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Sedimentary record of seismic events in the Eocene Green River Formation and its implications for regional tectonics on lake evolution (Bridger Basin, Wyoming)

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A B S T R A C T

Outcrops and cores from the top of the lacustrine Tipton Member and the base of the Wilkins Peak Member (~51.5 Ma) of the Eocene Green River Formation, Bridger Basin in southwestern Wyoming yield a wide variety of sedimentary deformation features many of which are laterally extensive for more than 50 km. They include various types of folds, load structures, pinch-and-swell structures, microfaults, breccias and sedimentary dikes. In most cases deformation is represented by hybrid brittle–ductile structures exhibiting lateral variation in deformation style. These occur in low-energy, profundal organic-rich carbonate mudstones (oil shales), trona beds, tuffs, and profundal to sublittoral silty carbonate deposited in paleolake Gosiute. The deformation is not specific to the depositional environment because sedimentary units stratigraphically higher with similar facies show no deformation.

The studied interval lacks any evidence for possible trigger mechanisms intrinsic to the depositional environment, such as strong wave action, rapid sediment loading, evaporite dissolution and collapse, or desiccation, so 'endogenic' causes are ruled out. Thus, the deformation features are interpreted as seismites, and change in deformation style and inferred increase in intensity towards the south suggest that the earthquakes were sourced from the nearby Uinta Fault System. The 22 levels exhibiting seismites recognized in cores indicate earthquakes with minimum magnitudes between 6 and 7, minimum epicentral intensity (MCS) of ~9, and varying recurrence intervals in the seismic history of the Uinta Fault System, with a mean apparent recurrence period of ~8.1 k.y. using average sedimentation rates and dated tuffs; in detail, however, there are two noticeably active periods followed by relative quiescence. The stratigraphic position of these deformed intervals also marks the transition between two distinct stages in lake evolution, from the balanced-filled Tipton Member to the overlying, underfilled Wilkins Peak Member. Thus, these seismites are evidence for regional-scale changes in lacustrine sedimentation of Eocene Lake Gosiute in response to syndepositional tectonic activity. Analysis of synsedimentary deformation features is, therefore, a promising yet under-utilized tool to trace the tectonic evolution of lacustrine deposits of the Green River Formation and other tectonically active marine and non-marine basins.

1. Introduction

Lacustrine sediments provide an unparalleled opportunity to study the sedimentary record of ancient earthquakes in continental basins. Lake deposits typically consist of rheologically susceptible, heterolithic sediments deposited in an overall low-energy setting (Renaut and Gierlowski-Kordesch, 2010), which increases the potential for preservation of deformation features and eliminates aseismic trigger mechanisms specific to other depositional environments (e.g., Sims, 1975; Moretti and Sabato, 2007). The sedimentary record of lacustrine basins has therefore been used successfully in paleoseismological studies of Quaternary deposits (e.g., Doig, 1986, 1990; Marco et al., 1996; Chapron et al., 1999; Rodríguez-Pascua et al., 2010; Beck, 2011; Strasser et al., 2013), and to identify tectonically active phases in older successions (e.g., Moretti and Sabato, 2007; Berra and Felletti, 2011; Törő and Pratt, 2015a, 2015b). Embracing the stratigraphic record of sedimentary deformation as a valid tectonic archive in low-energy lacustrine and marine strata opens the door to new avenues of appreciation of such basins and the rheological attributes of their sediments (e.g., Pratt, 1998b, 2001; Martín-Chivelet et al., 2011; El Taki and Pratt, 2012; Törő and Pratt, 2015a).

The Green River Formation (Eocene) represents one of the best documented ancient lake systems worldwide (e\.g., Smith et al., 2008; Smith and Carroll, 2015) and lacustrine deposits of the Greater Green River Basin in southwestern Wyoming are type examples of evolutionary lake phases (Carroll and Bohacs, 1999; Bohacs et al., 2000). This lake system was influenced by syndepositional tectonic activity related to

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the Sevier Fold and Thrust Belt and Laramide orogeny (Love, 1970; Steidtmann et al., 1983; Dickinson et al., 1988; DeCelles, 1994; Carroll et al., 2006; Smith et al., 2008). Although the sedimentology of the Green River Formation in the Greater Green River Basin or in adjacent Colorado and Utah has been studied extensively, only a few have recorded the presence of sedimentary deformation features and these have done so only in passing (e.g., Bradley, 1930; Picard, 1966; Dyni and Hawkins, 1981; Smoot, 1983). Sedimentary deformation features therefore comprise an essentially unexplored aspect of the geology of the Green River Formation (Törő et al., 2015; Törő and Pratt, 2015a, 2015b).

Törő et al. (2015) reported sedimentary deformation features from the lowermost Wilkins Peak Member of the Green River Formation and discussed syndepositional tectonics in relation to the regional basin evolution at the time (~51.5 Ma). That study was limited to outcrop data in the Bridger Basin of southwestern Wyoming, where sedimentary deformation features had not been reported previously. Here, we expand on this by describing the full suite of these kinds of features preserved in the uppermost ~10 m of the balanced-fill Tipton Member and the lowermost underfilled Wilkins Peak Member by combining observations both in cores and of outcrops over a larger area.

We studied the origin of deformed horizons using facies analysis of the host lacustrine deposits, and the stratigraphic, macroscopic, and microscopic attributes of the deformation features. This allowed us to: (1) determine the timing of deformation relative to shallow burial; (2) interpret the rheological properties of the sediments at that time; (3) deduce the most likely trigger mechanism; and ultimately (4) present the sedimentary record of late-stage Laramide tectonic movements that affected the evolution of Eocene Lake Gosiute. Our study shows that understanding the deformation features at certain stratigraphic horizons and the physical conditions under which these features formed can enhance interpretations of the evolution of the paleolake basin, and enable the refinement of the paleoenvironmental setting and the paleotectonic history of the region.

2. Geological and stratigraphic framework

2.1. Regional geology

Lacustrine sediments of the Green River Formation were deposited in three interconnected paleolakes in the foreland of the Sevier Fold and Thrust Belt of the central Rocky Mountain region: (1) Fossil Lake (Fossil Basin, southwestern Wyoming); (2) Lake Gosiute (Greater Green River Basin, southwestern Wyoming and adjacent Utah and Colorado); and (3) Lake Uinta (Piceance Creek Basin, northwestern Colorado, and Uinta Basin, northeastern Utah) during the early to middle Eocene (53–43 Ma) (Smith et al., 2008 and references therein) (Fig. 1).

The Greater Green River Basin is bounded by fault zones related to Laramide-style uplifts to the north (Wind River and Gros Ventre Mountain thrusts), east (Granite Mountain and Sierra Madre thrust), and south (Axial Basin Arch and the fault system of the Uinta Uplift), and the Sevier Fold and Thrust Belt to the west (Witkind and Grose, 1972; Love, 1970; Steidtmann et al., 1983; Dickinson et al., 1988; Steidtmann and Middleton, 1991; Roehler, 1992b, 1993; DeCelles, 1994, 2004; Johnston and Yin, 2001; Chamberlain et al., 2003; Yonkee

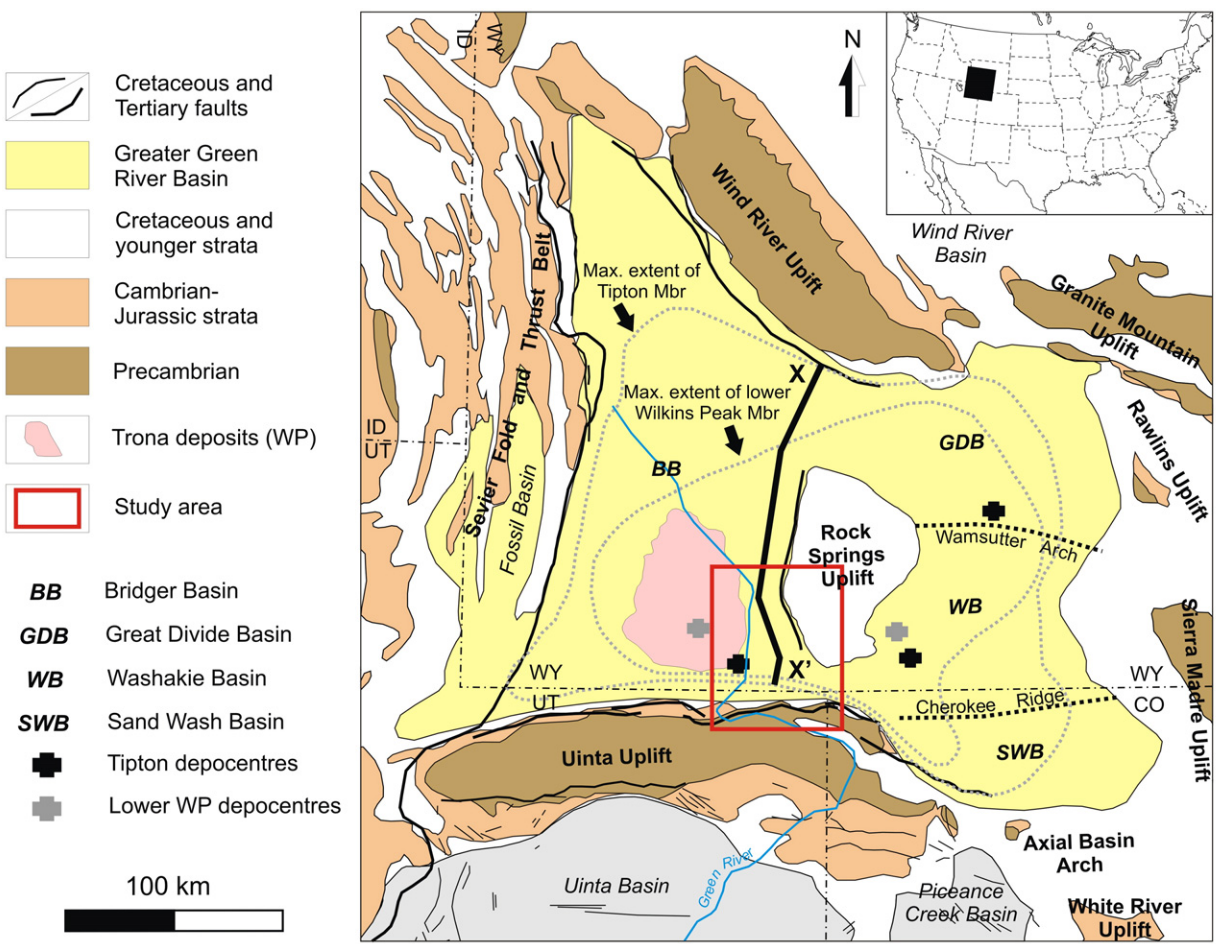

Fig. 1. Regional geological map of the Greater Green River Basin, southwestern Wyoming, USA (modified after Smith et al., 2008); depocentres after Roehler (1992b); extent of the Rife Bed of the Tipton and lower Wilkins Peak members from Roehler (1993); area of bedded evaporites after Wiig et al. (1995); Eocene faults from Love (1970), Witkind and Grose (1972), Steidtmann et al. (1983), and Bradley (1995). Cross-section X–X' section is shown in Fig. 2A. Area marked with red rectangle is shown on Fig. 2B.