# Geochemistry, Petrogenesis, and Metallogenesis of Komatiites in the Abitibi Greenstone Belt, Canada

**R.A. Sproule**[1], **C.M. Lesher**[1], **M.G.Houlé**[1], **R.R. Keays**[2], **J. A. Ayer**[3] and **P.C. Thurston**[1]
[1]Mineral Exploration Research Centre (Laurentian University, Willet Green Miller Centre, Ramsey Lake Road, Sudbury, Ontario, Canada, P3E 5B6)
[2]Department of Earth Sciences, VIEPS, Monash University, Clayton, VIC 3168 Australia
[3]Ontario Geological Survey (Willet Green Miller Centre, Ramsey Lake Road, Sudbury, Ontario, Canada, P3E 5B6)
e-mail: rsproule@nickel.laurentian.ca

The ~2.7 Ga Abitibi greenstone belt is one of the youngest parts of the Archean Superior Province. Komatiites in the Abitibi greenstone belt occur in four lithotectonic assemblages with well-defined ages based on high precision U-Pb single zircon geochronology: the 2750-2735 Ma Pacaud assemblage (PCA), the 2725-2720 Ma Stoughton-Roquemaure assemblage (SRA), the 2718-2710 Ma Kidd-Munro assemblage (KMA) and the 2710-2703 Ma Tisdale assemblage (TSA) (Ayer et al., in press; Sproule et al., in press). We have assembled a database of >2500 samples from this study, government data, company data, and the literature to examine the geochemistry, petrogenesis, and metallogenesis of komatiitic rocks in the Abitibi greenstone belt. The database has been filtered to remove altered samples, yielding a total of 1905 least-altered samples, all of which have been analyzed for major and minor elements and base metals, ~200 of which have been analyzed for lithophile trace elements, and ~60 of which have been analyzed for PGEs.

The major element compositions of Abitibi greenstone belt komatiites vary as a function of the composition of the parental magma and the degree of olivine accumulation. As discussed by Lesher and Stone (1996), Baird (1999), and Barnes and Brand (1999), one of the most useful ways to distinguish between cumulate rocks derived from komatiite magmas and komatiitic basalts is the abundance of Cr at a given MgO content (**Fig. 1**). Magmas with >~20% MgO are undersaturated in chromite and accumulate only olivine, whereas magmas with <~20% MgO are chromite-saturated and accumulate cotectic proportions (~50:1) of olivine and chromite (Murck and Campbell, 1986). Thus, cumulates derived from komatiitic magmas have relatively low Cr contents, those derived from komatiitic basaltic magmas have relatively high Cr contents, and those derived from magmas that became saturated in chromite *during* crystallization have intermediate Cr contents (Lesher and Stone, 1996).

The komatiites in the Abitibi greenstone belt with the highest Mg or Ni and lowest Cr contents are not necessarily those that are preferentially mineralized (Muir, 1979; Baird, 1999), because the differences in Cr/Mg and Cr/Ni simply reflect differences in the degree of replenishment and fractionation between channel-flow and sheet-flow facies (Lesher and Arndt, 1995; Lesher and Stone, 1996; Lesher et al., 2001). However it does appear that Cr contents may be used to distinguish lava channels, lava channel facies of channelized sheet flows, and magma conduits (olivine cumulates) from sheet flows and sheet sills (olivine + chromite cumulates) in komatiites (e.g., Abitibi, Western Australia, Zimbabwe), but they cannot distinguish facies in komatiitic basalts (e.g., Cape Smith, probably Thompson: see discussion by Lesher and Stone, 1996).

Based on the above criteria there are important differences between the komatiites in each of the komatiite-bearing assemblages of the Abitibi greenstone belt (see **Fig. 1** and also Houlé et al., 2001):

*Pacaud assemblage* komatiites formed from komatiitic basalt to low-Mg komatiitic magmas. They form predominantly spinifex-textured and pillowed komatiites; rare cumulate komatiites are komatiitic peridotites with orthocumulate textures. There are few mesocumulate and no adcumulate komatiites.

*Stoughton-Roquemaure assemblage* komatiites formed from komatiitic basalt and low to high-Mg komatiite magmas. All of the high-Mg komatiitic rocks occur in the Reaume-McCart trend (in the north-west portion of the Abitibi greenstone belt) and are likely intrusive. The remainder of the komatiites form spinifex-textured and pillowed komatiites. Rare cumulate zones are komatiitic peridotites with ortho- to mesocumulate textures, excluding rare komatiitic dunites with meso-adcumulate textures in the Reaume-McCart trend.

*Kidd-Munro assemblage* komatiites formed from low-Mg and high-Mg komatiite and lesser komatiitic basalt magmas. They include spinifex-textured, massive (cumulate > aphyric), pillowed (rarer), and volcanoclastic (rare) facies and commonly contain komatiitic peridotites and dunites with ortho-, meso-, and adcumulate textures.

*Tisdale assemblage* komatiites formed from komatiitic basalt and low-Mg and high-Mg komatiitic magmas. They include spinifex-textured, massive (cumulate > aphyric), pillowed (rarer), and volcanoclastic (rare) facies and commonly contain komatiitic peridotites and dunites with ortho-, meso-, and adcumulate textures.

Thus, the Kidd-Munro and Tisdale assemblages contain a greater abundance of meso- to adcumulate komatiitic peridotites and dunites compared to the Pacaud and Stoughton-Roquemaure assemblages (**Fig. 1**), which appear to represent lava channels or lava channel facies of channelized sheet flows. Komatiite-hosted Ni-Cu-(PGE) deposits have only been identified within the Kidd-Munro assemblage (e.g., Alexo, Dundonald, Marbridge, Dumont) and Tisdale assemblage (e.g., Sothman, Texmont, Redstone, Hart, Langmuir). This is consistent with the interpretation that komatiite-associated Ni-Cu-(PGE) deposits form primarily within lava channel facies or channelized sheet flow facies, not within sheet flow or lava lobe facies (Lesher, 1989).

The high MgO contents of the komatiites and komatiitic basalts in the Abitibi greenstone belt suggest that they formed in a mantle plume system. The duration of komatiite magmatism in the Abitibi greenstone belt spanned ~47 My, comparable to modern, long-lived hotspots, but was more protracted than the 1-2 My duration of modern plume systems. Thus, it seems probable that the komatiites in the Abitibi greenstone belt were generated from more than one plume.

The Abitibi greenstone belt komatiites exhibit stratigraphic and temporal variations in geochemistry. Komatiites in the Pacaud assemblage are Ti-depleted komatiites (TDK) with high $Al_2O_3/TiO_2$ (25-35) and low $[Gd/Yb]_{CN}$ (~0.6) (CN: normalization values from McDonough and Sun, 1995), suggesting a garnet-rich source or formation via dynamic melting similar to Gorgona komatiites (Arndt et al., 1997). Komatiites in the Stoughton-Roquemaure assemblage are largely Al-depleted to Ti-enriched komatiites (ADK–TEK) with lesser Al-undepleted komatiites (AUK) with variable $Al_2O_3/TiO_2$ (6-25) and $[Gd/Yb]_{CN}$ >1, suggesting some garnet fractionation during melting. Komatiites in the Kidd-Munro assemblage are dominated by AUK, with lesser ADK–TEK, suggesting a combination of relatively shallow (garnet-absent) and relatively deep (garnet-rich) sources. Komatiites in the Tisdale assemblage are exclusively AUK, suggesting a relatively shallow (garnet-poor) source. The temporal evolution in komatiite composition is consistent with a decreasing influence of garnet in the source region of the plume(s) with time. This may represent successively shallower depths of melting due to factors including plume(s) ascent or a decrease in the thickness of the lithosphere during plume ascent, perhaps related to lithospheric thinning by rising plume(s) (Sproule et al., in press).

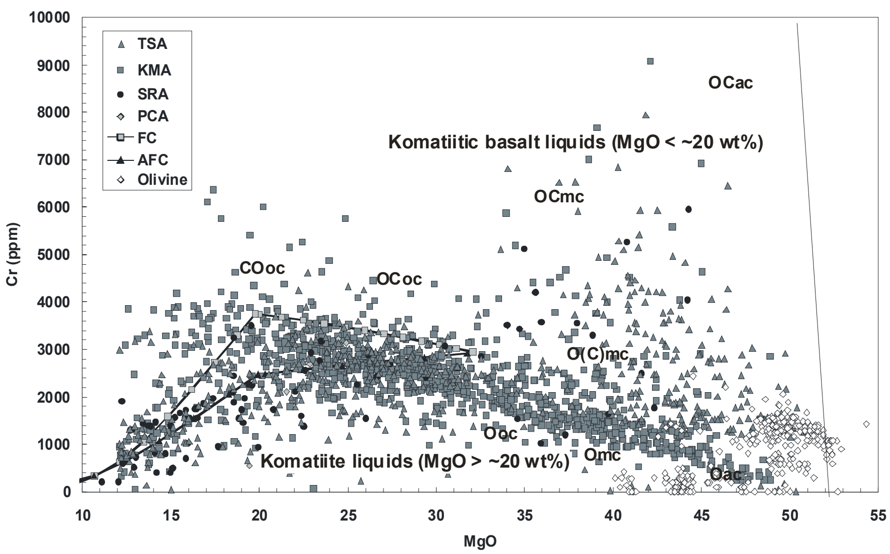


***Figure 1.*** *Cr (ppm) versus MgO (wt%) for komatiitic rocks from the Abitibi greenstone belt. AFC and FC modelling parameters from Lesher and Arndt (1995). O = olivine; C = Chromite; oc = orthocumulate; mc = mesocumulate; ac = adcumulate. Rocks which form from liquids with MgO < ~20 wt% crystallize olivine+chromite (predominantly komatiitic basalt liquids), whereas cumulates which form from liquids with MgO >~20 wt% crystallize olivine only (komatiites senso stricto).*

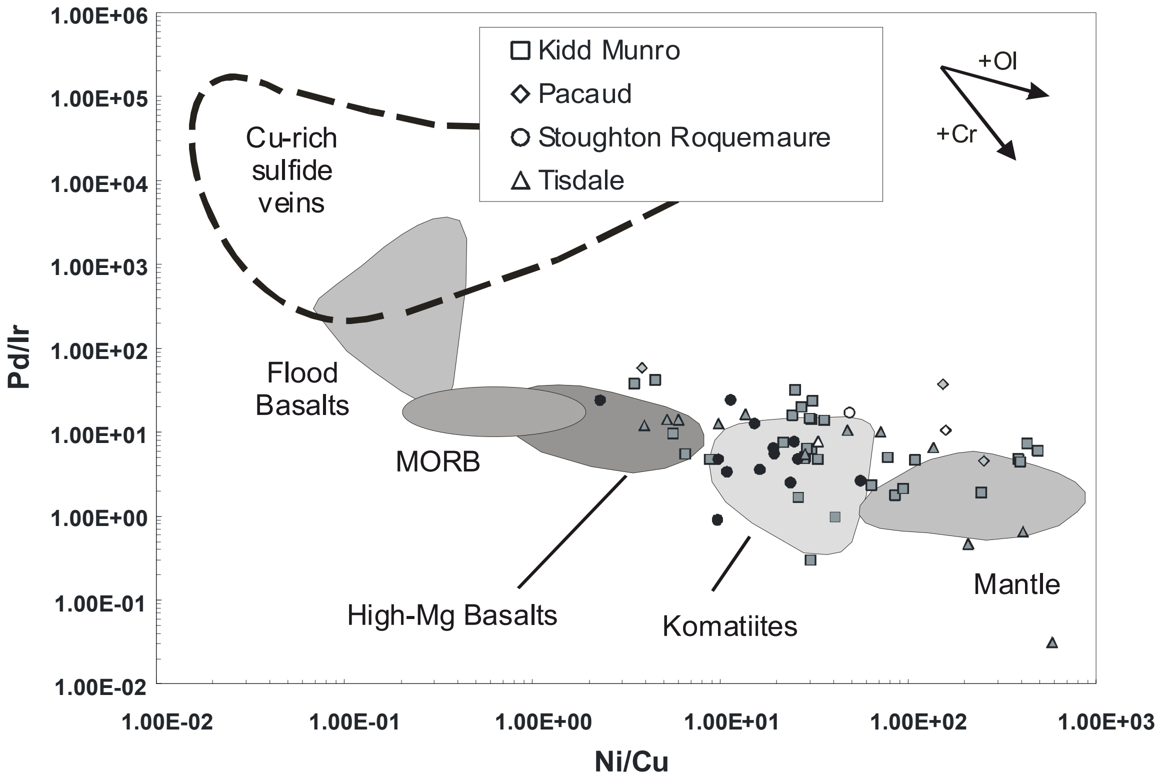


***Figure 2**. Pd/Ir versus Ni/Cu for unmineralized komatiitic rocks from the Abitibi greenstone belt. Comparsion fields from Barnes et al. (1988). Ol = Olivine; Cr = Chromite.*

$[Nb/Th]_{MN}$ and $[Th/Sm]_{MN}$ in the Kidd-Munro and Tisdale assemblages range between depleted upper mantle values and values similar to upper Archean continental crust indicating up to ~35% contamination (Sproule et al., in press). The eruption of Kidd-Munro and Tisdale assemblage komatiites through sialic crust is also supported by the presence of inherited zircons ranging in age up to 2725 Ma in associated felsic volcanic rocks. The sialic crust must have been juvenile, based on primitive Nd isotopic compositions (Machado et al., 1986). The relatively low $[Nb/Th]_{MN}$ and $[Th/Sm]_{MN}$ in the Pacaud and Stoughton-Roquemaure assemblages, which are much closer to depleted mantle, indicate that these lavas were not contaminated. This suggests a fundamental difference in the nature of the lithosphere through which the Pacaud and Stoughton-Roquemaure assemblage komatiites ascended and/or a fundamental difference in magma discharge rates. The presence of inherited zircons in the Stoughton-Roquemaure assemblage favours the latter. Crustal contamination in the Kidd-Munro and Tisdale assemblages is very localized, occurring on the scale of individual lava flows. Therefore, crustal contamination is not a source characteristic and probably not a consequence of contamination during ascent through the upper crust, which would result in contamination over a broader stratigraphic interval (Lesher & Arndt, 1995; Lesher et al., 2001). Thus, contamination most likely occurred during emplacement.

Sixty-one analyses of PGE in unmineralized komatiites from each of the assemblages, including samples from areas/assemblages that contain Ni-Cu-(PGE) mineralization and areas/assemblages that do not contain any mineralization are characterized by flat primitive mantle-normalized patterns, typified by low Ni/Cu and Pd/Ir ratios (**Fig. 2**). This suggests that *all* of the sampled komatiites in *all* of the assemblages represent high-degree partial melts of a normal depleted mantle source. No depletion in Pd or Pt is evident, indicating that the magmas were not sulfide-saturated in the source region and that they did not reach sulfide saturation during ascent or emplacement (e.g., Keays, 1995). Such magmas represent a favourable source for Ni-Cu-(PGE) mineralization, as they contain a complete chalcophile element budget.

Kambalda-type Ni-Cu-(PGE) mineralization in the Abitibi greenstone belt is hosted only by the Kidd-Munro and Tisdale assemblages. These komatiites are dominated by AUK, similar to many (e.g., Kambalda, Raglan, Zimbabwe), but not all (e.g., Crixàs, Forrestania, Ruth Well) mineralized komatiites world-wide. Thus, the depth of partial melting in not an important parameter in the genesis of magmatic Ni-Cu-(PGE) deposits (Lesher & Stone, 1996). More important are the physical volcanology and the nature of the underlying lithologies (Lesher, 1989). This is supported in the Abitibi greenstone belt by evidence of crustal interaction and, more importantly, greater degrees of lava channelization within the Kidd-Munro and Tisdale assemblages. Furthermore, sulphide-facies iron formations and graphitic sediments are present stratigraphically below the komatiitic sequences only in the Kidd-Munro and Tisdale assemblages, which may be an excellent S source. Thus, the Kidd-Munro and Tisdale assemblage komatiites are most prospective for Kambalda-style Ni-Cu-(PGE) mineralization.

**References**


Arndt, N.T., Kerr, A.C., Tarney, J., 1997. Dynamic melting in plume heads: the formation of Gorgona komatiites and basalts. Earth Planetary Science Letters, v.146, p.289-301.

Ayer, J.A., Amelin, Y., Corfu, F., Ketchum, J., Kwok, K., and Trowell, N.F., in press. Evolution of the southern Abitibi greenstone belt based on U-pb geochronology: authochthonous volcanic construction followed by plutonism, regional deformation and sedimentation. Precambrian Geology.

Baird, A.M., 1999, Geochemistry of Chromites in Intrusive and Extrusive Komatiites in the Abitibi Greenstone Belt, Ontario, unpublished MSc thesis, University of Alabama, 189p.

Barnes, S.J., and Brand, N.W., 1999. The distribution Cr, Ni, and chromite in komatiites, and application to exploration for komatiite-hosted nickel sulfide deposits, Economic Geology, v.94, p.129-132.

Barnes, S.-J., Boyd, R., Korneliussen, A., Nilsson, L-P., Often, M., Pederson, R.B., and Robins, B., 1988. The use of mantle normalisation and metal ratios in discriminating between the effects of partial melting, crystal fractionation and sulfide segregation on platinum-group elements, Gold, Nickel and Copper: Examples from Norway. *in* Geoplatinum 87, edited by H.M., Pritchard, P.J. Potts, P. J., J.F.W, Bowles, and S. Cribb, Elsevier, p.113-143.

Houlé, M. Lesher, C.M., Gibson, H.L., Fowler, A.D., and Sproule, R.A., 2001. Project Unit 99-021. Physical volcanology of komatiites in the Abitibi Greenstone Belt. Ontario Geology Survey, Open File Report 6070.

Keays, R.R., 1995. The role of komatiitic and picritic magmatism and S-saturation in the formation of ore deposits. Lithos, v. 34, p. 1-18.

Lesher, C.M., 1989, Komatiite-associated nickel sulfide deposits. Chapter 5 in Whitney JA and Naldrett, A.J. (Editors), Ore Deposition Associated with Magmas, Reviews in Economic Geology 4. Economic Geology Publishing Company, El Paso, p. 45-101.

Lesher, C.M., and Stone, W.E., 1996. Exploration geochemistry of komatiites*; in* Igneous Trace Element Geochemistry: Applications for Massive Sulphide Exploration. Geological Association of Canada, Short Course v.12, p.153-204.

Lesher, C.M., Arndt, N.T., 1995. REE and Nd isotope geochemistry, petrogenesis and volcanic evolution of contaminated komatiites at Kambalda, Western Australia. Lithos, 34, 127-157.

Lesher, C.M., Burnham, O.M., Keays, R.R., Barnes, S-J., and Hulbert, L., 2001. Geochemical discrimination of barren and mineralized komatiites associated with magmatic Ni-Cu-(PGE) sulfide deposits. Canadian Mineralogist, v.39, p.673-696.

Machado, N., Brooks, C., and Hart, S.R., 1986. Determination of initial (super 87εSr/ (super 86εSr and (super 143εNd/ (super 144εNd in primary minerals from mafic and ultramafic rocks; experimental procedure and implications for the isotopic characteristics of the Archean mantle under the Abitibi greenstone belt, Canada. Geochimica et Cosmochimica Acta, v.50, p.2335-2348.

Muir, J.E., Comba, C.D.A., 1979. The Dundonald deposit; an example of volcanic-type nickel-sulfide mineralization. The Canadian Mineralogist, v.17, p.351-359.

Murck, B.W., and Campbell, I.H., 1986. The effects of temperature, oxygen fugacity and melt composition on the behaviour of chromium in basic and ultrabasic melts. Geochimica et Cosmochimica Acta, vl.50, p.1871-1887

Sproule, R.A., Lesher, C.M., Ayer, J.A., and Thurston, P.C., in press. Spatial and Temporal Variations in the Geochemistry of Komatiites and Komatiitic Basalts in the Abitibi Greenstone Belt. Precambrian Research.