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Introduction

This report summarizes the results of detailed mapping carried out to investigate the structural evolution and stratigraphic architecture in a ~20 km^2 area at Kirkland Lake, Ontario (Figure 1). The Kirkland Lake area, located in the south-central portion of the Abitibi subprovince, is one of the most prolific mining districts in Ontario. The district is characterized by the occurrence of structurally controlled gold deposits, with a past production of >30 Moz. The primary structure hosting gold is known as the 'Main Break', which represents a second-order splay of the Larder Lake-Cadillac deformation zone (LLCdz). The LLCdz is a crustal scale, structure that extends for 100s of km along strike and is associated with numerous gold deposits along its length (Robert, 1989; Ispolatov et al., 2008; Lafrance, 2015). Most commonly, gold deposits do not occur within the LLCdz, but are hosted by second- to third-order, brittle-ductile deformation zones within 2-10 kilometers from the LLCdz (Robert et al., 1995). Thus, the across-strike distribution of structures were investigated to assess the localization of strain, which likely controlled the distribution of gold deposits in the district. Results of the new mapping (Figure 1) reveal that the 'Main Break' is one of a series of heterogeneously distributed shear zones that formed within second-order fault zones in a >6 kilometer area to the north of the LLCdz. Gold occurrences are spatially associated with each of the brittle-ductile deformation zones, suggesting that multiple splays of the LLCdz controlled the upflow of gold-bearing hydrothermal fluids in Kirkland Lake.

Lithologic Setting

The Precambrian geology of the Kirkland Lake area was compiled in portions of the Teck (Thomson, 1945; Ispolatov et al., 2005), Lebel (MacLean, 1944; Ispolatov et al., 2005), Bernhardt (Rupert and Lovell, 1970), and Morrisette (Rupert and Lovell, 1970) townships and new structural mapping was conducted in selected areas during the 2013-2015 field seasons (Figure 1). In the map area, supracrustal exposures are comprised of the Tisdale assemblage (2710-2704 Ma) in the south, the Blake River assemblage (2704-2695 Ma) in the north, and the Timiskaming assemblage (2679-2669 Ma) in the center. The Tisdale and Blake River assemblages consist of composite successions of tholeiitic basalt and andesite, emplaced in a submarine environment, and related synvolcanic intrusive rocks (Ayer et al., 2002). The Timiskaming assemblage consists of conglomerate, sandstone, and mudstone as well as alkaline volcanic rocks. These units were largely deposited in a subaerial, alluvial-fluvial and subaqueous, lacustrine or shallow marine environment in a fault-controlled basin associated with the LLCdz (Mueller et al., 1994).

In the Kirkland Lake area, the Timiskaming assemblage is consistently south facing, and defines a moderately to steeply south-dipping monocline that is truncated to the south by the LLCdz. The LLCdz is marked by juxtaposition of the Timiskaming assemblage with the

Tisdale assemblage and/or by intensely deformed, carbonate-altered, and fuchsite-bearing ultramafic rocks of unknown stratigraphic affinity. The northern boundary of the Timiskaming assemblage is an angular unconformity (Thomson, 1946; Corcoran and Mueller, 2007). Mafic volcanic rocks of the Blake River assemblage display upright folds with kilometer-scale spacing and west-northwest-trending axial planes. Along the contact zone, the moderately- to steeply-dipping and north-younging mafic volcanic rocks of the Blake River assemblage are overlain by shallowly- to moderately-dipping and south-younging sedimentary and volcanic rocks of the Timiskaming assemblage. The Blake River-Timiskaming unconformity is best preserved where strain is low, although, locally, the contact zone is highly strained.

Throughout the study area, the Tisdale, Blake River, and Timiskaming assemblages are intruded by alkaline intrusive rocks that are subdivided based on relative age, primary mineralogy, and textural characteristics. These intrusive rocks include, from oldest to youngest: mafic (augite) syenite, syenite, and syenite porphyry. These intrusive rocks typically cross-cut the stratified rocks of the Timiskaming assemblage or are intruded along bedding planes. Major and trace element geochemistry indicates that they are compositionally similar to extrusive rocks that comprise portions of the Timiskaming assemblage stratigraphy (Hattori and Hodgson, 1990), suggesting that they are broadly cogenetic. The mafic (augite) syenite is dark gray to black or dark green in color, coarse-grained, and contains distinctive augite phenocrysts and abundant K-feldspar. The syenite is gray to pink in color and primarily consists of K-feldspar with lesser biotite, hornblende, apatite, and magnetite. The syenite porphyry is pink to white or gray in color and contains abundant feldspar ± quartz phenocrysts. The syenite porphyritic rocks typically contains large, millimeter- to centimeter-scale feldspar porphyroclasts with lesser biotite, hornblende, and chlorite. The syenite porphyritic rocks form sill to dike-like intrusions that cross-cut both the mafic (augite) syenite and syenite intrusive rocks, indicating that they are the youngest of the intrusive rocks (Ispolatov et al., 2008).

The Timiskaming assemblage and younger intrusive rocks are host to the mineralized zones of the ‘Main Break’. In this structure, gold is hosted by quartz-carbonate vein systems with associated sericite and carbonate alteration (Ispolatov et al., 2008). Mineralized veins and breccia are penetratively foliated by late post-Timiskaming fabrics and/or affected by late chloritic-bearing slip surfaces (Ispolatov et al., 2008). Thus, gold deposited along the ‘Main Break’ is interpreted to have accompanied the later phases of deformation in Kirkland Lake (i.e., D_4; Ispolatov et al., 2008).

Structural Geology

In Kirkland Lake, pre-Timiskaming (D_1) structure is locally preserved as folds in the Blake River assemblage. These folds display different structural trends from those in the adjacent Timiskaming assemblage rocks and are truncated at the unconformity with the Timiskaming assemblage. No penetrative fabrics associated with D_1 are preserved. To the northwest, in the Timmins area, two phases of pre-Timiskaming deformation have been identified (Bleeker, 1999). However, due to a lack of direct timing constraints, the relationship between the two phases of deformation in the Timmins area and D_1 structure in the Kirkland Lake area is unclear.

Along the LLCdz in Ontario, deposition of the Timiskaming assemblage was followed by the formation of an east-trending foliation, tilting of the sedimentary and volcanic rocks into a south-facing monocline, and localized reverse faulting along the LLCdz (D_2; Ispolatov et al., 2008). A weak D_2 fabric is locally present in the Timiskaming assemblage, but, generally, it is difficult to identify due to the effects of later deformation. Along the LLCdz to the east, in the Larder Lake area, northwest-striking, steeply-dipping structures crenulate D_2

fabrics and are attributed to a phase of northeast-southwest shortening (D_3; Ispolatov et al., 2008). No evidence for this fabric has been recognized within the map area and immediate region.

A northeast-trending, steeply-dipping foliation (S_4) is well-developed along the LLCdz and in a series of deformation zones to the north, which has been interpreted as a result of regional dextral transpression (D_4 of Ispolatov et al., 2008). S_4 is best developed in discrete high-strain zones (HSZs) where it is commonly defined by sericite or carbonate mineral-rich folia with millimeter- to sub-millimeter scale spacing. In the HSZs, S_4 commonly overprints zones of prior brittle deformation, marked by the occurrence of cataclasite, fault gouge, and/or discrete faults (Ispolatov et al., 2008; this study). Detailed mapping indicates that several to 100s of meters wide HSZs are regularly spaced at ~500-750 meter intervals throughout the map area. Of these, the most significant deformation is associated with four named deformation zones: the Larder Lake-Cadillac, the Murdock Creek, the 'Main Break', and the Kirana deformation zones. The majority of gold deposits and occurrences in Kirkland Lake are spatially associated with these zones and each displays domains of pervasive sericite and/or carbonate alteration. The boundaries of the HSZs are gradational to sharp over the scale of meters. The HSZs are separated by low strain zones (LSZs), in which primary sedimentary and igneous textures are well preserved, S_4 occurs as a weak spaced (centimeter-scale), northeast-trending and steeply-dipping foliation, and alteration is typically weak. In the HSZs, dextral shear sense indicators (e.g., S/C fabrics, σ-clasts, and Z-folds) are exposed on horizontal erosional surfaces, and moderately to steeply northeast-plunging lineations (elongate clasts and/or mineral aggregates) are well developed. The same lineations are weakly developed in the LSZs. Because no overprinting relationships exist between S_4, the lineations, and the shear sense indicators, all are interpreted as having formed during D_4.

Discussion and Implications

The Kirkland Lake district preserves evidence for a series of progressive north-south shortening to dextral transpressional deformation events. The amount of shortening that resulted from D_1 folding is difficult to constrain, due to later structural overprint. D_2 folds and evidence for localized thrusting along the LLCdz indicate further shortening. It is unclear if the second-order faults along which the HSZs localized formed during D_2. In general, the brittle-ductile structure that predominates the map area is interpreted to have formed during D_4 deformation, based on correlative fabric elements, fault kinematics, and textural associations within the HSZs and LSZs. Locally, it is difficult to distinguish between S_2 and S_4 where no cross-cutting relationships exist, or where S_2 is strongly overprinted by D_4 structures. There is no evidence for the D_3 phase of deformation in Kirkland Lake and immediate areas. Therefore, D_3 structures (Ispolatov et al., 2008) may have been local, possibly related to variations in orientation of the LLCdz.

New mapping reveals that D_4 strain in the Kirkland Lake district is localized in a series of brittle-ductile HSZs to the north of the LLCdz (Figure 1). Brittle structures, including faults, cataclasite, and shear veins, occur within spaced, second-order fault zones that developed as splays of the LLCdz. Brittle structures are widely overprinted by penetrative, S_4 fabrics, which together define the HSZs in the map area. The cospatial association of brittle-ductile structure in the D_4 HSZs suggests that early brittle deformation processes created weak zones that localized later ductile shear. Furthermore, while the known deposits are primarily associated with the 'Main Break', each of the major HSZs is host to gold occurrences. Therefore, the HSZs in the study area and possibly other undiscovered ones in the district, may have localized the upflow of hydrothermal fluids and may host concealed gold deposits.

Thus, gold in the Kirkland Lake district may be distributed in a much broader area north of the LLCdz than previously known, along a series of second- to third-order, gold-bearing structures, similar to the across strike distribution in the Val d'Or district of Quebec (Robert et al., 1995).

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References

Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K., Trowell, N., 2002. Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: Autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation. Precambrian Research 115, 63–95.

Bleeker, W., 1999. Structure, stratigraphy, and primary setting of the Kidd Creek volcanogenic massive sulfide deposit: A semiquantitative reconstruction. Economic Geology Monograph 10, 71–122.

Corcoran, P.L., Mueller, W.U., 2007. Time-transgressive Archean unconformities underlying molasse basin-fill successions of dissected oceanic arcs, Superior Province, Canada. Journal of Geology 115, 655–674.

Hattori, K., Hodgson, C.J., 1990, Gold-related geology in the Kirkland Lake and Timmins camps, Ontario. International Association on the Genesis of Ore Deposits Symposium, 8th, Ottawa, Canada, Field Trip Guidebook 5, 57 p.

Ispolatov, V.O., Lafrance, B., Dubé, B., Hamilton, M., Creaser, R., 2005. Geology, Structure, and Gold Mineralization, Kirkland Lake and Larder Lake Areas: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6159, 170 p.

Ispolatov, V., Lafrance, B., Dubé, B., Creaser, R., Hamilton, M., 2008. Geologic and structural setting of gold mineralization in the Kirkland Lake-Larder Lake gold belt, Ontario. Economic Geology 103, 1309–1340.

Lafrance, B., 2015. Geology of the orogenic Cheminis deposit along the Larder Lake – Cadillac deformation zone, Ontario. Canadian Journal of Earth Sciences 52, 1093–1108.

MacLean, A., 1944. Township of Lebel, District of Timiskaming, Ontario. Ontario Department of Mines, Map 53a, scale 1:12 000.

Mueller, W., Donaldson, J.A., Doucet, P., 1994. Volcanic and tectono-plutonic influences on sedimentation in the Archean Kirkland Basin, Abitibi greenstone belt, Canada. Precambrian Research 68, 201–230.

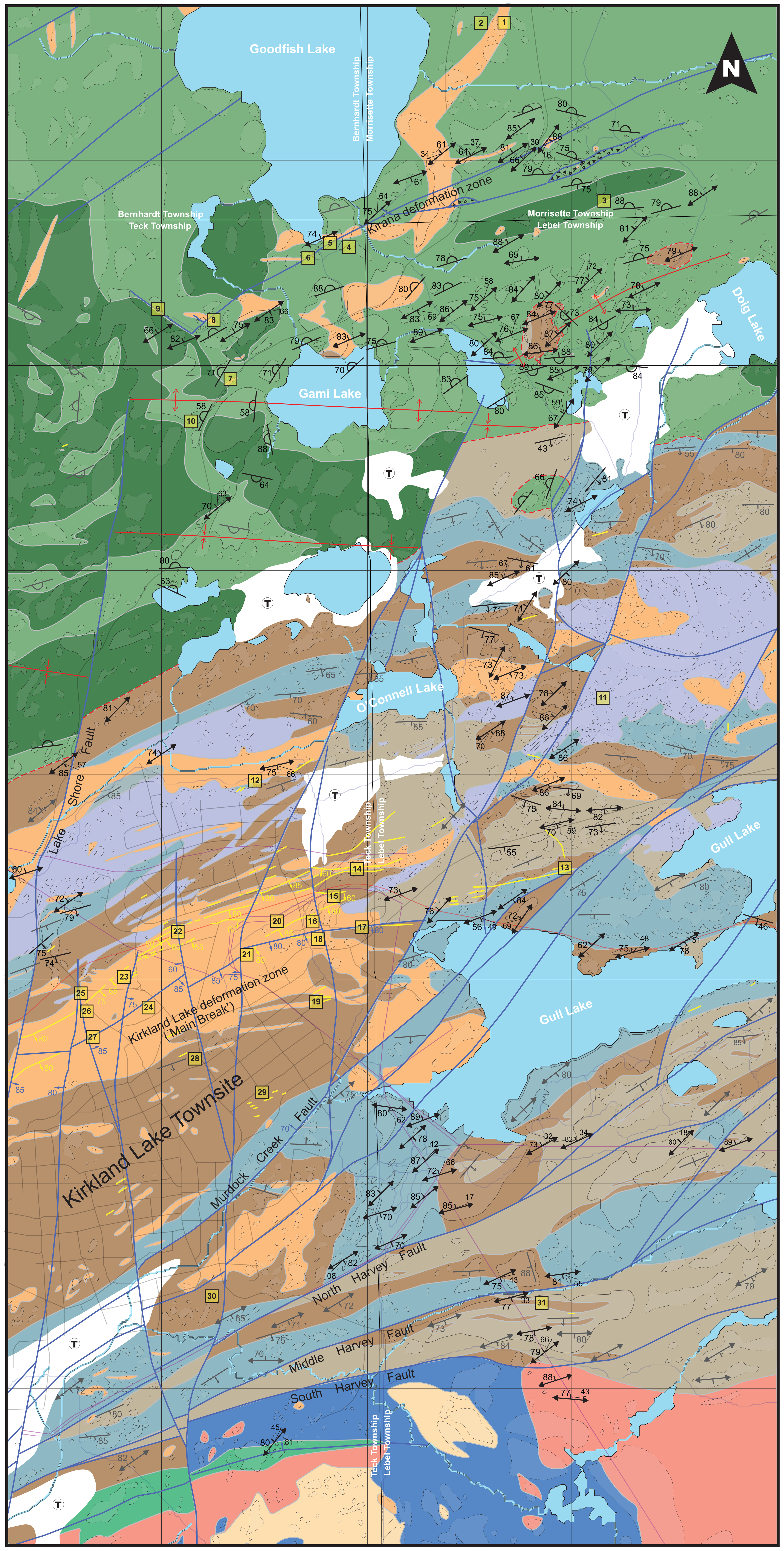
Robert, F., 1989. Internal structure of the Cadillac tectonic zone southeast of Val d'Or, Abitibi greenstone belt, Quebec. Canadian Journal of Earth Sciences 26, 2661–2675.

Robert, F., Boullier, A.-M., Firdaous, K., 1995. Gold-quartz veins in metamorphic terranes and their bearing on the role of fluids in faulting. Journal of Geophysical Research 100, 12861–12879.

Rupert, R.J., Lovell, H.L., 1970. Bernhardt and Morrisette Townships, Timiskaming District, Ontario. Ontario Geological Survey, 2000 Series Map M.2193, scale 1:31 680.

Thomson, J.E., 1945. Township of Teck, District of Timiskaming, Ontario. Ontario Department of Mines, Map 1945–1, scale 1:12 000.

Thomson, J.E., 1946. The Keewatin-Timiskaming unconformity in the Kirkland Lake district. Transactions of the Royal Society of Canada Section IV, II3–124.



Lithologic Units

Syn-deformation intrusions (2670-2660 Ma)

- Syenite porphyry
- Syenite
- Diorite, hornblendite
- Mafic (augite) syenite

INTRUSIVE CONTACT

Timiskaming assemblage (2679-2669 Ma)

- Conglomerate
  - minor sandstone and/or siltstone
- Sandstone and/or siltstone
  - minor conglomerate
- Alkaline volcanic rocks

ANGULAR UNCONFORMITY

Volcanic Assemblages

Blake River assemblage (2704-2695 Ma)

- Basalt to andesite
  - mafic to intermediate volcanic flows
- Andesite, diorite, and/or gabbro
  - locally contains coarse-grained volcanic flows

Tisdale assemblage (2710-2704 Ma)

- Basalt to andesite
  - mafic to intermediate volcanic flows

Fuchsite schist

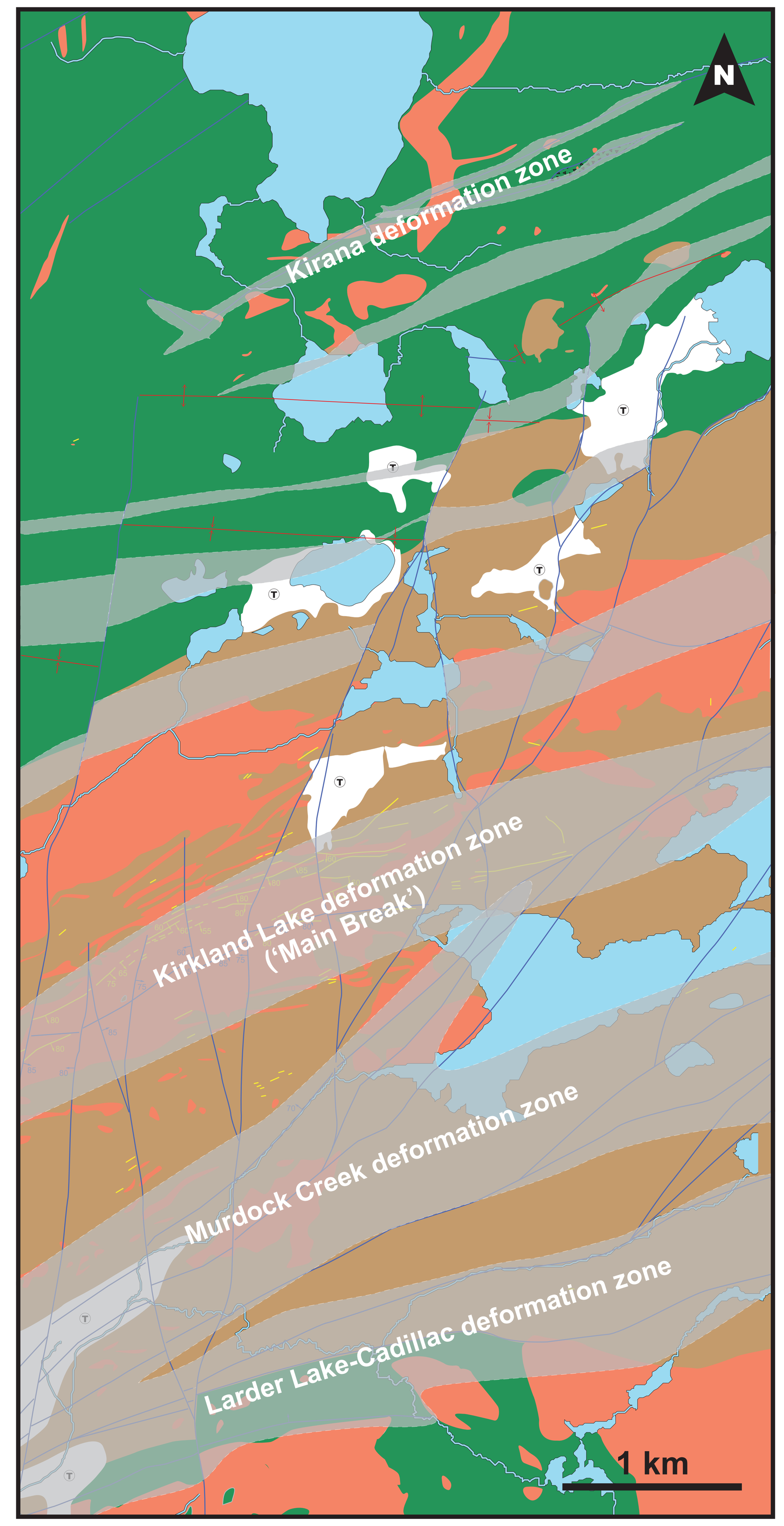
- Fuchsite schist, unknown affinity
  - altered ultramafic rock

Map Symbols

- Fault (inferred)
- Fault breccia
- Lithologic contact (inferred)
- Unconformable contact
- Axial trace (anticline, syncline)
- Bedding, facing unknown[1] (this study, compiled)
- Bedding, facing known[1] (this study, compiled)
- Bedding, vertical (this study, compiled)
- Volcanic facing[1] (this study, compiled)
- Volcanic facing, overturned[1] (this study, compiled)
- Foliation with lineation[1,2] (this study, compiled)
- Foliation, vertical (this study, compiled)
- Gold-bearing veins, exposed at surface or projected from underground workings
- Shaft sites, keyed to adjacent list
- Small bedrock outcrop (this study, compiled)
- Area of bedrock outcrop (this study, compiled)
- Tailings basin
- Lakes and streams
- Road
- Power line
- Trail
- Railroad
- Township boundary

[1]Where no dip or lineation is indicated, none was reported in source data
[2]Lineations defined by elongate clasts, minerals, and/or mineral aggregates

Interpreted distribution of high-strain zones in the Kirkland Lake map area



Simplified map units

- High-strain zones, boundaries inferred
- Syn- to post-Timiskaming intrusive rocks
- Timiskaming assemblage
- Composite volcanic greenstone successions

Selected Shafts

No. on Map	Property	Locality Name
1.	Goodfish	Goodfish No. 1
2.	Goodfish	Goodfish No. 2
3.	—	Chorzepa
4.	Kirana Kirkland	Kirana No. 1
5.	Kirana Kirkland	Kirana No. 2
6.	Kirana Kirkland	Kirana No. 3
7.	Kirana Kirkland	Kirana No.4
8.	Fidelity	Fidelity
9.	Fidelity	—
10.	—	—
11.	Continental-Kirkland	—
12.	Federal Kirkland	Terrex
13.	Glenora	—
14.	Toburn	'B' shaft
15.	Toburn	'A' shaft
16.	Toburn	'C' shaft
17.	Toburn	No. 2 shaft
18.	Toburn	No. 3 shaft
19.	Toburn	No. 4 shaft
20.	Sylvanite	—
21.	Sylvanite	No. 2 shaft
22.	Sylvanite	—
23.	Sylvanite	No. 4 shaft
24.	Wright-Hargreaves	No. 2 shaft
25.	Wright-Hargreaves	No. 1 shaft
26.	Wright-Hargreaves	No. 4 shaft
27.	Wright-Hargreaves	No. 3 shaft
28.	Kirkland Townsite	—
29.	Black	—
30.	Hudson-Rand	—
31.	Harvey Kirkland	Beltico

Figure 1 - Precambrian geology and new structural data, Kirkland Lake area, Ontario

Scale 1:10 000

0 0.25 0.5 1 km

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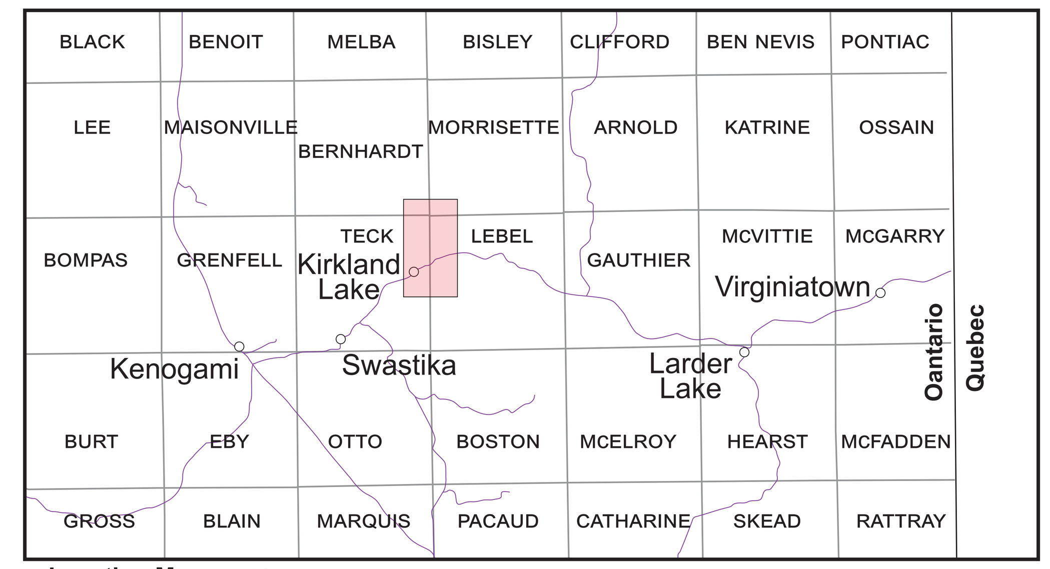
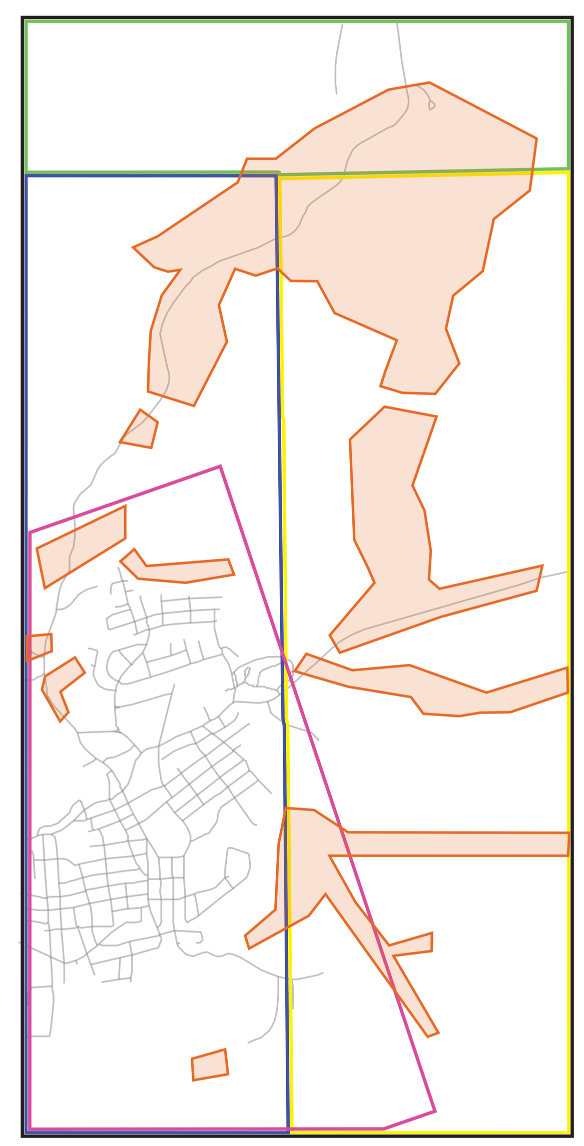


Location Map



Key to Sources of Information

- Mapping by Frieman, 2013-15
- Ispolatov et al., 2005
- Rupert and Lovell, 1970
- Thomson, 1945
- MacLean, 1944

Government of Canada Gouvernement du Canada

Base map information derived from the Ontario Land Information Warehouse, Land Information Ontario, Ontario Ministry of Natural Resources, scale 1:20 000.

Universal Transverse Mercator (UTM) co-ordinates are in North American Datum 1983 (NAD 83), Zone 17.

Magnetic declination approximately 13°W in 2013-15.

Credits

Compilation and geology by B.M. Frieman, 2013-2015.

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