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# Sedimentary controls on the sequence stratigraphic architecture in intra-cratonic basins: An example from the Lower Permian Shanxi Formation, Ordos Basin, northern China

Hongtao Zhu [a,b,*], Keyu Liu [c,d], Xianghua Yang [a,b], Qianghu Liu [a,b]

[a] Key Laboratory of Tectonics and Petroleum Resources, China University of Geosciences, Ministry of Education, Wuhan 430074, China
[b] Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, China
[c] Research Institute of Petroleum Exploration and Development, PetroChina, Beijing 100083, China
[d] CSIRO Earth Science and Resource Engineering, P.O. Box 1130, Bentley, WA 6102, Australia

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ABSTRACT

Intra-cratonic basins are characterized by stable tectonic regimes, closed depositional systems, finite sizes of receiving basins and extremely low morphological gradients. This paper examines the effect of sediment accumulation on the sequence stratigraphic architecture and quantitatively evaluates its controls on the development of intra-cratonic sedimentary sequences using numerical modelling. A well documented intra-cratonic sedimentary sequence, the Lower Permian Shanxi Formation in the Ordos Basin, northern China, was used to illustrate a sequence stratigraphic model developed for intra-cratonic sedimentary basins. The studied sequence is characterized by a typical backstepping or source-ward retrogradation. A 2-D simulation software (SEDPAK) and a 3-D simulation software (SEDSIM) were used to model the intra-cratonic sequence. The modelling results indicated that sediment accumulation alone can produce the classical retrogradational stratigraphic stacking patterns. The sediment accumulation can (1) increase the retrogradational range of the original retrogradational stacking sequences, (2) change an original aggradational stacking sequence to a retrogradational stacking one, and (3) decrease the progradational range of an original progradational stacking sequence, or (4) even change an original progradational stacking sequence to a retrogradational stacking sequence. Understanding the relationship between the sediment accumulation and the stratigraphic development in an intra-cratonic basin is essential for interpreting the sequence stratigraphic framework and stacking patterns, and for predicting the distribution of potential reservoir sand-bodies within such basins. This work enriches the classic sequence stratigraphic models by providing a new model for intra-continental basins, and offers new insight on hydrocarbon exploration in intra-cratonic basins.



## 1. Introduction

### 1.1. Sequence stratigraphy of intra-cratonic basins

Within the last few decades, research on the cratonic basins has been primarily focused on the mechanism of the basin formation (e.g. De Rito et al., 1983; Klein and Hsui, 1987; Quinlan, 1987; Ahern and Dikeou, 1989; Coakley et al., 1994; Hartley and Allen, 1994; Baird et al., 1995; Howell and van der Pluijm, 1999; Kaminski and Jaupart, 2000; Hanne et al., 2004; Artyushkov et al., 2008; Downey and Gurnis, 2009; Armitage and Allen, 2010), while development of sequence stratigraphic analysis has been emphasized on the controls of base level and tectonic movement (e.g. Bond and Kominz, 1991; Burgess and Gurnis, 1995; Witzke et al., 1996; Burgess et al., 1997; Howell and van der Pluijm, 1999; Runkel et al., 2007). However, classic sequence stratigraphic models focus primarily on the rift, sag and foreland basin settings (e.g. Xie and Li, 1993; DeCelles and Giles, 1996; Catuneanu et al., 1998; Catuneanu, 2004; Hancox et al., 2002; Li et al., 2002; Feng et al., 2004; Escalona and Mann, 2006; Yang and Miall, 2008, 2009; 2010; Yang, 2011; Lash and Engelder, 2011) with little

* Corresponding author. Key Laboratory of Tectonics and Petroleum Resources, China University of Geosciences, Ministry of Education, Faculty of Earth Resources, No. 388 Lumo Road, Hongshan District, Wuhan, Hubei 430074, China. Tel.: +86 27 67883563; fax: +86 27 67883051.
*E-mail address:* zhuoscar@sohu.com (Hongtao Zhu).

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research on intra-cratonic basins despite the fact that intra-cratonic basins are important hydrocarbon-bearing provinces throughout the world. Recent efforts of applying the sequence stratigraphic approach to the investigation of intra-cratonic basin stratigraphic sequences have yielded some progress (e.g. McLaughlin et al., 2004; Hoffmann et al., 2009; Zhu et al., 2010; Kanygin et al., 2010; Petty, 2010) but most of the investigations have been limited in geographic scope and some workers continue to question the suitability of such an approach (e.g. McLaughlin et al., 2004; Hoffmann et al., 2009; Petty, 2010). A stratigraphic framework comparable in scope and resolution to the comprehensive framework for the classic passive margin settings is yet developed for intra-cratonic stratigraphic sequences. It is clear that insufficient research efforts have been devoted to understanding the sequence stratigraphy of cratonic basins. Indeed, it is easy to understand how one may easily fall into the trap of trying to fit observations into rigid existing templates provided by various standard models (Catuneanu, 2006). Therefore this research on developing a sequence stratigraphic model for the intra-cratonic basin setting is of great importance for the completeness of the sequence stratigraphic models. The development of stratigraphic sequences is classically related to driving mechanisms, including eustasy, subsidence or uplift, and variations in sediment supply, and climate (Vail et al., 1991; Emery and Myers, 1996; Catuneanu, 2004). Moreover, the dominant factors for the formation of sequence stratigraphy vary among different basin types.

From previous research, we suggest that the spatial and temporal distributions of the sediment sequences in an intra-cratonic basin are characterized by a typical source-ward retrogradation controlled by the interplay among the structural configuration of the basin margin, sediment supply, base-level fluctuations, palaeotopography, sediment accumulation, and climate (Zhu et al., 2008, 2010). Investigations relating sediment accumulation effect to the sequence stratigraphic architectures are rare in the literature. In this paper we examine the sediment accumulation as an important factor that controls the development of intra-cratonic sedimentary sequences using numerical modelling. Based on the basic premise of mass balance and energy conservation, the volume of sediment accumulation supplied to a basin would result in the same new increment of accommodation space or water bodies within an enclosed intra-cratonic basin. Sediment accumulation can thus affect the sequence stratigraphic architecture of such a basin.

Intra-cratonic basins are characterized by generally stable tectonic regimes, closed depositional systems, finite sizes of receiving basins and extremely low morphological gradients (Fig. 1). Gradual sediment accumulation of the basin gives rise to a backstepping or retrogradational sequence due to the increase of relative accommodation space by sediment (including associated water) infill thereby causing the base level to “elevate” accordingly (e.g. Liang, 1996).

### 1.2. Quantitative forward stratigraphic modelling

Stratigraphic modelling has been increasingly used to assist stratigraphic interpretation and basin analysis, particularly in the field of petroleum exploration and production (e.g. Cross, 1990). Unlike traditional sequence stratigraphic analyses (Vail and Mitchum, 1977; Wilgus and Roskoski, 1988; Galloway, 1989; Van Wagoner et al., 1990), forward stratigraphic modelling provides a quantitative evaluation of the various geological parameters that control the formation of sedimentary sequences. It is an efficient tool to understand depositional processes and basin evolution intuitively.

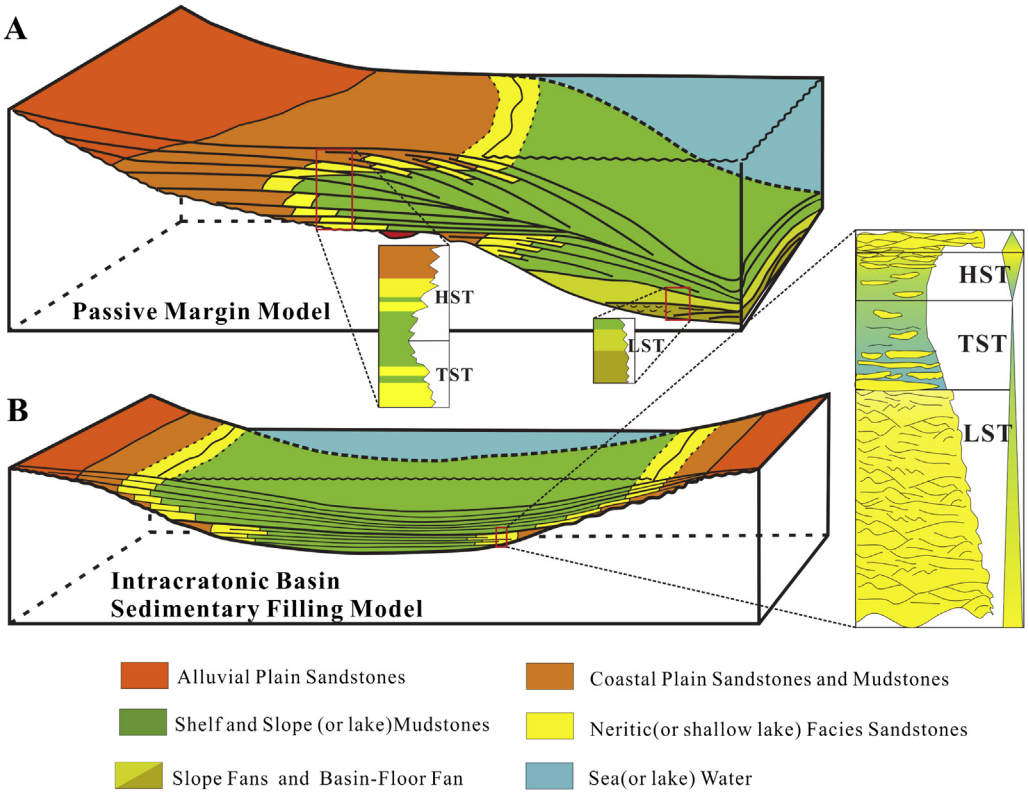


**Figure 1.** Comparison of the geological characteristics of typical passive continental margin basins and intra-cratonic basins during a basin fill cycle. Note that the overall sequence for the intra-cratonic basin succession shows a distinct upward fining (deepening).