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The roles of pedogenesis and diagenesis in clay mineral assemblages: Lower Cretaceous fluvial mudrocks, Nova Scotia, Canada

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ABSTRACT

Clay mineral assemblages in alluvial mudrocks are important for paleoclimatic interpretation and for understanding burial diagenetic cementation in sandstones, but it is commonly difficult to unravel the relative importance of source weathering, pedogenesis and diagenesis in their origin. The clay mineral assemblages in fluvial overbank mudrocks from the Lower Cretaceous Chaswood Formation in central Nova Scotia, investigated by X-ray diffraction analysis of the <2 μm fraction of 45 samples, include kaolinite, illite, vermiculite, and mixed layer kaolinite/expandable clay and mica/vermiculite. The assemblages vary with depositional facies. Wetland organic-rich mudrocks have large amounts of amorphous material and kaolinite is the dominant clay mineral. In the eastern part of the basin, where overbank mudrocks were episodically uplifted by syn-sedimentary strike-slip faulting, cumulate ultisol and alfisol paleosols are common. In the ultisols, hematite is enriched and kaolinite increases at the expense of illite in the B horizon. Alfisols contain more illite and vermiculite and the B horizon is enriched in goethite. In the western part of the basin, where thin sandstones with abundant diagenetic kaolinite cement are interbedded with the mudrocks, the distinctive clay mineral assemblage of mica/vermiculite mixed layer, vermiculite with 15.5 Å peak, and kaolinite/expandable mixed layer clay with a 17.7 Å peak is interpreted to result from bacterially-mediated oxidation of organic matter below the paleo-water table during early burial diagenesis. Deeper burial diagenesis may lead to slightly higher kaolinite crystallinity. Volcanic ash appears to alter to kaolinite/expandable mixed layer clay with a 7.9 Å peak. Comparison with the continuously subsiding and rapidly accumulated Wessex Formation of southern England, formed at a similar paleolatitude, shows the strong role of pedogenic processes and early diagenesis by meteoric water in development of clay mineral assemblages in the locally tectonically uplifted Chaswood Formation.

1. Introduction

Clay mineral assemblages are important indicators of paleoclimatic conditions (e.g., Retallack, 1988; Lee et al., 2003). In fluvial mudrocks, this paleoclimatic signature may be complicated by segregation of minerals at different horizons in paleosols and masked by the effects of burial diagenesis. Clay mineral assemblages in mudrocks are also important for understanding the cementation history of sandstones during burial diagenesis (e.g., Worden and Morad, 2003).

This study takes advantage of a Lower Cretaceous fluvial succession in southeastern Canada, the Chaswood Formation, where previous work based on X-ray diffraction of bulk mudrock samples (Pe-Piper et al., 2005a) suggested that the mineralogy of mudrocks is influenced by weathering conditions in the source area, neoformation during soil development (pedogenesis), and burial diagenesis. The purpose of this study is to evaluate the relative importance of variation in depositional environment, pedogenic processes, diagenetic processes involving meteoric water, and deeper burial diagenesis in the development of the clay mineral assemblages. The clay mineral assemblages of the Chaswood Formation are compared to other Lower Cretaceous alluvial sediments and paleosols, in order to assess regional variability of controls on clay mineral genesis. The clay minerals present in the Chaswood Formation were characterised by using oriented mounts of the <2 μm fraction and interpretation of pedogenesis was strengthened by use of bulk geochemical analyses.

The Chaswood Formation of southeastern Canada is a 200 m thick succession of loosely indurated fluvial conglomerate, sandstone, and mudrock of Valanginian to Albian age (Stea and Pullan, 2001; Falcon-Lang et al., 2007). It is the terrestrial equivalent of thick deltaic successions in the offshore Scotian basin (Fig. 1). Paleoclimatic reconstructions (e.g. Valdes et al., 1996; Hay et al., 1999) indicate that at that time, southeastern Canada was located at a paleolatitude of 30°–35°N, on the western side of a small Atlantic Ocean. The early to middle Cretaceous was a time of equable climates and generally high

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stands of sea level (e.g. Voigt et al., 1999). Oceanic marine anoxic events in the early Aptian and early Albian are related to short-lived warmer and more humid periods (e.g. Weissert et al., 1979). The overall climate at 20° to 40°N has been interpreted as monsoonal (Herrle et al., 2003).

Samples for this study were obtained from well-studied boreholes from the Elmsvale Basin of central Nova Scotia (Fig. 1). The <2 μm analyses were carried out on 45 samples representing the vertical and horizontal variability in mudrock facies in the Elmsvale Basin (Fig. 2). In addition, 22 new bulk mudrock samples from the reference borehole RR-97-23, combined with 13 bulk samples reported by Pe-Piper et al. (2005a), were analyzed for bulk mineralogy by X-ray diffraction and whole-rock chemistry, to further constrain mineral variation in paleosols.

2. Geological setting

2.1. Introduction

The Chaswood Formation is found principally in a few fault-bound basins in central Nova Scotia (Fig. 1). It is exposed in only two sand and gravel pits and one clay pit, and is largely known from boreholes. The Chaswood Formation unconformably overlies Carboniferous and Triassic strata. Deposition was synchronous with strike-slip faulting, basin formation, and uplift of horsts that shed local detritus (Pe-Piper and Piper, 2004). Syn-sedimentary tectonic deformation along strike-slip faults led to local uplift that created intraformational unconformities (Gobeil et al., 2006; Hundert et al., 2006). Sediment supply was from one or more rivers draining rocks of the Taconic orogen in northern New Brunswick, augmented by local detritus from horsts mainly in the Avalon terrane of southern New Brunswick and northern Nova Scotia (Pe-Piper and MacKay, 2006; Piper et al., 2007). The sediment supplied by these rivers was principally texturally mature and quartz rich, but with a variable component of locally-derived, texturally-immature sediment including lithic clasts, chlorite and feldspar. In addition, volcanic ash was an important sediment component at some stratigraphic horizons (Pe-Piper et al., 2006).

In the Elmsvale Basin of central Nova Scotia, the sedimentology and stratigraphy of a series of boreholes has previously been investigated in detail (Stea and Pullan, 2001; Pe-Piper et al., 2005a). Based on seismic-reflection profiles, four unconformity-bound seismic packets are recognised within the Chaswood Formation (Hundert et al., 2006). These packets provide a first order correlation between the boreholes, within which more detailed lithological correlation can be made (Piper et al., 2005).

Vitrinite reflectance Ro values are low (0.31±0.02%) in Packets II–IV of the upper part of the Chaswood Formation, but increase to 0.41–0.48±0.08% in the Packet I at the base of the formation (Davies et al., 1984; Stea et al., 1996). The present Chaswood Formation was buried by ~800 m of younger strata, based on the equilibrium moisture content of lignites in the Chaswood Formation (Hacquebard, 1984), apatite fission track data in underlying basement (Arne et al., 1990; Grist and Zentilli, 2003), and the presence of thick Upper Cretaceous–Paleogene strata above the Chaswood Formation equivalent rocks along strike in the Orpheus Graben (Fig. 1) (Wade and MacLean, 1990; Weir Murphy, 2004). The steep Ro gradient was the result of the hydrothermal circulation driven by early Albian volcanism, known

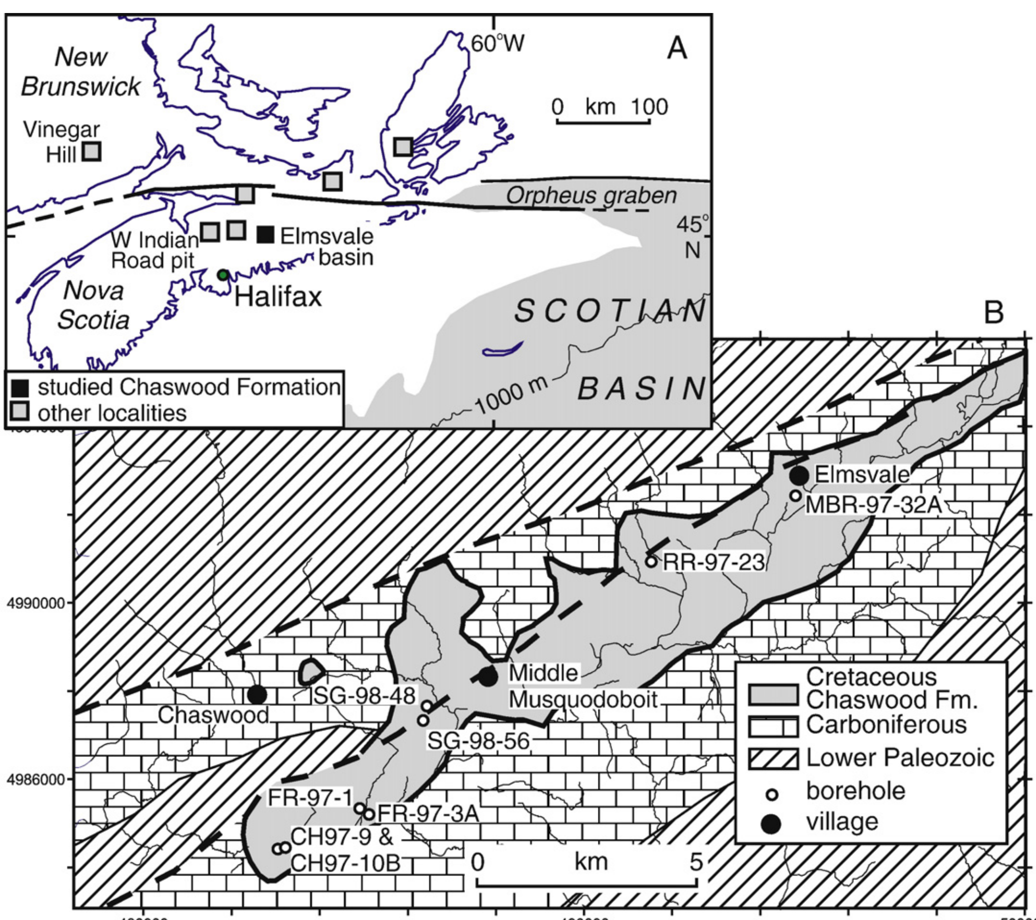

Fig. 1. (A) Regional map showing location of Chaswood Formation in southeastern Canada. (B) Detailed map showing location of studied boreholes of the Chaswood Formation in the Elmsvale Basin.