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Extensive carbonate cementation of fluvial sandstones: An integrated outcrop and petrographic analysis from the Upper Cretaceous, Book Cliffs, Utah

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A B S T R A C T

Extensive, large-scale pervasive cementation in the form of cement bodies within fluvial strata has rarely been documented although fluvial strata commonly act as important hydrocarbon reservoirs, as well as groundwater aquifers. Here, we present outcrop, petrographic and geochemical data for pervasive ferroan dolomite cement bodies up to 250 m in size from Upper Cretaceous Desert Member and Castlegate Sandstone fluvial strata exposed in the Book Cliffs in Utah. These cement bodies are present with coastal plain fluvial strata within both the Desert and Castlegate lowstand sandstones and are most abundant in the thin, distal fluvial strata. Cement bodies are almost entirely absent in updip, thicker, fluvial strata. Petrographic observations suggest a predominantly early diagenetic timing to the mildly ferroan dolomite, with a component of later burial origin. $\delta^{13}C$ values for the cement (+4.8 to −5.7‰ V-PDB) suggest a marine-derived source for the earliest phase with a burial organic matter source for later cement. $\delta^{18}O$ data (−6.3 to −11.8‰ V-PDB) suggest precipitation from freshwater dominated fluids. It is proposed here that dolomite was derived from leaching of detrital dolomite under lowstand coals and cementation took place in coastal aquifers experiencing mixed meteoric-marine fluids as a result of base-level fluctuations. This data presented here shows that large cement bodies can be an important component within fluvial sandstones with a potentially significant impact upon both reservoir quality and fluid flow within reservoirs, especially at the marine-non-marine interface.

1. Introduction

Carbonate cementation of sandstones leads to porosity and permeability loss, with resulting reduction in hydrocarbon reservoir quality. The nature and timing of carbonate cementation of marine sandstone successions has been extensively reported in the literature (e.g., Bjørkum and Walderhaug, 1990; Wilkinson, 1991; Hendry et al., 1996; Morad, 1998; Klein et al., 1999). Furthermore, the field- and basin-scale patterns of carbonate cementation have been elucidated within many marine successions, and this has resulted in an understanding of the sedimentological and stratigraphic controls on the distribution of cementation (e.g., Prosser et al., 1993; Morad, 1998; Al-Ramadan et al., 2005; Machent et al., 2007; Taylor and Machent, 2010). Extensive carbonate cementation has also been previously reported from fluvial strata (e.g., Mozley and Davis, 1996; Milliken, 1998; Salem et al., 2000; Rossi et al., 2002; McBride and Milliken, 2006; Cavazza et al., 2009; Khidir and Catuneanu, 2010), but there is less of an understanding of the stratigraphic and sedimentological controls on its large-scale distribution (but see El-Ghali et al., 2009; Kordi et al., 2011). Fluvial strata commonly act as important hydrocarbon reservoirs, as well as groundwater aquifers. Here we document an example of fluvial strata from Upper Cretaceous rocks exposed in the Book Cliffs of Utah, USA, where carbonate (dolomite) cement bodies up to 250 m in size are present and occlude a high proportion of primary porosity. Through the integration of outcrop, stratigraphic, petrographic and isotopic data we address three key questions: (1) what was the timing of cementation within these strata and what were the likely precipitating fluids? (2) What was the source of carbonate for cementation? (3) What were the spatial and stratigraphic controls on cement distribution? Despite extensive research on the downdip marine strata in this internationally important succession, the nature of the cementation within the fluvial strata has not been fully documented. Given the extensive distribution of Cretaceous non-marine strata in this area of the Western Interior seaway such observations have significant implications for understanding the nature and scale of diagenetic processes within this important sedimentary basin.

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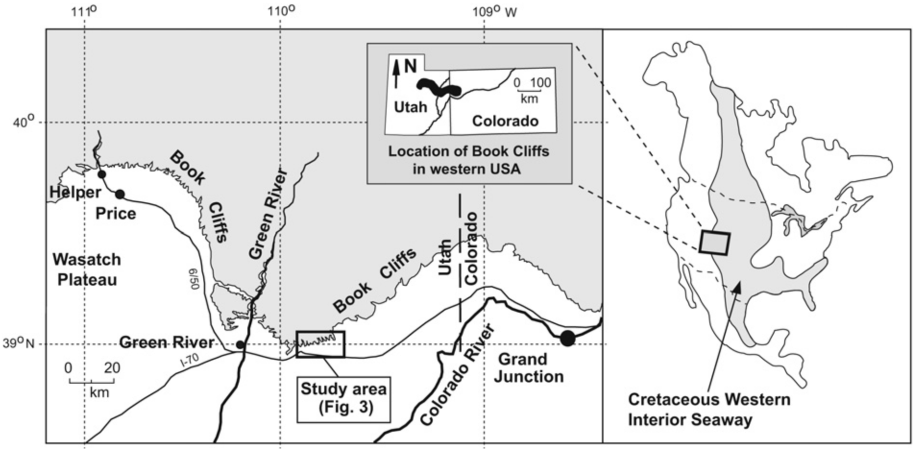

Figure 1. Location map illustrating the position of the Cretaceous Western Interior Seaway in the USA, the general outline of the Book Cliffs in east-central Utah and the extent of the study area east of Green River.

2. Study area

Earliest Cretaceous tectonism in western North America produced Cordilleran style foreland fold and thrust deformation, resulted in foreland basin development and formation of the Western Interior Seaway (Burchfiel et al., 1992). By Maastrichtian times the seaway extended through North America (Fig. 1) linking the Polar Ocean and subtropical Gulf of Mexico (Hay et al., 1993). The focus of this study is the Upper Cretaceous Desert Member of the Blackhawk Formation and Castlegate Sandstone of the Mesaverde Group and these were deposited on the western margin of the seaway. Storm-dominated shallow-marine facies and updip time-equivalent coastal plain and fluvial facies strata form eastward prograding wedges that dominate the Book Cliffs exposure in Utah and Colorado (Fig. 2). Due to excellent outcrops, this area has been the focus of several recent sedimentological and stratigraphic studies (e.g., Van Wagoner et al., 1990; Van Wagoner, 1995; O'Byrne and Flint, 1995; Pattison, 1995, 2005a, 2005b; Hampson et al., 1999, 2001; Hampson, 2000, 2010; Willis and Gabel, 2001; Hettinger and Kirschbaum, 2002; Howell and Flint, 2003; Pattison et al., 2007), which have significantly improved the understanding of stratigraphic and sedimentological processes in shoreface and coastal plain strata.

The fluvial strata within the Desert Member of the Blackhawk Formation and the Castlegate Sandstone of the Mesaverde Group comprise stacked braided fluvial deposits, with associated overbank mudstones (Yoshida et al., 1996; Yoshida, 2000; McLaurin and Steel, 2000, 2007; Miall and Arush, 2001; Adams and Bhattacharya, 2005). Within the Book Cliffs the Castlegate Sandstone has been subdivided into the Lower Castlegate, the Middle Castlegate and the Bluecastle Tongue (which forms the uppermost part of the succession). This study focuses on the Lower Castlegate Sandstone in an essentially proximal setting between Thompson Canyon and eastwards to Pinto Wash (Figs. 3 and 4). This unit takes the form of amalgamated sheet-like sandstone bodies with isolated overbank mudstones interpreted to have been deposited

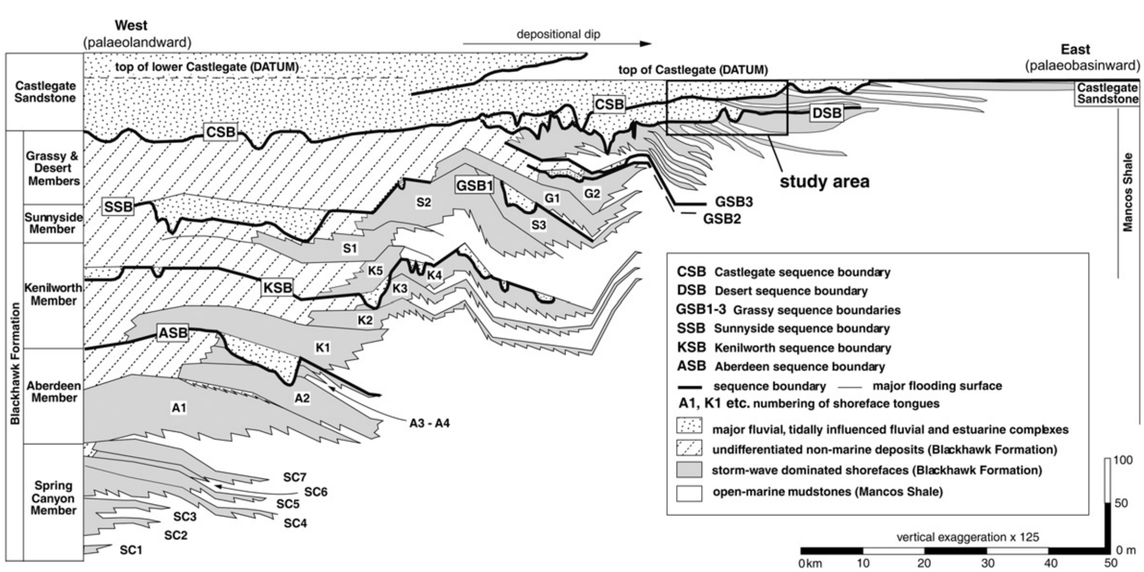

Figure 2. Summary stratigraphic cross-section of the Castlegate Sandstone and Blackhawk Formation of the MesaVerde Group. Datum horizons are regionally extensive lithostratigraphic markers. Sequence boundaries are labelled according to the key and are documented as follows: CSB and DSB, Van Wagoner (1995), GSB1–3 and SSB, O'Byrne and Flint (1995), KSB, Taylor and Lovell (1995) and ASB, Kamola and Huntoon (1995). Individual shoreface tongues are similarly labelled. The extent of the area described in this study is highlighted. Modified from Machent et al. (2007), after Balsley (1980) and Hampson and Storms (2003).