PRE- AND POST-KIMBERLITE EMPLACEMENT THERMAL HISTORY OF CRETACEOUS AND TERTIARY SEDIMENTS, LAC DE GRAS, NORTHWEST TERRITORIES, CANADA

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ABSTRACT

Optical analyses of contemporaneous, wood-derived organic matter, and older Cretaceous organic matter within shale xenoliths in DO-18 kimberlite, Lac de Gras, Northwest Territories, Canada, show that the kimberlite has undergone insignificant, if any burial since emplacement, and that Cretaceous strata in the area, prior to kimberlite emplacement, had reached thermal maturity levels equivalent to ~ 0.25-0.30 %Ro vitrinite. This level of maturity is corroborated by VIS fluorescence of sporinites, dinoflagellates and prasinophytes within the Cretaceous xenoliths. Porosity of shale xenoliths recovered from a number of kimberlites average 26 %. All data are consistent with a thickness of ~ > 1 to 1.5 km of Cretaceous strata (~ Albian to Maastrichtian ?) in the study area, most of which was likely eroded sometime prior to kimberlite emplacement (see Sweet et al., 2003).

INTRODUCTION

The study of Mesozoic sedimentary xenoliths and on-going strata preserved within the Lac de Gras Upper Cretaceous - Tertiary (Field and Scott Smith, 1998) kimberlite field in Northwest Territories, Canada, is leading to an understanding of the nature, extent, and geothermal/burial history of these sediments before, during, and after kimberlite emplacement (e.g. Stasiuk and Nassichuk, 1995; Stasiuk et al., 1999; Sweet et al., 2003). The impetus for this study comes from the hypothesis that significant Mesozoic strata in the Lac de Gras area may have influenced near surface kimberlite emplacement processes. Various models have been proposed for explaining the mechanism of pipe emplacement (e.g. Doyle et al., 1998; Field and Scott Smith, 1998; Kirkley et al; 1998) and are still the subject of much debate. In the present study, as a first step, organic petrology, organic geochemistry, palynology and petrophysical analyses have been used to assess the origin, thermal maturity level, age, and porosity of Albian (Cretaceous) to early Paleocene (Tertiary) shale xenoliths in the Lac de Gras kimberlites. The same methodologies have been applied to *in situ* non-kimberlitic crater-fill late Paleocene to early middle Eocene sediments and A significant period of kimberlite pipe emplacement and associated volcanism in the Lac de Gras region occurred in a marine setting, during the late Cretaceous and into a mainly terrestrial setting during the early Tertiary (Stasiuk and Nassichuk, 1995; Nassichuk and McIntyre, 1995; Field and Scott Smith, 1998). Plant derived macro and micro-fossils of various types occur within many of the upper most facies of the kimberlites both as detritus within a kimberlite matrix (e.g. wood particles) and as inclusions preserved within shale xenoliths incorporated into the kimberlites during their emplacement (ibid).

In this paper we present optical and geochemical thermal maturity data obtained on dispersed organic matter (DOM) preserved within the kimberlites and derived from (i) surficial Tertiary plants and/or peat accumulations, and (ii) DOM preserved within older shale xenoliths originally deposited within near shore to marine paleoenvironments. Also, porosity data are presented for selected shale samples to constrain depth-related changes in the degree of compaction. The objective of the thermal maturity and porosity assessment is to estimate the thickness of Tertiary and Cretaceous strata in the Lac de Gras area prior to, and/or during kimberlite emplacement, using principally per cent reflectance in oil (%Ro) of wood-derived vitrinite DOM, visible light region fluorescence of liptinite DOM, and shale porosity. Previous work by Stasiuk et al, (1999) on the Lac de Gras kimberlites used vitrinite reflectance and liptinite fluorescence to evaluate the thermal history of 'surficial' DOM inclusions in kimberlite facies during emplacement, and showed that the alteration temperatures ranged from ~ 20° in the uppermost crater to 700°C where hypabyssal dykes cross-cut, tuffisitic kimberlite.

Vitrinite Reflectance in Oil (%Ro)

Incident light microscopy of DOM has been used extensively for assessing the level of thermal maturation of sedimentary strata, and for identifying anomalous thermal alteration within country rocks intruded by igneous dykes and sills. Since the rate of reaction and per cent reflectance in oil (%Ro) of vitrinite increases exponentially with increasing temperature, DOM in Lac de Gras kimberlites or shale xenoliths provide an indirectgeothermometer for evaluating the thermal conditions prior to, and during, or subsequent to emplacement. Per cent reflectance of unaltered vitrinite in shale xenoliths dispersed within the kimberlites, would thus record pre-kimberlite thermal and burial history of the strata from which they were derived.

Visible Light Region Fluorescence

Visible light region fluorescence microspectrometry of hydrogen-rich liptinite DOM (e.g. alginite, sporinite, and cutinite) is a well established compliment to vitrinite reflectance for evaluating thermal maturity of organic matter. Liptinite from thermally immature strata (%Ro vitrinite < 0.50) exhibits blue-region, short wavelength fluorescence. During normal geothermal burial, with increasing thermal maturity (> 0.50 to 1.3 %Ro vitrinite) liptinite fluorescence emission progressively shifts to longer wavelengths disappearing at thermal maturity levels > 1.3 % Ro vitrinite, or at temperatures greater than 350-400 °C during rapid pyrolysis conditions (Ting and Lo, 1975).

EXPERIMENTAL

Wood-derived inclusions, mudstone clasts and portions of kimberlite lithology were collected from core provided by Kennecott Exploration Canada for DO18 kimberlite. Samples of the Nancy kimberlite were provided by BHP Billiton Diamonds Inc. For details of sample preparation and microscopic procedures used for data collection see Stasiuk et al. (1999; 2002). Selected samples were analysed with a Rock-Eval pyrolysis system for total organic carbon (TOC), hydrogen and oxygen indices, Tmax, quantity of free liquid hydrocarbons (S1) and quantity of hydrocarbons evolved from DOM during pyrolysis at 300 to 600 °C (S2). For experimental details and fundamentals of Rock-Eval pyrolysis refer to Tissot and Welte (1984). Only Tmax data are presented here.

RESULTS AND DISCUSSION

Data from DO18 kimberlite of the Tli Kwi Cho complex (see Doyle et al., 1998) are the focus of this paper, mainly to illustrate the pre-kimberlite emplacement burial/thermal history of Cretaceous-aged xenoliths, and the general lack of sedimentary cover/burial in the region following kimberlite emplacement. Details of the igneous petrology, geology and emplacement model of the Tli Kwi Cho kimberlite complex is provided in Doyle et al (1998). Palynological age constraints are provided by A.R. Sweet and are summarized in Stasiuk et al., (2002). The DO18 kimberlite was emplaced after ~ 74 Ma, most likely during the early Paleocene (Doyle et al., 1998).

A comparison of optical property-based, thermal maturity profiles of organic matter which was contemporaneous (i.e. 'surficial organic debris') with DO18 kimberlite emplacement, and organic matter within older Cretaceous kimberlite shale xenoliths in the Lac de Gras area reveals distinct differences as a consequence of their different geothermal histories. Contemporaneous, wood derived organic matter (or vitrinite) was most likely incorporated as epiclastic particles eroded into the crater facies atop pyroclastic kimberlite, which partially infilled the pipe and built fragment deposits on the rim (e.g. Kirkley et al. 1998). As a result, an assemblage of wood-derived contemporaneous vitrinite particles consists of: (i) vitrinites which were variably thermally altered by combustive processes (e.g. variably charred wood) caused either by fires or anomalous surface heating by hot material during ejection of the volcaniclastic material onto the surface, and (ii) vitrinites which were not altered by combustive processes but were eroded into the crater facies as essentially 'fresh' particles of wood. The latter, unaltered wood-derived vitrinites in DO18 have very low %Ro values averaging 0.18%Ro (Fig. 1a), which are essentially the values recorded for vitrinite from modern surface to near surface peats (Teichmuller and Durand, 1983; Stout and Spackman, 1989). The mere presence of very low reflecting vitrinite at the peat stage of thermal maturity in DO18, indicates that there was no thermal alteration of any sort after incorporation of the wood/vitrinite into the kimberlite, either from sedimentary burial-geothermal alteration or igneous or volcanic activity. The anomalously high %Ro value of 0.39 for contemporaneous wood at 43 m depth (Fig. 1a) represents a particle thermally altered at the surface by relatively high temperature combustion prior to

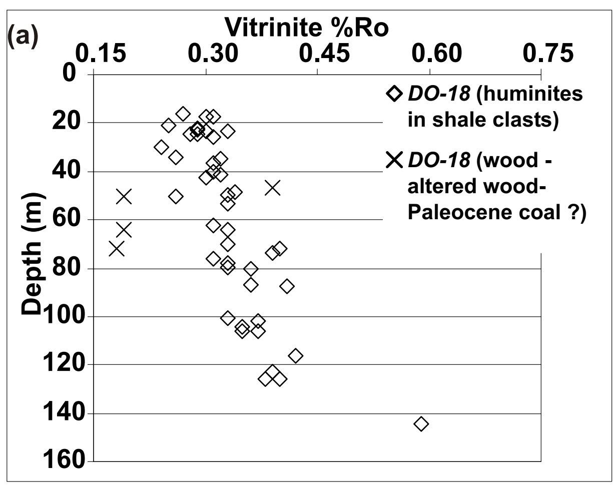

Figure 1(a). Per cent reflectance in oil (%Ro) of vitrinite in Cretaceous shale xenoliths and vitrinite (huminite) within altered and unaltered, woody, Tertiary-aged, particles in kimberlite matrix, for DO18 kimberlite, Tli Kwi Cho complex.

deposition into the crater. Since the altered vitrinite is from the same zone as the very low reflecting vitrinite, it was clearly not altered to its current %Ro level in place (Fig. 1a).

Shale xenoliths in the upper 160 m of the DO18 kimberlite range in age from late Albian to Mid-late Cenomanian at the base to a mid-late Cenomanian assemblage near the top (Doyle, et al., 1998; Stasiuk, et al., 2002). Per cent reflectance in oil of vitrinite macerals within Cretaceous shale xenoliths in DO18 have %Ro values ranging from 0.25 to 0.42 (Fig. 1a). The vitrinites within the shale xenoliths do not show any evidence for anomalous heating (e.g. fissures, high/low reflecting rims) or effects of low temperature oxidation above background geothermal gradients, and therefore are interpreted as recording pre-kimberlite, geothermal alteration related to sedimentary burial. For comparison, %Ro values of thermally altered vitrinite for contemporaneous woods from Nancy kimberlite (from Stasiuk et al., 1999) are provided in Figure 1b. The difference in the thermal maturity gradient of Nancy and DO18 are apparent (Fig. 1b), a direct consequence of their vastly different thermal histories. In addition, the degree of preservation of vitrinites varies greatly with the Cretaceous being unaltered and those from Nancy being highly altered and characterized by persistent pyrolytic devolatilization micro-textures within cell lumens and cell walls (Stasiuk et al., 1999).

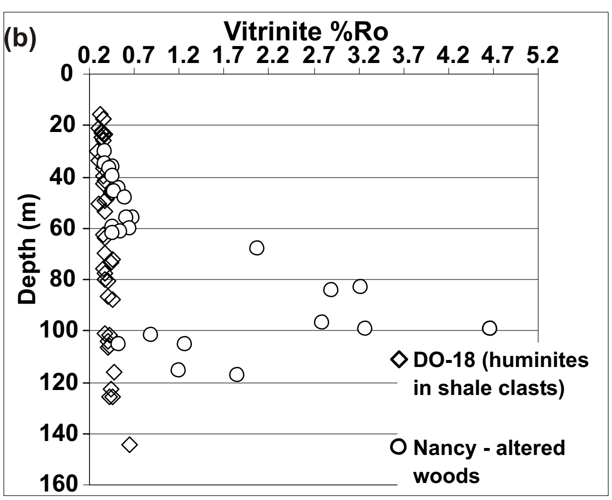

Figure 1(b). Per cent reflectance in oil (%Ro) of vitrinite in Cretaceous shale xenoliths in DO18 kimberlite and %Ro of vitrinite in Tertiary woods altered during emplacement of Nancy kimberlite pipe (Nancy data from Stasiuk et al., 1999).

The levels of thermal maturity and lack of any anomalous thermal alteration in shale xenoliths used for vitrinite reflectance measurements are also corroborated by fluorescence microspectrometry of dinoflagellate, sporinite, and pollen macerals (Fig. 2). The levels of

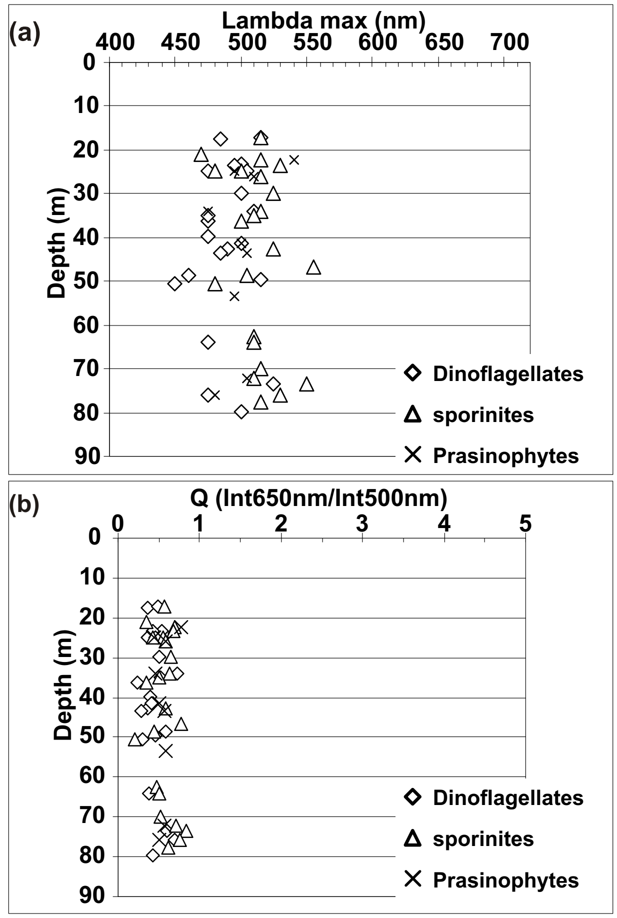

Figure 2. VIS fluorescence microspectrometry data for DO18 kimberlite showing lambda max (a) and Q (b) versus depth for sporinite, dinoflagellates and prasinophytes (marine alginite) in Cretaceous shale xenoliths.

thermal maturity and lack of any anomalous thermal alteration of organic matter in the Cretaceous xenoliths are supported by Tmax temperatures from Rock-Eval pyrolysis experiments. Average Tmax pyrolysis temperature of 414 °C for organic matter in shale xenoliths in the DO-18 kimberlite (Fig. 3) is consistent with vitrinite reflectance of 0.25 to 0.40 %Ro.

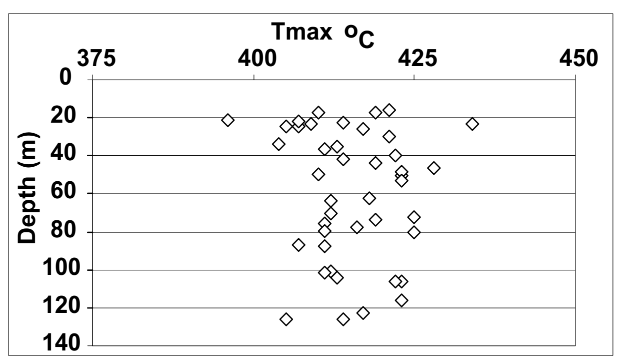

Figure 3. Rock-Eval pyrolysis data for shale xenoliths in DO18 kimberlite showing relationship of Tmax (°C) and depth.

Porosity measurements on unaltered Cretaceous shale xenoliths from a number of localities average 26 % (Fig. 4a), which is consistent with a maximum burial depth of ~ 1.5 km (Fig. 4b) prior to incorporation into the kimberlites based on comparison with data collected in Tertiary and Cretaceous strata, Beaufort-Mackenzie basin.

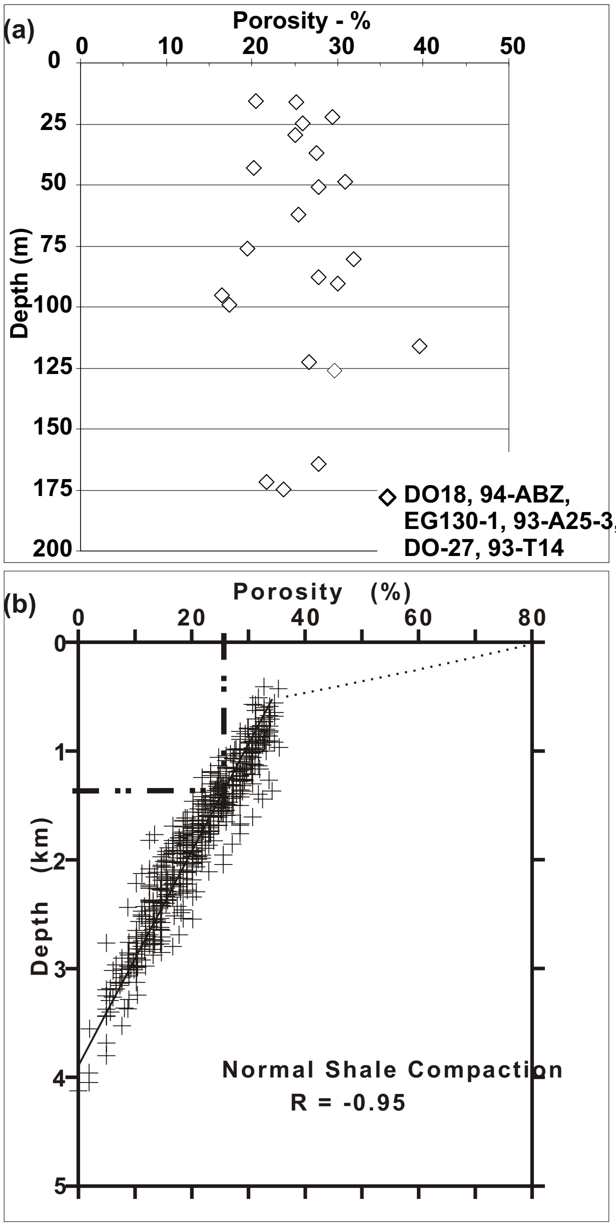

Figure 4. (a) Per cent porosity of shale xenoliths from a number of kimberlite occurrences versus depth including data from DO18. (b) Depth versus per cent porosity data for Tertiary and Cretaceous strata from Beaufort-Mackenzie delta, Northwest Territories, Canada (from Issler, 1992). Dashed lines extending from the x and y axes to porosity-depth trend of Beaufort-Mackenzie represent average porosity of shale xenoliths from DO18 kimberlite and extrapolation of this mean value in terms of maximum burial depth of Tertiary - Cretaceous strata in Beaufort-Mackenzie delta.

If one assumes an average geothermal gradient of 25-30 °C/km in the Lac de Gras region during Cretaceous deposition, a maximum temperatures of ~ 35-45 °C would be very close to the temperature required to reach thermal maturity levels equivalent to average vitrinite %Ro values between 0.25 and 0.30. Thus, it is proposed that ~ 1.5 km of Cretaceous strata were present in the Lac de Gras region prior to major uplift and erosion, although most was likely removed prior to ~73 Ma.. Thermally unaltered vitrinite in early-late Paleocene to middle Eocene sediments have average values ranging from 0.15 to 0.20 %Ro, suggesting insignificant post-emplacement burial (~ < 200-500 m).

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