline. The fact that the South Tisdale anticline and the Porcupine syncline fold axes plunge in different directions (northwest and east, respectively) shows that they cannot be wholly the product of the same generation of folds, if the two areas have undergone the same styles of deformation prior to F3. The Kayorum syncline is also probably an F3 fold, but it has an odd geometry that is interpreted here as a combination of F2 and F3 folding. S3 is also axial surface to folded trends of S2 (Map P.3555). The F3 South Tisdale anticline appears to terminate against the Porcupine-Destor deformation zone, and does not extend to the southern side of the deformation zone. These F3 folds also become less well defined to the northwest, with tight fold hinges becoming broad warps further northwest from the Porcupine-Destor deformation zone. These features may be interpreted to indicate that F3 folding was a result of oblique-slip movement along the major deformation zone, forming en echelon fold arrays. S2-S3 intersection lineations ( $\mathrm{L}^{2}$ 3) generally plunge east (Figure 17), and this most likely reflects the effects of later deformation, in particular the strong constrictional strain affecting the Timiskaming assemblage.


Figure 16. Stereoplot of poles to S 3 foliations, circles represent Tisdale assemblage basalts and dots represent Timiskaming assemblage sediments. Average $\mathrm{S} 3 \mathrm{dips} 77^{\circ}$, strike (RHR) $281^{\circ}$.


Photo 3. Intensely deformed Tisdale assemblage basalts, foliated in S2 and crenulated in S3. S3 is axial surface to the South Tisdale anticline. Location 04RJB0467, Vedron property, southeast of Timmins.


Figure 17. Stereoplot of S2-S3 intersection lineations, in Tisdale and Porcupine assemblage rocks in Tisdale Township.

S3 foliation cuts ankerite alteration in Tisdale assemblage basalts near Vedron mine (Photo 4), and quartz veins at Vedron within the South Tisdale anticline hinge are tightly folded with S3 along the axial surface (Photo 5). Thus, Vedron mineralization appears to be pre- to early-D3 deformation. In Whitney Township, S3 is recognized within S4 crenulations, where it is a penetrative foliation dipping moderately to steeply to the northwest within sedimentary rocks of the Timiskaming assemblage. Here, S3 commonly strikes more southwesterly (dip of $58^{\circ}$ toward $328^{\circ}$, see Figure 16) than the overprinting westsouthwesterly striking S4 foliation. S3 is present in Timiskaming assemblage rocks and so D3 is younger than 2679 Ma .

An important fact is that, while major F3 folds affect Tisdale and Porcupine assemblage rocks, rocks in the Timiskaming assemblage trough show only relatively local-scale F3 folding. An exception is the F3 folding (South Tisdale anticline) of the sliver of Timiskaming assemblage conglomerates at the BuffaloAnkerite mine (Kinkel 1948). There is no clear evidence for map-scale F3 folding of the unconformity surface, except east of Pamour mine (Map P.3555) (Price and Bray 1948). At Dome mine, the sedimentary trough is considered to be primarily a feature of palaeotopography on the unconformity surface (E. Barr, personal communication, 2004), although this ancient ravine may have been appressed during D3 strain.

Bedding-S3 foliation intersection lineations, mainly in Timiskaming assemblage rocks (Figure 18), have variable fold plunges that lie along a girdle, which suggest that these folds have been refolded with a northwest-southeast trend.


Photo 4. Tisdale assemblage basalts, foliated in S3. S3 crosscuts and encloses lenses of pre-S2 ankerite alteration. Location 04RJB0342, near Vedron property.


Photo 5. Tisdale assemblage basalts, foliated in S3. S3 folds quartz veins. Location 04RJB0465, Vedron property.


Figure 18. Stereoplot of bedding-S3 intersection lineations, mainly in Timiskaming assemblage rocks in Whitney Township.

## DOME FAULT

Brittle faulting (Photo 6) forms a later stage of movement along the Porcupine-Destor deformation zone postdating thrusting, and is not directly related to ductile shearing. In most locations, the southern edge of the Timiskaming sediments is marked by a brittle fault which is interpreted as the eastward continuation of the Dome fault (Davies 1977), which is defined around Dome mine west of the Burrows-Benedict fault (see Figure 3). This fault is narrow, typically characterized by brittle features including veining and brecciation. Carbonate alteration and S3 and S4 foliation all overprint the fault zone. The Dome fault approximately parallels the unconformity along the southern limb of the D4 syncline hosting Timiskaming assemblage sediments, but in places the north-facing unconformity between the Tisdale and Timiskaming assemblages is intact. Three-dimensional information derived from a number of scissor diamond drill holes indicates that this faulted contact dips steeply north (Figure 19). At the Dome mine, it dips south near the surface and to the north at depth (Brisbin 1997). It cuts folding of undetermined generation: in most cases bedding in Timiskaming assemblage sediments faces away from the fault, but in some cases facing is down toward the fault. Therefore there are folds that are older than the fault, and the Dome fault is younger than the first phase of post-Timiskaming folding, F3. Data from drill holes are insufficient to identify folding of this fault. Commonly, the zone across this fault is not marked by strong ductile foliation, and there is also an angular discordance in pre-Timiskaming foliation across it. One possible interpretation of the curve of the fault trace from a west-southwest strike to a south strike in the vicinity of Dome mine in Tisdale Township is that it has been rotated by left-lateral strike-slip motion along the Porcupine-Destor deformation zone, just as F3 folds and S3 have slightly curvilinear trends.


Photo 6. There is an angular discordance in foliation across the Timiskaming-Tisdale contact in places within the PorcupineDestor deformation zone. The sediments are much less deformed than the volcanics. Drill hole 18964, south of Pamour pit, Whitney Township (Porcupine Joint Venture).


Figure 19. Cross section through the Dome fault in the western part of the area, along easting 472500.

There are inconsistencies in timing of the Dome fault and folding of Timiskaming assemblage sediments. The fault cuts minor folds, likely to be F3 since small F4 are less common. However, foliations postdate the fault, yet F3 folds do not seem to have affected the broad outline of the syncline, in particular the trend of the unconformity, even though S3 is imposed on both Timiskaming and older assemblages. This may be interpreted to indicate that sedimentation was synchronous with D3 deformation, and hence that D3 generated the Timiskaming assemblage basin. The Dome fault may have formed as a fault during transtensional D3 deformation, with left-lateral strike-slip motion along an anticlockwise curve in the trend of the Porcupine-Destor deformation zone opening the basin. The Dome fault may be the structure marking the faulted southern edge of a syn-D3 half-graben hosting Timiskaming sediments.

At the Dome Mine, the Dome fault is occupied by a melange of altered porphyry intrusions, carbonatized serpentinites, talc-chlorite schists and Timiskaming sedimentary rocks (Holmes 1968; Brisbin 1997). High-grade quartz-fuchsite and quartz-tourmaline auriferous veins are hosted by highly carbonatized and sericitized rocks within or in the vicinity of the Dome fault (Holmes 1968; Moritz and Crocket 1990). South of the Pamour mine, the Dome fault is overprinted by S4 foliation and carbonate alteration. Quartz-tourmaline veins crosscut the fault, and so it predates mineralization in the Timiskaming sediments and some of the deformation. Gold mineralization is associated with strike-slip D3 faulting and dip-slip reverse D4 faulting.

## DEFORMATION D4

The major effects of D4 are mostly recorded in the eastern part of the study area (Map P.3547-Revised), where S4 is subparallel to the axial plane of the long trough containing the Timiskaming assemblage. S4 is a strong crenulation cleavage with a foliation spacing of 2-5 mm, overprinting S3. Its average strike is $254^{\circ}$, and dip is $70^{\circ}$ to the north (Figure 20). The D4 deformation phase resulted in the formation of the syncline in which the Timiskaming assemblage rocks are preserved, and the S 4 foliation is axial plane to this syncline. The syncline is asymmetrical, with a north-dipping, overturned northern limb. The southern limb is commonly cut off by the Dome fault, although restricted occurrences of north-facing sediments have been found: the Dome fault is broadly parallel to the syncline's southern limb. In general, the southern edge of Timiskaming sediments are not everywhere intensely deformed, and along its southern margin the Dome fault appears to be a brittle-ductile structure, and is likely a manifestation of PorcupineDestor deformation zone activity, postdating ductile D2 strain. Remnants of Timiskaming sediments at the Buffalo-Ankerite pits and at Naybob mine site in Ogden Township (Ayer et al. 2003) also have S4 foliation. The Buffalo-Ankerite Timiskaming assemblage remnants appear folded by the large F3 South Tisdale anticline (Kinkel 1948). D4 strain seems to be oblate in the east (Photo 7), whereas intense prolate strain is recorded in Tisdale Township, which is attributed to the D5 phase of deformation (see below). The age of D4 is post Timiskaming (Ayer et al. 2003).


Figure 20. Stereoplot of poles to S 4 foliation, mainly in Timiskaming assemblage rocks in Whitney Township. Average S4 dips $70^{\circ}$, strike (RHR) $254^{\circ}$.


Photo 7. Underside of bedding in Dome conglomerate in Timiskaming assemblage rocks, showing characteristic D4 flattening strain in pebbles ( $\sim 10 \mathrm{~cm}$ across). No stretching is evident. Station 03RJB0057, Hoyle pit.

S4 foliation and deformation are not recorded in the Kidd Creek area (Bleeker 1999), so this event does not appear to have been regional in the Timmins district. Thus, S 4 foliation is not widespread, and is largely restricted to the Timiskaming syncline along the Porcupine-Destor deformation zone. It is recognisable in the Tisdale assemblage lavas only as relatively weak and broad crenulations in the periphery of the Timiskaming trough. A number of minor folds (Z asymmetry, 1-100 m in amplitude) within the Timiskaming trough and between Pamour pit and the Hallnor fault (Photo 8) can be attributed to this event. Characteristically, these folds can not be followed far along the trend of the axial surfaces. These small folds mimic the Z asymmetry in S3 folded in F4 seen at the larger scale of the entire camp. The F4 fold axes, $\mathrm{L}^{0}{ }_{4}$ intersection lineations (bedding-S4: Figure 21) and $\mathrm{L}^{3}{ }_{4}$ intersection lineations (S3S4: Figure 22) are very variable in plunge and lie on girdles identical to that for $L^{0}{ }_{3}$ intersection lineations (bedding-S3). The intense constrictional strain best seen in Tisdale assemblage basalts and locally in Timiskaming pebbles evidently postdated S4 and these girdles are most likely the result of constriction and stretching superimposed on F4 axes. A major map-scale F4 fold with a southwest-trending axial surface is at the Hoyle Pond mine (southeast Hoyle Township). In this Z-asymmetry kink in the trend of the Hoyle Pond-Owl Creek volcanic belt, S4 is axial plane to these folds. Hoyle Pond quartz veins are also folded in F3 (Rhys 1999).

Quartz-albite-carbonate veins at Pamour mine within Timiskaming assemblage sediments formed late to post-S4. They are mostly straight and crosscut foliation, but some are weakly folded and are crosscut by S 4 foliation and pressure-solved against it (Photo 9). In relative chronology, these veins are late to post D4 in timing. This contrasts with pre- or early-S3 veins elsewhere in the camp.


Photo 8. Greywacke in the Timiskaming assemblage, showing $S 4$ foliation strain in pebbles ( $\sim 10 \mathrm{~cm}$ across) and shallowdipping extensional quartz-carbonate veins at high angle to the foliation. No stretching is evident. Station 03RJB022, Hoyle pit.


Photo 9. Minor folds in Timiskaming sediments are likely F3 folds. Looking east, location 04RJB01, north of South Porcupine townsite.


Figure 21. Stereoplot of bedding-S4 $\left(\mathrm{L}^{0}{ }_{4}\right)$ intersection lineations (squares) and F4 fold axes (dots), mainly in Timiskaming assemblage rocks in Whitney Township.


Figure 22. Stereoplot of $\mathrm{S} 3-\mathrm{S} 4\left(\mathrm{~L}^{3}{ }_{4}\right)$ intersection lineations, mainly in Timiskaming assemblage rocks in Whitney Township.

The generation of S3-S4 foliation may be related to movement along the Porcupine-Destor deformation zone. On the regional scale, this area of occurrence of S4 lies along the Porcupine-Destor deformation zone and diminishes in intensity further away from the deformation zone, and so shows a strain gradient across the deformation zone. It may be related to basin inversion postdating Timiskaming sedimentation. Below, under discussion of the kinematics of the Porcupine-Destor deformation zone, right-lateral strike-slip movement is inferred, which would have converted a dilatation pull-apart basin that received Timiskaming assemblage sediments into a compressional jog.

## D4 Dip Slip Faults

A number of faults have been identified in both the Pamour and Hoyle pit areas, some dipping moderately to the north and others dipping steeply south, with a reverse sense of movement (Aitken 1990). These structures host the 51, 62 and Three Nations fault-fill veins. Offsets can be seen in the open pit (Photo 10) that give north-over-south movement. Major faults can also be identified along the flanks of the maficultramafic belts in the eastern half of the gold camp, where the volcanic-sediment contact is almost invariably marked by intensely deformed graphitic schists. Kinematic indicators are not available in the drill core where these shears have been identified, so movement could only be inferred from map-scale patterns. The fault along the northern edge of the Hoyle Pond volcanic belt is interpreted to be a F2 thrust, but otherwise the faults between Hoyle Pond and Pamour are interpreted as D4 reverse faults. These are particularly closely related to Pamour syn- to late-D4 mineralization (Aitken 1990), where fault-fill veins were emplaced along steeply dipping faults. Accompanying these are shallowly dipping sheeted arrays of extension veins (Photo 11).

## CONSTRICTIONAL STRAIN D5

Deformation in southern Tisdale Township is characterized by locally intense constrictional strain (distinguished from intersection lineations and other weaker mineral stretching lineations), which produced very strongly stretched pillows (Photo 12), amygdales and variolites in Tisdale assemblage basalts and stretched lapilli in Krist formation volcaniclastic rocks over a large area (Map P.3555) of Tisdale Township, concentrated in an east-west-trending zone west of the Porcupine syncline. This constrictional strain is most prominent in the vicinity of the deviation of the Porcupine-Destor deformation zone from an east-northeast trend to the more northeast trend around Dome mine. Intense constriction is also found locally in pebbles in the Timiskaming assemblage sedimentary rocks at BuffaloAnkerite and Dome mines. Strain is almost pure constriction (prolate ellipsoid), with ellipse ratios of up to 1:1:10. The constrictional lineation has a regular orientation: it plunges eastward at an angle of about $55^{\circ}$ and is always slightly more shallow than the intersection lineation of S2 and S3, which plunges eastward at an angle of about $65^{\circ}$ (Figure 17). Shallowly dipping thin quartz veins that indicate moderately steep extension crosscut ankerite alteration and are interpreted as contemporaneous with the D5 constrictional strain event (Photo 13).


Photo 10. In northern Pamour pit, laminated fault-fill veins with associated extension quartz vein arrays indicate reverse north (right) block up during vein growth. Other quartz veins grew as extensional arrays.


Photo 11. South wall of Pamour pit in Three Nations formation, Timiskaming assemblage. Major veins dip east/left with a subordinate set in en echelon arrangement dipping more shallowly eastward. Location 03RJB0025.


Photo 12. Strongly stretched pillows deformed in intense constrictional strain formed cigar-shaped structures. Station 04RJB0471, Tisdale basalts, Maclean Street, north of Timmins


Photo 13. Blocks or lenses of early ankeritic alteration are cut by ladder quartz veins that are continuations of larger scale veins. The ladder veins are perpendicular to regional constrictional strain, and were opened during this event. Station 04RJB0331, on Highway 101 east of Timmins and south of McIntyre headframe.

The event to which this constriction can be assigned is not wholly clear, but enumerating it as an additional event makes most sense. Overprinting criteria are not useful as constriction postdating a foliation does not produce the same overprinting relationships as does one foliation overprinting another (Mason and Melnik 1986; Burrows et al. 1993). The constrictional lineation does not lie within the plane of S3, even after any hypothetical effects of D4 folding have been removed. Its orientation is at right angles to the intersection lineation $\mathrm{L}_{4}^{3}$ in the plane of S 4 (Figures 22 and 23). This lineation lies more closely to, but not exactly within, the plane of S4, between S3 and S4. It is sub-parallel to the S2-S3 intersection lineations (see Figure 17). Constriction and S4 foliation appear to be mutually exclusive, so one hypothesis is that this constrictional lineation is a late deformation increment of D4 strain. Constrictional strain does not appear to be consistent with F4, as the D4 fold axes have a variable plunge, and because most D4 strain in Whitney Township appears to be typically pure flattening (see Photo 8), not stretching. The variable $\mathrm{L}_{3}^{0}, \mathrm{~L}^{3}{ }_{4}$ and $\mathrm{L}^{0}{ }_{4}$ intersection lineations described above lie on very similar girdles, and are best interpreted as being due to this constrictional strain, postdating D3 and D4 deformation, and hence it is distinguished here as a later, D5 phase.


Figure 23. Stereoplot of D5 constrictional lineation, mainly in Tisdale assemblage basalts in Tisdale Township.

## PORCUPINE-DESTOR DEFORMATION ZONE

The Porcupine-Destor deformation zone has long been recognized as the major structure of the area (Hurst 1936; Pyke 1982). It is generally described as a poorly exposed regionally extensive fault, approximately 150 m wide and characterized by steeply dipping penetrative foliations and talc-chlorite schists and serpentinite (Pyke 1982). The fault has been described (Bleeker 1997) as a steeply dipping, long-lived strike-slip structure, more than 450 km long, active between ca. 2680-2600 Ma with no significant difference in crustal level on either side and consequently negligible net dip-slip component
but with a minimum lateral offset of several kilometres. However, interpretations concerning the Porcupine-Destor deformation zone lack data, detail and clarity because of its poor exposure. Various previous maps of the area show the fault as a discrete surface rather than a zone, and in a variety of locations (Hodgson, Hamilton and Piroschco 1990; Piroschco and Kettles 1991). The general strain gradient is generally moderate across zones to the north of the Porcupine-Destor deformation zone, whereas the strain gradient along the strike of the deformation zone is important, where the intensity of the constrictional strain vs. flattening strain is considered. Diamond drilling indicates that the ductile component of the Porcupine-Destor deformation zone is a zone some hundreds of metres across consisting of anastomosing zones of high strain enclosing lower strain lozenges. The deformation zone occurs principally in ultramafic volcanic rocks of the Tisdale assemblage, but S4-foliated rocks of the younger Timiskaming assemblage also record considerable strain locally. There is no major contrast in metamorphic grade across the deformation zone (Bleeker 1997), and Tisdale assemblage rocks are exposed on both sides, so while it is difficult to estimate dip-slip offset, it cannot be extreme. In this work, 12 unoriented diamond drill cores were examined from 3 areas along its length within the map area (Figures 3, 24). Orientations can generally be deduced from unoriented core in isolated holes based on the assumption that foliations dip steeply and not subhorizontally, but a few scissor holes allow for less ambiguous interpretations.

A multi-stage, prolonged kinematic history is proposed for the deformation zone. Diamond drill cores display C-S structures in which the S foliation dips steeply north and the C planes dip south, with a mineral stretching lineation at a high angle to the C-S intersection, indicating dip-slip movement with south block up displacement along south dipping shears (Photos 14, 15). These are the dominant structure within the eastern drill holes. The ultramafic volcanic rocks are variably deformed, with alternating lowstrain and high-strain intervals. This first phase of multi-stage deformation is concordant with D2 thrusting, and the Porcupine-Destor deformation zone is interpreted here as the root thrust from which the Fifth Avenue and other thrusts splay toward the north.


Photo 14. C-S fabric in intensely deformed Hersey Lake komatiites within the Porcupine-Destor deformation zone. These structures indicate dip-slip movement on a south-dipping zone of high strain. Drill core, hole 18986, from near Pamour mine (Porcupine Joint Venture).


Photo 15. Deflection of S planes near parallel to core axis into C shear planes oblique to core in komatiite. Drill core, hole 18986, from near Pamour mine (Porcupine Joint Venture).

Granitoid dykes in the Porcupine-Destor deformation zone in southeastern Denton Township, 40 km southwest of the Timmins gold camp, have provided an age of $2689.3 \pm 4.5 \mathrm{Ma}$ (Hall and Smith 2002). These dykes are syn-tectonic with respect to right lateral strike slip movement of D2 age (Hall and Smith 2002) as indicated by the fact that the dykes crosscut the mylonite foliation yet are boundinaged within it, and folded (Photo 16). The dyke age is within error of the age of the Krist formation and the quartzfeldspar porphyry intrusive rocks, implying that D2 ductile movement in this zone had largely finished before Timiskaming sedimentation, and was related to the D2 thrusting event. The Timiskaming assemblage sedimentary rocks did not record this early thrusting strain. Moreover, in places there is an angular discordance in foliation orientation between Timiskaming assemblage rocks and ultramafic Tisdale assemblage rocks (Figure 24C), and so Timiskaming deposition appears to coincide with the change from dip-slip movement to D3 transpressional strike slip motion along the Porcupine-Destor deformation zone (Bleeker 1995).

D3 folds such as the South Tisdale anticline and elements of the Porcupine syncline are interpreted above as an en echelon array of folds formed during strike-slip movement, possibly related to the opening of the Timiskaming assemblage trough in a left-lateral dilatational jog along the Porcupine-Destor deformation zone. Poorly preserved, strike-slip C-S structures found in one hole in the west may record this second phase of strike-slip movement. The Timiskaming assemblage sedimentary rocks generally show lower strain than the Tisdale assemblage ultramafic rocks, which may suggest that the bulk of Porcupine-Destor deformation zone strain predated Timiskaming sedimentation (although sedimentary rocks and ultramafic lavas have very different competencies). In places, ultramafic volcanic rocks adjacent to the contact with Timiskaming assemblage rocks have a relatively low strain state compared with those further from the contact (Photo 17), indicating the ductile deformation zone was not likely responsible for juxtaposition of the Timiskaming assemblage against the older Tisdale assemblage rocks.


Photo 16. Syntectonic granodiorite dykes with an age of $2689.3 \pm 4.5$ Ma cutting mylonitized mafic metavolcanic rocks and folded by steeply plunging F2 folds (Hall and Smith 2002) (axial surface marked) within the Porcupine-Destor deformation zone along the Tatachikapika River in southeast Denton Township (NAD 83 UTM 453686E, 5350395N).


Photo 17. Brecciation and veining marks the contact between Timiskaming sediments and Hersey Lake komatiites within the Porcupine-Destor deformation zone. The ultramafic rocks are not highly deformed adjacent to the contact, but become more deformed further from the contact. The sediments are much less deformed than the volcanics. Drill hole 18964, south of Pamour pit, Whitney Township (Porcupine Joint Venture).


Figure 24. Three cross-sections through the Porcupine-Destor deformation zone, as mapped in diamond drill holes. Location of section shown in Figure 3.

The relationship between S3 and S4 foliations within Timiskaming assemblage rocks (plunge of intersection lineation, foliation vergence) can be interpreted as indicating oblique right lateral strike-slip movement. In Photo 18, S4 foliation in Timiskaming assemblage sediments crosscuts S3, which itself cuts quartz veining. The lower-strain lens of S 3 foliation and deformed vein is deformed and wrapped by S4, very different to the D4 crenulations that typically deform S3 and are seen elsewhere in Photo 18, can be interpreted as indicating D4 right lateral movement. On the regional scale (Tisdale and Whitney townships), S3 foliation strikes northwest, but within the Timiskaming rocks where S4 is best developed, S3 commonly strikes northeast as a result of D4 folding in the F4 syncline holding Timiskaming assemblage sediments. Thus, S 3 shows Z asymmetry with respect to S 4 . This suggests D 4 deformation as part of late Porcupine-Destor deformation zone, similar to interpretations of the Larder Lake-Cadillac deformation zone (Wilkinson, Cruden and Krogh 1999). D5 constrictional strain is intense in a belt parallel to the Porcupine-Destor deformation zone adjacent to the inflection in its trend. This inflection would be compressional with right-lateral movement. D5 constriction is thus interpreted here as the result of strain in such a compressional jog during right-lateral transpression.


Photo 18. Highly strained and foliated Timiskaming assemblage sediments. Foliation S 3 cuts early quartz veins, and is preserved within low-strain S4 pods. Asymmetry implies right-lateral movement during S4 formation. Hammer handle points north. Field station 03RJB08, Highway 101, 10 km east of Timmins, Whitney Township.

Tisdale and Porcupine assemblage rocks are identified on both sides of the deformation zone. On the south side of the Porcupine-Destor deformation zone, the structural history appears to be partly similar to that to the north. An early recumbent isoclinal fold involves chert and banded iron formation of the upper Deloro assemblage (southwest corner of Map P.3547-Revised). These folds are akin to those recognized as F2 thrust hanging-wall anticlines on the north side. Major folds in Whitney Township south of the Porcupine-Destor deformation zone with a east-northeast strike (subparallel to the Timiskaming trough) may be F4 folds, and map patterns (non-parallel limbs) suggest a significant northeast plunge for the fold axes. However, a northwest-striking major fault of unknown generation separates the 2 very distinct zones just described (with F2 and with F4 folds). Geologically and aeromagnetically, this inferred fault clearly terminates against the Porcupine-Destor deformation zone, and hence predates it.

## DEFORMATION D6

The sixth deformation phase identified in the Timmins camp consists of flat-lying crenulations with relatively coarse microlithons up to 1 cm , that may be a product of late extensional collapse (Bleeker 1999), following D4-D5 basin inversion. D6 was a very minor deformation phase and generated no mapor outcrop-scale structures of any importance relative to gold mineralization.

## DEFORMATION D7

The D7 deformation phase also appears to be a geometrically minor event with no F7 folds recognized at the map scale, and only a few structures at the outcrop scale. It consists of sporadic kinks and chevron folds (Photo 19) that strike north or north-northeast, and a steep axial surface and steep kink hinges. Z asymmetries are most common, and conjugate sets also occur. They are typically discontinuous and F7 affected zones have not been traced over any distance. Its effects are widespread, and have been noted by others (Bleeker 1999; Hall and Smith 2002). In particularly well-foliated rocks, such as around the Porcupine-Destor deformation zone, chevron-style folds are developed (Photo 19).


Photo 19. Schistose basalts in the Porcupine-Destor deformation zone. These have been strongly folded into chevron F7 folds. Location 04RJB240, powerline south of Timmins.

Some local geometrical features may be attributed to this event. In Broulan and Pamour pits, quartz veins normally occur as simple veins in swarms. Toward the tips of some, the veins break down into an array of en echelon veins (Photo 20). These arrays are parallel to the major single veins, but the arrays can also be interpreted as either rock bridges (Robert, Poulsen and Dubé 1994) or as a the product of east-over-west reverse movement. Also in Pamour pit are larger-scale en echelon sigmoid veins that are the product of west-over-east reverse movement. This orogen-parallel shortening is consistent with the kinematics of the kinks, and shows that vein growth occurred through D7 (Bateman, Ayer and Dubé 2003). The apparent continuity of D4 and D7 vein growth suggests that D7 was part of the major

Archaean deformation, and not some late event, unrelated to Archaean deformation. It is not known if these veins carried appreciable gold.


Photo 20. Quartz veins, Broulan pit. The veins that form extensional fracture arrays with respect to the major D4 fault-fill veins are in places themselves composed of en echelon vein arrays at the terminations of the first-order form extensional fracture arrays. The sense of shear implies east-over-west reverse shear. Looking southeast, location 03RJB091.

## Late Strike Slip Faults

A suite of late, north-trending, strike-slip faults (Map P.3547-Revised), both left lateral and right lateral, crosscut both the Pamour and Hoyle Pond mafic belts. Maximum displacements of about 500 m (right lateral) are found on the Hallnor fault, and on an un-named fault on the south side of the PorcupineDestor deformation zone (west of Bob's Lake). Otherwise, typical displacements of up to 50 m , both left lateral and right lateral, are distributed with no clear pattern along the length of the Timiskaming conglomerates. No sense of movement is dominant over the other, and total displacements for each movement sense appears equal (except that the 2 faults with 500 m displacement are both left lateral). Faults are brittle-ductile, with chlorite foliation only present within 10 cm of the fault plane. Subhorizontal striations confirm map-scale interpretation of strike slip. Since left-lateral and right-lateral strike-slip fault trends are bisected by the trend of S4, the strike-slip faults can be interpreted to have formed within the D4 stress field.

There is no correlation between gold and any strike-slip faulting. At Pamour pit, examination of historic level plans down to 165 m below surface ( $60 \mathrm{~m}(200 \mathrm{ft}$ ) level, $120 \mathrm{~m}(400 \mathrm{ft})$ level, and 180 m $(600 \mathrm{ft}$ ) level shows that the alteration zones and the dip-slip faults are offset by these faults. These faults crosscut both the Timiskaming trough and the fault along its southern margin. Hence, this episode of faulting postdates gold mineralization, and is not important to it except as far as these faults dissect the ore zones.

## Multiple Metamorphisms and Foliations

A foliation predating Timiskaming assemblage sedimentation in the Timmins gold camp has not previously been recognized or identified. However, evidence for such an early foliation is relatively widespread albeit not systematically interpreted in terms of regional folding. Folds interpreted regionally as D1 are commonly refolded and transposed by later deformation events, but where F1 fold trends have been discernible, they are typically northerly in orientation. Three examples include a broad anticline cored by the Kenogamissi Batholith (Ames et al. 1997); F1 folds with well-developed axial planar cleavages such as those observed in the Swayze belt (Heather 2001; Becker and Benn 2003); and northwest-trending folds in Deloro assemblage-aged iron formations in west-central Deloro Township (L.A.F. Hall, personal communication, 2004). These folds are cut by unfolded porphyry dykes which have been interpreted to be coeval with ca. 2690 Ma Krist formation volcanic units and syn-volcanic porphyry intrusions based on their identical geochemical characteristics. All these early folds have a welldeveloped axial planar fabric south of the Porcupine-Destor deformation zone.

Foliated clasts occur in Timiskaming assemblage sediments, with the internal foliation at a high angle to that of the enclosing conglomeratic sediments (Photo 21). There are several clasts observed of mafic composition, with a strong foliation internal to the clasts, that lies at a high angle to the S 4 foliation in the enclosing Timiskaming assemblage sediments. This observation demonstrates that a strong foliation had been developed before erosion at the Timiskaming assemblage unconformity. The inference is that a greenschist grade foliation predates the deposition of Timiskaming assemblage rocks (Bleeker 1999), which are themselves foliated at greenschist grade. This has the important implication that Tisdale assemblage rocks were at a depth of $\sim 10 \mathrm{~km}$ (Thompson 2004) when S2 foliation was acquired, ascended to the surface to be eroded prior to deposition of Timiskaming assemblage rocks, and went to a similar depth again to acquire S3 and S4. This process cannot have spanned much more than 10 Ma , and implies rapid rates of exhumation.


Photo 21. Mafic cobbles included in the basal conglomerate of the Timiskaming assemblage are outlined in both photos. In the close-up (left), the internal foliation of the pebble is shown truncated against the cobble edge. In the smaller-scale view (right), S4 foliation marked by flattened clasts lies at a high angle to the foliation internal to the clasts. Location 03RJB011, classic unconformity on ski trail, north of South Porcupine village.

# Re-Os Geochronology of Timmins Gold-Molybdenite 


#### Abstract

Re-Os dating of molybdenite at the University of Alberta has provided a more direct method of determining the timing of molybdenite precipitation associated with gold deposition and thus could provide a more direct method to date gold mineralization than has the $\mathrm{U}-\mathrm{Pb}$ zircon technique on the host rocks (Stein et al. 1998). A molybdenite selvedge to a quartz-dominated vein containing visible gold at the Dome mine provided a model age of $2670 \pm 10 \mathrm{Ma}$, and a sample containing molybdenite and chalcopyrite in altered Pearl Lake porphyry gave a model age of $2661 \pm 13 \mathrm{Ma}$ for the age of the disseminated $\mathrm{Cu}-\mathrm{Au}$ mineralizing event (Ayer et al. 2003). However, as this latter age had a large error and was therefore inconclusive, a second sample was taken from adjacent core in the same diamond-drill hole and was analysed as twin samples at the lab. Both of the second analyses are within the uncertainty of the first sample analysis. The weighted mean of the above analyses is $2672 \pm 7 \mathrm{Ma}$, and this new date is the best indication of the age of the molybdenite and therefore the copper-gold mineralization in the Pearl Lake porphyry (Bateman et al. 2004). The value of the above Re-Os model ages overlap in error but in general supports the interpretation for an early disseminated $\mathrm{Au}-\mathrm{Cu}$ event at McIntyre mine, followed by a later quartz-carbonate vein event at Dome mine.


## Gold Mineralization: Kinematics and Timings

## THE EASTERN ABITIBI SUBPROVINCE


#### Abstract

The Abitibi greenstone belt hosts diverse styles of gold deposits showing various chronological relationships relative to deformation and metamorphism, and consequently were formed at different times and at different crustal levels (see Figure 2). These deposits are now juxtaposed along major crustal-scale faults such as the Porcupine-Destor and Larder Lake-Cadillac deformation zones (Robert and Poulsen 1997; Poulsen, Robert and Dubé 2000). Deposits that were formed before main-stage deformation include the LaRonde deposit and the Doyon mine located between Noranda and Val d'Or in the Doyon-BousquetLaRonde gold camp (Dubé et al. 2003). LaRonde is a giant pre-deformation Au-rich syn-volcanic volcanogenic massive sulphide deposit (Mercier-Langevin et al. 2004; Dubé et al. 2004) whereas Doyon is a world-class $\mathrm{Au}-\mathrm{Cu}$ sulphide-rich vein-type deposit. The gold-bearing stockwork and sheeted veins at Doyon are deformed by the main foliation and mineralized veins in the West Zone are cut by pre-D2 deformation diorite dykes. These features suggest that the mineralization is pre- or early main-stage deformation. The Doyon deposit may be associated with the emplacement of a late magmatic phase (tonalite) of the multistage Mooshla pluton (Gosselin 1998; Galley, Pilote and Davis 2003). A pre-main stage deformation model has also been proposed for syenite-associated disseminated gold deposits (Robert 2001). The Sigma mine is a classic syn-deformation (orogenic) deposit (Robert and Brown 1986).


## THE TIMMINS-PORCUPINE GOLD CAMP

Two key aspects in understanding gold mineralization are timing and kinematics. With these determined, it is possible to place a mineral deposit in the context of the district's deformation history, and to propose a structural model for its formation. It is also only then that predictions can be made: knowing the way a given deposit formed and the general structural history of the relevant district, loci of repeats of the critical combinations of stratigraphic and structural factors can be identified. The following is a distillation of published data on Timmins-Porcupine gold deposits relevant to this question. As indicated in this report, the geological setting of gold deposits in Timmins is highly complex and the timing relative
to deformation is commonly difficult to establish due to the complex structural evolution and the multiple generations of folds and foliations. However, the Timiskaming unconformity and the various porphyry intrusions combined with the detailed geochronological information available in the camp provide key chronological relationships that help to define the timing of the gold mineralization.

There have been suggestions that there are several relative timings for gold mineralization, and this is a particular line of enquiry here. The $\mathrm{Cu}-\mathrm{Au}-\mathrm{Ag}-\mathrm{Mo}$ porphyry-style ore body hosted by the Pearl Lake porphyry at depth in the McIntyre mine has long been considered to be early (Mason and Melnik 1986). This early phase may be more widely developed that hitherto believed, as at Blueberry Hill near Dome mine (Gray and Hutchinson 2001). The presence of clasts of colloform-crustiform ankerite vein in the basal conglomerate of the Dome formation at Dome mine (Dubé, Williamson and Malo 2003) is good evidence for early hydrothermal alteration and low grade mineralization. Auriferous clasts found in the Timiskaming conglomerate at Pamour mine (Gray and Hutchinson 2001) have been interpreted as evidence for hydrothermal activity and mineralization predating the Timiskaming unconformity, however the timing of gold within the mineralized clasts has been disputed (Poulsen, Robert and Dubé 2000).

## The Hollinger-McIntyre-Coniaurum Mines

The Hollinger-McIntyre deposit is the largest gold deposit in Canada. Mineralization is emplaced in south-facing mafic lavas of the Tisdale assemblage (Figure 3, Map P.3555). Early stage(s) of gold mineralization in the camp is indicated by the $\mathrm{Cu}-\mathrm{Au}-\mathrm{Ag}-\mathrm{Mo}$ porphyry-style ore body hosted by the Pearl Lake porphyry ( $\sim 2690 \mathrm{Ma}$ ) at depth in the McIntyre mine (Mason and Melnik 1986; Marmont and Corfu 1989). It also postdates an albitite dyke with an age of $2672 \pm 1 \mathrm{Ma}$ (see details above). Four stages are described (Burrows and Spooner 1986) comprising 1) chalcopyrite, hematite, molybdenite, anhydrite, pyrite, tourmaline, and ankerite; 2) bornite, chalcopyrite, albite; 3) sericite, pyrite; and 4) molybdenite, chalcopyrite, tetrahedrite. Stages 2 and 3 overprint the central anhydrite zone of stage 1 . Overall, the $\mathrm{Au}: \mathrm{Ag}$ ratio in the $\mathrm{Cu}-\mathrm{Au}-\mathrm{Ag}-\mathrm{Mo}$ porphyry-style ore is about 1:5. Mineralization occurs as a series of lenses over 1200 vertical metres, plunging eastward parallel to the D5 constrictional lineation. The McIntyre Cu -Au-Ag-Mo mineralization is paragenetically early as it is cut by main-stage quartz-carbonate-Au veins.

Earlier components of the main stage mineralization consist of narrow ankerite-quartz veins that are crosscut by tourmaline and scheelite but little gold (Wood et al. 1986). Main-stage quartz-carbonate-Au veins comprise the major single concentration of gold ore ( 32 million ounces) in the Timmins-Porcupine camp. They crosscut veins that contain dominant quartz with subordinate ankerite-albite-scheelite-tourmaline-sulphides (sphalerite, chalcopyrite, pyrite, galena)-tellurides, and gold. Some early tourmaline veins show chocolate-tablet boudinage (Burrows et al. 1993), which cannot be an effect of late constriction. Wallrock alteration consists of sericite, ankerite, rutile, chlorite and sulphides. Veining is concentrated around the north and west of the Pearl Lake porphyry and along an east-northeast-trending belt of high strain. Maximum dimensions of the mineralized zone are $500 \mathrm{mx}>5000 \mathrm{~m}$ length x 2400 m depth, with individual veins extending up to 300 m . The main stage Au veins cut the albitite dyke, the quartz-feldspar porphyry, and Cu-Au-Ag-Mo mineralization (Burrows et al. 1993; Rhys 2003). Vein geometries and kinematic indicators indicate vein formation during shear zone movement, with a sense of right lateral - oblique movement dominant over left lateral movement (Burrows et al. 1993; Rhys 2003). Other vein sets are confined within or between lithological units such as flows, and are controlled by competency contrasts (Burrows et al. 1993).

Vein arrays strike northeast and north-northeast. In the vein arrays, the main foliation (here enumerated S3) is rotated in the same manner as veins in the core of the array, and hence the shear is inferred to have been active during this deformation event (Burrows et al. 1993; Rhys 2003): D3. Veins
are in part strongly folded, boudinaged and transected by foliation (Rhys 2003), which is here interpreted as S4. A set of flat veins are also present, and were mined (Hall 1985). These flat veins splay off vertical veins and are probably a component of the same extensional fracture array.

The main-stage quartz-gold veins were interpreted (Mason and Melnik 1986) as the outermost zone of a porphyry-type hydrothermal system with a porphyry Cu core. This interpretation has not been accepted by other, later authors (Burrows et al. 1993).

These deposits represent the bulk of the gold mineralization in the Timmins district. However, a recent Re-Os molybdenite age of $2672 \pm 7$ Ma indicates that this stage of Cu -Au-Ag-Mo porphyry-style mineralization is not as early as originally thought (Mason and Melnik 1986), as it overlaps with the $2670 \pm 10 \mathrm{Ma}$ Re-Os age of molybdenite associated with an auriferous quartz vein at the Dome mine (Ayer et al. 2004), discussed above. This age, while having considerable uncertainty, is probably postTimiskaming assemblage age. This early $\mathrm{Cu}-\mathrm{Au}-\mathrm{Ag}-\mathrm{Mo}$ stage of mineralization could thus have formed early in the emplacement of the albitite dyke magmatic system, whereas the bulk of the quartz-carbonate gold veins post-date albitite dykes (Corfu et al. 1989). Dome mine contains comparable $\mathrm{Cu}-\mathrm{Au}-\mathrm{Mo}$ mineralization (Gray and Hutchinson 2001).

## The Dome Mine

The Dome mine (Map P.3555) was the first deposit discovered in the Timmins-Porcupine camp. It consists of a complex assemblage of several vein types, some of which are found in both Timiskaming and Tisdale assemblage rocks. Ankerite( $\pm$ quartz $\pm$ tourmaline) veins extend over 500 m in strike, 900 m vertically, 2 m in width, and occur in arrays of sheeted veins subparallel to lithological layering (Pressacco 1999). They appear to occur exclusively in Tisdale assemblage volcanic rocks, and the presence of clasts of colloform-crustiform ankerite vein in the basal conglomerate of the Dome Formation at Dome mine (Dubé, Williamson and Malo 2003) suggests that these veins may predate Timiskaming assemblage sedimentation. Local millimetre-scale ankerite veinlets are injected into the basal conglomerate and suggest that ankerite veining outlasted the Timiskaming assemblage deposition. This suggests that the colloform-crustiform ankerite veins are pre- to syn-deposition of the conglomerate at the base of the Timiskaming unconformity. Steeply to moderately dipping quartz-tourmaline veins are well mineralized with gold. The relative timing of these 2 vein types is not clear, although small quartztourmaline veins are known to cut the ankerite veins (E. Barr, personal communication, 2003). At AunorDelnite mine (see below) the quartz-tourmaline veins form a younger crosscutting set. The most productive type of veins is the quartz veins hosted by the "dacite ore" and the sedimentary trough (Pressacco 1999). The dacite ore consists of intensely iron-carbonatized mafic lavas with arrays of goldbearing quartz-ankerite veins that individually dip moderately to the northwest, and may comprise extensional vein arrays generated in both dip-slip and right-lateral shears. Distribution of dacite ore shows in places a spatial relationship to conglomerate-filled embayments in the Timiskaming assemblage unconformity. Porphyry ore, by definition, occurs in the Preston Porphyry and adjacent Tisdale assemblage mafic volcanics. It consists of quartz-ankerite-sulphide-gold veins that dip shallowly to the northwest, and so appear similar to dacite ore. "Sedimentary trough" ore is found in Timiskaming assemblage basal conglomerate and overlying slates (Pressacco 1999), and also extends into Tisdale assemblage rocks ("greenstone ore"), and is comprised of swarms of randomly oriented and locally folded quartz veins. Distribution is in part controlled by thickness of the conglomerate or irregularities in the unconformity surface. Arrays of gold-bearing moderately to shallowly dipping extensional quartz veins cut the ankerite veins at high angle. They are commonly better developed in the neck of the boudinaged ankerite veins and are consequently most probably contemporaneous with layer-parallel extension superimposed on these competent veins.

The quartz-fuchsite vein in the Dome mine is the highest grade part of the ore deposit (Moritz and Crocket 1991). It is a steeply southeast-dipping vein that strikes east-west parallel to lithological layering. The vein system is $500 \times 500 \times 3.5 \mathrm{~m}$ in extent, and it is emplaced into intensely carbonatized ultramafic volcanic rocks of the Tisdale assemblage, adjacent to greywackes of the Timiskaming assemblage to the north. It apparently does not occur in these sediments. Only subsidiary, associated quartz veining occurs in both Tisdale and Timiskaming assemblage rocks. It consists of both massive and discontinuous ribbontextured quartz veins, which are coeval as they crosscut each other. The fuchsite is found in the laminae within ribbon veins. En echelon arrays of steeply dipping extension quartz veins indicate both left-lateral and right-lateral strike-slip movement. Timing of formation of the quartz-fuchsite vein is constrained by inclusions of foliated wall rock, serrated vein margins, folded quartz veins and crosscutting foliation (Moritz and Crocket 1990). The main foliation in the host rocks may be either S3 or S4 as described above, and cuts and postdates the quartz-fuchsite vein. Copper-Mo-Au mineralization is reported at Blueberry Hill (Gray and Hutchinson 2001), in close association with intrusive quartz-feldspar rocks. This form of mineralization is cut by a variety of quartz-gold veins.

Extensional quartz ladder veins also occur, crosscutting the ankerite, quartz-tourmaline, and ribbon quartz-fuchsite veins, some in association with boudinage of the quartz-fuchsite vein, and perpendicular to a slickenside striation that plunges steeply to the east. These observations imply that these veins were formed during D5 constrictional strain and near-vertical extension. They do not contain gold (Moritz and Crocket 1990; Pressacco 1999). A Pb-Pb age of $2266 \pm 49 \mathrm{Ma}$ (Worden, Cumming and Krstic 1995) may indicate a hydrothermal event, widespread in the Abitibi Subprovince. This event remobilized sulphides, and hence may have resulted in significant beneficiation of the ore. Thus, several episodes can be distinguished: the barren to low-grade ankerite veins are pre- to early-Timiskaming assemblage deposition; the quartz-fuchsite vein is possibly also of this age. Several styles of quartz-gold veins occur in both the sediments and volcanics, generally in arrays related to shears, but detailed kinematics and timings are not clear. Ladder and extension quartz veins date from D5 constrictional strain, but may not have introduced new gold.

## The Aunor-DeInite and Buffalo-Ankerite Mines

The host rocks to these mines are pillowed mafic volcanics, which are enclosed within ultramafic lavas of the Tisdale assemblage Hersey formation. Veins comprise quartz-ankerite-pyrite-gold veins ( 5 mm to 5 m ), contain some fuchsitic laminae, and have been compared to the ankerite veins at Dome mine (Brisbin 1997). Younger quartz-tourmaline-pyrite-gold veins crosscut and offset the quartz-ankerite veins. Individual veins strike east-northeast, and dip steeply to the north, subparallel to ore zones and to S3. Ore shoots plunge west at a shallow to moderate angle. Quartz-tourmaline veins occur in 2 apparent conjugate sets, the principal east-west set having right-lateral strike-slip offsets (Brisbin, Speidel and Mason 1987; Rhys 2003).

These 2 veins types are boudinaged and crosscut by a variety of quartz veins. Quartz-carbonate veining in the Buffalo-Ankerite pit extends across the Timiskaming unconformity into the sediments and conglomerates, where en echelon quartz-carbonate vein sets are found that indicate both northwest and southeast block up reverse movements (Photo 22). They crosscut S4 foliation, and may be akin in timing and kinematics to vein sets described below at Pamour mine. These may thus be syn- or late-D4. Some of these quartz veins carry gold adjacent to older veins, but do not everywhere contain gold, and so this gold may well be simply remobilized. They lie perpendicular to the host vein wall, and dip southwest perpendicular to the strong stretching lineation. Some are described as ladder veins, and are likely associated with D5 constriction.


Photo 22. En echelon quartz veins in Timiskaming assemblage conglomerate. Veins of this type crosscut ankerite veins in the mafic rocks. These veins indicate south block up reverse movement. Other veins in this mine are similar to the pre-Timiskaming ankerite veins at Dome mine. Location 04RJD0365, Buffalo-Ankerite pit, looking west.

The comparison of ankerite veins in the Delnite-Aunor-Buffalo-Ankerite-Vedron corridor with those at Dome mine suggest a pre-Timiskaming age for at least a component of the mineralization. Goldbearing quartz veins and S2 foliation at Vedron are crosscut by S3 (see Photo 5) associated with the South Tisdale anticline. Hence, the Delnite-Aunor-Buffalo-Ankerite-Vedron mineralized corridor was likely originally a linear belt, later folded in F3. En echelon veins at Buffalo-Ankerite mine are younger still. These deposits may have formed in D2, with further mineralization in D4 post-Timiskaming assemblage sedimentation.

## The Pamour Mine

At Pamour mine, 20 km east of Timmins (Figure 3, Map P.3547-Revised), the gold-bearing quartzcarbonate veins are mainly hosted by the Timiskaming sediments and in adjacent Tisdale (ultra)mafic volcanic rocks that lie to the north and below the Timiskaming unconformity. The major structures are the D4 syncline hosting the Timiskaming assemblage and the easterly extension of the F2 North Tisdale Anticline. F3 folds deform the sediments locally. Veins consist of quartz-albite-carbonate-gold $\pm$ tourmaline and sulphides (pyrite-sphalerite $\pm$ chalcopyrite $\pm$ pyrrhotite $\pm$ arsenopyrite). Minor sericite occurs in the alteration halo. Three veining styles are recognized (Aitken 1990). Narrow veins ( $<1-3 \mathrm{~m}$ ) hosted by the volcanics dip moderately north, more shallowly than the unconformity to the south. These veins crosscut stratigraphy, but are not fully developed in talc-chlorite schists. A set of veins that occur within the Timiskaming assemblage rocks are termed 'TN' veins (from Three Nations formation and lake). These dip steeply south, and converge slightly in strike eastward with the volcanic-hosted veins. These 2 veins types can extend for 500 m along dip and strike. These 2 vein types are associated with dip-slip fault movement (see Photo 10), consistent with D4 deformation, and are interpreted (Aitken 1990) as fault-fill veins. Quartz-pyrite(-other sulphides) extension fracture arrays occur to form bulk-minable ore, predominately in the Timiskaming assemblage sediments, and best within conglomerates. Where the volcanic-hosted veins approach the unconformity, they flatten in dip, and extension vein arrays appear in
the vein footwalls (Aitken 1990). Extension veins dip shallowly to the east-southeast and form shallowly east-plunging shoots. They are interpreted (Aitken 1990) as forming in extension fracture arrays associated with formation of the fault-fill veins.

The extension vein arrays crosscut S4 foliation, although they are locally crosscut (see Photo 10) and folded by this foliation. Strike-slip faults interpreted above as late in D4, crosscut and offset the ore bodies. Thus, Pamour ore formation is interpreted as syn-to late-D4 deformation (Bateman, Ayer and Dube 2003). Several smaller mines in the area (Hallnor, Broulan, Hoyle, Bonetal) appear to exploit very similar deposits (Brisbin 1997). These deposits end around Pamour, and east of this point the dip of the unconformity is shallower. Perhaps this geometry, where volcanic-hosted veins and the unconformity dip at similar angles, prevents the intersection of the north-dipping volcanic-hosted veins with the unconformity, which is a prerequisite for the development of extension vein arrays.

## The Hoyle Pond Mine

The Hoyle Pond mine lies 18 km northeast of Timmins (Figure 3, Map P.3547-Revised). It is a quartz vein-hosted gold deposit (Brisbin 1986; Pressacco 1999; Rhys 2003) hosted in folded Tisdale assemblage mafic-ultramafic volcanic rocks. This fold is interpreted here as the northernmost of the series of D2 thrust-related structures. Three vein types are recognized (Rhys 1999). The oldest veins, ribboned grey quartz veins ( $<3 \mathrm{~m}$ ) with albite-tourmaline-hydromuscovite-carbonate-coarse gold, are folded and boudinaged in the main foliation ( S 3 or perhaps S 4 ), and are folded around the map-scale fold (Figure 3, Map P.3547-Revised). Ribboned white quartz with folia of chlorite-muscovite-carbonate-pyrite-fine gold commonly dilate the older grey quartz veins, and splay off the grey vein footwalls as extension fracture arrays. Others of the set crosscut the grey veins and the map-scale fold. The white quartz veins may be deformed in the same event as the grey quartz veins, but to a lesser extent. They form oblique, rightlateral extension fracture arrays. Late extension quartz veins (a few centimetres thick, $<4 \mathrm{~m}$ long) commonly occur in south-dipping extension fracture arrays, implying south block up reverse movement. Veins are localized within mafic volcanic rocks, or along their contacts.

The early vein distribution is complex, and has been folded in the main deformation interpreted as D3 in the area (Rhys 2003). Cross-cutting relationships with S3 foliation suggest a syn-D3 timing for the grey quartz and white quartz vein mineralization as a 2 -stage early extensional fracture array (Rhys 1999). However, the axial trace of the major fold at Hoyle Pond mine lies at a high angle to other F3 folds such as the South Tisdale anticline and Porcupine syncline, yet parallels the F4 fold hosting Timiskaming assemblage sediments: the Hoyle Pond fold may therefore be F4, and hence it is possible that early veining is syn-D3 or at least pre-D4. The white quartz veins that are not folded at the map scale may be infill to fractures formed during late D3 shear after folding. Some veins parallel the axial surfaces of this F4 fold deforming the Porcupine and Tisdale assemblage (see Figure 3). The early mineralization at Hoyle Pond is thus most probably contemporaneous with D3, and later extension arrays with D4 deformation.

## The Owl Creek Mine

The Owl Creek deposit (1.4 million ounces (Pressacco 1999)), northeast of Timmins and west of Hoyle Pond mine in the same northern belt of Tisdale assemblage mafic-ultramafic volcanic rocks, lies 4 km north of the Porcupine-Destor deformation zone (Map P.3547-Revised). It is a system of gold-bearing quartz-ankerite veins, lying in subvertical and subhorizontal orientations (Kingston 1987), emplaced into a sliver of Tisdale assemblage rocks along the contact with graphitic phyllite on the southern edge of this belt. This margin of the volcanic rocks marked by a graphitic phyllite is described as gouge material
(Coad et al. 1998) or a deformation zone characterized by dip-slip movement (Kingston 1987), and these faults strike parallel to lithological units. To the north and south of the Tisdale assemblage rocks are Porcupine assemblage greywackes (Coad et al. 1998; Pressacco 1999). Milled breccia and crack-seal vein textures suggest syn-deformation quartz vein formation (Coad et al. 1998). Cross-sections of gold-bearing veins (Coad et al. 1998; Pressacco 1999) suggest that veining was formed as relatively steep fault-fill veins (with wall-rock breccia fill) fringed by sets of subhorizontal or shallowly dipping arrays of extensional quartz veins. Veins are deformed by folding in shallowly dipping veins and boudinage of steeper veins (Brisbin 1986), and crosscut by 2 sets of left-lateral and right-lateral strike-slip faults (Brisbin and Pressacco 1999). By analogy with Pamour, these data may be interpreted as indicating synD4 ore formation, with late D4 folding and faulting of veins.

## Conclusions and Implications

One new conclusion from this work is that a specific fabric (foliation or lineation) can be ascribed to 4 of the 5 major deformation events that affected the Timmins-Porcupine gold camp. D1 (no foliation) and D2-S2 predate the Timiskaming unconformity, whereas S3 and S4 postdate deposition of Timiskaming assemblage sediments. D5 constriction is a final component of this protracted orogeny. Other results include the identification of D1 extension, D2 south-over-north thrusting in the Porcupine-Destor deformation zone and the recognition of a stacked series of D2 thrust sheets north of the PorcupineDestor deformation zone within the Timmins-Porcupine gold camp, with Tisdale assemblage lavas thrust over Porcupine assemblage sediments. The gold deposits lie in the hanging wall of these thrusts. Previous to identifying the stacked thrust sheets, these deposits appeared to lie in the footwall of the PorcupineDestor deformation zone, a situation which conflicts with common observations for Archaean gold deposits elsewhere in the Abitibi Subprovince and the world generally (Robert 1990; Goldfarb, Groves and Gardoll 2001). D3 deformation is interpreted to represent oblique left-lateral transpressive deformation in the vicinity of the Porcupine-Destor deformation zone (Bleeker 1995). It is this event that opened the dilatation jog that was progressively filled with Timiskaming assemblage sediments. D4 showed an inversion to right-lateral strike-slip. These events were followed by intense D5 constrictional strain, especially in the area west of the flexure within the Porcupine-Destor deformation zone. Elsewhere in the Abitibi Subprovince, the Larder Lake-Cadillac deformation zone is interpreted as a zone of rightlateral transpression (Robert 1989). The Porcupine-Destor deformation zone went through a change in strike-slip movement similar to the Larder Lake-Cadillac deformation zone (Wilkinson, Cruden and Krogh 1999), where anticlockwise deviations of deformation zone trend underwent left-lateral motion. D2 (D3 in the scheme presented here for Timmins) had both left- and right-lateral strike-slip movement (within overall bulk shortening) along different parts of a curved Larder Lake-Cadillac deformation zone (Bleeker 1995; Wilkinson, Cruden and Krogh 1999). Their D3 event (D4 in Timmins) comprised rightlateral movement regardless of the variations in trend of the deformation zone. Data around Timmins do not allow for this more regional-scale interpretation.

Lesser components of hydrothermal and low-grade mineralization associated with extensive ankerite veining in the south (Dome, Aunor mines) predates the Timiskaming unconformity. The kinematictectonic setting is obscure, but may be related to D2 thrusting. Foliation identified as S3 was synchronous with extensional fracture arrays and quartz veining, and main-stage gold-quartz mineralization at Hollinger-McIntyre mines and in other deposits was early- to syn-D3. This stage was likely composite too, as the $\mathrm{Cu}-\mathrm{Au}-\mathrm{Ag}-\mathrm{Mo}$ mineralization in the Pearl Lake porphyry is dated as being post-Timiskaming but is older than main-stage quartz-gold veins in Hollinger-McIntyre. The quartz veining was dominated by oblique (right-lateral-south block up) shear. D3 has been interpreted as left lateral, so these vein systems may represent antithetic $\mathrm{R}^{\prime}$ shear arrays. Late mineralization crosscuts S 4 foliation with a minimum of deformation, as at Pamour mine. This was formed under north-south shortening, dip-slip
fault movement and related extensional fracture arrays. D5 constriction generated quartz ladder veins, but the evidence for introduction (rather than local remobilization) of additional gold is not conclusive.

This leads to the inference that some deposits hosted in the Tisdale and Timiskaming assemblage sediments comprise several distinguishable timings. The Cu-Au-Ag-Mo porphyry-style ore in the Pearl Lake porphyry in the McIntyre mine is considered to be early (Mason and Melnik 1986). Similar mineralization occurs at Blueberry Hill near Dome mine (Gray and Hutchinson 2001). Auriferous clasts found in the Timiskaming conglomerate at Pamour mine (Gray and Hutchinson 2001) have been interpreted as evidence for hydrothermal activity and mineralization predating the Timiskaming unconformity, but the timing of gold introduction in the clasts has been questioned (Poulsen, Robert and Dube 2000). The presence of clasts of colloform-crustiform ankerite vein in the basal conglomerate of the Dome formation at Dome mine (Dubé, Williamson and Malo 2003) is better evidence for early hydrothermal low-grade mineralization. The post-Timiskaming deposits are likely to result from a single prolonged episode spanning 3 distinguishable but continuous deformation phases that may well represent 2 gold-bearing strain increments of a single large-scale protracted transpressive deformation and metallogenic event.

The protracted history of deformation, alteration and gold mineralization described in this report suggest a long-lived or multi-stage auriferous hydrothermal system, and indicates a plumbing system geometrically stable enough, and for long enough, to feed gold into a relatively small volume of rock throughout a period of transpressional deformation (Bateman, Hagemann et al. 2001). Diversity in timing emphasizes the need to consider the potential for diversity in style (veining, vein mineralogy, disseminated, sulfide-rich mineralization), alteration mineralogy (massive ankerite, sericite), sulphide and ore minerals (pyrite, tellurides) and metallic signature ( $\mathrm{Ag}, \mathrm{Cu}, \mathrm{Mo}, \mathrm{W}$ ). Orogenic quartz-carbonate vein deposits are commonly spatially associated at the regional scale with Timiskaming-like regional unconformities and suggest an empirical relationship between large-scale greenstone quartz-carbonate gold deposits and regional unconformities (Hodgson 1993; Robert 2000; Dubé, Williamson and Malo 2003; Dubé et al. in press). In Timmins, geochronological results from the present study suggest a greater extent of Timiskaming assemblage sediments than previously recognized, since sediments previously assigned to the Porcupine assemblage contain young detrital zircons that suggest a Timiskaming assemblage age. Consequently, this expands the area that may contain large-scale gold deposits into areas previously not considered very prospective and hence secure guidance in seeking for hitherto unrecognized Timiskaming assemblage sediments - which clearly remain a first order key exploration target in the area.

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## Appendix A

## Table of Geochemical Data

Abbreviations:<br>GL-MNDM -Geoscience Laboratories, Ontario Ministry of Northern Development and Mines; ActLab - Activation Laboratories Ltd (Ancaster, Ontario);<br>XRF - x-ray fluorescence;<br>IRC - infrared absorption;<br>ICP-MS - closed beaker solution, inductively coupled plasma mass spectrometry;<br>MS-AHT - acid solution with hydride generation, inductively coupled plasma mass spectrometry;<br>AAT-100 - atomic absorption spectrometry;<br>ICP-AES - closed beaker solution, inductively coupled plasma atomic emission spectrometry; n.d. - not detected.




| Station ID | 04RJB0258 | 04RJB0259 | 04RJB0260 | 04RJB0275 | 04RJB0283 | 04RJB0230 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0258_1_1 | 04RJB0259_1_1 | 04RJB0260_1_1 | 04RJB0275_1_1 | 04RJB0283_1_1 | 04RJB0230_1_1 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Easting | 475223 | 475223 | 475293 | 484391 | 484130 | 473666 |
| Northing | 5369131 | 5369197 | 5369410 | 5372121 | 5372714 | 5366081 |
| Assemblage | Tisdale-Vipond | Porcupine | Tisdale-Vipond | Tisdale-Vipond | Tisdale-Vipond | Porcupine |
| Rock Unit | basalt | Clastic sediments | basalt | basalt | basalt | Clastic sediments |
| Rock Type | pillows | graphitic phyllite | massive | massive | pillows | siltstone |
| Rock Texture |  | laminated |  |  | variolitic | laminated |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 56.98 | 47.18 | 51.35 | 50.91 | 54.99 | 64.23 |
| TiO2 | 1.43 | 1.34 | 1.46 | 1.45 | 1.14 | 0.56 |
| Al2O3 | 14.18 | 13.31 | 12.95 | 13.79 | 13.96 | 15.98 |
| Fe2O3 | 9.61 | 14.65 | 11.92 | 15.14 | 9.31 | 5.58 |
| FeO |  |  |  |  |  |  |
| MnO | 0.166 | 0.256 | 0.188 | 0.203 | 0.189 | 0.058 |
| MgO | 4.14 | 5.28 | 5.19 | 4.75 | 4.34 | 2.70 |
| CaO | 5.58 | 7.43 | 7.46 | 8.95 | 8.13 | 1.53 |
| K2O | 0.08 | 0.58 | 0.05 | 0.16 | 0.14 | 2.42 |
| Na 2 O | 4.01 | 3.90 | 2.23 | 2.30 | 3.31 | 3.25 |
| P2O5 | 0.13 | 0.12 | 0.13 | 0.16 | 0.12 | 0.16 |
| Cr2O3 | -0.01 | 0.01 | -0.01 | 0.01 | 0.02 | 0.02 |
| LOI | 4.77 | 5.56 | 7.19 | 2.50 | 4.09 | 2.63 |
| Total | 101.06 | 99.62 | 100.10 | 100.32 | 99.74 | 99.12 |
| CO2 |  |  | 3.92 | 0.25 | 2.23 |  |
| S |  |  | 0.01 | 0.05 | 0.07 |  |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 48 | 38 | 33 | 98 | 141 | 185 |
| Nb | 5 | 4 | 11 | 6 | 4 | 7 |
| Ni | 86 | 39 | 24 | 46 | 58 | 69 |
| V | 364 | 359 | 389 | 254 | 279 | 106 |
| Y | 36 | 38 | 36 | 32 | 35 | 14 |
| Zr | 114 | 107 | 109 | 86 | 111 | 128 |
| As |  |  |  |  |  |  |
| Ba |  |  | 21.64 | 25.26 | 42.67 |  |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce |  |  | 18.05 | 15.39 | 17.32 |  |
| Cs |  |  | 0.123 | 0.103 | 0.069 |  |
| Dy |  |  | 7.072 | 5.836 | 6.59 |  |
| Er |  |  | 4.601 | 3.752 | 4.283 |  |
| Eu |  |  | 1.697 | 1.456 | 1.39 |  |
| Gd |  |  | 6.012 | 5.045 | 5.583 |  |
| Hf |  |  | 3.4 | 2.6 | 3.3 |  |
| Ho |  |  | 1.527 | 1.245 | 1.415 |  |
| La |  |  | 6.31 | 5.62 | 6.56 |  |
| Lu |  |  | 0.697 | 0.568 | 0.629 |  |
| Nb |  |  | 4.9 | 4 | 4.6 |  |
| Nd |  |  | 15.09 | 12.77 | 14.17 |  |
| Pr |  |  | 2.905 | 2.454 | 2.742 |  |
| Rb |  |  | 0.43 | 2.19 | 2.29 |  |
| Sm |  |  | 4.58 | 3.94 | 4.36 |  |
| Sr |  |  | 318.9 | 206.2 | 134.3 |  |
| Ta |  |  | 0.29 | 0.24 | 0.27 |  |
| Tb |  |  | 1.041 | 0.854 | 0.997 |  |
| Th |  |  | 0.61 | 0.52 | 0.59 |  |
| Tm |  |  | 0.693 | 0.563 | 0.636 |  |
| U |  |  | 0.171 | 0.131 | 0.156 |  |
| Y |  |  | 39.84 | 32.38 | 37.76 |  |
| Yb |  |  | 4.54 | 3.69 | 4.17 |  |
| Zr |  |  | 121.3 | 91.3 | 117.2 |  |
| Bi |  |  |  |  |  |  |
| Sb |  |  | 0.36 | 0.11 | 0.1 |  |
| Ag |  |  |  |  |  |  |
| Be |  |  | 0.41 | 0.4 | 0.38 |  |
| Cd |  |  | N.D. | N.D. | N.D. |  |
| Co |  |  | 26 | 34 | 31 |  |
| Cu |  |  | N.D. | 54 | 71 |  |
| Li |  |  | 18 | 7 | 8 |  |
| Mo |  |  | N.D. | N.D. | N.D. |  |
| Ni |  |  | 40 | 55 | 61 |  |
| Sc |  |  | 34.1 | 30.3 | 32 |  |
| Sr |  |  | 277.9 | 185.1 | 119.8 |  |
| V |  |  | 313.5 | 222.2 | 238.2 |  |
| W |  |  | 2 | N.D. | N.D. |  |
| Zn |  |  | 43 | 92 | 60 |  |


| Station ID | 04RJB0374 | 04RJB0378 | 04RJB0301 | 04RJB0514 | $04 \mathrm{RJB0527}$ | 04RJB-TW04-005 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0374_1_1 | 04RJB0378_1_1 | 04RJB0301_1_1 | 04RJB0514 | 04RJB0527 | 04RJB-TW04-005 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Ogden |
| Easting | 481015 | 483427 | 480203 | 479108 | 477802 | 474553 |
| Northing | 5371765 | 5374452 | 5369636 | 5369815 | 5369775 | 5362785 |
| Assemblage | Tisdale-Vipond | Tisdale-Vipond | Tisdale-Vipond | Tisdale-Vipond | Tisdale-Vipond | Tisdale-Vipond |
| Rock Unit | basalt | basalt | basalt | Basalt | Basalt | Basalt |
| Rock Type | pillows | pillow breccia | pillow breccia | pillows | pillows | flow breccia |
| Rock Texture |  |  | variolitic | variolitic | schistose | flattened clasts |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 54.31 | 53.88 | 54.02 | 50.19 | 61.8 | 58.29 |
| TiO2 | 1.37 | 1.95 | 1.50 | 1 | 0.52 | 0.57 |
| Al2O3 | 13.55 | 13.09 | 14.70 | 12.34 | 14.02 | 17.64 |
| Fe2O3 | 12.69 | 12.79 | 11.37 | 10.01 | 9.22 | 4.95 |
| FeO |  |  |  |  |  |  |
| MnO | 0.225 | 0.229 | 0.135 | 0.185 | 0.134 | 0.052 |
| MgO | 4.80 | 4.24 | 4.07 | 4.46 | 5.18 | 3.64 |
| CaO | 6.02 | 8.30 | 4.06 | 8.75 | 1.87 | 2.72 |
| K2O | 0.06 | 0.06 | 1.06 | 0.05 | 1.18 | 0.18 |
| Na 2 O | 3.24 | 2.15 | 2.91 | 3.15 | 0.87 | 7.59 |
| P2O5 | 0.13 | 0.12 | 0.16 | 0.11 | 0.15 | 0.24 |
| Cr2O3 | -0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| LOI | 3.18 | 4.11 | 5.23 | 9.7293 | 5.0968 | 4.088 |
| Total | 99.56 | 100.93 | 99.22 | 99.98 | 100.06 | 99.98 |
| CO2 | 0.88 | 1.9 | 2.34 | 6.64 | 1.45 | 2.29 |
| S | 0.01 | 0.02 | 0.07 | 0.12 | 0.99 | N.D. |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 36 | 35 | 63 | 135 | 142 | 158 |
| Nb | 4 | 1 | 0 | 4 | 0 | 4 |
| Ni | 43 | 54 | 80 | 59 | 58 | 70 |
| V | 344 | 489 | 390 | 283 | 146 | 110 |
| Y | 37 | 23 | 31 | 35 | 11 | 16 |
| Zr | 113 | 80 | 106 | 111 | 87 | 148 |
| As |  |  |  |  |  |  |
| Ba | 24.26 | 30.25 | 177.35 | 7.98 | 161.05 | 216.37 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 18.8 | 10.46 | 11.83 | 17.59 | 12.34 | 55.38 |
| Cs | 0.094 | 0.151 | 0.815 | 0.042 | 0.739 | 0.163 |
| Dy | 7.056 | 4.491 | 6.349 | 6.638 | 0.66 | 2.68 |
| Er | 4.71 | 2.871 | 4.083 | 4.444 | 0.473 | 1.228 |
| Eu | 1.443 | 1.309 | 1.191 | 1.228 | 0.308 | 1.453 |
| Gd | 6.048 | 3.799 | 5.538 | 5.619 | 0.867 | 4.347 |
| Hf | 3.4 | 2.5 | 3.2 | 3.3 | 2.5 | 4 |
| Ho | 1.549 | 0.956 | 1.371 | 1.47 | 0.134 | 0.472 |
| La | 6.71 | 3.62 | 3.61 | 6.45 | 5.38 | 25.03 |
| Lu | 0.723 | 0.414 | 0.591 | 0.669 | 0.101 | 0.157 |
| Nb | 4.9 | 3.5 | 4.6 | 4.4 | 3.1 | 5 |
| Nd | 14.9 | 9.11 | 11.9 | 14.02 | 6.97 | 29.15 |
| Pr | 2.907 | 1.692 | 2.084 | 2.759 | 1.649 | 7.108 |
| Rb | 0.36 | 0.79 | 22.65 | 0.36 | 26.56 | 3.47 |
| Sm | 4.63 | 2.94 | 4.12 | 4.24 | 1.33 | 5.56 |
| Sr | 133.4 | 102.6 | 40.1 | 159 | 43.9 | 239.5 |
| Ta | 0.29 | 0.2 | 0.27 | 0.27 | 0.18 | 0.34 |
| Tb | 1.064 | 0.674 | 0.969 | 1 | 0.116 | 0.529 |
| Th | 0.62 | 0.36 | 0.32 | 0.56 | 1.25 | 3.69 |
| Tm | 0.709 | 0.422 | 0.599 | 0.669 | 0.082 | 0.165 |
| U | 0.165 | 0.107 | 0.144 | 0.149 | 0.446 | 1.117 |
| Y | 38.85 | 23.99 | 34.05 | 38.23 | 3.56 | 12.95 |
| Yb | 4.68 | 2.77 | 3.88 | 4.39 | 0.64 | 1.06 |
| Zr | 121.6 | 86.8 | 114.5 | 115.5 | 95 | 153.3 |
| Bi |  |  |  |  |  |  |
| Sb | 0.12 | 0.09 | 0.06 | 0.5 | 0.58 | 0.86 |
| Ag |  |  |  |  |  |  |
| Be | 0.46 | 0.27 | 0.38 | 0.27 | 0.23 | 0.91 |
| Cd | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Co | 37 | 49 | 48 | 33 | 38 | 19 |
| Cu | 72 | 118 | 75 | 70 | 46 | N.D. |
| Li | 6 | 8 | 16 | 27 | 35 | 60 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 55 | 68 | 87 | 61 | 71 | 68 |
| Sc | 34.4 | 42.6 | 32.4 | 29.2 | 9.8 | 8.1 |
| Sr | 120.8 | 93.2 | 36.9 | 137.2 | 38.5 | 208.9 |
| V | 308.4 | >320.0 | 312.3 | 200 | 109.3 | 81.1 |
| W | N.D. | N.D. | N.D. | N.D. | 6 | N.D. |
| Zn | 94 | 150 | 72 | 60 | 900 | 50 |
|  |  |  | 70 |  |  |  |


| Station ID | 04RJB0389 | 04RJB0166 | 04RJB0221 | 04RJB0222 | 04RJB0229 | 04RJB0370 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0389_1_1 | 04RJB0166_1_1 | 04RJB0221_1_1 | 04RJB0222_1_1 | 04RJB0229_1_1 | 04RJB0370_1_1 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Mountjoy | Tisdale |
| Easting | 483043 | 480904 | 476793 | 476716 | 474726 | 481379 |
| Northing | 5372684 | 5370029 | 5367798 | 5367860 | 5367268 | 5370226 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | basalt | basalt | basalt | basalt | basalt | basalt |
| Rock Type | pillows | basaltic komatiite | pillows | pillows | pillow breccia | flow |
| Rock Texture | flattened pillows | polysutured | variolitic | schistose | schistose |  |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 50.47 | 48.09 | 45.95 | 52.11 | 47.21 | 46.25 |
| TiO2 | 1.23 | 1.35 | 1.21 | 1.37 | 1.30 | 1.30 |
| Al2O3 | 14.47 | 13.28 | 11.84 | 15.99 | 14.08 | 15.48 |
| Fe2O3 | 11.32 | 15.25 | 13.20 | 7.92 | 9.91 | 12.85 |
| FeO |  |  |  |  |  |  |
| MnO | 0.231 | 0.194 | 0.281 | 0.197 | 0.202 | 0.162 |
| MgO | 6.32 | 5.91 | 3.31 | 2.39 | 3.10 | 6.06 |
| CaO | 7.67 | 8.84 | 10.76 | 7.18 | 9.44 | 6.52 |
| K2O | 0.17 | 0.49 | 0.18 | 1.50 | 0.61 | 0.13 |
| Na 2 O | 3.45 | 2.22 | 1.77 | 3.80 | 2.85 | 3.80 |
| P2O5 | 0.09 | 0.08 | 0.12 | 0.09 | 0.09 | 0.09 |
| Cr2O3 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 |
| LOI | 4.55 | 3.88 | 11.14 | 7.74 | 9.93 | 7.24 |
| Total | 99.99 | 99.61 | 99.77 | 100.31 | 98.73 | 99.91 |
| CO2 | 1.97 |  | 8.23 |  | 7.36 | 3.63 |
| S | N.D. |  | 0.14 |  | 0.2 | 0.02 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 148 | 110 | 94 | 133 | 132 | 132 |
| Nb | 0 | 3 | 0 | 0 | 0 | 0 |
| Ni | 108 | 54 | 78 | 81 | 111 | 96 |
| V | 348 | 392 | 378 | 479 | 439 | 425 |
| Y | 23 | 22 | 22 | 20 | 20 | 20 |
| Zr | 58 | 51 | 50 | 54 | 56 | 57 |
| As |  |  |  |  |  |  |
| Ba | 63.17 |  | 36.96 |  | 192.46 | 30.74 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 8.58 |  | 14.09 |  | 8.52 | 9.61 |
| Cs | 0.059 |  | 0.179 |  | 1.075 | 0.225 |
| Dy | 4.061 |  | 4.206 |  | 3.588 | 3.633 |
| Er | 2.688 |  | 2.764 |  | 2.375 | 2.279 |
| Eu | 0.873 |  | 0.893 |  | 0.777 | 0.842 |
| Gd | 3.429 |  | 3.566 |  | 3.013 | 3.188 |
| Hf | 1.7 |  | 1.5 |  | 1.8 | 1.7 |
| Ho | 0.884 |  | 0.914 |  | 0.778 | 0.776 |
| La | 3.1 |  | 5.9 |  | 3.11 | 3.44 |
| Lu | 0.4 |  | 0.42 |  | 0.353 | 0.348 |
| Nb | 2.3 |  | 2.2 |  | 2.5 | 2.3 |
| Nd | 7.56 |  | 9.68 |  | 7.24 | 7.64 |
| Pr | 1.4 |  | 2.046 |  | 1.385 | 1.496 |
| Rb | 1.87 |  | 3.2 |  | 20.03 | 1.82 |
| Sm | 2.5 |  | 2.75 |  | 2.26 | 2.44 |
| Sr | 58.4 |  | 63.2 |  | 102.2 | 64.2 |
| Ta | N.D. |  | N.D. |  | N.D. | N.D. |
| Tb | 0.606 |  | 0.639 |  | 0.532 | 0.548 |
| Th | 0.24 |  | 0.23 |  | 0.25 | 0.24 |
| Tm | 0.402 |  | 0.416 |  | 0.345 | 0.34 |
| U | 0.07 |  | 0.066 |  | 0.071 | 0.07 |
| Y | 23.45 |  | 23.64 |  | 20.23 | 20.74 |
| Yb | 2.62 |  | 2.69 |  | 2.3 | 2.24 |
| Zr | 57.6 |  | 53.1 |  | 62.6 | 59.3 |
| Bi |  |  |  |  |  |  |
| Sb | 0.11 |  | 0.09 |  | 0.1 | 0.07 |
| Ag |  |  |  |  |  |  |
| Be | 0.22 |  | 0.12 |  | 0.32 | 0.37 |
| Cd | N.D. |  | N.D. |  | N.D. | N.D. |
| Co | 46 |  | 44 |  | 58 | 51 |
| Cu | 68 |  | 84 |  | 122 | 143 |
| Li | 11 |  | 24 |  | 29 | 24 |
| Mo | N.D. |  | N.D. |  | N.D. | N.D. |
| Ni | 107 |  | 79 |  | 109 | 100 |
| Sc | 36 |  | 34.4 |  | 32 | 40.9 |
| Sr | 51 |  | 56 |  | 90.4 | 57.6 |
| V | 319 |  | 281.7 |  | >320.0 | >320.0 |
| W | N.D. |  | N.D. |  | N.D. | N.D. |
| Zn | 66 |  | 112 |  | 61 | 73 |
|  |  |  | 71 |  |  |  |


| Station ID | 04RJB0319 | 04RJB0390 | 04RJB0401 | 04RJB0447 | 04RJB0537 | $04 R J B 0437$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0319_1_1 | 04RJB0390_1_1 | 04RJB0401_1_1 | 04RJB0447 | $04 \mathrm{RJB0537}$ | 04RJB0437 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Easting | 479821 | 482992 | 482635 | 477362 | 481020 | 479729 |
| Northing | 5367598 | 5372553 | 5374512 | 5366760 | 5370352 | 5368272 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | basalt | basalt | basalt | Basalt | Basalt | Basalt |
| Rock Type | massive | pillows | pillows | pillows | pillows | pillows |
| Rock Texture | amydaloidal | amydaloidal |  | variolitic | amygdaloidal | variolitic |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 44.69 | 49.77 | 45.30 | 52.49 | 47.66 | 49.03 |
| TiO2 | 1.13 | 1.20 | 1.17 | 1.3 | 1.17 | 1.21 |
| Al2O3 | 12.48 | 14.47 | 12.84 | 15.17 | 14.02 | 14.71 |
| Fe2O3 | 13.37 | 11.83 | 12.82 | 13.06 | 10.96 | 14.29 |
| FeO |  |  |  |  |  |  |
| MnO | 0.180 | 0.233 | 0.153 | 0.245 | 0.234 | 0.221 |
| MgO | 5.24 | 6.36 | 5.60 | 4.99 | 5.57 | 2.79 |
| CaO | 9.58 | 9.91 | 9.04 | 3.94 | 8.54 | 7.29 |
| K2O | 0.18 | 0.23 | 0.24 | 0.08 | 0.05 | 0.3 |
| Na 2 O | 2.52 | 1.89 | 2.38 | 3.71 | 2.99 | 1.94 |
| P2O5 | 0.07 | 0.09 | 0.08 | 0.1 | 0.1 | 0.11 |
| Cr2O3 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 |
| LOI | 10.84 | 4.04 | 10.17 | 5.4481 | 8.4637 | 8.5909 |
| Total | 100.29 | 100.05 | 99.80 | 100.54 | 99.78 | 100.50 |
| CO2 | 7.36 | 1.52 | 6.95 | 2.28 | 5.1 | 5.82 |
| S | 0.03 | 0.03 | 0.13 | 0.01 | 0.01 | 0.33 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 106 | 150 | 112 | 124 | 158 | 125 |
| Nb | 0 | 1 | 0 | 0 | 0 | 1 |
| Ni | 70 | 107 | 66 | 94 | 112 | 65 |
| V | 403 | 298 | 412 | 430 | 359 | 396 |
| Y | 17 | 22 | 19 | 17 | 24 | 25 |
| Zr | 44 | 55 | 46 | 60 | 55 | 73 |
| As |  |  |  |  |  |  |
| Ba | 39.98 | 84.61 | 189.43 | 25.36 | 19 | 78.16 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 5.68 | 8.73 | 7.34 | 6.76 | 8.12 | 10.23 |
| Cs | 0.305 | 0.104 | 0.123 | 0.066 | 0.046 | 0.49 |
| Dy | 2.896 | 4.085 | 3.576 | 3.133 | 4 | 4.63 |
| Er | 1.927 | 2.719 | 2.382 | 2.119 | 2.653 | 3.081 |
| Eu | 0.634 | 0.889 | 0.602 | 1.295 | 0.887 | 0.963 |
| Gd | 2.416 | 3.48 | 2.982 | 2.606 | 3.341 | 3.885 |
| Hf | 1.3 | 1.7 | 1.7 | 1.8 | 1.6 | 2.2 |
| Ho | 0.635 | 0.899 | 0.782 | 0.689 | 0.863 | 1.019 |
| La | 2.04 | 3.42 | 2.64 | 2.37 | 2.96 | 3.65 |
| Lu | 0.312 | 0.411 | 0.365 | 0.312 | 0.381 | 0.468 |
| Nb | 1.8 | 2.2 | 2 | 2.3 | 2.2 | 3 |
| Nd | 5.11 | 7.7 | 6.45 | 5.63 | 7.26 | 8.97 |
| Pr | 0.917 | 1.43 | 1.181 | 1.049 | 1.331 | 1.676 |
| Rb | 3.07 | 5.22 | 3.83 | 1.12 | 0.26 | 7.38 |
| Sm | 1.7 | 2.53 | 2.12 | 1.87 | 2.35 | 2.88 |
| Sr | 137.2 | 119.1 | 77.6 | 54.1 | 103.4 | 86.4 |
| Ta | N.D. | N.D. | N.D. | N.D. | N.D. | 0.17 |
| Tb | 0.432 | 0.599 | 0.532 | 0.457 | 0.587 | 0.697 |
| Th | 0.18 | 0.25 | 0.2 | 0.24 | 0.22 | 0.3 |
| Tm | 0.287 | 0.406 | 0.358 | 0.311 | 0.391 | 0.469 |
| U | 0.047 | 0.069 | 0.073 | 0.073 | 0.066 | 0.086 |
| Y | 16.66 | 23.58 | 20.21 | 17.36 | 23.13 | 26.54 |
| Yb | 1.93 | 2.67 | 2.35 | 2.05 | 2.55 | 3.07 |
| Zr | 44.4 | 59.8 | 60.7 | 64.6 | 55.9 | 79 |
| Bi |  |  |  |  |  |  |
| Sb | 0.48 | 0.19 | 0.17 | 1.12 | 0.26 | 0.42 |
| Ag |  |  |  |  |  |  |
| Be | 0.17 | 0.21 | 0.14 | 0.26 | 0.27 | 0.22 |
| Cd | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Co | 44 | 48 | 47 | 51 | 47 | 33 |
| Cu | 149 | 83 | 280 | 84 | 60 | 105 |
| Li | 24 | 12 | 19 | 18 | 16 | 22 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 80 | 114 | 76 | 97 | 110 | 73 |
| Sc | 35.1 | 36.3 | 35.7 | 27 | 34.3 | 28.6 |
| Sr | 118.7 | 104.7 | 68.8 | 46.7 | 90.5 | 75.3 |
| V | 309.1 | 312.4 | 318.8 | 305.8 | 293.9 | 286.6 |
| W | N.D. | N.D. | 3 | N.D. | 3 | N.D. |
| Zn | 73 | 62 | 50 | 90 | 72 | 67 |
|  |  |  | 72 |  |  |  |


| Station ID | 04RJB0523 | 04RJB0142 | $04 \mathrm{RJB0147}$ | $04 \mathrm{RJB0168}$ | 04RJB0150 | 04RJB0174 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0523 | 04RJB0142_1_1 | 04RJB0147_1_1 | 04RJB0168_1_1 | 04RJB0150_1_1 | 04RJB0174_1_1 |
| Township | Tisdale | Tisdale | Mountjoy | Murphy | Tisdale | Tisdale |
| Easting | 478966 | 474313 | 474691 | 481775 | 476126 | 483275 |
| Northing | 5370513 | 5370055 | 5370190 | 5376334 | 5370221 | 5375403 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Porcupine | Tisdale-Central | Tisdale-Central |
| Rock Unit | Basalt | Basalt | Basalt | clastic sediments | Basalt | Basalt |
| Rock Type | massive | pillow breccia | massive | sandstone | massive | pillows |
| Rock Texture | aphanitic |  | flattened pillows | crossbedded |  | flattened pillows |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 46.94 | 46.37 | 47.90 | 50.76 | 48.44 | 54.54 |
| TiO2 | 0.59 | 0.58 | 0.78 | 0.83 | 0.72 | 1.23 |
| Al2O3 | 13.25 | 11.10 | 14.06 | 13.97 | 11.43 | 14.44 |
| Fe2O3 | 10.53 | 12.05 | 13.53 | 11.00 | 11.47 | 9.57 |
| FeO |  |  |  |  |  |  |
| MnO | 0.176 | 0.200 | 0.317 | 0.160 | 0.340 | 0.225 |
| MgO | 6.81 | 12.65 | 6.36 | 9.02 | 4.52 | 5.16 |
| CaO | 9.61 | 9.92 | 10.03 | 5.27 | 10.01 | 6.36 |
| K2O | 0.05 | 0.18 | 0.26 | 3.54 | 0.52 | 0.24 |
| Na 2 O | 2.16 | 2.03 | 1.61 | 1.68 | 1.03 | 4.42 |
| P2O5 | 0.05 | 0.05 | 0.06 | 0.06 | 0.06 | 0.11 |
| Cr2O3 | 0.04 | 0.14 | 0.01 | 0.02 | -0.01 | 0.01 |
| LOI | 9.3416 | 4.88 | 5.54 | 3.31 | 11.25 | 3.16 |
| Total | 99.55 | 100.15 | 100.46 | 99.62 | 99.78 | 99.46 |
| CO2 | 5.58 | 1.76 |  | 0.22 |  |  |
| S | 0.02 | 0.06 |  | N.D. |  |  |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 316 | 998 | 109 | 172 | 58 | 82 |
| Nb | 0 | 0 | 0 | 0 | 0 | 2 |
| Ni | 79 | 367 | 65 | 83 | 77 | 363 |
| V | 244 | 213 | 259 | 318 | 278 | 380 |
| Y | 16 | 15 | 21 | 19 | 18 | 31 |
| Zr | 34 | 35 | 45 | 49 | 45 | 77 |
| As |  |  |  |  |  |  |
| Ba | 13.69 | 47.96 |  | 650.04 |  |  |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 4.81 | 4.33 |  | 5.39 |  |  |
| Cs | 0.094 | 0.098 |  | 0.655 |  |  |
| Dy | 2.51 | 2.276 |  | 2.861 |  |  |
| Er | 1.7 | 1.517 |  | 2.198 |  |  |
| Eu | 0.515 | 0.428 |  | 0.456 |  |  |
| Gd | 1.959 | 1.855 |  | 2.092 |  |  |
| Hf | 1 | 0.9 |  | 1.4 |  |  |
| Ho | 0.559 | 0.5 |  | 0.664 |  |  |
| La | 1.75 | 1.7 |  | 1.97 |  |  |
| Lu | 0.277 | 0.232 |  | 0.375 |  |  |
| Nb | 1.2 | 1.2 |  | 1.8 |  |  |
| Nd | 4.05 | 3.79 |  | 4.34 |  |  |
| Pr | 0.792 | 0.713 |  | 0.858 |  |  |
| Rb | 0.37 | 3.37 |  | 62.63 |  |  |
| Sm | 1.41 | 1.35 |  | 1.5 |  |  |
| Sr | 124.6 | 69.3 |  | 55.8 |  |  |
| Ta | N.D. | N.D. |  | N.D. |  |  |
| Tb | 0.358 | 0.343 |  | 0.399 |  |  |
| Th | 0.15 | 0.14 |  | 0.24 |  |  |
| Tm | 0.266 | 0.234 |  | 0.348 |  |  |
| U | 0.038 | 0.036 |  | 0.059 |  |  |
| Y | 14.78 | 13.16 |  | 17.39 |  |  |
| Yb | 1.76 | 1.52 |  | 2.38 |  |  |
| Zr | 35.2 | 31.2 |  | 49.7 |  |  |
| Bi |  |  |  |  |  |  |
| Sb | 0.09 | 0.1 |  | 0.08 |  |  |
| Ag |  |  |  |  |  |  |
| Be | 0.11 | 0.12 |  | 0.19 |  |  |
| Cd | N.D. | N.D. |  | N.D. |  |  |
| Co | 42 | 64 |  | 37 |  |  |
| Cu | 82 | 67 |  | 22 |  |  |
| Li | 9 | 25 |  | 22 |  |  |
| Mo | N.D. | N.D. |  | N.D. |  |  |
| Ni | 86 | 338 |  | 100 |  |  |
| Sc | 34.8 | 31.1 |  | 38.5 |  |  |
| Sr | 103.4 | 60.7 |  | 50.2 |  |  |
| V | 201.9 | 191.9 |  | 281.1 |  |  |
| W | 3 | N.D. |  | N.D. |  |  |
| Zn | 51 | 68 |  | 42 |  |  |


| Station ID | 04RJB0184 | 04RJB0262 | 04RJB0276 | $04 \mathrm{RJB0287}$ | 04RJB0288 | 04RJB0285 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0184_1_1 | 04RJB0262_1_1 | 04RJB0276_1_1 | 04RJB0287_1_1 | 04RJB0288_1_1 | 04RJB0285_1_1 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Easting | 478440 | 483483 | 484750 | 483879 | 483778 | 484059 |
| Northing | 5374375 | 5368978 | 5372128 | 5373152 | 5373307 | 5372922 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | Basalt | Basalt | basalt | Basalt | Basalt | Basalt |
| Rock Type | basaltic komatiite | tuff | massive | pillows | pillows | pillows |
| Rock Texture | flattened pillows | laminated |  | variolitic | variolitic | variolitic |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 52.23 | 50.83 | 49.32 | 50.91 | 51.18 | 49.98 |
| TiO2 | 0.79 | 0.96 | 0.68 | 0.68 | 0.71 | 0.84 |
| Al2O3 | 13.86 | 14.19 | 15.67 | 14.39 | 13.22 | 13.71 |
| Fe2O3 | 10.64 | 13.50 | 8.75 | 8.96 | 8.90 | 10.83 |
| FeO |  |  |  |  |  |  |
| MnO | 0.224 | 0.133 | 0.157 | 0.213 | 0.215 | 0.264 |
| MgO | 6.38 | 6.87 | 8.13 | 5.52 | 5.61 | 4.92 |
| CaO | 9.59 | 4.76 | 12.49 | 11.53 | 11.98 | 11.72 |
| K2O | 0.16 | 0.76 | 0.58 | 0.07 | 0.07 | 0.06 |
| Na 2 O | 2.36 | 3.60 | 1.44 | 2.05 | 1.94 | 0.95 |
| P205 | 0.07 | 0.08 | 0.05 | 0.05 | 0.07 | 0.07 |
| Cr2O3 | 0.02 | 0.01 | 0.05 | 0.04 | 0.02 | 0.01 |
| LOI | 2.97 | 4.16 | 3.30 | 5.77 | 5.64 | 6.14 |
| Total | 99.29 | 99.85 | 100.62 | 100.18 | 99.55 | 99.50 |
| CO2 | 0.81 | 1.44 | 0.96 | 3.78 | 3.45 | 3.54 |
| S | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 162 | 80 | 437 | 311 | 155 | 82 |
| Nb | 0 | 2 | 0 | 0 | 0 | 0 |
| Ni | 62 | 35 | 168 | 101 | 72 | 75 |
| V | 258 | 346 | 224 | 221 | 226 | 256 |
| Y | 22 | 24 | 17 | 16 | 17 | 18 |
| Zr | 47 | 60 | 40 | 41 | 43 | 45 |
| As |  |  |  |  |  |  |
| Ba | 62.39 | 106.86 | 242.1 | 13.87 | 17.08 | 13.14 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 6.83 | 7.38 | 6.65 | 6.09 | 6.03 | 6.63 |
| Cs | 0.066 | 1.18 | 0.206 | 0.067 | 0.054 | 0.068 |
| Dy | 3.471 | 3.993 | 2.973 | 2.773 | 2.978 | 3.16 |
| Er | 2.359 | 2.758 | 1.985 | 1.868 | 2.004 | 2.089 |
| Eu | 0.707 | 0.708 | 0.664 | 0.61 | 0.667 | 0.673 |
| Gd | 2.76 | 3.255 | 2.504 | 2.274 | 2.414 | 2.613 |
| Hf | 1.4 | 1.8 | 1.3 | 1.3 | 1.3 | 1.4 |
| Ho | 0.767 | 0.888 | 0.66 | 0.609 | 0.651 | 0.69 |
| La | 2.51 | 2.58 | 2.43 | 2.24 | 2.22 | 2.49 |
| Lu | 0.36 | 0.418 | 0.296 | 0.285 | 0.309 | 0.314 |
| Nb | 1.7 | 2.1 | 1.9 | 1.6 | 1.6 | 1.9 |
| Nd | 6.01 | 6.53 | 5.63 | 4.99 | 5.16 | 5.66 |
| Pr | 1.114 | 1.214 | 1.078 | 0.986 | 0.973 | 1.082 |
| Rb | 3.37 | 18.29 | 17.72 | 0.54 | 0.93 | 0.82 |
| Sm | 2.01 | 2.23 | 1.86 | 1.65 | 1.7 | 1.88 |
| Sr | 69.5 | 157.9 | 127.7 | 100.8 | 69.5 | 97.4 |
| Ta | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Tb | 0.502 | 0.585 | 0.447 | 0.407 | 0.438 | 0.466 |
| Th | 0.21 | 0.26 | 0.22 | 0.22 | 0.2 | 0.22 |
| Tm | 0.362 | 0.413 | 0.297 | 0.288 | 0.301 | 0.317 |
| U | 0.062 | 0.176 | 0.056 | 0.065 | 0.057 | 0.063 |
| Y | 20.18 | 23.52 | 17.7 | 15.61 | 17.37 | 18.67 |
| Yb | 2.35 | 2.74 | 1.95 | 1.9 | 1.96 | 2.08 |
| Zr | 48.6 | 63.8 | 46.9 | 44.3 | 43.3 | 50.1 |
| Bi |  |  |  |  |  |  |
| Sb | 0.08 | 0.4 | 0.23 | 0.2 | 0.16 | 0.07 |
| Ag |  |  |  |  |  |  |
| Be | 0.16 | 0.22 | 0.19 | 0.2 | 0.18 | 0.16 |
| Cd | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Co | 41 | 41 | 48 | 43 | 40 | 42 |
| Cu | 89 | 58 | 63 | 84 | 86 | 99 |
| Li | 10 | 48 | 16 | 9 | 9 | 11 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 73 | 54 | 173 | 102 | 76 | 79 |
| Sc | 37.1 | 36.5 | 29.5 | 37.9 | 37.9 | 37.1 |
| Sr | 61.5 | 143.2 | 112.3 | 90 | 61.4 | 84.9 |
| V | 244.9 | 281.2 | 223.7 | 223.9 | 229.7 | 251.3 |
| W | N.D. | N.D. | N.D. | 3 | N.D. | N.D. |
| Zn | 62 | 50 | 50 | 51 | 43 | 54 |


| Station ID Sample number | 04RJB0300 <br> 04RJB0300 1 | 04RJB0307 <br> 04RJB0307 11 | 04RJB0353 <br> 04RJB0353 11 | 04RJB0354 04RJB0354 11 | 04RJB0366 <br> 04RJB0366 11 | 04RJB0416 04RJB0416 11 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number Township | 04RJB0300_1_1 | 04RJB0307_1_1 | 04RJB0353_1-1 | 04RJB0354_1_1 | 04RJB0366_1_1 | 04RJB0416_1_1 |
| Easting | 480528 | 481513 | 475398 | 475610 | 480248 | 484767 |
| Northing | 5369627 | 5367826 | 5371238 | 5371148 | 5365051 | 5376059 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | Basalt | Basalt | basalt | Basalt | basalt | basalt |
| Rock Type | flow breccia | pillows | massive | pillows | schist | massive |
| Rock Texture | flattened clasts | variolitic |  | flattened pillows | schistose |  |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 47.94 | 45.13 | 52.15 | 52.09 | 51.89 | 52.62 |
| TiO2 | 0.87 | 0.88 | 0.90 | 0.79 | 0.89 | 0.55 |
| Al2O3 | 16.08 | 13.54 | 14.82 | 13.80 | 14.45 | 14.81 |
| Fe2O3 | 8.34 | 10.81 | 11.37 | 11.10 | 8.70 | 12.35 |
| FeO |  |  |  |  |  |  |
| MnO | 0.145 | 0.202 | 0.153 | 0.241 | 0.238 | 0.218 |
| MgO | 6.50 | 4.86 | 6.14 | 6.07 | 5.24 | 6.27 |
| CaO | 10.17 | 10.79 | 9.46 | 6.80 | 9.45 | 7.34 |
| K2O | 0.11 | 0.18 | 0.17 | 0.18 | 0.11 | 0.13 |
| Na 2 O | 2.73 | 0.89 | 2.51 | 2.09 | 4.02 | 2.90 |
| P205 | 0.05 | 0.06 | 0.08 | 0.07 | 0.08 | 0.05 |
| Cr2O3 | 0.06 | 0.04 | 0.03 | 0.01 | 0.01 | -0.01 |
| LOI | 6.83 | 12.26 | 2.44 | 6.64 | 5.14 | 3.14 |
| Total | 99.82 | 99.64 | 100.22 | 99.88 | 100.22 | 100.37 |
| CO2 | 3.66 | 8.38 | 0.27 | 3.32 | 3.09 | 0.73 |
| S | 0.02 | N.D. | 0.09 | 0.05 | N.D. | 0.01 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 413 | 358 | 212 | 115 | 73 | 49 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 131 | 113 | 97 | 83 | 71 | 73 |
| V | 280 | 344 | 299 | 265 | 280 | 257 |
| Y | 19 | 18 | 23 | 19 | 19 | 20 |
| Zr | 53 | 50 | 56 | 52 | 51 | 35 |
| As |  |  |  |  |  |  |
| Ba | 58.74 | 26.96 | 29.05 | 45.88 | 49.16 | 47.2 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 6.8 | 7.65 | 8.07 | 8.62 | 7.26 | 5.58 |
| Cs | 0.16 | 0.194 | 0.071 | 0.157 | 0.068 | 0.057 |
| Dy | 3.161 | 3.362 | 3.716 | 3.219 | 3.359 | 3.177 |
| Er | 2.073 | 2.186 | 2.666 | 2.173 | 2.197 | 2.962 |
| Eu | 0.683 | 0.736 | 0.864 | 0.768 | 0.759 | 0.508 |
| Gd | 2.667 | 2.809 | 2.958 | 2.66 | 2.75 | 1.916 |
| Hf | 1.7 | 1.5 | 1.7 | 1.5 | 4.6 | 1.1 |
| Ho | 0.686 | 0.74 | 0.862 | 0.723 | 0.735 | 0.825 |
| La | 2.4 | 2.75 | 2.97 | 3.31 | 2.61 | 2.2 |
| Lu | 0.32 | 0.338 | 0.416 | 0.331 | 0.318 | 0.583 |
| Nb | 2.3 | 2.2 | 2 | 1.9 | 2 | 1.4 |
| Nd | 5.82 | 6.45 | 6.48 | 6.71 | 6.21 | 3.98 |
| Pr | 1.103 | 1.226 | 1.245 | 1.339 | 1.148 | 0.827 |
| Rb | 1.37 | 2.94 | 2.3 | 4.07 | 0.97 | 1.16 |
| Sm | 1.91 | 2.18 | 2.15 | 2.02 | 2.02 | 1.23 |
| Sr | 102 | 87.5 | 65.4 | 101.3 | 97.6 | 112.4 |
| Ta | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Tb | 0.477 | 0.503 | 0.533 | 0.476 | 0.486 | 0.403 |
| Th | 0.24 | 0.21 | 0.26 | 0.39 | 0.23 | 0.25 |
| Tm | 0.319 | 0.33 | 0.405 | 0.331 | 0.329 | 0.483 |
| U | 0.067 | 0.059 | 0.069 | 0.102 | 0.064 | 0.06 |
| Y | 17.9 | 19.14 | 22.89 | 18.82 | 19.01 | 22.09 |
| Yb | 2.12 | 2.18 | 2.74 | 2.16 | 2.1 | 3.52 |
| Zr | 59.9 | 50.6 | 59.9 | 53.4 | 188.4 | 38.5 |
| Bi |  |  |  |  |  |  |
| Sb | 0.08 | 0.26 | 0.06 | N.D. | 0.08 | 0.1 |
| Ag |  |  |  |  |  |  |
| Be | 0.23 | 0.22 | 0.21 | 0.2 | 0.17 | 0.11 |
| Cd | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Co | 48 | 42 | 37 | 49 | 44 | 47 |
| Cu | 97 | 95 | 99 | 77 | 107 | 58 |
| Li | 13 | 68 | 12 | 19 | 14 | 16 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 119 | 104 | 107 | 93 | 77 | 84 |
| Sc | 30.7 | 30.2 | 39.4 | 34.6 | 39.2 | >50.0 |
| Sr | 88.8 | 77 | 57.5 | 91.7 | 85.9 | 98.3 |
| V | 266.6 | 254.5 | 280.9 | 247.1 | 268.1 | 246.2 |
| W | N.D. | 3 | N.D. | N.D. | 2 | N.D. |
| Zn | 44 | 55 | 64 | 69 | 58 | 67 |


| Station ID | $04 \mathrm{RJB0189}$ | $04 \mathrm{RJB0400}$ | $04 \mathrm{RJB0292}$ | 04RJB0151 | $04 \mathrm{RJB0493}$ | $04 \mathrm{RJB0495}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0189_1_1 | 04RJB0400_1_1 | 04RJB0292_1_1 | 04RJB0151 | 04RJB0493 | 04RJB0495 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Easting | 483390 | 481782 | 482607 | 476771 | 478553 | 476403 |
| Northing | 5374176 | 5374152 | 5373545 | 5370718 | 5370568 | 5371695 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | basalt | Basalt | Basalt | Basalt | Basalt | Basalt |
| Rock Type | massive | pillows | pillows | pillows | pillows | pillows |
| Rock Texture | brecciated | amygdaloidal | amygdaloidal |  | amygdaloidal | amygdaloidal |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 47.21 | 51.64 | 51.28 | 51.07 | 45.33 | 54.69 |
| TiO2 | 0.90 | 0.95 | 0.72 | 0.73 | 0.73 | 1.02 |
| Al2O3 | 14.30 | 14.83 | 14.20 | 13.99 | 12.3 | 11.67 |
| Fe2O3 | 13.81 | 12.30 | 12.17 | 9.13 | 12.05 | 8.92 |
| FeO |  |  |  |  |  |  |
| MnO | 0.216 | 0.238 | 0.167 | 0.274 | 0.278 | 0.227 |
| MgO | 8.56 | 6.73 | 8.36 | 4.96 | 5.77 | 3.35 |
| CaO | 10.26 | 6.11 | 7.99 | 13.1 | 10.39 | 10.27 |
| K2O | 0.21 | 0.21 | 0.07 | 0.07 | 0.04 | 0.12 |
| Na 2 O | 2.01 | 4.44 | 2.12 | 2.66 | 1.76 | 2.82 |
| P2O5 | 0.07 | 0.08 | 0.06 | 0.06 | 0.06 | 0.09 |
| Cr2O3 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| LOI | 2.54 | 2.48 | 3.06 | 4.3507 | 11.7685 | 6.7878 |
| Total | 100.10 | 100.03 | 100.22 | 100.41 | 100.49 | 99.97 |
| CO2 |  |  | 0.11 |  | 8.22 | 5.05 |
| S |  |  | N.D. |  | 0.08 | 0.04 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 133 | 193 | 168 | 134 | 90 | 83 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 62 | 149 | 56 | 61 | 73 | 102 |
| V | 307 | 315 | 250 | 268 | 294 | 309 |
| Y | 22 | 24 | 17 | 17 | 18 | 29 |
| Zr | 52 | 60 | 42 | 46 | 44 | 65 |
| As |  |  |  |  |  |  |
| Ba |  |  | 15.1 |  | 7.36 | 25.73 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce |  |  | 5.94 |  | 6.06 | 9.27 |
| Cs |  |  | 0.062 |  | 0.047 | 0.056 |
| Dy |  |  | 2.736 |  | 2.875 | 4.836 |
| Er |  |  | 1.917 |  | 1.969 | 3.447 |
| Eu |  |  | 0.586 |  | 0.593 | 0.83 |
| Gd |  |  | 2.177 |  | 2.205 | 3.692 |
| Hf |  |  | 1.3 |  | 1.2 | 1.9 |
| Ho |  |  | 0.612 |  | 0.636 | 1.116 |
| La |  |  | 2.23 |  | 2.26 | 3.4 |
| Lu |  |  | 0.301 |  | 0.297 | 0.533 |
| Nb |  |  | 1.6 |  | 1.6 | 2.3 |
| Nd |  |  | 4.89 |  | 5.11 | 7.72 |
| Pr |  |  | 0.968 |  | 0.974 | 1.499 |
| Rb |  |  | 0.2 |  | 0.42 | 2.3 |
| Sm |  |  | 1.6 |  | 1.62 | 2.6 |
| Sr |  |  | 105 |  | 62.8 | 62.1 |
| Ta |  |  | N.D. |  | N.D. | N.D. |
| Tb |  |  | 0.398 |  | 0.407 | 0.668 |
| Th |  |  | 0.19 |  | 0.16 | 0.3 |
| Tm |  |  | 0.291 |  | 0.295 | 0.523 |
| U |  |  | 0.052 |  | 0.054 | 0.079 |
| Y |  |  | 16.22 |  | 16.74 | 30.86 |
| Yb |  |  | 1.97 |  | 1.92 | 3.49 |
| Zr |  |  | 44.5 |  | 42.8 | 70.6 |
| Bi |  |  |  |  |  |  |
| Sb |  |  | 0.06 |  | 0.77 | N.D. |
| Ag |  |  |  |  |  |  |
| Be |  |  | 0.13 |  | 0.15 | 0.18 |
| Cd |  |  | N.D. |  | N.D. | N.D. |
| Co |  |  | 45 |  | 38 | 30 |
| Cu |  |  | 69 |  | 51 | 88 |
| Li |  |  | 10 |  | 9 | 11 |
| Mo |  |  | N.D. |  | N.D. | N.D. |
| Ni |  |  | 70 |  | 79 | 101 |
| Sc |  |  | 39.4 |  | 30.5 | 32.5 |
| Sr |  |  | 91.8 |  | 53.4 | 53.9 |
| V |  |  | 238 |  | 215.1 | 273.5 |
| W |  |  | N.D. |  | N.D. | N.D. |
| Zn |  |  | 66 |  | 66 | 50 |


| Station ID | 04RJB0501 | 04RJB0504 | 04RJB0505 | 04RJB0539 | 04RJB-TGP002 | 04RJB0146 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0501 | 04RJB0504 | 04RJB0505 | 04RJB0539 | 04RJB-TGP002 | 04RJB0146_1_1 |
| Township | Tisdale | Tisdale | Tisdale | Deloro | Tisdale | Mountjoy |
| Easting | 478151 | 477738 | 477719 | 476128 | 475920 | 474660 |
| Northing | 5370259 | 5369926 | 5370160 | 5364556 | 5369200 | 5370236 |
| Assemblage | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central | Tisdale-Central |
| Rock Unit | Basalt | Basalt | Basalt | Basalt | Basalt | Basalt |
| Rock Type | pillows | pillows | pillows | flow breccia | pillows | pillows |
| Rock Texture | amygdaloidal | amygdaloidal | variolitic |  | brecciated | variolitic |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 48.09 | 45.37 | 47.45 | 43.55 | 49.28 | 49.17 |
| TiO2 | 0.76 | 0.82 | 1.12 | 0.76 | 0.8 | 0.36 |
| Al2O3 | 12.54 | 13.55 | 11.99 | 13.79 | 13.31 | 17.45 |
| Fe2O3 | 10.3 | 13.38 | 10.5 | 16.43 | 8.92 | 9.36 |
| FeO |  |  |  |  |  |  |
| MnO | 0.242 | 0.229 | 0.302 | 0.312 | 0.188 | 0.168 |
| MgO | 5.05 | 5.12 | 3.23 | 9.07 | 4.38 | 9.17 |
| CaO | 9.8 | 8.57 | 12.2 | 6.22 | 9.97 | 9.48 |
| K2O | 0.27 | 0.31 | 1.67 | 0.06 | 0.88 | 0.03 |
| Na 2 O | 2.42 | 1.65 | 0.12 | 0.83 | 1.96 | 0.42 |
| P2O5 | 0.05 | 0.06 | 0.1 | 0.07 | 0.06 | 0.04 |
| Cr2O3 | 0.01 | 0.01 | 0 | 0.01 | 0.01 | 0.03 |
| LOI | 10.7927 | 10.6255 | 11.7012 | 8.7376 | 10.7605 | 4.34 |
| Total | 100.32 | 99.69 | 100.38 | 99.84 | 100.52 | 100.02 |
| CO2 | 7.86 | 6.92 | 8.59 | 4.7 | 7.7 | 0.11 |
| S | 0.25 | 0.01 | 0.23 | 0.84 | 0.01 | 0.02 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 92 | 92 | 11 | 101 | 109 | 276 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 72 | 83 | 35 | 75 | 82 | 161 |
| V | 290 | 329 | 413 | 349 | 331 | 147 |
| Y | 17 | 20 | 25 | 21 | 18 | 15 |
| Zr | 43 | 48 | 75 | 47 | 46 | 28 |
| As |  |  |  |  |  |  |
| Ba | 173.94 | 97.93 | 147.18 | 10.36 | 268.33 | 4.3 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 6.22 | 6.75 | 8.43 | 6.08 | 4.43 | 4.09 |
| Cs | 0.3 | 0.23 | 0.793 | 0.115 | 1.315 | 0.052 |
| Dy | 3.023 | 3.143 | 4.821 | 3.523 | 2.703 | 2.012 |
| Er | 2.113 | 2.135 | 3.31 | 2.405 | 1.811 | 1.759 |
| Eu | 0.64 | 0.553 | 1.053 | 0.575 | 0.395 | 0.341 |
| Gd | 2.402 | 2.425 | 4.013 | 2.612 | 1.966 | 1.315 |
| Hf | 1.3 | 1.3 | 2.3 | 1.4 | 1.4 | 0.8 |
| Ho | 0.671 | 0.709 | 1.072 | 0.781 | 0.597 | 0.525 |
| La | 2.29 | 2.46 | 2.82 | 2.14 | 1.53 | 1.59 |
| Lu | 0.325 | 0.345 | 0.516 | 0.392 | 0.276 | 0.339 |
| Nb | 1.6 | 1.8 | 3 | 1.8 | 1.7 | 1.1 |
| Nd | 5.24 | 5.55 | 7.81 | 5.22 | 3.8 | 2.98 |
| Pr | 1.02 | 1.057 | 1.43 | 0.98 | 0.721 | 0.618 |
| Rb | 9.83 | 8.27 | 53.81 | 1.4 | 26.56 | 0.17 |
| Sm | 1.66 | 1.78 | 2.79 | 1.73 | 1.29 | 0.95 |
| Sr | 91.8 | 67.9 | 38.6 | 34.8 | 113.9 | 145 |
| Ta | N.D. | N.D. | 0.19 | N.D. | N.D. | N.D. |
| Tb | 0.439 | 0.458 | 0.707 | 0.496 | 0.388 | 0.26 |
| Th | 0.18 | 0.2 | 0.33 | 0.23 | 0.18 | 0.15 |
| Tm | 0.315 | 0.333 | 0.495 | 0.374 | 0.277 | 0.299 |
| U | 0.055 | 0.061 | 0.084 | 0.078 | 0.05 | 0.037 |
| Y | 17.89 | 18.72 | 27.06 | 20.27 | 15.27 | 14.32 |
| Yb | 2.08 | 2.2 | 3.34 | 2.47 | 1.82 | 2.07 |
| Zr | 46 | 46.8 | 79.3 | 49.2 | 47.4 | 28.3 |
| Bi |  |  |  |  |  |  |
| Sb | 0.65 | 0.24 | 0.37 | 1.18 | 0.14 | 0.46 |
| Ag |  |  |  |  |  |  |
| Be | 0.16 | 0.14 | 0.22 | 0.15 | 0.16 | 0.12 |
| Cd | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Co | 41 | 37 | 32 | 54 | 44 | 46 |
| Cu | 107 | 45 | 162 | 167 | 103 | 28 |
| Li | 8 | 16 | 15 | 38 | 28 | 21 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 78 | 85 | 42 | 86 | 79 | 144 |
| Sc | 34.6 | 36.2 | 34.5 | 38.2 | 32.7 | 37 |
| Sr | 79.5 | 58 | 33.7 | 29.7 | 95.7 | 127.4 |
| V | 223 | 249.3 | 298.2 | 250.2 | 239.9 | 152.2 |
| W | N.D. | 5 | N.D. | 3 | N.D. | N.D. |
| Zn | 57 | 109 | 57 | 143 | 49 | 43 |
|  |  |  | 77 |  |  |  |


| Station ID | 04RJB0173 | 04RJB0181 |  |
| :--- | ---: | ---: | ---: |
| le number |  |  |  |
| $04 R J B 0173$ | 1 | 1 | $04 R J B 0181$ |

 04RJB0183_1_1 4RJB0224_1_1 14 RJB0254_1_1 4RJJB0232_1_1 4RRJB0349_1_1

| Sample number | 04RJB0173_1_1 | 04RJB0181_1_1 | 04RJB0183 | JB0224 | B0254_1_1 | RJB0232_1_1 | 4RJB0349_1_1 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Township | Tisdale | Tisdale | Tisdale | Deloro | Deloro | Mountjoy | Tisdale |
| Easting | 483225 | 476221 | 478357 | 475571 | 480391 | 475060 | 475790 |
| Northing | 5375432 | 5377965 | 5375669 | 5364882 | 5365097 | 5366824 | 5372753 |
| Assemblage | Tisdale-Central | Porcupine | Tisdale-Central | Tisdale-Central | Timiskaming | Tisdale-Central | Tisdale-Central |
| Rock Unit | Basalt | clastic sediments | Basalt | Basalt | Timiskaming | Basalt | Basalt |
| Rock Type | pillows | sandstone | pillows | pillows | conglomerate | pillows | pillows |
| Rock Texture | amygdaloidal | bedded | flattened pillows | schistose | flattened clasts | amygdaloidal | brecciated |




| Station ID | $04 \mathrm{RJB0492}$ | 04RJB0500 | 04RJB0169 | 04RJB0170 | 04RJB0255 | 04RJB0344 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0492 | 04RJB0500 | 04RJB0169_1_1 | 04RJB0170_1_1 | 04RJB0255_1_1 | 04RJB0344_1_1 |
| Township | Tisdale | Tisdale | Tisdale | Tisdale | Deloro | Tisdale |
| Easting | 480110 | 477969 | 482873 | 482809 | 480284 | 476173 |
| Northing | 5371110 | 5370787 | 5375294 | 5375214 | 5365024 | 5373379 |
| Assemblage | Tisdale-Central | Tisdale-Central | porphyry dyke | porphyry dyke | Tisdale-Hersey Lake | Tisdale-Hersey Lake |
| Rock Unit | Basalt | Basalt | porphyry dyke | porphyry dyke | ultramafic volcanic | ultramafic volcanic |
| Rock Type | massive | pillow breccia | quartz-feldspar | quartz-feldspar | basaltic komatiite | spinifex |
| Rock Texture |  | flattened pillows | porphyry | porphyry | sheared | polysutured |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| SiO2 | 49.38 | 53.45 | 38.25 | 36.90 | 32.74 | 44.76 |
| TiO2 | 1.14 | 1.02 | 0.27 | 0.40 | 0.30 | 0.35 |
| Al2O3 | 12.95 | 12.02 | 3.69 | 6.74 | 4.18 | 4.80 |
| Fe2O3 | 11.29 | 12.91 | 8.27 | 9.21 | 8.85 | 11.83 |
| FeO |  |  |  |  |  |  |
| MnO | 0.126 | 0.141 | 0.131 | 0.184 | 0.166 | 0.184 |
| MgO | 3.43 | 4.59 | 17.80 | 15.78 | 17.78 | 24.56 |
| CaO | 9.05 | 5.87 | 6.96 | 10.44 | 9.50 | 6.86 |
| K2O | 1.02 | 0.31 | 0.02 | 0.03 | 0.02 | 0.05 |
| Na 2 O | 1.54 | 1.93 | 0.01 | 0.06 | 0.03 | 0.03 |
| P2O5 | 0.1 | 0.1 | 0.02 | 0.03 | 0.03 | 0.03 |
| Cr2O3 | 0.01 | 0.01 | 0.25 | 0.32 | 0.26 | 0.32 |
| LOI | 9.9545 | 7.6919 | 23.82 | 19.73 | 26.16 | 6.37 |
| Total | 99.99 | 100.04 | 99.49 | 99.83 | 100.01 | 100.14 |
| CO2 | 7.01 | 4.68 | 20.3 | 14.6 | 22.8 | 0.22 |
| S | 0.07 | 0.07 | 0.02 | 0.02 | 0.01 | 0.01 |
|  | ActLab | ActLab | ActLab | ActLab | ActLab | ActLab |
| Cr | 76 | 82 | 2110 | 2678 | 2172 | 2142 |
| Nb | 1 | 1 | 0 | 0 | 0 | 0 |
| Ni | 46 | 49 | 1386 | 1013 | 1367 | 1672 |
| V | 369 | 308 | 116 | 185 | 131 | 139 |
| Y | 24 | 27 | 9 | 11 | 8 | 10 |
| Zr | 85 | 102 | 15 | 23 | 18 | 18 |
| As |  |  |  |  |  |  |
| Ba | 168.44 | 91.13 | 3.36 | 5.09 | 1.73 | 9.1 |
| Ga |  |  |  |  |  |  |
| Pb |  |  |  |  |  |  |
| Rb |  |  |  |  |  |  |
| Sn |  |  |  |  |  |  |
| Sr |  |  |  |  |  |  |
| Ta |  |  |  |  |  |  |
| Th |  |  |  |  |  |  |
| Ce | 12.3 | 14.74 | 1.76 | 2.65 | 1.97 | 1.7 |
| Cs | 0.924 | 0.354 | 0.062 | 0.048 | 0.048 | 0.839 |
| Dy | 4.463 | 5.327 | 1.139 | 1.502 | 1.056 | 1.203 |
| Er | 3.018 | 3.531 | 0.69 | 0.943 | 0.635 | 0.717 |
| Eu | 0.957 | 1.11 | 0.148 | 0.512 | 0.225 | 0.181 |
| Gd | 3.867 | 4.626 | 0.979 | 1.251 | 0.905 | 1.071 |
| Hf | 2.6 | 3.1 | 0.5 | 0.7 | 0.5 | 0.7 |
| Ho | 0.988 | 1.143 | 0.239 | 0.311 | 0.214 | 0.252 |
| La | 4.43 | 5.36 | 0.58 | 0.97 | 0.69 | 0.57 |
| Lu | 0.478 | 0.546 | 0.088 | 0.132 | 0.082 | 0.091 |
| Nb | 3.6 | 4.2 | 0.4 | 0.6 | 0.6 | 0.5 |
| Nd | 9.8 | 11.43 | 1.76 | 2.36 | 1.81 | 1.82 |
| Pr | 1.9 | 2.243 | 0.31 | 0.439 | 0.339 | 0.33 |
| Rb | 26.84 | 8.3 | 0.33 | 0.23 | 0.17 | 2.04 |
| Sm | 3.06 | 3.53 | 0.68 | 0.86 | 0.62 | 0.72 |
| Sr | 76.1 | 85.6 | 28 | 28.6 | 94.7 | 8.8 |
| Ta | 0.21 | 0.25 | N.D. | N.D. | N.D. | N.D. |
| Tb | 0.68 | 0.804 | 0.174 | 0.231 | 0.158 | 0.188 |
| Th | 0.44 | 0.54 | N.D. | N.D. | N.D. | N.D. |
| Tm | 0.457 | 0.53 | 0.096 | 0.134 | 0.09 | 0.101 |
| U | 0.113 | 0.139 | 0.031 | 0.019 | 0.018 | 0.018 |
| Y | 25.19 | 29.16 | 6.2 | 8.36 | 5.83 | 6.35 |
| Yb | 3.11 | 3.56 | 0.59 | 0.86 | 0.58 | 0.62 |
| Zr | 93.6 | 108.2 | 17.1 | 23.6 | 16.2 | 22.1 |
| Bi |  |  |  |  |  |  |
| Sb | 0.38 | 0.45 | 0.09 | 0.07 | 0.5 | 0.25 |
| Ag |  |  |  |  |  |  |
| Be | 0.31 | 0.2 | N.D. | N.D. | N.D. | N.D. |
| Cd Co | N.D. 34 | N.D. 37 | N.D. 75 | N.D. 80 | N.D. 71 | N.D. 99 |
| Cu | 41 | 73 | 59 | 125 | 12 | 7 |
| Li | 23 | 7 | 25 | 8 | 26 | 2 |
| Mo | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Ni | 54 | 60 | 1031 | 769 | 962 | 1418 |
| Sc | 32.5 | 29.1 | 13.3 | 22.1 | 13.7 | 17.1 |
| Sr | 64.8 | 77.6 | 24.6 | 24.9 | 82.2 | 7.7 |
| V | 266.6 | 220.7 | 75.1 | 129.9 | 81.3 | 112.8 |
| W | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Zn | 65 | 73 | 26 | 44 | 42 | 58 |
|  |  |  | 80 |  |  |  |


| Station ID | 04RJB0351 | 04RJB0405 04RJB0194 | 04RJB-TW04-010 | 04RJB-TW04-011 |
| :---: | :---: | :---: | :---: | :---: |
| Sample number | 04RJB0351_1_1 | 04RJB0405_1_1 04RJB0194 | 04RJB-TW04-010 | 04RJB-TW04-011 |
| Township | Tisdale | Tisdale Tisdale | Ogden | Ogden |
| Easting | 475498 | 481488481765 | 475092 | 472548 |
| Northing | 5372319 | 53745145373171 | 5362959 | 5362701 |
| Assemblage Rock Unit Rock Type Rock Texture | Tisdale-Hersey Lake T | Tisdale-Hersey Lake Porcupine | Krist | Tisdale-intermediate |
|  | ultramafic volcanic | ultramafic volcanic Clastic Sediments | Felsic Volcanic | Intermediate Volcanic |
|  | spinifex | basaltic komatiite graphitic phyllite | lapilli tuff | pyroclastic breccia |
|  | polysutured | cumulate laminated | flattened clasts | porphyritic |
|  | ActLab | ActLab ActLab | ActLab | ActLab |
| SiO2 | 37.68 | 40.61 51.66 | 67.2 | 52.34 |
| TiO2 | 0.38 | 0.35 0.78 | 0.34 | 1.81 |
| Al2O3 | 5.16 | 4.78 15.02 | 16.51 | 14.11 |
| Fe2O3 | 10.73 | 11.90 7.48 | 2.57 | 10.45 |
| FeO $0.10{ }^{\text {a }}$ |  |  |  |  |
| MnO | 0.196 | 0.1820 .164 | 0.031 | 0.118 |
| MgO | 23.12 | 29.14 | 1.91 | 5.62 |
| CaO | 11.16 | 3.35 8.91 | 1.47 | 5.99 |
| K2O | 0.04 | 0.04 0.91 | 1.74 | 0.23 |
| Na 2 O | 0.06 | 0.04 2.11 | 5.25 | 3.14 |
| P2O5 | 0.03 | 0.03 0.06 | 0.12 | 0.14 |
| Cr2O3 | 0.32 | 0.33 0.02 | 0 | 0.02 |
| LOI | 11.18 | 9.498 .0427 | 2.7507 | 5.8684 |
| Total | 100.06 | 100.24 | 99.89 | 99.84 |
| CO2 | 4.63 |  | 1.17 | 2.64 |
| S | 0.01 |  | N.D. | 0.01 |
|  | ActLab | ActLab ActLab | ActLab | ActLab |
| Cr | 2223 | 2037128 | 30 | 187 |
| Nb | 0 | 00 | 2 | 8 |
| Ni | 1457 | 1815 57 | 46 | 135 |
| V | 132 | 119226 | 32 | 178 |
| Y | 9 | 96 | 8 | 19 |
| Zr | 18 | $20 \quad 42$ | 122 | 113 |
| As |  |  |  |  |
| $\begin{array}{lll}\text { Ba } & 7.72 & 412.05\end{array}$ |  |  |  |  |
|  |  |  |  |  |
| GaPb |  |  |  |  |
| Rb |  |  |  |  |
| Sn |  |  |  |  |
| Sr |  |  |  |  |
| Ta |  |  |  |  |
| Th |  |  |  |  |
| Ce | 1.86 |  | 43.69 | 20.44 |
| Cs | 0.507 |  | 0.807 | 0.309 |
| Dy | 1.092 |  | 0.996 | 3.66 |
| Er | 0.712 |  | 0.449 | 1.773 |
| Eu | 0.198 |  | 0.803 | 1.472 |
| Gd | 0.865 |  | 1.863 | 4.387 |
| Hf | 0.6 |  | 3.4 | 3.3 |
| Ho | 0.241 |  | 0.166 | 0.666 |
| La | 0.66 |  | 21.11 | 7.97 |
| Lu | 0.102 |  | 0.05 | 0.205 |
| Nb | 0.7 |  | 2.8 | 7.9 |
| Nd | 1.72 |  | 19.22 | 15.98 |
| Pr | 0.313 |  | 5.129 | 3.169 |
| Rb | 1.95 |  | 47.14 | 5.41 |
| Sm | 0.63 |  | 3.03 | 4.28 |
| Sr | 86.1 |  | 251.8 | 278.7 |
| Ta | N.D. |  | N.D. | 0.46 |
| Tb | 0.16 |  | 0.205 | 0.652 |
| Th | N.D. |  | 3.41 | 0.79 |
| Tm | 0.102 |  | 0.058 | 0.235 |
| U | 0.018 |  | 1.014 | 0.237 |
| Y | 5.94 |  | 4.73 | 17.24 |
| Yb | 0.65 |  | 0.37 | 1.44 |
| Zr | 19.5 |  | 129.9 | 122.3 |
| Bi |  |  |  |  |
| Sb | 0.22 |  | 0.66 | 0.33 |
| Ag 0.22 0.33 |  |  |  |  |
| Be | N.D. |  | 0.68 | N.D. 0.53 |
| Cd | N.D. |  | N.D. |  |
| Co | 90 |  | 9 | 34 |
| Cu | 34 |  | 13 | 37 |
| Li | 1 |  | 34 | 39 |
| Mo | N.D. |  | N.D. | N.D. |
| Ni | 1218 |  | 48 | 126 |
| Sc | 16.2 |  | 2.7 | 13.4 |
| Sr | 75.5 |  | 226 | 231.8 |
| V | 102.3 |  | 28.4 | 126.6 |
| W | N.D. |  | 6 | N.D. |
| Zn | 56 |  | 41 | 96 |



Station ID 03-0273-0001 03-0273-0002 03-0273-0003 03-0273-0004 03-0273-0005 Sample number 03RJB10894-2 03RJB10894-3 03RJB10894-6 03RJB18968-2 03RJB18968-4

03-0273-0006 03RJB18967-3 Whitney
492548 5,373,764 Deloro
komatiite massive talc chlorite schist talc chlomatiite massive talc chlorite schist talc chlorite schist
Rock Texture fine grained fine grained fine grained fine grained fine grained fine grained fine grained


| Station ID | 03-0273-0008 | 03-0273-0009 | 03-0273-0010 | 03-0273-0011 | 03-0273-0012 | 03-0273-0013 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 03RJB10889-5 | 03RJB10893-1 | 03RJB10893-3 | 03RJB10893-4 | 03RJB18969-1 | 03RJB18969-7 |
| Township | Hoyle | Hoyle | Hoyle | Hoyle | Whitney | Whitney |
| Easting | 489956 | 489936 | 489936 | 489936 | 494334 | 494334 |
| Northing | 5,377,798 | 5,377,739 | 5,377,739 | 5,377,739 | 5,372,956 | 5,372,956 |
| Assemblage | Tisdale | Tisdale | Tisdale | Tisdale | Deloro | Deloro |
| Rock Unit | komatiite | komatiite | komatiite | komatiite | komatiite | komatiite |
| Rock Type talc chlorite schist talc chlorite schist talc chlorite schist talc chlorite schist talc chlorite schist talc chlorite schist Rock Texture fine grained fine grained fine grained fine grained fine grained fine grained |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL |
| SiO2 | 40.38 | 42.69 | 46.04 | 50.53 | 44.39 | 39.17 |
| TiO2 | 0.28 | 0.56 | 0.43 | 0.4 | 0.27 | 0.4 |
| Al2O3 | 5.92 | 12.4 | 16.51 | 17 | 6.31 | 9.03 |
| Fe2O3 | 11.19 | 9.52 | 10.06 | 9.2 | 11.15 | 11.74 |
| FeO | 9.18 | 7.72 | 8.5 | 6.43 | 8.99 | 9.59 |
| MnO | 0.17 | 0.19 | 0.24 | 0.18 | 0.18 | 0.12 |
| MgO | 21.74 | 5.53 | 7.45 | 7.84 | 22.3 | 25.84 |
| CaO | 8.48 | 12.62 | 6.77 | 7.82 | 8.26 | 2.75 |
| K2O | 0.00 | 0.05 | 1.51 | 0.03 | 0.00 | 0.13 |
| Na 2 O | 0.1 | 3.63 | 2.14 | 3.15 | 0.14 | 0.05 |
| P205 | 0.02 | 0.03 | 0.04 | 0.04 | 0.02 | 0.01 |
| Cr2O3 |  |  |  |  |  |  |
| LOI | 11.6 | 13.28 | 9.59 | 4.53 | 6.15 | 9.64 |
| Total | 99.88 | 100.50 | 100.78 | 100.72 | 99.17 | 98.88 |
| CO2 | 6.39 | 10.8 | 5.33 | 1.32 | 1.4 | 2.06 |
| S | 0 | 0.15 | 0.03 | 0.09 | 0.01 | 0 |
|  | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM |
| Cr | 2550 | 60 | 174 | 199 | 2698 | 3348 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni |  |  |  |  |  |  |
| V |  |  |  |  |  |  |
| Y | 7 | 15 | 15 | 14 | 7 | 2 |
| Zr | 15 | 34 | 30 | 28 | 16 | 19 |
| As | 6 | 17 | 22 | 0 |  | 0 |
| Ba | 0 | 86 | 784 | 0 | 0 | 0 |
| Ga | 8 | 13 | 12 | 11 | 8 | 13 |
| Pb | 0 | 7 | 0 | 0 | 0 | 0 |
| Rb | 0 | 0 | 37 | 0 | 0 | 12 |
| Sn | 0 | 0 | 0 | 0 | 0 | 0 |
| Sr | 35 | 144 | 80 | 83 | 27 | 65 |
| Ta | 0 | 0 | 0 | 0 | 0 | 0 |
| Th | 0 | 0 | 0 | 0 | 0 | 0 |
| Ce | 2.06 | 4.37 | 3.93 | 4.52 | 1.73 | 0.96 |
| Cs | 0.2 | 0.07 | 1.17 | 0.11 | 0.14 | 4.28 |
| Dy | 1.46 | 2.72 | 2.49 | 2.21 | 1.39 | 0.51 |
| Er | 0.87 | 1.91 | 2.12 | 1.88 | 0.86 | 0.34 |
| Eu | 0.24 | 0.52 | 0.33 | 0.41 | 0.15 | 0.08 |
| Gd | 1.14 | 2.27 | 1.57 | 1.5 | 1.04 | 0.41 |
| Hf | 0.5 | 1.1 | 0.9 | 0.9 | 0.5 | 0.6 |
| Ho | 0.31 | 0.62 | 0.66 | 0.55 | 0.29 | 0.11 |
| La | 0.75 | 1.6 | 1.49 | 1.71 | 0.91 | 0.43 |
| Lu | 0.12 | 0.31 | 0.4 | 0.37 | 0.12 | 0.05 |
| Nb | 0.5 | 1.2 | 1.3 | 1.3 | 0.4 | 0.8 |
| Nd | 2.09 | 4.01 | 3.24 | 3.23 | 1.47 | 0.75 |
| Pr | 0.36 | 0.73 | 0.6 | 0.7 | 0.28 | 0.16 |
| Rb | 0.08 | 0.83 | 36.93 | 0.49 | 0.16 | 11.46 |
| Sm | 0.78 | 1.37 | 1.07 | 1.11 | 0.67 | 0.27 |
| $\begin{array}{llllll}\text { Sr } & 36.8 & 150.8 & 88 & 90.6 & 26.1\end{array}$ |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Tb | 0.21 | 0.4 | 0.32 | 0.29 | 0.21 | 0.07 |
| Th |  | 0.14 | 0.13 | 0.15 |  | 0.08 |
| Tm | 0.12 | 0.3 | 0.36 | 0.32 | 0.12 | 0.05 |
| U | 0.02 | 0.04 | 0.04 | 0.04 | 0.03 | 0.05 |
| Y | 7.49 | 16.62 | 16.68 | 15.82 | 7.05 | 2.73 |
| Yb | 0.87 | 1.98 | 2.49 | 2.19 | 0.78 | 0.36 |
| Zr | 16.8 | N.D. $\begin{aligned} & 36.4 \\ & 1.79\end{aligned}$ | N.D. $\begin{aligned} & 32.6 \\ & 0.51\end{aligned}$ | N.D. $\begin{aligned} & 30.7\end{aligned}$ | 15.9 | N.D. ${ }^{19.5}$ |
| Bi | N.D. 0.15 |  |  |  | 0.11 |  |
| Sb | 0.15 |  |  |  | 0.11 | 0.19 |
| Ag | 4 | 4 | 4 | 3 | 3 | 3 |
| Be Cd | 0.13 | 0.48 | 1.02 | 0.17 | 0.34 | 0.19 |
| Cd |  |  |  |  |  |  |
| Co | 89 | 38 | 48 | 45 | 92 | 103 |
| Cu | 62 | 72 | 49 | 61 | 0 | 0 |
| Li |  |  |  |  |  |  |
| MoNi | 0 | 0 | 0 | 0 | 0 | 0 |
|  | 893 | 57 | 131 | 106 | 951 | 1080 |
| ScSr | 17.3 | 33.3 | 37.1 | 36.2 | 22.4 | 25.8 |
|  | 35 | 141.8 | 79.6 | 80.7 | 26.8 | 64.5 |
| V | 116.2 | 224.6 | 171.9 | 171.8 | 122.1 | 140.7 |
| WZn | 2 | 3 | 5 | 0 | 0 | 0 |
|  | 79 | 83 | 80 | 69 | 93 | 85 |



| Station ID | 03-0273-0020 | 03-0273-0021 | 03-0273-0022 | 03-0273-0023 | 03-0273-0024 | 03-0273-0025 | 03-0273-0029 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 03RJB5422-1 | 03RJB5282-1 | 03RJB5282-2 | 03RJB5282-3 | 03RJB6025-3 | 03RJB6025-6 | 03RJB5698-1 |
| Township | Hoyle | Hoyle | Hoyle | Hoyle | Hoyle | Hoyle | Hoyle |
| Easting | 490323 | 490831 | 490831 | 490831 | 492912 | 492913 | 491437 |
| Northing | 5,377,762 | 5,377,807 | 5,377,807 | 5,377,807 | 5,377,540 | 5,377,540 | 5,377,394 |
| Assemblage | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Rock Unit | komatiite | komatiite | komatiite | komatiite | Basalt | Basalt | komatiite |
| Rock Type | chlorite schist | c chlorite schist | lc chlorite schist | c chlorite schist | pillow breccia | pillow breccia | chlorite schist |
| Rock Texture | fine grained | fine grained | fine grained | fine grained | fine grained | fine grained | fine grained |
|  | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL |
| SiO2 | 39.92 | 42.48 | 36.13 | 38.45 | 42.14 | 46.71 | 42.31 |
| TiO2 | 0.44 | 0.33 | 0.31 | 0.43 | 0.49 | 0.42 | 0.24 |
| Al2O3 | 7.03 | 7.29 | 6.48 | 7.86 | 17.01 | 17.74 | 5.45 |
| Fe2O3 | 12.81 | 11.15 | 9.84 | 12.66 | 9.4 | 9.32 | 10.43 |
| FeO | 10.21 | 8.3 | 8.11 | 10.29 | 7.89 | 7.65 | 8.62 |
| MnO | 0.16 | 0.17 | 0.19 | 0.15 | 0.2 | 0.23 | 0.12 |
| MgO | 20.76 | 23.07 | 20.32 | 21.87 | 7.27 | 6.89 | 23.13 |
| CaO | 6.48 | 8.54 | 8.51 | 6.31 | 7.01 | 7.29 | 4.93 |
| K2O | 0.00 | 0.00 | 0.00 | 0.00 | 0.27 | 0.37 | 0.00 |
| Na 2 O | 0.48 | 0.03 | 0.68 | 0.24 | 3.64 | 1.48 | 0.05 |
| P2O5 | 0.03 | 0.02 | 0.01 | 0.02 | 0.05 | 0.04 | 0.02 |
| Cr 2 O 3 |  |  |  |  |  |  |  |
| LOI | 10.92 | 5.9 | 16.51 | 10.34 | 12.47 | 10.41 | 12.28 |
| Total | 99.03 | 98.98 | 98.98 | 98.33 | 99.95 | 100.90 | 98.96 |
| CO2 | 5.3 | 11.3 | 12.1 | 4.63 | 10.2 | 5.87 | 7.25 |
| S | 0.01 | 0.03 | 0.05 | 0.27 | 0.65 | 0.09 | 0 |
|  | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM |
| Cr | 3103 | 2670 | 2971 | 4500 | 206 | 180 | 2374 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni |  |  |  |  |  |  |  |
| V |  |  |  |  |  |  |  |
| Y | 8 | 5 | 6 | 8 | 18 | 14 | 4 |
| Zr | 20 | 14 | 15 | 21 | 34 | 30 | 10 |
| As | 4 | 13 | 7 | 2 | 94 | 23 | 3 |
| Ba | 0 | 0 | 0 | 0 | 35 | 53 | 0 |
| Ga | 10 | 8 | 7 | 11 | 12 | 10 | 8 |
| Pb | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rb | 0 | 0 | 0 | 0 | 7 | 8 | 0 |
| Sn | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sr | 29 | 36 | 38 | 37 | 85 | 61 | 34 |
| Ta | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Th | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ce | 2.42 | 1.48 | 1.56 | 2.37 | 5.66 | 3.79 | 0.75 |
| Cs | 0.69 | 0.12 | 0.35 | 0.66 | 0.27 | 0.24 | 0.16 |
| Dy | 1.7 | 1.22 | 1.18 | 1.74 | 2.68 | 2.25 | 0.83 |
| Er | 0.97 | 0.79 | 0.83 | 1.07 | 2.26 | 1.88 | 0.6 |
| Eu | 0.14 | 0.21 | 0.17 | 0.42 | 0.41 | 0.34 | 0.11 |
| Gd | 1.32 | 0.93 | 0.92 | 1.41 | 1.81 | 1.36 | 0.71 |
| Hf | 0.7 | 0.5 | 0.5 | 0.7 | 1 | 0.9 | 0.3 |
| Ho | 0.35 | 0.26 | 0.27 | 0.37 | 0.7 | 0.56 | 0.2 |
| La | 0.83 | 0.54 | 0.6 | 0.75 | 2.3 | 1.38 | 0.24 |
| Lu | 0.13 | 0.12 | 0.12 | 0.15 | 0.41 | 0.38 | 0.08 |
| Nb | 0.8 | 0.4 | 0.4 | 0.9 | 1.5 | 1.3 | 0.4 |
| Nd | 2.22 | 1.38 | 1.43 | 2.43 | 4.37 | 2.97 | 0.82 |
| Pr | 0.41 | 0.25 | 0.27 | 0.43 | 0.89 | 0.59 | 0.15 |
| Rb | 0.19 | 0.09 | 0.07 | 0.14 | 7.16 | 7.69 | 0.17 |
| Sm | 0.79 | 0.55 | 0.59 | 0.98 | 1.33 | 0.96 | 0.42 |
| Sr | 29.6 | 38 | 38 | 39.2 | 89 | 62.8 | 34 |
| Ta |  |  |  |  |  |  |  |
| Tb | 0.24 | 0.17 | 0.16 | 0.26 | 0.36 | 0.3 | 0.13 |
| Th | 0.06 |  |  | 0.09 | 0.21 | 0.11 |  |
| Tm | 0.14 | 0.12 | 0.11 | 0.16 | 0.38 | 0.34 | 0.08 |
| U | 0.02 | 0.01 | 0.01 | 0.02 | 0.06 | 0.04 | 0.01 |
| Y | 9.28 | 6.51 | 6.63 | 8.93 | 18.53 | 14.9 | 4.92 |
| Yb | 0.87 | 0.8 | 0.77 | 1.04 | 2.53 | 2.28 | 0.56 |
| Zr | 22.3 | 17 | 15.9 | 25.3 | 37.3 | 31.9 | 11.2 |
| Bi | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Sb | 0.19 | 0.11 | 0.14 | 0.19 | 0.34 | 0.16 | 0.24 |
| Ag |  | 2 | 3 | 3 | 3 | 3 | 3 |
| Be | 0.19 | 0.13 | 0.11 | 0.15 | 0.34 | 0.18 | 0.1 |
| Cd |  |  |  |  |  |  |  |
| Co | 105 | 82 | 93 | 124 | 47 | 45 | 79 |
| Cu | 71 | 41 | 57 | 84 | 42 | 51 | 16 |
| Li |  |  |  |  |  |  |  |
| Mo | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 1087 | 968 | 1046 | 1531 | 137 | 133 | 880 |
| Sc | 23.9 | 18.6 | 20.1 | 25.4 | 37.4 | 35.9 | 13.4 |
| Sr | 30 | 36.9 | 38.4 | 40 | 80 | 61.7 | 31.4 |
| V | 148.5 | 109.6 | 121.7 | 136.2 | 180.9 | 178.7 | 95.6 |
| W | 0 | 0 | 0 | 0 | 24 | 0 | 0 |
| Zn | 92 | 73 | 70 | 85 | 84 | 77 | 81 |


| Station ID | 03-0273-0030 | 03-0273-0034 | 03-0273-0035 | 03-0273-0036 | 03-0273-0037 | 03-0273-0038 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 03RJB5698-2 | 03RJB18973-12 | 03RJB18973-17 | 03RJB18973-21 | 03RJB18974-3 | 03RJB18974-8 |
| Township | Hoyle | Whitney | Whitney | Whitney | Whitney | Whitney |
| Easting | 491437 | 492148 | 492148 | 492148 | 491388 | 491388 |
| Northing | 5,377,394 | 5,375,256 | 5,375,256 | 5,375,256 | 5,374,844 | 5,374,844 |
| Assemblage | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale |
| Rock Unit | komatiite | Basalt | Basalt | Basalt | komatiite | komatiite |
| Rock Type | chlorite schist | Basaltic komatiite | Basaltic komatiite | Basaltic komatiite | chlorite schist | chlorite schist |
| Rock Texture | fine grained | spinifex | spinifex | spinifex | fine grained | fine grained |
|  | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL |
| SiO2 | 37.08 | 29.78 | 42.52 | 42.11 | 33.43 | 38.82 |
| TiO2 | 0.42 | 0.3 | 0.62 | 0.32 | 0.29 | 0.58 |
| Al2O3 | 7.36 | 5.29 | 8.8 | 13.86 | 4.96 | 7.97 |
| Fe2O3 | 11.93 | 9 | 15.03 | 8.86 | 8.98 | 10.39 |
| FeO | 9.9 | 7.37 | 11.81 | 7.02 | 7.44 | 8.41 |
| MnO | 0.14 | 0.18 | 0.34 | 0.16 | 0.17 | 0.19 |
| MgO | 20.67 | 14.84 | 11.13 | 8.16 | 16.98 | 13.71 |
| CaO | 6.31 | 14.31 | 12.21 | 11.78 | 9.91 | 7.64 |
| K2O | 0.00 | 0.00 | 0.13 | 0.68 | 0.00 | 0.00 |
| Na 2 O | 0.07 | 0.05 | 0.41 | 1.55 | 0.02 | 1.16 |
| P2O5 | 0.02 | 0.02 | 0.04 | 0.03 | 0.02 | 0.04 |
| Cr2O3 |  |  |  |  |  |  |
| LOI | 14.45 | 24.42 | 7.88 | 12.46 | 23.98 | 18.39 |
| Total | 98.45 | 98.19 | 99.11 | 99.97 | 98.74 | 98.89 |
| CO2 | 9.25 | 21.4 | 4.68 | 9 | 20.8 | 15.4 |
| S | 0.02 | 0.21 | 0.09 | 0.42 | 0.03 | 0.07 |
|  | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM |
| Cr | 3189 | 2770 | 2624 | 666 | 2537 | 1989 |
| Nb | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni |  |  |  |  |  |  |
| V |  |  |  |  |  |  |
| Y | 7 | 5 | 13 | 11 | 6 | 14 |
| Zr | 18 | 16 | 31 | 21 | 13 | 31 |
| As | 4 | 78 | 4 | 18 | 216 | 318 |
| Ba | 0 | 0 | 58 | 154 | 0 | 0 |
| Ga | 9 | 7 | 12 | 8 | 6 | 10 |
| Pb | 0 | 0 | 0 | 0 | 0 | 0 |
| Rb | 0 | 0 | 3 | 13 | 0 | 0 |
| Sn | 0 | 0 | 0 | 0 | 0 | 0 |
| Sr | 36 | 91 | 33 | 37 | 51 | 34 |
| Ta | 0 | 0 | 0 | 0 | 0 | 0 |
| Th | 0 | 0 | 0 | 0 | 0 | 0 |
| Ce | 2.23 | 2.31 | 4.08 | 2.99 | 2.35 | 4.84 |
| Cs | 0.205 | 0.073 | 0.25 | 0.146 | 0.072 | 0.052 |
| Dy | 1.419 | 1.123 | 2.348 | 1.655 | 1.541 | 2.488 |
| Er | 0.901 | 0.725 | 1.521 | 1.403 | 0.974 | 1.732 |
| Eu | 0.203 | 0.259 | 0.46 | 0.226 | 0.322 | 0.449 |
| Gd | 1.143 | 0.925 | 1.96 | 1.056 | 1.247 | 1.918 |
| Hf | 0.6 | 0.5 | 0.9 | 0.6 | 0.5 | 1 |
| Ho | 0.308 | 0.239 | 0.516 | 0.412 | 0.33 | 0.557 |
| La | 0.75 | 0.86 | 1.39 | 1.18 | 0.82 | 1.71 |
| Lu | 0.117 | 0.1 | 0.223 | 0.27 | 0.12 | 0.261 |
| Nb | 0.6 | 0.7 | 1.3 | 0.9 | 0.5 | 1.2 |
| Nd | 2.2 | 2.07 | 3.98 | 2.32 | 2.22 | 4.16 |
| Pr | 0.395 | 0.391 | 0.72 | 0.473 | 0.421 | 0.793 |
| Rb | 0.33 | 0.28 | 2.99 | 15.09 | 0.39 | 0.24 |
| Sm | 0.78 | 0.67 | 1.42 | 0.72 | 0.8 | 1.42 |
| Sr | 38.6 | 100.3 | 35.2 | 40.4 | 57.3 | 38.4 |
| Ta |  |  | 0.19 |  |  | 0.18 |
| Tb | 0.209 | 0.164 | 0.354 | 0.213 | 0.229 | 0.362 |
| Th |  | 0.07 | 0.1 | 0.1 |  | 0.12 |
| Tm | 0.125 | 0.103 | 0.221 | 0.227 | 0.129 | 0.258 |
| U | 0.014 | 0.021 | 0.029 | 0.027 | 0.013 | 0.032 |
| Y | 8.26 | 6.58 | 13.18 | 11.7 | 9.2 | 15.2 |
| Yb | 0.81 | 0.67 | 1.44 | 1.63 | 0.83 | 1.72 |
| Zr | 21.5 | 17.8 | 30.7 | 23.1 | 16.4 | 34.8 |
| Bi | N.D. | 0.06 | N.D. | N.D. | 0.07 | N.D. |
| Sb | 0.2 | 0.2 | 0.5 | 0.15 | 1.09 | 1.65 |
| Ag | 2 | 3 | 3 | 3 | 2 | 0 |
| Be | 0.14 | 0.15 | 0.34 | 0.17 | 0.19 | 0.24 |
| Cd |  |  |  |  |  |  |
| Co | 93 | 90 | 105 | 58 | 74 | 73 |
| Cu | 96 | 55 | 89 | 74 | 44 | 80 |
| Li |  |  |  |  |  |  |
| Mo | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 971 | 1007 | 611 | 376 | 887 | 726 |
| Sc | 22.1 | 17.5 | 32.1 | 29.5 | 16.4 | 25 |
| Sr | 34.7 | 92.5 | 33.1 | 37.4 | 52.1 | 34 |
| V | 144 | 107.9 | 203.2 | 140.6 | 103.5 | 189 |
| W | 0 | 0 | 0 | 0 | 0 | 0 |
| Zn | 84 | 72 | 113 | 69 | 62 | 82 |


| Station ID | 03-0273-0039 | 03-0273-0040 | 03-0273-0041 | 03-0273-0046 | 03-0273-0047 03-0273-0048 03-0273-0049 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sample number | 03RJB18974-11 | 03RJB18974-13 | 03RJB18974-17 | 03RJB18966-15 |  |  |  |
| Township | Whitney | Whitney | Whitney | Whitney | Whitney | Whitney | Whitney |
| Easting | 491388 | 491388 | 491388 | 492270 | 492270 | 493028 | 493028 |
| Northing | 5,374,844 | 5,374,844 | 5,374,844 | 5,374,290 | 5,374,290 | 5,372,884 | 5,372,884 |
| Assemblage | Tisdale | Tisdale | Tisdale | Tisdale | Tisdale | Deloro | Deloro |
| Rock Unit | Basalt | Basalt | komatiite | komatiite | komatiite | Basalt | Basalt |
| Rock Type | Basaltic komatiite | Basaltic komatiite | talc chlorite schist | talc chlorite schist | talc chlorite schist | massive | massive |
| Rock Texture | brecciated | brecciated | fine grained | fine grained | fine grained | fine grained | fine grained |
|  | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL | OGS-GL |
| SiO2 | 49.62 | 38.99 | 36.97 | 43.99 | 41.62 | 51.36 | 49.66 |
| TiO2 | 1.26 | 0.29 | 0.38 | 0.3 | 0.22 | 0.85 | 0.86 |
| Al2O3 | 13.91 | 13.12 | 5.47 | 6.27 | 6.02 | 14.75 | 15.06 |
| Fe2O3 | 9.83 | 8.56 | 10.23 | 10.28 | 9.97 | 11.73 | 13.08 |
| FeO | 7.89 | 7.06 | 8.98 | 8.28 | 6.22 | 8.53 | 8.79 |
| MnO | 0.2 | 0.16 | 0.14 | 0.15 | 0.16 | 0.27 | 0.18 |
| MgO | 4.67 | 8.35 | 23.1 | 24.64 | 25.11 | 6.8 | 7.36 |
| CaO | 6.27 | 10.27 | 6.24 | 6.09 | 7.99 | 9.57 | 10.26 |
| K2O | 0.13 | 0.4 | 0.00 | 0.52 | 0.07 | 0.09 | 0.21 |
| Na 2 O | 5.2 | 4.46 | 0.02 | 0.41 | 0.44 | 2.5 | 1.97 |
| P205 | 0.09 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 0.06 |
| Cr2O3 |  |  |  |  |  |  |  |
| LOI | 9.55 | 15.07 | 16.77 | 6.47 | 7.96 | 3.32 | 2.44 |
| Total | 100.73 | 99.69 | 99.34 | 99.13 | 99.57 | 101.31 | 101.14 |
| CO2 | 8.05 | 13.5 | 12.8 | 0.56 | 1.84 | 0.94 | 0.09 |
| S | 0.13 | 0.54 | 0.07 | 0.2 | 0.05 | 0.01 | 0.17 |
|  | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM | GL-MNDM |
| Cr | 118 | 646 | 3088 | 2944 | 2840 | 106 | 95 |
| Nb | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni |  |  |  |  |  |  |  |
| V |  |  |  |  |  |  |  |
| Y | 32 | 10 | 6 | 5 | 8 | 19 | 19 |
| Zr | 75 | 19 | 16 | 15 | 15 | 46 | 48 |
| As | 28 | 89 | 43 | 3 | 0 | 0 | 0 |
| Ba | 57 | 89 | 0 | 0 | 0 | 35 | 62 |
| Ga | 17 | 9 | 8 | 7 | 7 | 14 | 16 |
| Pb | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rb | 0 | 6 | 0 | 28 | 3 | 2 | 4 |
| Sn | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sr | 51 | 74 | 40 | 58 | 92 | 72 | 117 |
| Ta | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Th | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ce | 10.95 | 2.44 | 2.41 | 2.73 | 1.59 | 6.79 | 6.71 |
| Cs | 0.055 | 0.119 | 0.186 | 3.564 | 1.058 | 0.037 | 0.126 |
| Dy | 5.182 | 1.517 | 1.089 | 0.938 | 1.353 | 3.413 | 3.434 |
| Er | 3.713 | 1.318 | 0.669 | 0.565 | 0.919 | 2.39 | 2.393 |
| Eu | 0.948 | 0.203 | 0.251 | 0.233 | 0.236 | 0.713 | 0.723 |
| Gd | 4.014 | 0.968 | 0.952 | 0.797 | 1.04 | 2.738 | 2.722 |
| Hf | 2.2 | 0.6 | 0.5 | 0.4 | 0.5 | 1.4 | 1.5 |
| Ho | 1.188 | 0.378 | 0.228 | 0.193 | 0.305 | 0.778 | 0.776 |
| La | 4.02 | 0.94 | 0.86 | 1.16 | 0.59 | 2.44 | 2.42 |
| Lu | 0.572 | 0.245 | 0.089 | 0.082 | 0.143 | 0.364 | 0.388 |
| Nb | 2.9 | 0.8 | 0.6 | 0.7 | 0.4 | 1.7 | 1.9 |
| Nd | 8.94 | 1.96 | >100.00 | 1.88 | 1.54 | 5.87 | 5.81 |
| Pr | 1.712 | 0.387 | 0.412 | 0.398 | 0.281 | 1.096 | 1.099 |
| Rb | 2 | 6.8 | 0.24 | 27.65 | 2.78 | 2.05 | 4.62 |
| Sm | 2.9 | 0.66 | 0.73 | 0.6 | 0.64 | 1.96 | 1.96 |
| Sr | 54.5 | 79.9 | 44.8 | 61 | 98.4 | 77.1 | 125.2 |
| Ta | 0.28 |  |  |  |  | 0.21 | 0.22 |
| Tb | 0.752 | 0.195 | 0.167 | 0.143 | 0.198 | 0.499 | 0.501 |
| Th | 0.33 | 0.08 |  | 0.16 |  | 0.2 | 0.2 |
| Tm | 0.554 | 0.21 | 0.094 | 0.081 | 0.136 | 0.358 | 0.368 |
| U | 0.087 | 0.022 | 0.012 | 0.073 | 0.011 | 0.052 | 0.054 |
| Y | 31.74 | 10.65 | 6.01 | 5.04 | 8.28 | 20.72 | 20.79 |
| Yb | 3.74 | 1.5 | 0.6 | 0.55 | 0.9 | 2.37 | 2.45 |
| Zr | 80 | 20.2 | 17.5 | 14.6 | 13.5 | 48 | 50.2 |
| Bi | N.D. | 0.11 | N.D. | N.D. | N.D. | N.D. | N.D. |
| Sb | 0.32 | 0.21 | 0.16 | 0.2 | 0.18 | 0.13 | 0.16 |
| Ag | 2 | 2 | 2 | 3 | 3 | 3 | 3 |
| Be | 0.38 | 0.18 | 0.13 | 0.62 | 0.12 | 0.34 | 0.33 |
| Cd |  |  |  |  |  |  |  |
| Co | 45 | 49 | 99 | 89 | 98 | 46 | 47 |
| Cu | 148 | 41 | 72 | 23 | 40 | 93 | 135 |
| Li |  |  |  |  |  |  |  |
| Mo | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ni | 149 | 255 | 1113 | 1064 | 1212 | 86 | 77 |
| Sc | 37.7 | 27.8 | 17.1 | 19.6 | 20.7 | 43.2 | 43.4 |
| Sr | 49.2 | 71.5 | 40.4 | 58.1 | 86.7 | 70 | 113.3 |
| V | 320 | 129.1 | 113.9 | 117 | 100.2 | 290.9 | 299.4 |
| W | 0 | 15 | 0 | 0 | 0 | 0 | 0 |
| Zn | 107 | 70 | 74 | 78 | 70 | 101 | 98 |

Station ID 03-0273-0050 03-0273-0052

| Sample number )3RJB18971-7 | 03RJB18972-5 |  |
| ---: | ---: | ---: |
| Township | Whitney | Whitney |
| Easting | 493028 | 491548 |
| Northing | $5,372,884$ | $5,372,704$ |
| Assemblage | Deloro | Deloro |
| Rock Unit | Basalt | Basalt |
| Rock Type | massive | massive |
| Rock Texture | fine grained | fine grained |
|  | OGS-GL | OGS-GL |


| SiO2 | 49.7 | 44.59 |
| :---: | :---: | :---: |
| TiO2 | 0.71 | 0.65 |
| Al2O3 | 15.11 | 13.75 |
| Fe2O3 | 11.82 | 9.83 |
| FeO | 8.12 | 7.85 |
| MnO | 0.17 | 0.2 |
| MgO | 8.45 | 9.39 |
| CaO | 10.8 | 8.76 |
| K2O | 0.32 | 0.07 |
| Na 2 O | 1.2 | 4.52 |
| P205 | 0.05 | 0.06 |
| Cr2O3 |  |  |
| LOI | 2.79 | 8.9 |
| Total | 101.12 | 100.72 |
| CO2 | 0.07 | 5.5 |
| S | 0.09 | 0.08 |
|  | GL-MNDM | GL-MNDM |
| Cr | 319 | 1154 |
| Nb | 0 | 0 |
| Ni |  |  |
| V |  |  |
| Y | 16 | 13 |
| Zr | 38 | 34 |
| As | 0 | 13 |
| Ba | 83 | 0 |
| Ga | 15 | 15 |
| Pb | 0 | 0 |
| Rb | 9 | 0 |
| Sn | 0 | 0 |
| Sr | 98 | 52 |
| Ta | 0 | 0 |
| Th | 0 | 0 |
| Ce | 5.58 | 4.32 |
| Cs | 0.142 | 0.805 |
| Dy | 2.903 | 2.456 |
| Er | 2.057 | 1.684 |
| Eu | 0.615 | 0.543 |
| Gd | 2.318 | 1.981 |
| Hf | 1.2 | 1 |
| Ho | 0.65 | 0.54 |
| La | 1.98 | 1.59 |
| Lu | 0.319 | 0.259 |
| Nb | 1.4 | 1.3 |
| Nd | 4.81 | 3.82 |
| Pr | 0.916 | 0.708 |
| Rb | 8.37 | 1.25 |
| Sm | 1.64 | 1.38 |
| Sr | 102.4 | 55.1 |
| Ta | 0.2 | 0.18 |
| Tb | 0.427 | 0.367 |
| Th | 0.17 | 0.16 |
| Tm | 0.304 | 0.249 |
| U | 0.043 | 0.052 |
| Y | 17.61 | 14.13 |
| Yb | 2.03 | 1.64 |
| Zr | 39.3 | 35.9 |
| Bi | N.D. | N.D. |
| Sb | 0.11 | N.D. |
| Ag | 3 | 3 |
| Be | 0.28 | 0.28 |
| Cd |  |  |
| Co | 48 | 58 |
| Cu | 118 | 116 |
| Li |  |  |
| Mo | 0 | 0 |
| Ni | 116 | 307 |
| Sc | 40.5 | 36.1 |
| Sr | 96.1 | 50.1 |
| v | 254.3 | 223.6 |
| W | 0 | 0 |
| Zn | 126 | 73 |

## Metric Conversion Table

| Conversion from SI to Imperial |  |  | Conversion from Imperial to SI |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| SI Unit | Multiplied by | Gives | Imperial Unit | Multiplied by | Gives |
| LENGTH |  |  |  |  |  |
| 1 mm | 0.03937 | inches | 1 inch | 25.4 | mm |
| 1 cm | 0.39370 | inches | 1 inch | 2.54 | m |
| 1 m | 3.28084 | feet | 1 foot | 0.3048 | m |
| 1 m | 0.049709 | chains | 1 chain | 20.1168 | m |
| 1 km | 0.621371 | miles (statute) | 1 mile (statute) | 1.609344 | km |
| AREA |  |  |  |  |  |
| $1 \mathrm{~cm}^{2}$ | 0.1550 | square inches | 1 square inch | 6.4516 | cm 2 |
| $1 \mathrm{~m}^{2}$ | 10.7639 | square feet | 1 square foot | 0.09290304 | $\mathrm{m}^{2}$ |
| $1 \mathrm{~km}{ }^{2}$ | 0.38610 | square miles | 1 square mile | 2.589988 | km2 |
| 1 ha | 2.471054 | acres | 1 acre | 0.4046856 | ha |
| VOLUME |  |  |  |  |  |
| 1 cm 3 | 0.061023 | cubic inches | 1 cubic inch | 16.387064 | cm3 |
| 1 m 3 | 35.3147 | cubic feet | 1 cubic foot | 0.02831685 | m3 |
| 1 m 3 | 1.307951 | cubic yards | 1 cubic yard | 0.76455486 | m3 |
| CAPACITY |  |  |  |  |  |
| 1 L | 1.759755 | pints | 1 pint | 0.568261 | L |
| 1 L | 0.879877 | quarts | 1 quart | 1.136522 | L |
| 1 L | 0.219969 | gallons | 1 gallon | 4.546090 | L |
| MASS |  |  |  |  |  |
| 1 g | 0.035273962 | ounces (avdp) | 1 ounce (avdp) | 28.349523 | g |
| 1 g | 0.032150747 | ounces (troy) | 1 ounce (troy) | 31.1034768 | g |
| 1 kg | 2.2046226 | pounds (avdp) | 1 pound (avdp) | 0.45359237 | kg |
| 1 kg | 0.0011023 | tons (short) | 1 ton (short) | 907.18474 | kg |
| 1 t | 1.1023113 | tons (short) | 1 ton (short) | 0.90718474 |  |
| 1 kg | 0.00098421 | tons (long) | 1 ton (long) | 1016.0469088 | kg |
| 1 t | 0.9842065 | tons (long) | 1 ton (long) | 1.01604690 | t |
|  |  | CONCEN | RATION |  |  |
| $1 \mathrm{~g} / \mathrm{t}$ | 0.0291666 | ounce (troy)/ <br> ton (short) | 1 ounce (troy)/ ton (short) | 34.2857142 | $\mathrm{g} / \mathrm{t}$ |
| $1 \mathrm{~g} / \mathrm{t}$ | 0.58333333 | pennyweights/ ton (short) | 1 pennyweight/ ton (short) | 1.7142857 | $\mathrm{g} / \mathrm{t}$ |
| OTHER USEFUL CONVERSION FACTORS |  |  |  |  |  |
| Multiplied by |  |  |  |  |  |
| 1 ounce (troy) per ton (short) 3 |  |  | 103477 gra | grams per ton (short) |  |
| 1 gram per ton (short) |  |  | ounces (troy) per ton (short) |  |  |
| 1 ounce (troy) per ton (short) 20.0 |  |  |  | pennyweights per ton (short) |  |
| 1 pennyweight per ton (short) |  |  | 05 ounces | ounces (troy) per ton (short) |  |

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[^0]:    © Queen's Printer for Ontario, 2005

[^1]:    Bateman, R., Ayer, J.A., Dubé, B. and Hamilton, M.A. 2005. The Timmins-Porcupine gold camp, northern Ontario: the anatomy of an Archaean greenstone belt and its gold mineralization: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6158, 90p.

[^2]:    ${ }^{4}$ Jack Satterley Geochronology Laboratory, University of Toronto, Toronto, Ontario, M5S 3BI, Canada mahamilton@geology.utoronto.ca

[^3]:    Note: Conversion factors which are in boldtype are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

