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# Origin of "ultramafic" rocks in the Jean Lake area, Quetico metasedimentary belt: Contribution of komatiitic basalt

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## Introduction

The Quetico metasedimentary belt of 1,200km long and 70km wide consists essentially of metamorphosed, quartz-rich greywackes, and derived migmatites and peraluminous granites. A variety of geological setting has been proposed for the sedimentation, including a trench-like environment (Devaney and Williams, 1989; Fralick et al., 1992), an accretionary prism (Percival et Williams, 1989), a forearc setting (Davis, 1998), and a back-arc basin (e.g. Ansdell et al., 1995). In the Jean Lake area, south of Jellicoe, a lens of "ultramafic" rocks was noted by previous workers (Williams, 1991; Fralick et al., 1992). This "ultramafic" lens of ~ 3k long and 200 m wide (Fig. 1) is made of three units: a biotite-amphibole-rich unit, a amphibole-rich unit and a felsic unit. They were interpreted to be a weathering product of serpentinite diapirs or ophiolites (Fralick et al., 1992). A study of the "ultramafic" sedimentary rocks was initiated during the summer 2000 with three objectives: (i) to characterize the metamorphism and deformation of these rocks, (ii) to evaluate the origin of these "ultramafic" rocks, and (iii) to determine the ultimate sources.

## Structural analysis

The rocks in the Jean Lake area show well-preserved sedimentary textures and no penetrative foliations, suggesting localized deformation. Two stages of deformation are recognized. The first phase of deformation produced a steeply dipping foliation oriented N95 and symmetrical vertical folds. The axial planes are parallel to the bedding of N95 and have a dip of S80. Decimeter-scale folds were apparent in the rocks and hectometer-scale folds were inferred from the variations of younging directions in the sedimentary rocks.

The second phase of deformation is represented by the local development of shear planes. They are also parallel to bedding with an orientation of N95 and a steep plunge southward. A dextral strike slip motion was inferred from the geometry of SCC' structures. This sense of motion is further supported by Z folds of amphibole-rich bands, and also by centimeter-scale Z folded quartz veins in the host rocks.

## Petrological study

The rocks surrounding the "ultramafic" lens consist of quartz + plagioclase + biotite ± muscovite ± garnet ± staurolite ± sillimanite ± chlorite with accessory Fe-oxides and tourmaline. In thin sections, staurolite apparently crystallized under static condition, followed by millimetre-scale symmetric tight folds (Fig. 2). Foliation is developed in the axial planes of the folds. This planar fabric, parallel to the bedding, is made of an assemblage of garnet + biotite + sillimanite at the expense of staurolite. The evidence suggests a synkinematic heating, by the reaction of staurolite => biotite + sillimanite + garnet + $H_2O$ (Spear, 1993)(Fig. 3). A second foliation defined by the preferred orientation of biotite is locally developed and cut by shear planes made of biotite. S-C geometry and asymmetrically folded quartz veins suggest a dextral strike slip motion oriented N95.

In the "ultramafic" lens, the volumetrically predominant biotite-amphibole-rich unit is made of quartz + biotite + amphibole + plagioclase + chlorite + oxide ± tourmaline. The deformation is heterogeneous with locally developed foliation, which is defined by preferred orientation of biotite and amphibole. Steeply dipping shear planes made of biotite and amphibole are oriented N95 and are parallel to the foliation. Secondary centimetric shear bands containing syn-kinematic chlorite occurs. Sense and direction of shear are inferred from S-C-C' relationships, indicating dextral strike-slip motion along a N95 trending direction (Fig. 4). The dextral shear sense is confirmed by asymmetric folds of centimetric chlorite veins.

The amphibole-rich unit consists of amphibole + plagioclase + quartz + oxide ± biotite ± chlorite ± tourmaline. The deformation is heterogeneous with the local development of Z fold. The felsic unit consist of quartz + plagioclase + biotite + chlorite + oxide ± amphibole ± tourmaline. This unit is mineralogically similar to the surrounding Quetico sedimentary rocks.

**Metamorphic conditions**

The assemblage of metamorphic minerals suggests that the rocks underwent a peak metamorphism of amphibolite facies condition (T = 600-650°C) under low pressures (< 5 kbar). The metamorphism likely took place during the emplacement of voluminous peraluminous granite (Williams, 1991). This event was accompanied by symmetrical folding with axial planes oriented N95 and steeply dipping southward. Subsequently the rocks were retrogressed to greenschist facies conditions during dextral strike motion along N95 shear planes (Fig. 5).

**Origin of ultramafic lens**

The quartzo-feldspathic host rocks exhibit sedimentary structures such as bedding, flame and loading (Fig. 6). In the "ultramafic" lens, the felsic unit is identical to the host rocks; and the amphibole-biotite-rich unit contains millimeter-size quartz-rich clasts and exhibit sedimentary textures including climbing ripples, loading and stratification (Fig. 7). The decametric long lenticular bands and metric lenses of amphibole-rich unit occur parallel to bedding and form high relief in biotite-amphibole-rich rocks. The amphibole-rich unit contains millimeter-scale quartz-rich clasts and amphibole-quartz-bearing clasts which also suggests a sedimentary origin (Fig. 8). The evidence suggests sedimentary origin of the "ultramafic" rocks.

**Geochemistry:**

After a detailed thin section examination, 18 samples were selected for geochemical analysis. The samples show a significant compositional variation. The $SiO_2$ contents range between 53.9 .wt% and 65.5 .wt%; $Al_2O_3$ and MgO vary from 9.8 to 17.9 .wt% and from 3.0 to 12.5 wt%, respectively. Aluminum, Ti, Mg, and Cr form linear arrays with high correlation coefficients, suggesting that they were immobile after sedimentation (Fig. 9). The concentrations of other elements against these immobile elements also show linear arrays on variation diagrams, suggesting that Ca, K, Ga, Rb, Ba, V, Zn, Co, and Ni are also relatively immobile. In contrast, Si, Na, Sr, Zr, Y, Nb, P and Th show large scatters with low correlation coefficients (<0.7). It is likely that Si, Sr and Na were mobile during post-depositional processes. Low concentrations of Y, Nb and Th close to the detection limit, ~ 5 ppm, may explain the scatters of these elements.

Correlations between two elements may be attributed to three possible processes; constant sum effect, hydraulic sorting, and mixing of two end-members. Constant sum effect is rejected because the ratios of elements also show a linear array. For example, the ratios of Ti/Mg and Al/Mg vary widely and show a positive correlation (Fig. 10). Hydraulic sorting was suggested to explain the compositional variation of sedimentary rocks in the area between Beardmore-Jellicoe and Jean Lake area (Fralick and Kronbert, 1997). Hydraulic sorting would concentrates elements in heavy minerals and it does not necessary produce positive correlation between elements in silicate minerals and those in oxides. Our samples show a positive correlation between Cr, MgO and CaO.

The linear trends of our samples in variation diagrams are, therefore, attributed to mixing between two end-components.

**Sources**

One end-member of the mixing corresponds to quartzo-feldspathic rocks (felsic unit and host rocks) similar to the Quetico felsic sedimentary rocks. The other end-member is amphibole-rich unit and biotite-amphibole-rich rocks are plotted between the two end members. The amphibole-rich unit contains high MgO (up to 12.5.wt%) and Cr (up to 806ppm). The concentrations of these elements are greater than those of most mafic igneous rocks, suggesting a contribution of ultramafic rocks to these sedimentary rocks.

Possible ultramafic rocks include komatiites and mantle-derived rocks. Mixing lines of these hypothetical end members fit well with our data. One major difference between mantle-derived rocks and komatiites is Ca contents. Komatiites contain higher CaO than the mantle rocks. CaO would have been removed from the source during weathering and the CaO contents of clastic sedimentary rocks should be lower than the source.

Lherzolithic and harzburgitic rocks contain too low concentration of CaO to account for the composition of our samples from the Jean Lake area. In contrast, the CaO contents of clastic rocks expected from komatiitic basalt source are slightly higher than the observed values (Fig. 11). Therefore, we suggest that weathering of komatiitic basalt was added to the Quetico felsic sedimentary rocks, producing the mafic sedimentary rocks in the Jean Lake area.

**Conclusions**

Field and petrological evidence suggests that the "ultramafic" rocks are of sedimentary origin. They were metamorphosed under upper amphibolite condition, and underwent a retrogression to greenschist facies during dextral strike slip shears along N95 direction. Chemical compositions of the samples show linear mixing arrays, indicating a contribution of komatiitic basalt to the Quetico felsic sedimentary rocks.

**REFERENCES**


Ansdell, K.M., Lucas, S.B., Connors, K., Stern, R.A, 1995. Kisseynew metasedimentary gneiss belt, Trans-Hudson Orogen (Canada); back-arc origin and collisional inversion. Geology, 23, 1039-1043.

Ayer, J., 1999, Petrogenesis and Tectonic Evolution of the Lake of the Woods Greenstone Belt, Western Wabigoon Subprovince, Ontario, Canada, unpublished PhD thesis at University of Ottawa, 213p.

Davis, D.W., 1998. "Speculation on the formation and crustal structure of the Superior Province from U-Pb geochronology. Lithoprobe Report vol 65, p. 21-28.

Devaney, J.R., and Williams, H.R., 1989. Evolution of an Archean Subprovince boundary: A sedimentological and structural study of part of the Wabigoon-Quetico boundary in northern Ontario: Canadian Journal of Earth Sciences 26, 1013-1026.

Fralick, P.W., Kronberg, B.I., 1997. Geochemical discrimination of clastic sedimentary rock sources. Sedimentary Geology 113, 111-124.

Fralick, P.W., Wu, J., Williams, H.R., 1992. Trench and slope basin deposits in an Archean metasedimentary belt, Superior Province, Canadian Shield. Can. T. Earth Sci. 29, 2551-2557.

Percival, J.A. and Williams, H.R., 1989. The Quetico accretionary complex, Superior Province, Canada. Geology, v.17, p.23-25.

Spear, S., 1993. Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths. Mineralogical Society of America Monograph 799p. 375 p.

Williams, H.R., 1991. Quetico Subprovince, In Geology of Ontario. Ontario Geological Survey Special Vol. 1, p. 383-403.

**FIGURE CAPTIONS**

Figure 1. Location of the Jean Lake area and the distribution of "ultramafic" sedimentary rocks, modified after Williams (1991).

Figure 2. Staurolite (St) in the hinge of a fold and the foliation parallel to the axial plane in the quartzo-feldspathic host rocks. The foliation is defined by the preferred orientation of biotite (Bt).

Figure 3. Staurolite (St) is replaced by garnet (Gt), biotite (Bt) and sillimanite (Sil) in the quartzo-feldspathic host rocks.

Figure 4. SCC' structure in the biotite-amphibole-rich unit

Figure 5. PT path of the rocks in the Jean Lake area. The diagram is modifed after Spear (1993). Figure 6. Flame structure in the quartzo-feldspathic host rock.

Figure 7. Loading structure in the biotite-amphibole-rich unit.

Figure 8. Photomicrograph showing a quartz-rich clast in the amphibole-rich unit

Figure 9. $TiO_2$ vs. $Al_2O_3$ contents of mafic rocks in the Jean Lake area.

Figure 10. Weight ratios of $Al_2O_3$/MgO vs $TiO_2$/MgO for mafic rocks in the Jean Lake area.

Figure 11. Mixing lines between Quetico felsic sedimentary rocks and possible ultramafic source rocks. The regression line (solid line) of samples is compared with various mixing lines; komatiitic basalt (dash dot line), harzburgite (dashed line) and lherzolite (dot line).