Marine and Petroleum Geology 27 (2010) 1297–1310

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Systematic sequence-scale controls on carbonate cementation in a siliciclastic sedimentary basin: Examples from Upper Cretaceous shallow marine deposits of Utah and Coloradao, USA

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ARTICLE INFO

Article history:
Received 29 January 2010
Received in revised form
15 April 2010
Accepted 27 April 2010
Available online 5 May 2010

Keywords:
Diagenesis
Dolomite
Sandstone
Cretaceous
Utah
Stratigraphy

ABSTRACT

Whilst the relationship between stratigraphic development and carbonate cementation within siliciclastic succession has been documented through a number case studies, these studies have been generally restricted to observations upon individual sequences and/or limited sub-surface data. In this paper, long-term (5 million years), large-scale (>200 km) stratigraphic controls on carbonate cementation patterns are documented from the Upper Cretaceous Panther Tongue Member, Blackhawk Formation and Castlegate Sandstone exposed in the Book Cliffs in Utah and Colorado, USA. Together, these comprise eight progradational wedges of sandstones, which interfinger with the Mancos Shale, deposited within the Western Interior Seaway foreland basin. Petrographic analyses of ferroan dolomite cement bodies within these sandstone wedges show that the ferroan dolomite cements are all early, relative to burial diagenesis within the host sandstones. Stable isotope analyses indicates that a significant meteoric component was present in precipitating fluids and this is consistent with the observation that cements, are always present down-dip of sequence boundaries and/or leached whitecaps beneath coals. In addition, the lateral distribution of cement bodies increases consistently up-succession from less than 5 km in extent in the older sequences, to 30 km in extent in the youngest sequences. These changes in distribution are in response to the increased progradation and increased and more aerially extensive sequence-boundary development in younger sequences. The implications of these data are that whilst localized spatial patterns of diagenesis, and in particular carbonate cementation, are predictable and controlled by the nature and presence of individual stratal surfaces, systematic diagenetic alteration patterns are also present at the sedimentary basin scale and controlled by the nature of larger-scale stratigraphic development and basin evolution. This evolution may be driven by eustatic shifts, or through tectonic or climatic driven base-level shifts. These observations allow an improved insight into the basin-scale processes that control the macroscopic diagenetic properties of sedimentary successions and sub-surface hydrocarbon reservoirs.

1. Introduction

The diagenetic alteration of clastic marine sedimentary strata has a major influence upon both their macroscopic characteristics in outcrop and their flow properties when acting as sub-surface hydrocarbon reservoirs (see Morad et al., 2000 for an extensive review). It has been suggested that this alteration can be controlled in many instances by the stratigraphic development of these strata (Taylor et al., 2000; Taylor and Gawthorpe, 2003; Ketzer et al., 2002a, b, 2003; Al-Ramadan et al., 2005; Machent et al., 2007). Specifically, the development of sequence boundaries has been documented to control meteoric-fluid driven carbonate cementation and kaolinitization (Taylor and Gawthorpe, 2003; Cavazza et al., 2009), whilst marine flooding surfaces have been shown to commonly result in laterally extensive carbonate cementation (Klein et al., 1999; Taylor et al., 2000; Machent et al., 2007). Whilst these models give important insights into patterns of diagenetic alteration, they are invariably based on individual sequence- or parasequence-scale observations, often focused around only one or two stratal surfaces (e.g., Klein et al., 1999). The recognition of true basin-scale patterns of diagenesis within siliciclastic successions has generally been limited to mesogenetic (burial diagenetic) processes (e.g., Machel et al., 1996; Bjørlykke et al., 1988; Davies et al., 2008), although it is noted that within carbonate-

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doi:10.1016/j.marpetgeo.2010.04.009

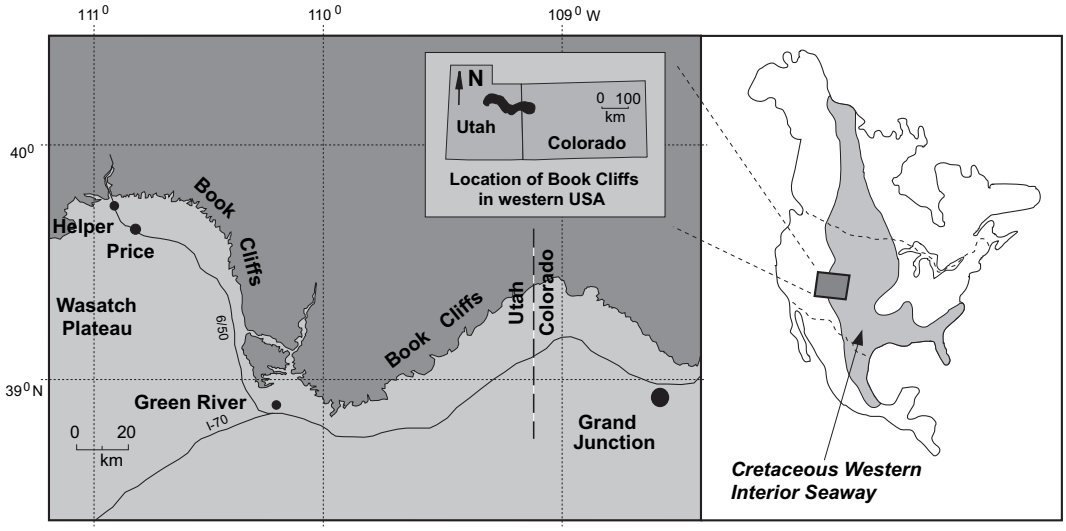

Fig. 1. Map showing the location of the Book Cliffs outcrop.

dominated successions meteoric fluid eogenetic alterations related to uncomformity development have been documented (e.g., Dorobek, 1987; Rheinhold and Kaufmann, 2010).

Three key questions present themselves regarding the scale of early diagenetic processes operating within clastic sedimentary basins, and the resulting patterns of mineral cementation: (1) can patterns observed in individual small-scale studies be confirmed to hold true in larger-scale studies; (2) if so, how do the patterns observed at the sequence-scale compare to those present at the larger, sedimentary basin-scale; and (3) if systematic patterns are indeed observed at the sedimentary basin-scale, are these simply stacked packages of sequence-scale patterns, or are sedimentary-basin scale controls also operating? In the study presented here, long-term (>5 million years), large-scale (>200 km) stratigraphic controls on carbonate cementation patterns are documented from the Upper Cretaceous succession exposed in Book Cliffs, in Utah and

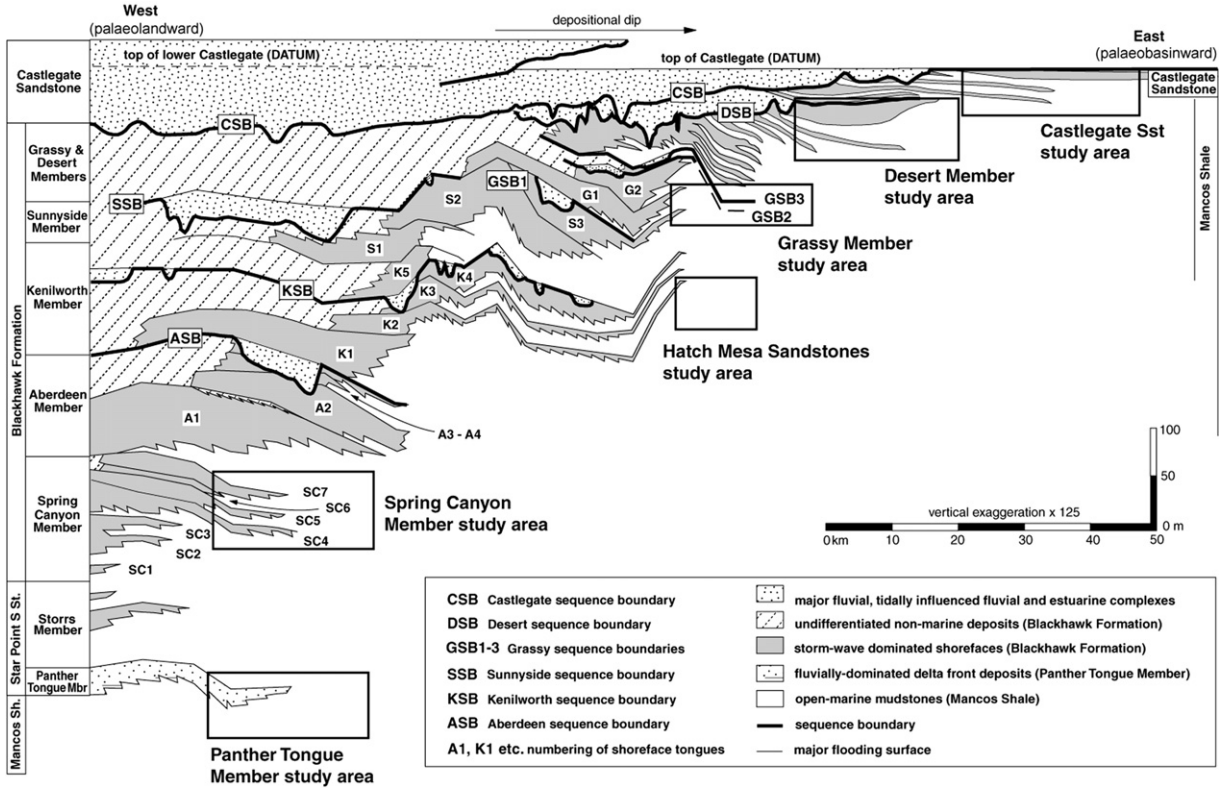

Fig. 2. Stratigraphic details of the Panther Tongue Member, Blackhawk Formation and Castlegate Sandstone of the Mesaverde Group in the studied area. The stratigraphic locations of the sections from which data is reported in this paper are highlighted. Sequence boundaries are labelled according to the 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. Modified from Machent et al. (2007), after Balsley (1980) and Hampson and Storms (2003).