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Triggers for Organic Matter Accumulation in the Middle and Upper Devonian Horn River Shale, Canada, Identified from Microsampling of Drill Cores

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Summary

Organic matter (OM) enrichment is mainly controlled by productivity, redox conditions and dilution. However, these parameters also affect each other in ways that often conceal the factor actually triggering OM burial. At the scale we commonly sample drill cores, interplays or feedback loops between productivity and redox controls commonly result in apparently synchronous variation in proxies for these parameters. For example, shifts to both higher productivity and more anoxic conditions may be indicated at points in a shale formation where total organic carbon (TOC) increases. Our research applied chemical analysis at 1 – 2 mm stratigraphic resolution to directly distinguish triggers for organic richness of Horn River Shale, Horn River Basin, Western Canada Sedimentary Basin.

Theory and Method

OM is oxidized and decayed as it sinks from the ocean surface to seafloor in normal oxic marine environment. However, reducing environment can preserve OM during deposition and nutrients in water cycles to control organic richness. On the other hand, even in a normally oxygenated marine water column, high primary productivity can provide enough organic matter for OM enrichment in black shales. In some cases, dilution also controls OM burial. Increased transport of terrigenous sediment to seafloor and enhanced burial efficiency can decrease the duration of OM contacting oxygen and therefore enhance OM accumulation but excessive detritus, in turn, will dilute OM concentration. These models are summarized in Katz (2005) and Tyson (2005).

Some elements are sensitive to the redox conditions change and can be applied as proxies to reconstruct oxygen level at the time of sediment deposition. S/Fe and Fe/Al are commonly used as redox conditions proxies (Raiswell et al., 2018; Ross & Bustin, 2009); biogenic silica has been applied as a proxy for bioproductivity (Schieber et al., 2000). The thermal maturation of Horn River Shale is within the gas window, TOC reflects relative initial organic carbon richness before thermal loss during late diagenesis. Therefore, we apply TOC to reflect OM accumulation, biogenic Si for productivity, S/Fe with Fe/Al for redox conditions, and Al, K, Ti, and Ca for dilution.

Feedback loops during OM deposition between productivity and redox conditions exist. The organic matter generated during higher bioproductivity can consume oxygen as it sinks to the seafloor; thus, bottom waters may become anoxic. On the other hand, anoxic bottom water can preserve dissolved nutrients to surface water, which, in turn, enhances primary productivity. At the scale we typically do our sample (1 m), feedback loops are hard to distinguish. Microsampling in our study can work so quickly and high-resolution that we can identify the leading trigger.

We study the Middle and Upper Devonian Horn River Group which includes the Muskwa Formation, Otter Park Member and Evie Member. We examined 28 core slabs from EOG HZ Tattoo D-A028-F/094-O-10 core, each representing 7 cm to 10 cm of vertical sections. For each core slab, we are building a high-resolution geochemical dataset including high-resolution inorganic geochemical analyses by benchtop EDXRF and high-resolution TOC analyses by hyperspectral imagery, supplemented and calibrated by whole rock geochemical analyses by ICP-MS and Leco TOC analyses. EDXRF obtains inorganic geochemical data with 1 – 2 mm vertical resolution, which we estimate is equivalent to approximately 32 – 88 yr and TOC is obtained from hyperspectral imagery (Rivard et al., 2018) with 0.8 – 1.5 mm vertical resolution, corresponding to approximately 26 – 66 yr.

Results

Geochemical analysis of the slab samples provides information on general distribution trends of productivity, redox conditions and dilution in Horn River Shale. Carbonate input is enriched in the Evie Member and terrigenous components (represented by aluminum concentration) are higher in the Otter Park Member, while the Muskwa Formation has the highest biogenic silica content (Dong et al., 2017). In high-resolution profiles based on EDXRF and hyperspectral imagery data, TOCs tracks consistently with biogenic Si or S/Fe in different parts of the section indicating productivity or redox controls affect organic richness. In some profiles, dilution predominates during OM burial usually demonstrated by abrupt shifts to higher Al concentration in some thin layers (less than 1 cm thick) with reducing TOC and biogenic Si concentration. At points in a shale section, Al concentration and ratios of K/Al and Ti/Al fluctuate sharply marking detrital sources change (Fig 1).

A comparison of biogenic Si and S/Fe also uncovers interplays between productivity and redox controls. In one example, biogenic Si concentration changes about 2 mm ahead (~ 64 – 88 yr) before S/Fe changes in profiles (Fig 2); this phenomenon coupled with good correlations between biogenic Si content and TOC and low Al concentration, indicates that productivity triggered OM deposition and influenced bottom water oxygenation (Fig 2). In another example (3275.75 – 3275.785 m in Fig 3), under reducing environment (S/Fe > 0.42), S/Fe changes 1.5mm (~ 48 – 66 yr) earlier than biogenic Si. In this example, development of reducing conditions was the trigger of the feedback by preserving nutrients to increase primary productivity; TOC shifts at the same points with S/Fe reflecting redox conditions as the control for OM burial. This is less common but effectively observed in intervals we analyzed.

Conclusions

Our results identify triggers among productivity, redox conditions and dilution for OM accumulation in different intervals of the Horn River Shale. Interplays between productivity and redox conditions are demonstrated, but different triggers for OM deposition predominate in different parts of the section.

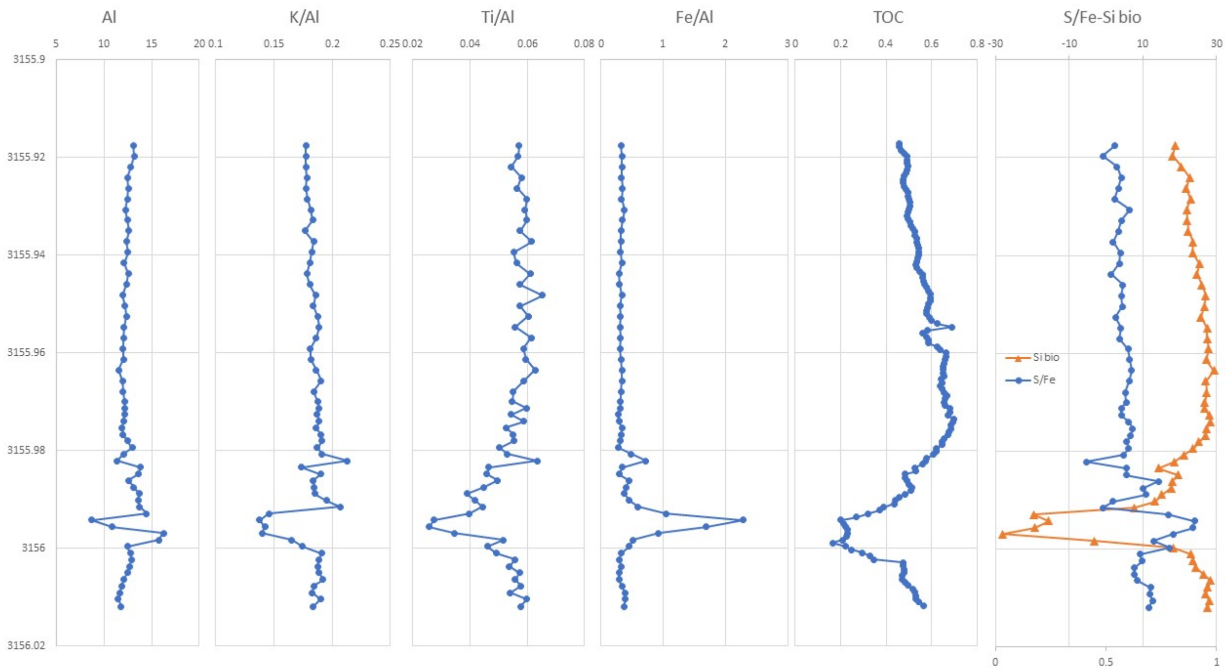

Figure 1. Profiles of Al, K/Al, Ti/Al, Fe/Al, TOC, S/Fe and biogenic Si for 3155.92 – 3156.012 m interval (Muskwa Formation). Si bio: biogenic Si.

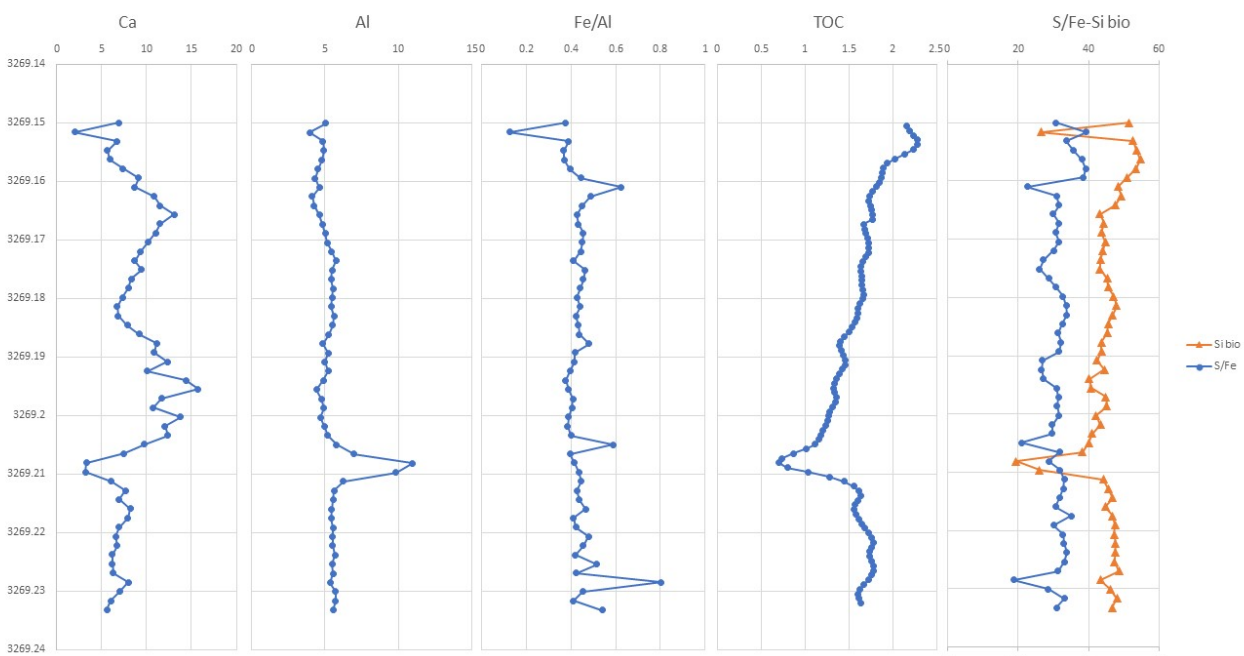

Figure 2. Profiles of Ca, Al, Fe/Al, TOC, S/Fe and biogenic Si for 3269.15 – 3269.233 m interval (Evie Member). Si bio: biogenic Si.

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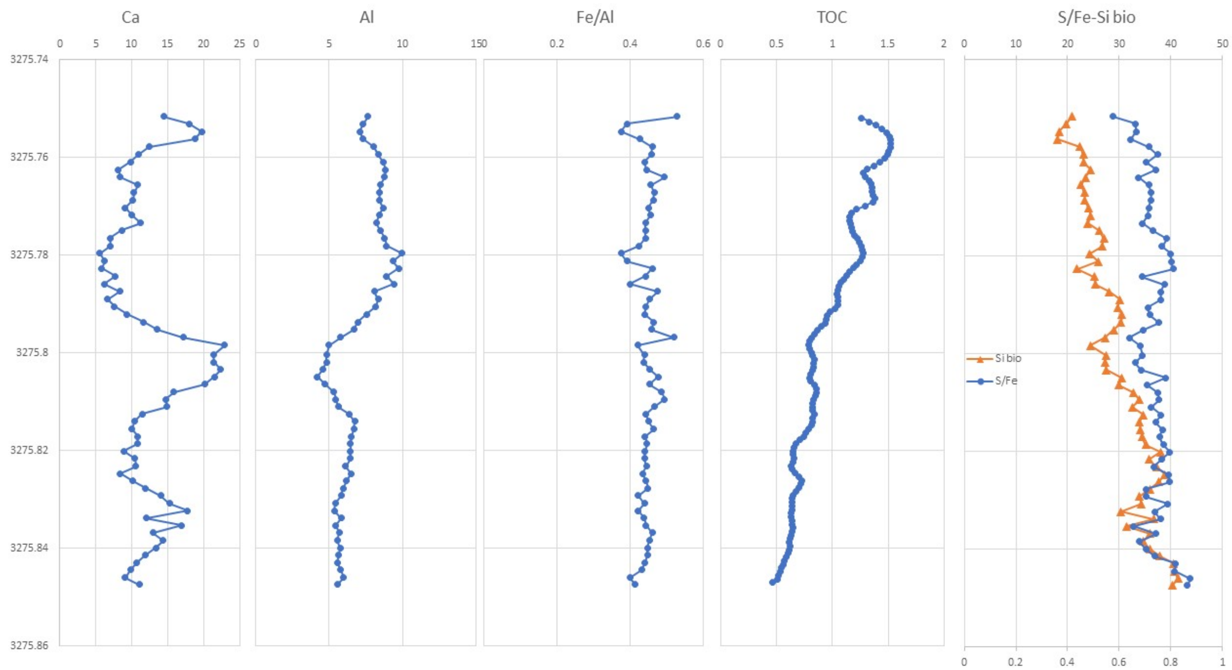

Figure 3. Profiles of Ca, Al, Fe/Al, TOC, S/Fe and biogenic Si for 3275.75 – 3275.85m interval (Evie Member). Si bio: biogenic Si. (Katz, 2005)

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