



# Palynology and geochemistry of channel-margin sediments across the tidal–fluvial transition, lower Fraser River, Canada: Implications for the rock record



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## ABSTRACT

In the tidally influenced Fraser River, Canada, palynological and carbon isotope ( $\delta^{13}\text{C}_{\text{org}}$ ) signatures of channel-margin sediments are compared to environmental parameters (e.g., grain size, water salinity) to establish how the signatures vary across the tidal–fluvial transition. Palynological assemblages in the Fraser River are dominated by tree pollen, which constitutes between 85% and 95% of all assemblages. Dinocyst abundances do not exceed 2% of the total palynological assemblage, and the number and diversity of dinocysts gradually decreases landward. The calculated landward limit for dinocysts is at approximately 83 river km, which is relatively close to the upstream limit of the tidal backwater (at  $\sim 100$  km).  $\delta^{13}\text{C}_{\text{org}}$  values show minimal variability across the tidal–fluvial transition, and the average value is approximately  $-26\text{‰}$ . The  $\delta^{13}\text{C}_{\text{org}}$  signature of river sediments indicates a dominance of terrestrially sourced organic matter regardless of brackish-water and tidal influence on sediment deposition.

Six palynological and geochemical trends are identified as relevant to the rock record. 1) In deltaic environments, palynological and geochemical characteristics are less useful than sedimentological and ichnological characteristics for establishing depositional conditions. 2) In marginal-marine settings, low abundances and low species diversities of dinocysts, coupled with a “terrestrial” geochemical signature ( $\delta^{13}\text{C}_{\text{org}} < -25\text{‰}$ ) do not necessarily indicate deposition in a terrestrial environment. 3) Dinocyst abundances above 1% of the total palynomorph population can indicate a significant marine influence on sediment deposition. 4) Mud beds, preferably bioturbated, should be preferentially sampled in order to maximize palynomorph recovery. 5) Marine palynomorphs can occur, albeit in very low concentrations, to the landward limit of the tidal–backwater zone. 6) Palynological and geochemical data should be compared across the paleo-depositional environment in order to establish general trends and remove local variations caused by biases such as grain size.

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## 1. Introduction

Palynology is recognized as a valuable tool for refining paleo-environmental interpretations of ancient sedimentary deposits. This is because palynomorphs are ubiquitous in marine and continental settings, can be transported significant distances into connected water bodies, and most importantly, have high preservation potential owing to the chemically and erosively resistant

composition of their outer walls (e.g. Dale, 1983; de Vernal et al., 2001; de Vernal et al., 1998; Mudie and Harland, 1996; Wall and Dale, 1966). The deposition of allochthonous palynomorphs in marginal-marine settings such as estuaries and deltas provides a mechanism for differentiating continental, transitional (i.e., brackish-water), and fully marine deposits (Loboziak et al., 2005; MacDonald, 1990). In addition, when palynomorph distributions are compared to the corresponding carbon isotope values for organic carbon ( $\delta^{13}\text{C}_{\text{org}}$ ) in the same deposits, there is greater certainty in differentiating the relative position of sediment deposition along the continental-to-marine continuum. At present, there is a paucity of research that demonstrates the integration of palynology

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and geochemistry to better resolve the interplay of fluvial and marine influences on sediment deposition in tidal–fluvial channels. To address this apparent lack of data, palynomorph and carbon isotope data were acquired from the tidally influenced Fraser River and delta in British Columbia, Canada, and compared to sediment grain size, water salinity, and channel position (distance upstream). These data are then used to define and quantify how palynological and geochemical signatures vary in sediments across the tidal–fluvial transition (TFT).

Palynological assemblages include grains that are deposited near the site of origin (autochthonous), as well as those that have been entrained in wind or water and transported from another location (allochthonous; e.g. Hutchinson et al., 1998). Palynological assemblages can, therefore, comprise grains supplied from markedly different depositional settings and provide an observable connection between these environments. In continental settings, dispersal mechanics of spores and pollen are dictated by the evolutionary strategy of the source flora. For example, anemophilous (wind-disseminated) pollen is over-produced by plants to ensure a higher probability of successful transport and reproduction (MacDonald, 1990). The over-production of pollen coupled with effective transport commonly results in an over-representation of anemophilous microflora in both marine and continental palynological assemblages.

The presence of continental, low-salinity, and marine palynomorphs can vary as a function of marine influence; hence, the relative proportions of these microflora have been used to make inferences regarding the hydrodynamic conditions controlling sediment deposition in ancient marginal-marine settings (Demchuk et al., 2008). The distribution of palynomorphs in sediment is dependent on the physical properties of the grains such as size, specific gravity, and shape, as well as environmental conditions that include depositional energy and fluid dynamics (e.g. Davis and Brubaker, 1973; Muller, 1959; Tett et al., 1993; Timothy and Soon, 2001). In general, palynomorphs have depositional characteristics similar to silt-sized particles because most palynomorphs range between 20 and 60  $\mu\text{m}$  in diameter (Anderson et al., 1985; Dale, 1976, 1996; Kapp et al., 2000; Mudie et al., 2002; Rochon, 1999; Zonneveld and Brummer, 2000). Furthermore, palynomorphs tend to sort with comparatively smaller mineral grains because their specific gravities ( $\sim 1.4$ ) are lower than that of mineral matter ( $\sim 2.65$ ; Traverse, 1999).

Stable carbon isotope geochemistry is routinely employed to complement palynological studies, and is used to resolve the provenance of organic matter in marginal-marine systems (Chmura et al., 2004; Limoges et al., 2010; Pospelova et al., 2002; Thornton and McManus, 1994). Isotopic carbon ( $\delta^{13}\text{C}_{\text{org}}$ ) signatures are attributed to differences in photosynthetic efficiencies of primary producers. Isotopic fractionations of primary producers vary with respect to environmental conditions, and therefore the isotopic signature of organic material can be used to infer the provenance of that material. For example, terrigenous plants have an isotopically lighter signature than marine plants owing to increased carbon fractionation in the atmosphere. Conversely, marine autotrophs discriminate less against  $^{13}\text{C}$  due to the slower diffusion of  $\text{CO}_2$  in seawater, resulting in isotopically heavier signatures (e.g. Lucas and Berry, 1985; O'Leary, 1981).

Dinoflagellate cyst (dinocyst) assemblages have been used in paleoenvironmental studies to determine past sea-surface temperature, sea-surface salinity, primary productivity, sea-ice coverage, and coastal proximity (e.g. Dale, 1996; de Vernal et al., 2001; Ellegaard, 2000, 2006; Holzwarth et al., 2007; Limoges et al., 2010; Marret and Zonneveld, 2003; Pospelova et al., 2008; Rochon, 1999; Verleye and Louwye, 2010; Zonneveld et al., 2013). Studies of modern dinocysts have demonstrated that sea-surface temperature,

sea-surface salinity, availability of nutrients, and pollution levels are major factors controlling cyst distributions (e.g. Blanco, 1995; de Vernal and Giroux, 1991; Krepakevich and Pospelova, 2010; McMinn, 1989, 1991; Mudie and Short, 1985; Pospelova et al., 2004, 2005; Pospelova and Kim, 2010; Radi et al., 2007; Richerol et al., 2012), and that cyst assemblages reflect hydrographic conditions even at small spatial scales (Pospelova et al., 2004, 2005). For example, Pospelova et al. (2002) suggested that dinocyst distributions differ by environment, particularly for estuarine environments (e.g. fjords, embayments, lagoons, and river-dominated estuaries), largely because the primary mechanisms that influence phytoplankton production such as flushing rate, salinity, and light regime, vary with estuarine hydrography (Boynton et al., 1982). Only a few studies have focused on dinocysts in river-dominated systems (Bouimetarhan et al., 2009; Dale et al., 2002; Marret et al., 2004; Matsuoka and Shin, 2010; Radi et al., 2007; Richerol et al., 2012; Wang et al., 2004; Zonneveld et al., 2009) and none of them discuss dinocyst distributions across the TFT. In general, absolute abundances of dinocysts in estuarine waters range from less than 100 to over 30 000 cysts  $\text{g}^{-1}$  of sediment, and they decrease with proximity to fluvial point sources (Marret, 1994).

In the rock record, such as in the Early Cretaceous McMurray Formation, the extent of marine influence on sediment deposition in tidal–fluvial channels remains an ongoing source of debate (e.g., Hein et al., 2001; Ranger and Pemberton, 1997). This is because sedimentological and ichnological evidence suggests a brackish-water/estuarine depositional environment (Rennie, 1987), while the sediment is generally bereft of marine palynomorphs (Flach and Mossop, 1985). Demchuk et al. (2008), Michoux (2002), and Hubbard et al. (2011) reported that assemblages of land-derived plants, specifically bisaccate (conifer) pollen and trilete (fern and moss) spores, dominate the palynoflora. They also identified a minor planktonic fraction of freshwater, brackish-water, and marine-derived dinocysts that typically comprise 1%–3% (up to 10%) of the palynological assemblage (Demchuk et al., 2008; Hubbard et al., 2011). Based on observations of dinocyst abundance, diversity, and distribution in the ancient estuarine valley-fill deposits of the McMurray Formation, the interpreted depositional environment is that of a low-salinity, fluvial-dominated environment with some marine influence (Demchuk et al., 2008; Hubbard et al., 2011; Michoux, 2002).

A few recent palynological studies in the Strait of Georgia (SoG) were focused primarily on understanding the ecology of dinocysts and observing annual variations in populations with respect to environmental conditions and food availability (Pospelova et al., 2010; Price and Pospelova, 2011; Radi et al., 2007). These studies have identified a dominance of cysts of heterotrophic taxa in the spring, coinciding with annual blooms in their primary food source – diatoms. Prodeltaic sediments of the Fraser River Delta predominantly contain terrestrially derived palynomorphs (e.g. pollens and spores), and subordinate, autochthonous populations of marine dinoflagellates (Hutchinson et al., 1998). Radi et al. (2007) observed that dinocyst concentrations in the SoG range from 200 to 13 000 cysts  $\text{g}^{-1}$ , with an average of  $\sim 3000$  cysts  $\text{g}^{-1}$ . The diversity of taxa in each sample varied from 9 to 22. Despite extensive studies in the subtidal zones of the Fraser River Delta, there is little information available regarding microfaunal and palynological assemblages in channel sediments of the tide-influenced, brackish-water, and freshwater reaches of the Fraser River itself. Hutchinson et al. (1998) observed that channel banks contain palynomorphs derived from riparian woodland biota, including alders, spruces, and ferns. They also noted that the delta-plain/tidal-flat assemblages contain allochthonous deposits of fresh and fresh-to-brackish palynomorphs derived from distributary channel margins and brackish-water marshes (Hutchinson et al., 1998).

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