Sedimentary Record of Regional Tectonic Events in the Mahogany Oil Shale Zone of the Lacustrine Green River Formation (Eocene), in Colorado and Utah

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Summary

Laterally extensive syndepositional deformation features were investigated in the lacustrine Green River Formation (Eocene) across the Piceance Creek and Uinta Basins (Colorado and Utah, USA), specifically in the Mahogany Oil Shale Zone. This is an extensive stratigraphic marker interval that contains several organic-rich shale beds. Deformation structures are characterized by horizons with pervasive sedimentary injection features, sheared, brecciated and folded layers, as well as extensive mass-transport deposits. The style of deformation was governed by the rheological properties of the sediment. Their great lateral extent and confinement to a thin (20–30 m), well-defined stratigraphic interval indicates regional tectonic events ~49 Myr ago, which caused dewatering, hydrofracturing and lake-floor instability and slumping of low energy, profundal lacustrine deposits in different areas of the basins.

Introduction

The carbonate-rich sediments of the Green River Formation (Eocene; 53–43 Ma) were deposited in a complex lake system in present-day Wyoming, Colorado and Utah during the Laramide Orogeny (Dickinson et al., 1988; Smith et al., 2008). Lacustrine deposits of the Piceance Creek and Uinta basins accumulated in a large and long-lived lake, called Lake Uinta (e.g. Johnson et al., 2010; Tänavsuu-Milkeviciene & Sarg, 2012). The two basins are surrounded by active tectonic features related to Laramide uplifts (i.e. Uinta Uplift, Sevier Fold and Thrust Belt, Douglas Creek Arch, Axial Basin Arch, White River Uplift; e.g. DeCelles, 1994; Bader, 2008, 2009). These structures were active during deposition and influenced the basin shape, lake-floor gradients, and the distribution of sedimentary environments (Smith et al., 2008). Although syndepositional tectonic activity has been inferred previously for the Green River Formation, sedimentary deformation features linked to ancient earthquakes have never previously been studied. This study focuses on an extensive stratigraphic marker interval called the Mahogany Oil Shale Zone (MOSZ), which contains several organic-rich intervals in profundal carbonate mudstones and can be recognized and correlated across the Piceance Creek and Uinta basins (e.g. Bradley, 1931; Cashion, 1967; Cashion & Donnell, 1972; Remy, 1992; Smith et al., 2008).

Theory and Method

Sediments deposited in lacustrine environments are regarded as particularly suitable for the analysis of deformational structures induced by shaking during ancient earthquakes, termed ‘seismites’ (e.g. Rodríguez-Pascua et al., 2000; Moretti & Sabato, 2007). The heterolithic nature of these facies gives them a high susceptibility to deformation owing to their variable rheological properties, and deposition in an overall quiet-water environment eliminates other trigger agents (Sims, 1975; Renaut & Gierlowski-Kordesch, 2010). The stratigraphic and geographic distribution of such features can provide information about the location, timing, and intensity of the movements of structural elements in the study area (e.g. Weidlich & Bernecker, 2004; Marco & Agnon, 2005; El Taki & Pratt, 2012). Tectonic events, in turn, may have induced changes in the paleohydrology (e.g. Carrillo et al., 2006; Beck et al., 2007).

Outcrops and cores of the MOSZ were studied at several locations in the Piceance Creek and Uinta basins. Observed sedimentary deformation features were classified based on centimeter to decimeter-scale visual description and a combination of macroscopic and microscopic attributes, plus sedimentological analysis of the host strata.

Examples

Finely laminated lacustrine carbonates of the MOSZ were deposited in profundal environment (below the storm wave base), with negligible (<1°) slope. These strata host several, laterally extensive deformed horizons. Deformation style ranges from brittle (fragmented laminites, breccias, microfaulted beds) to plastic (convolution, folding), to fluidization and injection into centimeter- to metre-scale dikes (dewatering structures), and mass-transport deposits (Fig. 1A–F). Deformed layers are bound above and below by undeformed beds of similar facies and exhibit horizontal bedding plane surfaces, which imply short-lived, recurring events that affected only sediments with the appropriate rheological state at the time stresses were imposed. The presence of the undeformed beds enables autokinetic trigger mechanisms, such as internal and ordinary sedimentary and/or erosive processes, to be discarded. The style of deformation was governed by the rheological state of the sediment – original sediment properties plus any early lithification – while the degree of ductility in these profundal deposits was controlled mainly by the amount of organic matter.

Conclusions

Based on the tectonic setting of the basins, the sedimentary environment of the succession in which the deformation occurs, and the lateral extent of the affected beds, these structures are interpreted as the result of increased pore pressures from cyclic loading, combined with vertical and horizontal stresses induced by ground motion. Mass-transport deposits, contain mixed brittle-ductile structures, with complex folding and faulting, indicate seismically induced instability of the lake-floor. Consequently, the deformation features identified in the MOSZ reveal synsedimentary tectonic activity along nearby fault systems ~49 Myr ago. The stratigraphic distribution of seismites reflects variable timing of strong earthquakes. The occurrence of such features in an otherwise low-energy lacustrine environment is important for interpretation its sedimentological record in its near-field tectonic context. Seismites have yet to be fully appreciated as a critical link between deposition and tectonic activity in marine basins as well.

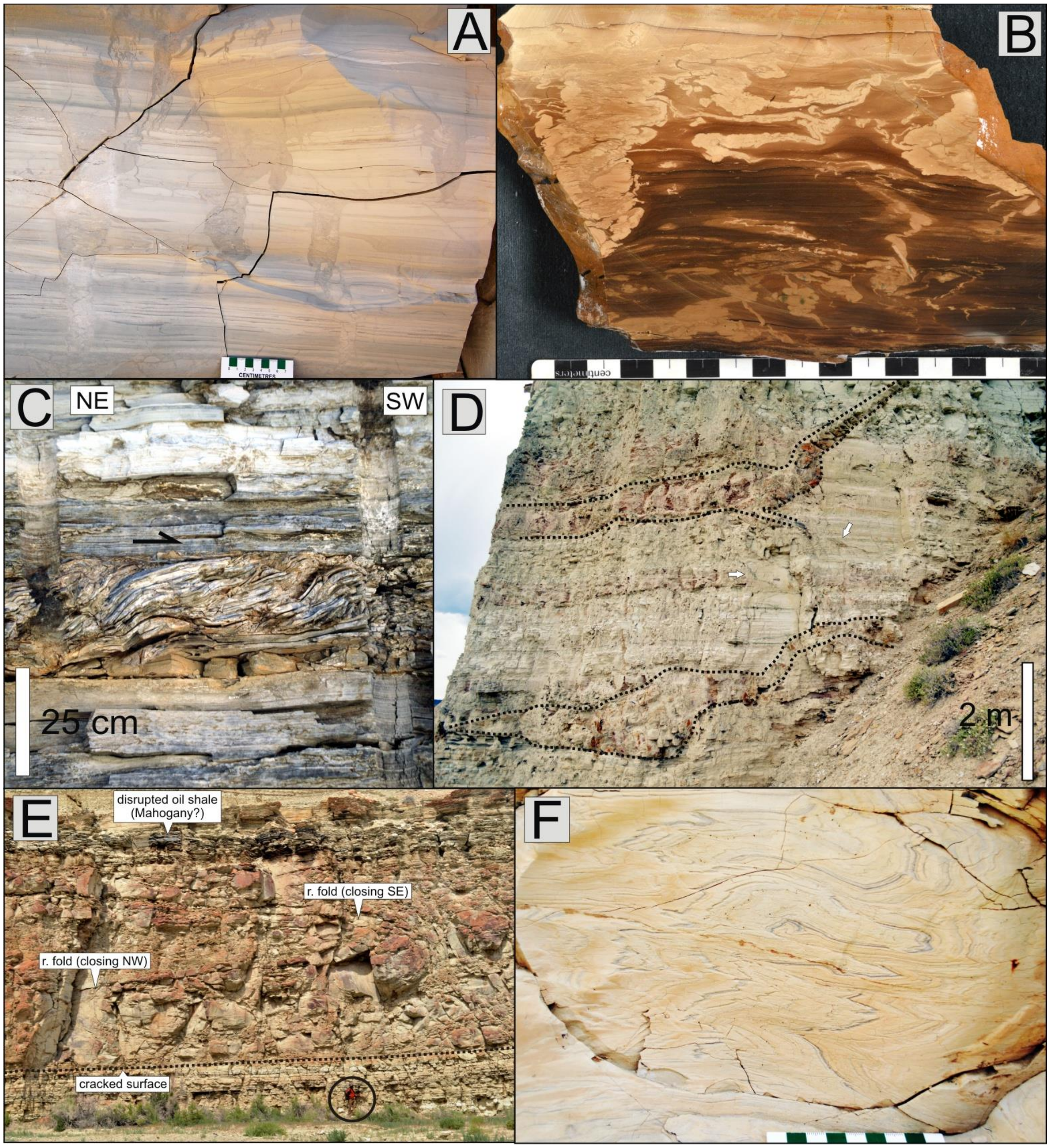

Figure 1. Examples of sedimentary deformation features in profundal facies of the Mahogany Oil Shale Zone, Utah. A. Sedimentary injections in silty lime mudstones showing multiple fluidization events and formation of sedimentary dikes. Indian Canyon; B. Sedimentary injections (dewatering structures), filled with carbonate mud, in organic-rich oil shale. Indian Canyon; C. Sheared fabric, showing en-echelon fabric, shear related propagation folds, kink and sheat folds, shear duplexes, and thrusting. Evacuation Creek Canyon; D. Sedimentary injection features (dikes and sills) filled with silicified mudstone. North Franks Canyon; E. Large-scale recumbent folded interval in a mass-transport complex, below rafts of organic rich shales, Sand Wash; F. Deformed oil shale clasts in a mass-transport complex deposit, Sand Wash.

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