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Full Length Article

Carbon and oxygen isotope variation and its implication for marine sequence: A case study of Ordovician in Tarim Basin

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ABSTRACT

Carbon and oxygen isotopes of marine carbonate rocks or fossil shells could indicate global sea-level relative change. Generally, heavier carbon isotopes or lighter oxygen isotopes reflected rise of global sea-level relative changes, and vice versa. For carbonate rocks deposited before Tertiary, carbon isotope was more stable than oxygen isotope, and thus it was more suitable to indicate global sea-level relative fluctuation. Within time limit of the 3rd-order sequence (1-10Ma), large scale migration of carbonate platforms would not occur and carbonate productivity would not change greatly, therefore, a research method of marine tectonic sequence (i.e, a contrastive analysis method of carbon and oxygen isotopes-sedimentary cycles) was proposed. Thus, the marine 3rd-order sequences were divided the global sea-level sequence which was controlled by global sea-level change and the tectonic sequence which was controlled by regional tectonic subsidence and uplift. The global sea-level fluctuation indicated by carbon and oxygen isotopes were consistent with variation of sedimentary cycles and water depth of the global sea-level sequence, but were not consistent with variation of sedimentary cycles and water depth of the tectonic sequence. As a case study of Ordovician in Tarim Basin, two 3rd-order global sea-level sequences were identified in the Lower Ordovician, while six 3rd-order tectonic sequences controlled by collision and compression between Arkin island arc, Kudi active continental margin uplift and Tarim Plate were identified in the Middle and Upper Ordovician. Particularly, OSQ6 in the Upper Ordovician (Lianglitage Formation) was a typical tectonic sequence.

1. Introduction

Up to now, although different researchers have different classification of sequence orders, and the main difference was time limit of different-order sequences (Schlager, 2004), a large number of previous analyses (Vail et al., 1977, 1991; Ramsbottom, 1979; Heckel, 1986; Einsele et al., 1991; Goldhammer et al., 1991; Tucker, 1992; Mei, 1995; Sarg et al., 1999; Miall, 2000) showed that the sedimentary sequence order could be divided into seven orders (Table 1). For 1st-order and 2nd-order sequences, researchers had the relative consistent understandings about sequence genesis and global correlation (Vail et al., 1977; Miall, 2000; Hallam, 1963; Sloss, 1963; Soares et al., 1978; Einsele et al., 1991; Plint et al., 1992; Worsley et al., 1984); for 4th-order to 6th-order sequences, researchers also had the relative consistent understanding that periodic variation of the sun's radiation to the Earth (the astronomical Milankovitch cycles) resulted in the global sea-level changes of the glacier fluctuation type (Broecker et al., 1968; Goodwin and Anderson, 1985; Herbert and Fischer, 1986; Arthur and Garrison, 1986; Goldhammer et al., 1987; Algeo and Wilkinson, 1988; Strasser, 1988; Mitchum and Van Wagoner, 1991; Park et al., 1993; Schwarzacher, 1993; De Boer and Smith, 1994; Sadler, 1994; House and Gale, 1995; Howell and Aitken, 1996; Pasquier and Strasser, 1997; Fiet and Gorin, 2000; Gale et al., 2002; D'Argenio et al., 2004; Hofmann et al., 2004). But currently, there have two different views in the understanding of the genetic mechanisms of the 3rd-order sequence and its main controlling factors: (1) the 3rd-order sequence mainly was controlled by the global sea-level change, and thus could be correlated globally (Vail et al., 1977; Haq et al., 1987; Posamentier et al., 1988; Haq and Schutter, 2008); (2) the 3rd-order sequence was controlled by regional tectonic activities and crustal equilibrium subsidence, and could not be correlated globally (Morner, 1976; Cloetingh, 1986; Burchette, 1988; Sabadini et al., 1990; Cathles and Hallam, 1991; Macdonald, 1991; Plint et al., 1992; Miall, 1994, 2000; Duncan et al., 1999; Ward, 1999; Abbott and

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Table 1
Sequence-order classification and its characteristics.

Sequence order	Terminology of sequence stratigraphy	Formation time/Ma	Genetic mechanism	
1st-order	Megasequence	200–400	Tectonic-type sea-level changes caused by plate movements	Global sea-level change caused by Pangea formation and disintegration
2nd-order	Supersequence	10–40		Global sea-level change caused by expansion of mid-ocean ridge
3rd-order	sequence	1–10		Global sea-level change caused by mid-ocean ridge change as well as continental glacier growth and ablation + regional sea-level change influenced by tectonic subsidence and uplift within the plate
4th-order	Parasequence set	0.4	Glacier-type sea-level changes caused by Milankovitch astronomical cycles	long eccentricity cycle
5th-order	Parasequence	0.1		short eccentricity cycle
6th-order	Rhythmite/meter-scale cycles	0.02 or 0.04		Precession cycles or obliquity cycles
7th-order	Alternating laminae	0.002–0.005	Glacier ablation and geoid change	

Sweet, 2000; Lazauskiene et al., 2003; Horton et al., 2004; Ruiz-Ortiz et al., 2004), especially the 3rd-order sequences in foreland basins, strike-slip basins and active rift basins, mainly were controlled by regional tectonic movements (Macdonald, 1991; Duncan et al., 1999; Ward, 1999; Lazauskiene et al., 2003; Horton et al., 2004). Therefore, in practical work, how to identify development and evolution of the 3rd-order sequences whether controlled by the global sea-level changes or regional tectonic movements, had became an important content in studies of sequence stratigraphy and sedimentology.

As a case of the Ordovician in Tarim Basin, the controlling factors and identification marks of the 3rd-order sequences were discussed to improve research methods of marine sequence stratigraphy.

2. Index of global sea-level relative change

2.1. Concepts and its interrelationships

As shown in Fig. 1, the global sea level referred to the sea level with the core of Earth as a reference point, its location could be measured by the distance from the core of Earth to the sea level; the relative sea level referred to the sea level with the depositional base level as a reference point, its location could be measured by the distance from the depositional base level from the sea level. The depositional base level also was called the sediment bottom, its location was measured by the distance from the core of Earth to the depositional base level or the sediment bottom, and changes of the depositional base level were controlled by tectonic movements as well as lifting and subsidence. The water depth referred a distance from the top of sediments to the sea level. Therefore, the following formulas could be obtained:

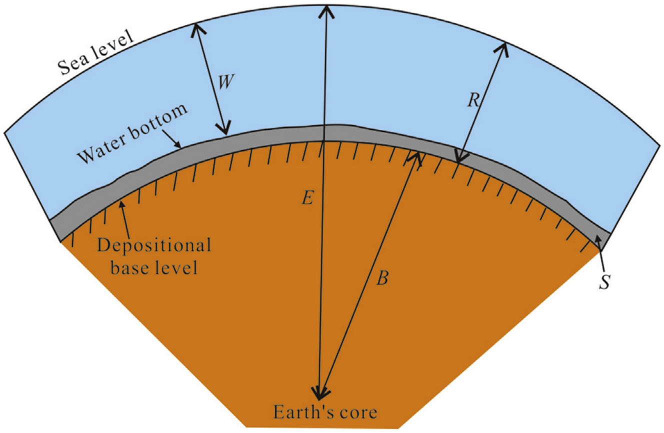

Fig. 1. Concepts of the global sea level, the relative sea level and the water depth.

$$W = E - B - S \tag{1}$$

$$R = E - B = W + S \tag{2}$$

In formulas, W was the water depth, m; E was the distance from the core of Earth to the sea level, m; B was the distance from the core of Earth to the depositional base level or the sediment bottom, m; S was the thickness of the sediment, m; R was the distance from the depositional base level to the sea level, m.

The water depth (W) and its changes could be obtained by analysis of sedimentary facies. The global sea-level changes in the geological time were very difficult to identify. The method of Christopher et al. (1988) was mainly used to measure changes of the relative sea level (R) or ancient water depth (W). Changes of tectonic lifting and subsidence of the depositional base level (B) in the geological time were also very difficult to obtain.

2.2. Changes of carbon and oxygen isotopes

According to numerous studies (Broecker and Van Donk, 1970; Shackleton and Opdyke, 1973; Fillon and Williams, 1983; Matthews, 1984; Chappell and Shackleton, 1986; Williams, 1988; Feeley et al., 1990), changes of oxygen isotopes of marine carbonate sediments mainly reflected the global sea-level relative changes which resulted from glacier fluctuations. Generally, heavier values of $\delta^{18}O$ indicated the glacial growth and fall of the global sea level, on the contrary, lighter values of $\delta^{18}O$ suggested the glacial ablation and rise of the global sea level. The principle was that formation of glaciers would take more ^{16}O away from seawater, thus more ^{18}O were remained in the seawater, and ratios of $^{18}O/^{16}O$ ($\delta^{18}O$) of the seawater became heavier. Short-term (1000 a) variation of seawater oxygen isotope could up to 1‰–2‰, and mainly was controlled by climate (glacial) cycles; while long-term (100–250 Ma) exchange of isotopes between ocean floor basalt and seawater would cause seawater oxygen isotope to 0‰ (Sharp, 2007). The time limits of 3rd-order to 6th-order sequences were far less than 100 Ma, so the oxygen isotopes of sediments had not yet reached equilibrium, therefore, if sediments not experienced significant