

PALEONTOLOGY AND DIAMONDS: GEOLOGICAL ENVIRONMENTS ASSOCIATED WITH KIMBERLITE EMPLACEMENT, LAC DE GRAS, NORTHWEST TERRITORIES, CANADA

Sweet AR¹, Stasiuk LD¹, Nassichuk WW¹, Catuneanu O², McIntyre, DJ³

¹Natural Resources Canada; ²University of Alberta, Canada; ³Manuka Palynologic Consulting, Canada

ABSTRACT

Abundant fossil spores, pollen and marine algal cysts from individual shale xenoliths and finer clastic matrix in kimberlite samples allow the determination of depositional environments and ages of rock units in the inferred but now eroded cratonic sedimentary cover. Through analysis of depositional environments it is quite clear that the interior seaway extended over the craton in the early Late Cretaceous and again, at least partially, in the late Campanian, but by the Maastrichtian it had withdrawn, leaving a terrestrial landscape into which most Lac de Gras kimberlites erupted. The ages allow correlation of sequences in the Lac De Gras region with those of western Canada. Plant microfossils characteristic of latest Turonian through early Campanian, latest Campanian through early Maastrichtian, and late Paleocene ages have not been confirmed in the Lac de Gras xenoliths suggesting depositional hiatuses occurred within the now eroded sedimentary cover. During some of these times, erosion may have been removed strata leaving behind only enhanced thermal maturity profiles as a signature of their former presence. The synchronicity between the emplacement of the Greenland mantle plume and the concentration of kimberlite eruptions in the late Paleocene and earliest Eocene is discussed.

INTRODUCTION

Shale and mudstone xenoliths in the crater fill of kimberlite pipes in the Lac de Gras area (Fig. 1) contain a record of a now eroded sedimentary cover. Microscopic plant fossils (miospores and dinoflagellates) provide: 1) the ages of rocks in the pre-eruptive sedimentary cover, 2) inferences of maximum ages for kimberlite emplacement; and, 3) the interpretation of depositional environments. From such evidence Nassichuk and McIntyre (1995, 1996) and Nassichuk and Dyck (1998) determined that pre-eruptive strata included marine Albian to Maastrichtian rocks and nonmarine Paleocene rocks and concluded that the Interior Seaway had extended farther eastward than previously thought. Similar conclusions were reached by Doyle et al. (1998), Graham et al. (1998), McKinlay et al. (1998).

This study builds on the previous work with the objectives of: 1) recognizing major hiatuses that reflect uplift events; 2) correlating Lac de Gras area stratigraphy with Cretaceous and

Paleogene successions regionally in order to provide an analog for probable thickness of the Cretaceous and Paleocene sedimentary cover over the Slave Province; 3) illustrating the paleogeographic and phytogeographic implications of the xenoliths preserved in kimberlites of the Lac de Gras region; 4) discussing tectonic mechanisms involved in base level changes and the regional geological context during kimberlite emplacement.

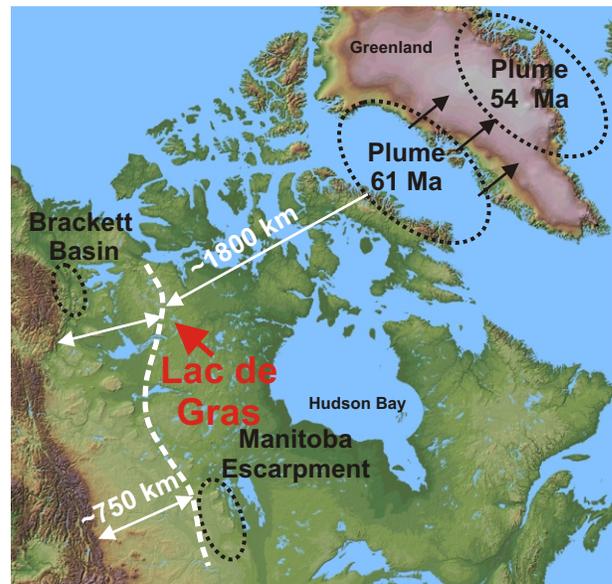


Figure 1. Local locality map showing a equal-distance trace (white dashed line) following the orogenic outline, and the position of mantle plumes during the late Paleocene and early Eocene.

Materials and Methods

The absolute ages used herein are approximated from Berggren et al. (1995). The palynological component of this study is based on samples from 9 different craters (DO18-08, DO18-12, DO18-13, EG-130-1, 93-A25-1B, 94-ABZ-1, 93-T14-1, and ECH95-16 (Scorpion) and 35 samples from post-eruptive sediments (BHP bore holes "Giraffe pipe; CH93-29; CH93-13; KBS-3). Paleoenvironmental interpretations based on the microfossils present are complemented evidence from the types of kerogen present.

INFERRED CHRONOLOGICAL UNITS AND PALYNOLOGICAL ASSEMBLAGES

Middle to Late Albian Age (~100-105 Ma)

Two samples from the DO18-12 bore hole contained rich assemblages of terrestrial spores (including *Concavissimisporites punctatus*, *Concavissimisporites variverrucatus*, *Cooksonites*, *Distaltriangulisporites* spp., *Kuylisporites lunaris*, *Lycopodiumsporites expansus*, *L. marginatus*, *Sestrosporites pseudoalveolatus*, *Tigrisporites scurrandus*, *T. reticulatus*, *Trilobosporites humilis* and *T. trioreticulosus*), gymnosperm pollen (including *Nicholsipollis mimas*, *Rugubivesiculites microsaccus* and *R. rugosus*) and monocolpate and tricolpate angiosperm pollen, and few to numerous marine algae (including *Luxadinium propatulum*, *Ovoidinium scabrosum* and *Gingiodinium evitii*). A marginal marine to near-shore marine depositional environment is inferred, implying both the eastward extension of the Mowry Sea (Williams and Stelck, 1975) into the Lac de Gras region (Fig. 2), and a proximity to land.

Early? to Mid Cenomanian? (~95-98? Ma)

Several samples in the DO18-08 and DO18-12 bore holes contain a generalized spore and pollen assemblage and dinoflagellates that do not allow recognition of subdivisions within the Cenomanian or even between the late Albian and Cenomanian. The precise age of these samples is therefore inconclusive leaving open the possibility that this chronological interval spans a hiatus (Fig. 3).

Mid Cenomanian? to Turonian (~90-95 Ma)

Mid Cenomanian to Turonian assemblages occur in all the kimberlitic bore holes and in the majority of the samples. The assemblages are rich in marine algae (including *Chatangiella ditissima*, *Heterosphaeridium difficile*, *Isabelidinium magnum* and *Trithyrodinium suspectum*), and consistently contain *Rugubivesiculites* “tuberculate” and tricolporate angiosperm pollen. The abundance and diversity of dinoflagellates and the dominance of lipid-rich amorphous kerogen indicates open and deep marine waters implying the transgression of the

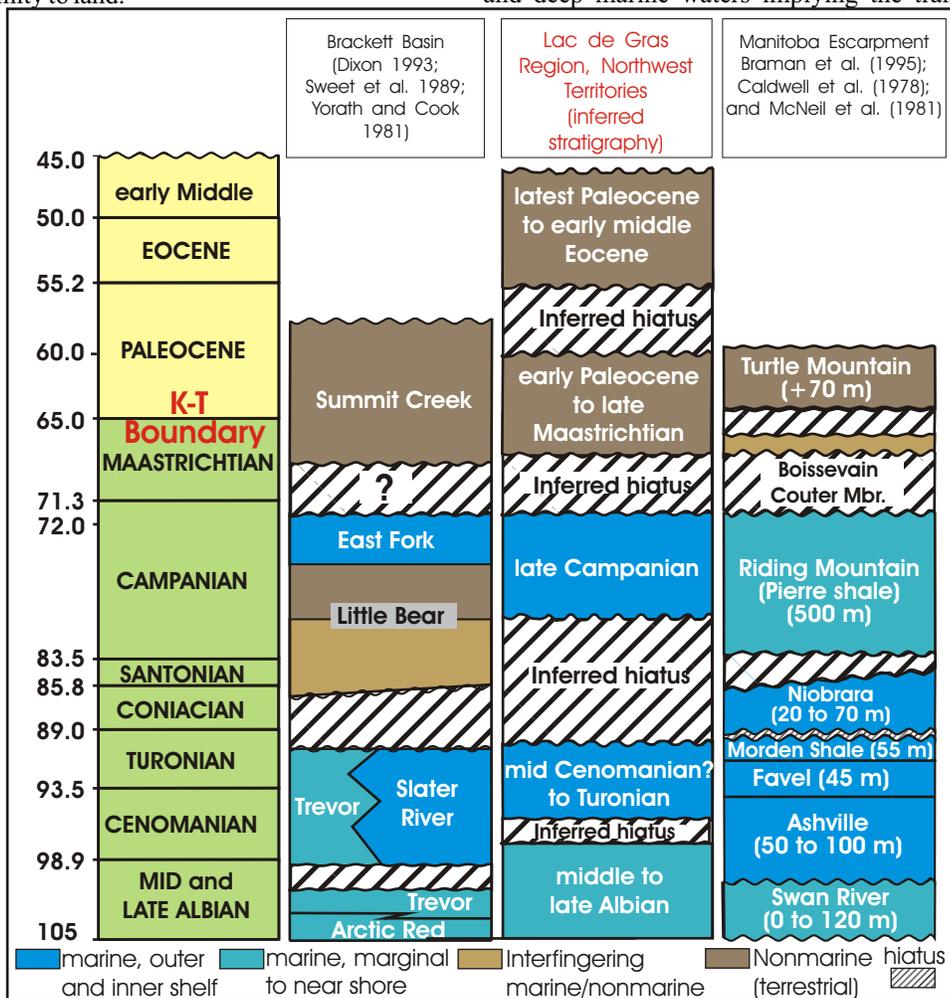


Figure 2. Time scaled, lithostratigraphic sections for the Brackett Basin, Manitoba Escarpment and that inferred for the Lac de Gras region. Unit thicknesses have been included on the Manitoba Escarpment section as it is a similar distance from the orogen as Lac de Gras.

continental seaway over the northwestern part of the craton during this time (Fig. 2).

Late Turonian?, Coniacian, Santonian and Early Campanian (~80-90 Ma)

Assemblages identifying these ages were not encountered and it is possible that this absence is indicative of a significant hiatus (Fig. 2).

Late but not Latest Campanian (~73-80 Ma)

Two samples from near the base of EG-130-1 bore hole are rich in both angiosperm pollen (including *Aquilapollenites* sp. Cf. *A. Trialatus*, *Expressipollis*, *Fibulapollis*, *Loranthacidites pilatus*, *Pseudoplicapollis* and *Translucentipollis*) and marine algae (including *Chatangiella ditissima*, *Dinogymnium sibiricum*, *Fromea chytra*, *Horologinella* sp., and *Laciniadinium williamsii*), which indicate a late Campanian age. The angiosperm pollen are allied with those in correlative strata in the Anderson Plains (McIntyre, 1974) and the Arctic Islands (Felix and Burbridge, 1973). The late Campanian interior seaway presumably restricted pollen input from the west and southwest leaving emergent land to the north and northeast as the source area. The upper age limit on this assemblage is then constrained by the timing of the withdrawal of the interior seaway.

Latest Campanian to Early Maastrichtian (73 to 69 Ma)

A number of species (*Aquilapollenites augustus*, *A. oblatius*, *A. quadrilobus*, *A. reticulatus*, *Callistopollenites radiostriatus*, *Cranwellia rumseyensis*, *Kurtzipites trispissatus*, *Liliacidites complexus*, *Orbicularpollis lucidus*, *Pulcheripollenites krempi*, *Tripogonites magnus*, *T. unicus* and *Wodehouseia gracile*), known from both the Maastrichtian and early late Maastrichtian, occur together with the definitive late Maastrichtian taxa listed below. As none of these are specifically indicative of a latest Campanian or early Maastrichtian age, it might be assumed that a hiatus occurred during all or most of this time (Fig. 2).

Late Maastrichtian to Early Paleocene? (61 to 69 Ma)

The major pollen and spore component of seven samples from the EG-130-1, 94-AB2-1 and 93-T14-1 bore holes is typical of late Maastrichtian sediments in the Western Canada and Brackett basins (includes *Aquilapollenites conatus*, *A. delicatus?*, *A. reductus*, *Cranwellia* sp. (5 colps), *Ephedripites multipartitus*, *Mancicorpus notabile*, *Myrtipites scabratus*, *Porosipollis porosus*, *Tripogonites plektosus*, *Wodehouseia octospina*, and *Wodehouseia spinata*). This change to a western or southwestern pollen source is consistent with a latest Campanian/early Maastrichtian interior seaway withdrawal. A few taxa, *Alnipollenites*, Betulaceae pollen and *Paraalnipollenites alterniporus* suggest that clasts of early Paleocene age are also present. Recycled Cretaceous spores

and dinoflagellates, Permo-Triassic pollen and Carboniferous spores are commonly present.

Late Paleocene (56 to 61 Ma)

A hiatus is inferred for this time (Fig. 2), as unambiguous late Paleocene assemblages were not identified.

Post-eruptive Latest Paleocene? to Mid Eocene (~45-56 Ma)

Angiosperm pollen assemblages from the BHP bore holes "Giraffe pipe" ; CH93-29, CH93-13 and KBS-3 record the post-eruptive phase of crater fill. Nassichuk and McIntyre (1995) reported late Paleocene ages from the three latter bore holes, which is now revised to early Eocene based on the finding of *Platycaryapollenites swasticoidus* and a gemmate monolete spore, both indicative of Eocene. More recently a well developed late early Eocene and/or early middle Eocene terrestrial pollen and spore assemblage has been documented from bedded lacustrine and swamp, post-eruptive crater fill sediments (see Hamblin et al., 2003, this volume).

GEOLOGICAL CONTEXT FOR THE POST-ERUPTIVE SEDIMENTARY COVER

A pattern of base level change during deposition of the sedimentary cover in the Lac de Gras region can be inferred from the ages and depositional environments recorded by palynological assemblages and kerogen types (Fig. 2). For comparison, and to place the interpreted sequences into a regional context, the Albian through Paleocene sequences along the Manitoba Escarpment and contemporaneous sequences in the Brackett Basin are also illustrated (Fig. 2). The Manitoba Escarpment is more or less along depositional strike and the Brackett Basin is up depositional dip from Lac de Gras (Fig. 1). The total maximum thickness of the succession along the Manitoba Escarpment is approximately 1000 m. This thickness is of the order necessary to achieve the thermal maturity of Albian and early Late Cretaceous sediments in the Lac de Gras area (see Stasiuk et al., 2003, this volume).

Several of the hiatuses in the Manitoba Escarpment and Brackett Basin successions are in comparable positions to those inferred for the interpreted sedimentary cover in the Lac de Gras area (Fig. 2). Exceptions are the presence of a late late Maastrichtian to earliest Paleocene hiatus in Manitoba and a much more extensive latest Turonian to early Campanian hiatus inferred for the Lac de Gras region. This latter hiatus may well represent a time when accumulated sedimentary cover, which left its mark by the elevated thermal maturity of Albian and early Late Cretaceous sediments, was partially removed. Equally, younger hiatuses may also represent times of partial removal of accumulated sedimentary cover.

Notwithstanding these probable erosional events, there were at

least four Late Cretaceous rock sequences still present in the early Tertiary. If one were to take the number of samples with assemblages assignable to specific chronological units as an indication of their relative thickness, late Cenomanian to Turonian sediments would be by far the thickest and Albian and late Campanian sediments the thinnest. In addition, the proportions of various aged clasts in different pipes and/or bore holes varies. The dominant assemblages in the EG-130 and A2 holes are of late Maastrichtian/Paleocene age whereas those from DO18, T14 and A25 are of Albian and/or Cenomanian/Turonian age. This suggests that there may have been corresponding variations in the sedimentary cover over the Lac de Gras area, either through differential erosional events or restricted areas of deposition.

LARGE AMPLITUDE REGIONAL CONTROLS ON BASE LEVEL CHANGES

The formation of accommodation for the deposition of sedimentary stacks approaching 1500 m-thick (see Stasiuk et al., 2003, this volume) over what is now exposed craton requires the manifestation of continental scale subsidence of comparable magnitudes. The geographic position of the study area (Fig. 1), as well as the general stratigraphic and paleo-environmental similarities with the age-equivalent succession preserved in the Manitoba Escarpment (Fig. 2) argue that

the Lac de Gras region was once part of the same western Canada foreland system. Accommodation space in distal forelands, generally subject to flexural uplift of the forebulge, is attributed to subduction-related dynamic loading, which generates long-wavelength subsidence on continental scales (Mitrovica et al., 1989; Gurnis, 1992). Dynamic subsidence is documented to have been an important factor in the accumulation and preservation of relatively thick sequences in the distal part of the southern Canadian foreland system (Catuneanu et al., 1997), so it is likely that the same mechanism generated the inferred amount of accommodation in the Lac de Gras region. Changes in the amount of dynamic loading, as well as renewed flexural uplift of the distal foreland in relation to thrusting episodes in the Cordilleran belt, can explain the inferred stratigraphic hiatuses.

In addition to obvious regional extension, another tectonic factor may have affected the Lac de Gras area during late Paleocene and early Eocene time. Starting at about 61 Ma the emplacement of a plume in the vicinity of Baffin Island is evidenced by the initiation of uplift and volcanism followed by basalt flows and subsidence (Harrison et al., 1999). Plume driven uplift can occur at scale=s of 1000's of km, as can associated dikes (Harrison et al., 1999), well within the range of the Lac de Gras area, especially during the earlier phases of

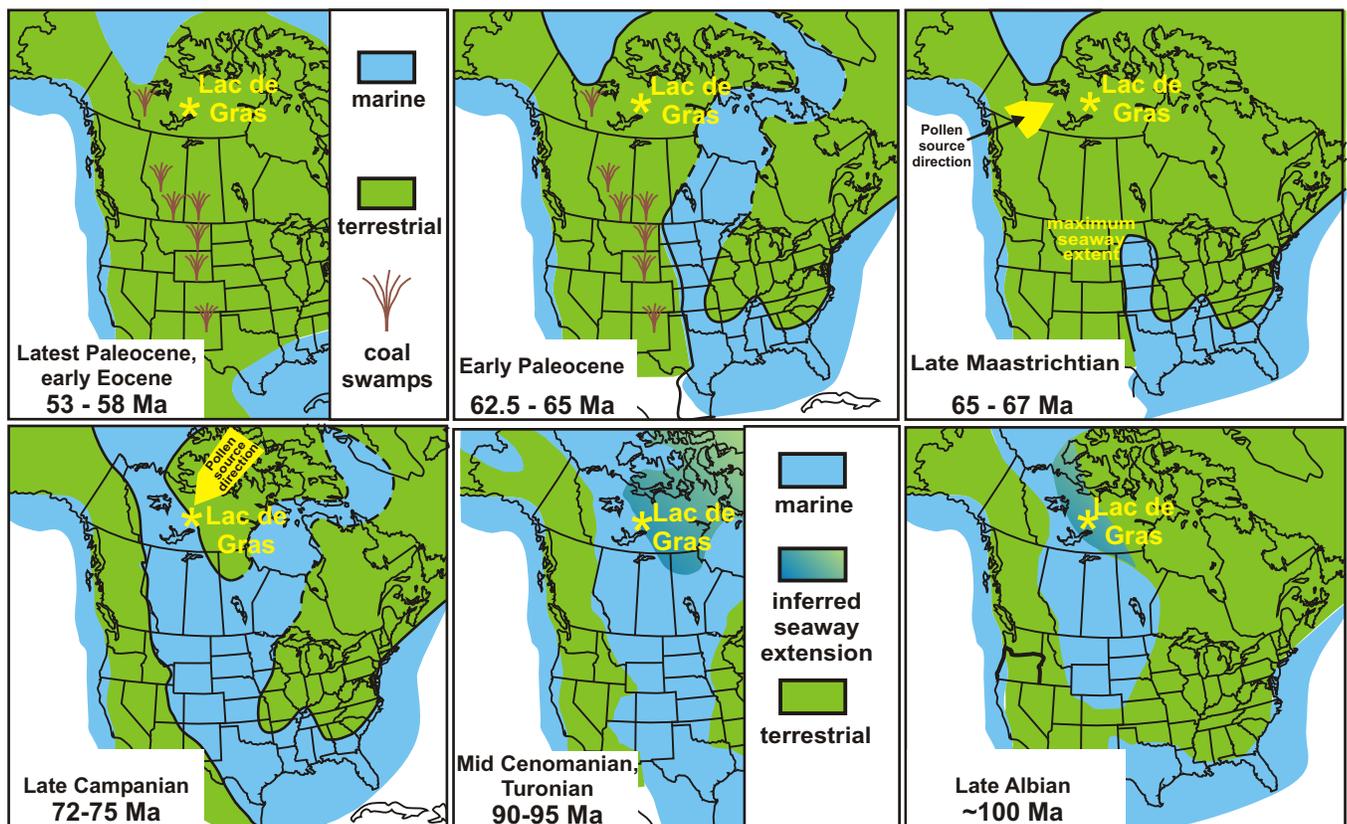


Figure 3. Paleogeographic maps for six time units mostly modified after Williams and Stelck (1975).

plume activity (Fig. 1). From 61 Ma to 54 Ma the position of the plume shifted to the eastern margin of Greenland. This timing of an active mantle plume under the Baffin Island/Greenland region corresponds with the inferred ages for many of the Lac de Gras kimberlites. Therefore, the late Paleocene-early Eocene interval seems to have been a time of tectonic instability dominated by continental scale plume-driven uplifts, which may explain the erosion of much of the distal foreland fill in the Lac de Gras region and the timing of kimberlite emplacement.

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- Arthur R. Sweet, Ph.D., Natural Resources Canada, 3303-33rd St NW, Calgary, Alberta T2L 2A7; asweet@NRCan.gc.ca