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Invited review

Evolution of fluvial systems in salt-walled mini-basins: A review and new insights

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ABSTRACT

The preserved sedimentary expression of fluvial successions accumulated in salt-walled mini-basins records the complex history of basin subsidence, the style of sediment supply, and the pattern of sediment distribution in response to a range of fluvial processes throughout the evolution of such basins. Temporal and spatial variations in the rate of basin subsidence govern the generation of accommodation space, whereas the rate and style of sediment supply govern how available accommodation is filled; together these parameters act as principal controls that dictate the gross-scale pattern of fluvial sedimentation. Additional factors that influence fluvial stratigraphic architecture in salt-walled mini-basins are: (i) the trend and form of inherited basement lineations and faults that control the geometry, orientation and spacing of salt walls that develop in response to halokinesis; (ii) salt thickness and composition that dictate both the maximum potential basin-fill thickness within a developing mini-basin and the rate of evacuation (migration) of salt from beneath evolving mini-basins, leading to the growth of confining salt walls, uplift of which may generate surface topographic expression that influences fluvial drainage patterns; (iii) climate that dictates fluvial style and the processes by which sediment is distributed; and (iv) the inherited direction of drainage relative to the trend of elongate salt walls and locus of sediment supply that dictates how sediments are distributed both within a single mini-basin and between adjacent basins.

Examples of fluvial sedimentary architectures preserved in salt-walled mini-basins from a number of geographic regions are used to illustrate and document the primary controls that influence patterns of fluvial sediment accumulation. The distribution of fluvial architectural elements preserved within mini-basins follows a predictable pattern, both within individual basin depocentres and between adjoining basins: drainage pathways preferentially migrate to topographic lows within basins, such as developing rim-synclines, and away from topographic highs, such as uplifting salt walls or developing turtle-back structures.

This paper demonstrates a range of fluvial–halokinetic interactions through consideration of a series of case studies, which demonstrate the current understanding of fluvial response to salt-walled mini-basin evolution and which highlight gaps in the current understanding.

1. Introduction

Globally, there exist in excess of 120 provinces in which evaporite basins are known to have been influenced by salt deformation (Hudec and Jackson, 2007; Fig. 1). Numerous studies have been previously conducted to demonstrate how various sedimentary environments are influenced by coeval halokinesis that results in high rates of basin subsidence (e.g., Prather et al., 1998), diversion of sediment transport pathways by uplifting topography (e.g., Kneller and McCaffrey, 1995; Banham and Mountney, 2013a), and reworking of uplifted sediments or diapir-derived detritus (e.g., Lawton and Buck, 2006). Studies show how the effects of these phenomena are expressed in the preserved stratigraphic record: in deep-water environments, turbidity currents can be deflected, diverted or reflected by uplifting salt topography resulting in a complex arrangement of turbidite deposits (Kelling et al., 1979; Kneller and McCaffrey, 1995; Byrd et al., 2004; Kane et al., 2012); in shallow-marine environments, enhanced rates of subsidence can locally increase sediment accumulation rates (Dyson, 2004; Kernen et al., 2012); and in aeolian environments, surface topography arising from salt-wall growth can encourage dune-field construction, accumulation and preservation by shielding such environments from reworking by fluvial processes (Venus, 2013). Of these and other studies, only a modest number have attempted to document and account for the style of accumulation of fluvial successions in salt-walled mini-basins and show how fluvial systems can be diverted by salt-wall-generated topography. Despite having hitherto been the attention of only relatively few studies, understanding the detailed sedimentology and stratigraphy of fluvial successions preserved in salt-walled mini-basins is important since such successions act as economically important hydrocarbon reservoirs in several salt-basin provinces globally (Smith et al., 1993; Barde et al., 2002a,b; Newell et al., 2012).

The aim of this paper is to review the current state of literature regarding controls on the style of accumulation of fluvial successions

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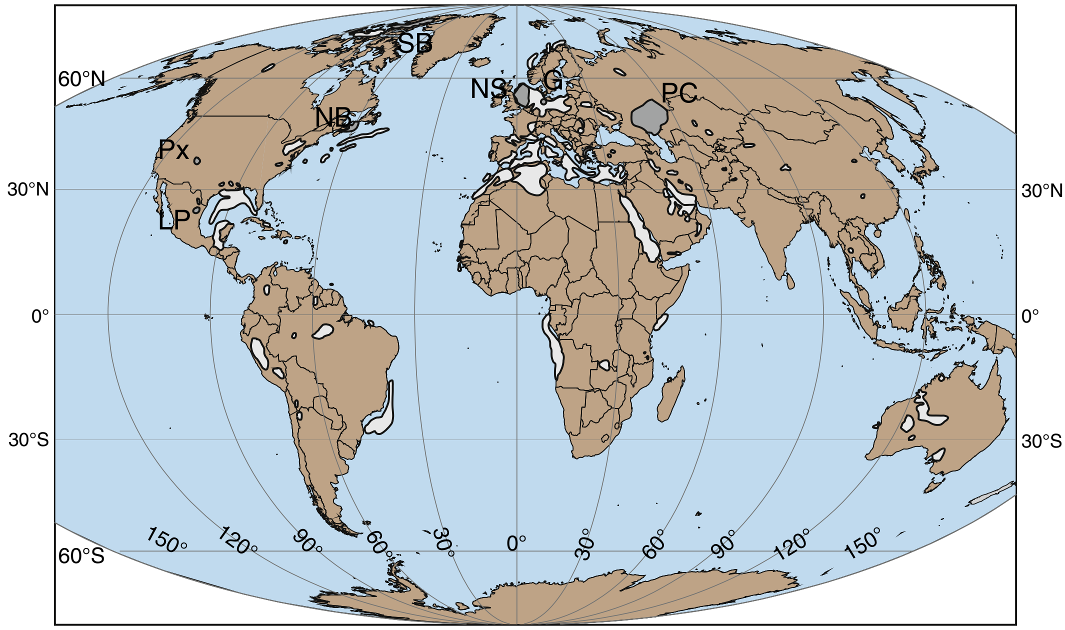

Fig. 1. Overview of halokinetic provinces world-wide. Light grey indicates halokinetic provinces not covered in this study. Dark grey denotes province mentioned in this study. G: German case studies; LP: La Popa Basin; NB: New Brunswick; NS: North Sea; PC: Precaspian Basin; Px: Paradox Basin; SB: Sverdrup Basin.
Modified after Hudec and Jackson (2007).

in salt-walled mini-basins and to highlight gaps in the current understanding. Specific objectives are as follows: (i) to establish a standard set of terminology for the description of various attributes associated with the spatial and temporal evolution of salt-walled mini-basins; (ii) to highlight the numerous ways in which halokinetic and sedimentary processes can interact; (iii) to illustrate how these different styles of interaction are known to be expressed through examination of a series of reviewed case studies; (iv) to present a series of summary tectono-stratigraphic models with which to relate preserved fluvial stratigraphic architecture present in mini-basins to the principal halokinetic and sedimentary controls; (v) to show how such models can be used as predictive tools; and (vi) to discuss potential approaches to future research which will address issues that currently remain unresolved in this field of research.

This work is of broad appeal for the following reasons: (i) the terminology describing the attributes and style of infill of salt-walled mini-basins is currently poorly defined and this study provides clarification and discussion through development of a generic classification framework; (ii) this work identifies and discusses a series of controls that operate to determine the style of evolution of salt-walled mini-basins and the manner by which these basins become filled by fluvial successions; and (iii) this work distills our current understanding into a series of generic models that describe the influence of key controls on fluvial sedimentation for a variety of types of basin fill.

2. Terminology

The terminology required for the description of basin subsidence, gross-style of basin fill and basin-fill state at any given time during the evolution of a series of salt-walled mini-basins is inherently complex because many dependent and independent variables are known to interact during the evolution of such systems. To resolve this issue, terminology describing the primary variables that govern mini-basin evolution and their fill states is defined here in an attempt to standardise descriptions of basin attributes (Fig. 2).

Basin-fill thickness (T) describes the current total thickness of accumulated sediment within a subsiding mini-basin. This thickness may vary across a single basin in cases where differential subsidence has generated variable accommodation; for example, a rim syncline structure (R) will locally increase accommodation, whereas accommodation will be less above a turtle-back structure (Tb).

Maximum basin-fill thickness (M) describes the maximum potential thickness of fill that can be accommodated by continued subsidence and accumulation within a mini-basin. This is governed by both

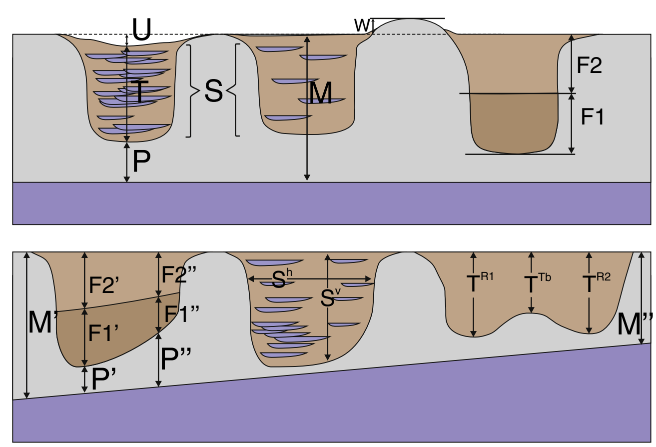

Fig. 2. Description of basin-fill attributes defining basin-fill thickness, fill style, pre-existing basin fill, and remaining subsidence potential of the basin. These parameters can vary both between mini-basins and within a single mini-basin. T = Basin-fill thickness, which can vary within a single basin, e.g., features such as turtle-back structures & rim synclines. F =Fill inheritance, which records the state of basin-fill at the onset of a subsequent episode of deposition and which can vary spatially across a mini-basin due to variations in differential subsidence rate or existing basin fill-thickness. M = Maximum basin-fill level (fill potential) is determined by the original thickness of salt and can vary due to the presence of a dipping basement or the presence of pre-salt basement structures. P = Remnant basin-fill potential, describes the salt remaining beneath an evolving mini-basin and can vary across a basin due to differential subsidence or due to sub-salt basement geometries. S = Basin-fill style is a general concept describing the overall nature of the sediment fill (e.g. sand-prone or sand-poor). S^h = horizontal fill style; S^v = vertical fill style. U = Available accommodation (space remaining unfilled) and can be negative if the basin fill becomes elevated above a "baseline of erosion". W = Salt-wall height above "regional" elevation.