KIMBERLITE EMPLACEMENT TEMPERATURES DERIVED FROM THE THERMAL HISTORY OF ORGANIC MATTER, LAC DE GRAS, CANADA

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An optical investigation of dispersed organic matter (DOM) inclusions from eight Lac de Gras kimberlite pipes indicates: (i) crater facies DOM is thermally unaltered; (ii) diatreme facies DOM not associated with hypabyssal facies has undergone low level thermal alteration characteristic of temperatures on the order of 150-200°C and; (iii) DOM from diatreme facies intruded by later hypabyssal dykes show a progressive increase in thermal alteration towards the hypabyssal contact where DOM appears to have been exposed to temperatures as high as 600 -700°C. Near the contact, DOM undergoes a rapid thermal transformation and produces a variety of thermal alteration products. These products include: (i) degasified wood chars; (ii) liquefied wood residues; (iii) petroleum bitumens derived from terrestrial resinites and cutinites; and (iv) petroleum-derived semi-graphitic coke.

Optical incident light microscopy of DOM has been used extensively for assessing the level of thermal maturation (coalification level) of strata within a sedimentary basin and for identifying thermal anomalies associated with intruded country rocks, particularly organic-enriched shales and coal-bearing strata. Two principal methods in optical microscopy are used for monitoring thermally-induced changes in DOM: (i) per cent reflectance in oil (%Ro) of wood-derived huminite DOM; and (ii) fluorescence microspectrometry of liptinite DOM. This study evalutes the organic and thermal history of huminites, huminite alteration products, associated liptinite (resinite, sporinite and cutinite) and bitumen DOM that were incorporated as a result of thermally-induced reactions within crater and diatreme facies of seven Lac de Gras kimberlites. The optical properties and microtextures of DOM from these kimberlites are compared with %Ro and optical textural data reported from bench scale pyrolysis (Fig. 1), gasification and liquefaction experiments conducted on huminites of brown coal to lignitic level of coalification.

%Ro of wood-derived huminite DOM is the most common optical method used for evaluating the thermal history. Since the rate of reaction and %Ro of woody huminite DOM increases exponentially with increasing temperature, following first order Arrenhius kinetics, this method provides a valuable geothermometer for evaluating the thermal conditions during intrusion of the Cretaceous-Tertiary kimberlites at Lac de Gras. Three kimberlite samples enriched in DOM were examined from crater facies rocks (Koala and Torrie pipes; present day depths: 51 to 63 m). Diatreme facies samples with DOM inclusions were examined from four pipes (Point Lake, Hawk, Gazelle, and Caribou West; present day depths: 70 to 280m). The most continuous data profile was collected from the Nancy pipe with 26 samples examined over a 95 m interval (present day depths: 30 to 117 m). This pipe is also unique in that the diatreme facies rocks have been intruded by later hypabyssal facies and thin hypabyssal dykes.

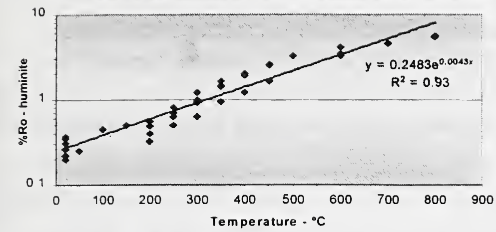
Thermally unaltered to highly altered DOM has been noted within crater and diatreme facies of the Lac de Gras kimberlite pipes, based on variations in huminite %Ro, liptinite DOM fluorescence properties, and changes in organic matter optical micro-textures. DOM within crater facies rocks has clearly not been subjected to any level of thermal alteration (Fig. 2), defining a low temperature thermal zone (Thermal Zone A). The consistent very low reflectance (< 0.20 %Ro) and cellulose-enrichment of huminites and the short wavelength fluorescence properties of liptinites confirm that the thermal maturity is still essentially at the peat level of coalification. Holocene peats by comparison have huminite Ro values on the order of 0.15 to 0.20 %Ro. In addition, the complete lack of microtextures such as devolatilization slits and vacuoles in the huminites supports a very low-level temperature zone.

The %Ro values of huminites from diatreme facies which were not affected by hypabyssal facies (Hawk, Point Lake, Gazelle, and Caribou West) are markedly higher than the reflectance of crater facies huminites, ranging from 0.30 to 0.47 %Ro (Thermal Zone B). The vast majority of the huminite macerals in diatreme facies samples with %Ro ranging from 0.30-0.40 show no evidence of micro-texture thermal alteration features to the huminite cellular structure. Exceptions include: (i) laminated huminite-enriched, peat clasts from Hawk pipe which clearly show evidence for rapid and extremely short-lived oxidative thermal alteration; and (ii) large stem-like inclusions which exhibit high-reflecting outer rims (0.44 %Ro) and a low-reflecting inner core (0.33-0.38 %Ro). Assuming that the increase in huminite %Ro has been a consequence of thermally-induced reactions resulting from heat of diatreme kimberlite intrusions, an estimation of temperature is possible. By comparing the range of huminite %Ro values for these diatremes with %Ro and temperature data compiled from the literature (Bostick, 1979; Kybett et al, 1982; Li, et al.,1991; Huang,1995) for rapid pyrolysis experiments using low rank woody huminite as a feedstock (Fig. 1), a thermal alteration temperature on the order of 150-200 °C is suggested for Thermal Zone B.

Huminite in tuffisitic kimberlite diatreme facies rocks of the Nancy pipe exhibit a systematic increase in reflectance with increasing depth and proximity to the hypabyssal kimberlite facies (Fig.3). Huminites within the upper part of the diatreme facies (30-45 m depth) in Nancy have %Ro values of 0.32 to 0.47, which are similar to those huminites from pipes with diatreme facies not affected by hypabyssal facies. The Nancy huminites, however, are characterized by unique, early devolatilization micro-textures (e.g. radiating slit-like fissures). Between 48 and 100 m in Nancy, huminite reflectance shows a dramatic increase from 0.55 to 3.3 %Ro, with the greatest rate of increase occurring between 65 and 100 m. This zone contains thin hypabyssal dikes (72-78 m) and macrocrystic kimberlite breccia hypabyssal facies (83-114 m). Significant amounts of huminites with reflectance values as high as 4.6 %Ro are also present in this zone. Devolatilization of huminite macerals is extensive between 48 and 100 m depth in the Nancy pipe, progressively increasing in severity towards the diatreme-hypabyssal facies contact.

A comparison of huminite %Ro data from Nancy pipe with data from bench scale rapid pyrolysis of low rank huminite suggests a wide range in thermal conditions with a progressive increase in the degree of thermal alteration towards the diatreme-macrocrystic hypabyssal facies contact. Huminite %Ro (0.32-0.47) between 30 and 45 m depth suggests an alteration temperature of 150 to 200 °C (Thermal Zone B1). Between 45 and 63 m depth, huminite %Ro ranges from 0.50 to 1.0, indicating an alteration temperature on the order of 200 to 300 °C (Thermal Zone C). Between 68 and 100 m depth huminite %Ro ranges from 1.8 to a maximum 4.6, suggesting an alteration temperature on the order of 400 °C at 68 m (Thermal Zone D) to approximately 600-700 °C at 100 m depth (Thermal Zone E). Semi-graphitic cokes derived from high temperature thermal cracking of petroleum liquids are present in a restricted zone in the Nancy pipe between 68 and 106 m depth. Petroleum cokes begin to form from thermal cracking of liquid petroleum at around 400-450 °C during rapid carbonization in an O_2-free system (Marsh et al., 1971; White, 1976; Khorasani and Michelson, 1993), thus corroborating the alteration temperatures indicated by huminite % Ro for Thermal Zone D. The petroleum cokes in this zone were most likely sourced from rapid thermal alteration of hydrogen-rich terrestrial resinite and cutinite DOM noted at various levels in the pipe.

Figure 1. Pyrolysis Experiments



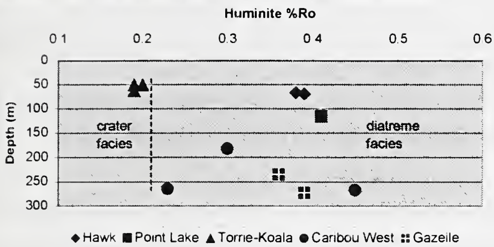
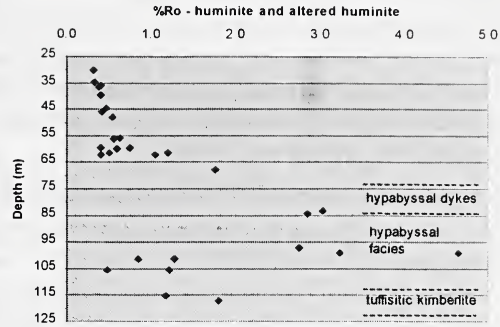


Figure 2. Huminite %Ro crater and diatreme facies

Figure 3. Huminite %Ro from Nancy Kimberlite



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