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Sedimentary Geology 176 (2005) 43–65
Sedimentary Geology
www.elsevier.com/locate/sedgeo

Research paper

Controls on Precambrian sea level change and sedimentary cyclicity

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Received 2 March 2004; received in revised form 11 May 2004; accepted 20 December 2004

Abstract

Although uniformitarianism applies in a general sense to the controls on relative and global sea level change, some influences thereon were more prominent in the Precambrian. Short-term base level change due to waves and tides may have been enhanced due to possibly more uniform circulation systems on wide, low gradient Precambrian shelves. The lack of evidence for global glacial events in the Precambrian record implies that intraplate stresses and cyclic changes to Earth's geoid were more likely explanations for third-order sea level change than glacio-eustasy. Higher heat flow in the earlier Precambrian may have led to more rapid tectonic plate formation, transport and destruction, along with an increased role for hot spots, aseismic ridges and mantle plumes (superplumes), all of which may have influenced cyclic sedimentation within the ocean basins. A weak cyclicity in the occurrence of plume events has an approximate duration comparable to that of first-order (supercontinental cycle) sea level change. Second-order cyclicity in the Precambrian largely reflects the influences of thermal epeirogeny, changes to mid-ocean ridge volume as well as to ridge growth and decay rates, and cratonic marginal downwarping concomitant with either sediment loading or extensional tectonism. Third-order cycles of sea level change in the Precambrian also reflected cyclic loading/unloading within flexural foreland basin settings, and filling/deflation of magma chambers associated with island arc evolution.

The relatively limited number of studies of Precambrian sequence stratigraphy allows some preliminary conclusions to be drawn on duration of the first three orders of cyclicity. Archaean greenstone basins appear to have had first- and second-order cycle durations analogous to Phanerozoic equivalents, supporting steady state tectonics throughout Earth history. In direct contrast, however, preserved basin-fills from Neoarchaean–Palaeoproterozoic cratonic terranes have first- and second-order cycles of considerably longer duration than Phanerozoic examples, supporting less evolved tectonism affecting cratonic plates. It is possible that oceanic tectonic realms underwent more rapid and dynamic plate movements and arc generation, whereas early continental cratonic plates offered more stable platforms and may have been subject to slower migration rates. The wide range of controls on Precambrian sea level change, allied to their apparent variability (in rates and periodicity) through

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0037-0738/$ - see front matter
doi:10.1016/j.sedgeo.2004.12.008

Precambrian time supports the conclusion that each order of cyclicity is relative and must be defined within the stratigraphic context of each individual case study. This underlines the importance of establishing a hierarchical order of cyclicity in sequence stratigraphic interpretations of Precambrian basins based on the relative importance of sequences rather than their temporal duration.

Keywords: Precambrian; Sequence stratigraphy; First- to third-order depositional cyclicity; Cycle duration; Relative sea level change; Eustasy

1. Introduction

Sea level change, one of the most important variables in sedimentological and sequence stratigraphic studies, forms the theme of this special issue dedicated to Pradip K. Bose, one of the prominent scientists who has studied this topic for most of a lifetime. This paper aims to review briefly the controls on sea level change during the Precambrian Era, and to address major influences on higher-order depositional cycles. We here use "higher-order" to denote more important cycles (cf. sequences) which are of larger scale and lower frequency, as opposed to "lower-order" cycles of greater frequency. Although the principle of Lyell (1830) uniformitarianism can generally be applied to the Precambrian sedimentary record (e.g., Donaldson et al., 2002; Eriksson et al., this volume), certain influences on Precambrian eustasy require either qualification or further discussion, which will be attempted here. Although not of great significance in Phanerozoic sequence stratigraphic studies, factors like Earth surface and mantle heat flow, continental crustal growth rates, global rotation rates and celestial mechanics, palaeo-atmospheric composition (and its changes over time), the "faint young Sun" and the concomitant inferred global greenhouse, mantle superplumes and superplume events (SPEs) and divergent views on early Precambrian plate tectonic regimes loom large in Precambrian examples (e.g., Eriksson et al., 2004a and references therein).

The concepts of sequence stratigraphy (see Miall, 1997, for a balanced commentary) owe much of their origin to the early ideas of Sloss (e.g., 1963), which were refined through the concepts of seismic stratigraphy by the "Exxon school" led by Vail (e.g., Vail et al., 1977), to result in the well known seismic stratigraphic volume edited by Payton (1977). The hierarchy of depositional cycles identified by many workers in many areas, both prior to and after this seminal 1977 publication, was ascribed by this school to predominant eustasy, against a background of relatively constant tectonic subsidence along an extensional continental margin (Miall, 1997; Miall and Miall, 2001, 2002).

Depositional cycles were classified into 1st-, 2nd-, 3rd-, 4th- and 5th-order cycles (Sloss, 1963; Vail et al., 1977; Miall, 1990; Duval et al., 1992). First-order (300–225 My in the Vail et al., 1977 model; generally 500–200 My in duration) cycles are ascribed by most workers to changes in ocean basin volume consequent upon the plate tectonic or supercontinent cycle (e.g., Dewey and Burke, 1974; Pitman, 1978; Worsley et al., 1984; Gurnis, 1988; Nance et al., 1988; Hoffman, 1989) and can thus be identified in the Phanerozoic record on formerly adjacent continents. In the Precambrian, there is evidence to support a first supercontinent ("Kenorland") at c. 2.7 Ga (e.g., Condie, 2004), and the Wilson-cycle of breakup–ocean growth–reassembly appears to have been more protracted than Phanerozoic equivalents (Aspler and Chiarenzelli, 1998; Aspler et al., 2001). The widely favoured concept of more rapid plate movements in the earlier Precambrian (e.g., Hargraves, 1986) stands in contrast to this, leading some workers to emphasise variable rather than universally more rapid rates of plate movement for these times (e.g., Catuneanu, 2001; Eriksson and Catuneanu, 2004a). Duration of these first-order cycles may thus have reached c. 300–650 My in the Neoarchaean–Palaeoproterozoic (Aspler and Chiarenzelli, 1998; Catuneanu and Eriksson, 1999), longer than the duration range found for the Phanerozoic rock record (e.g., Miall, 1997, his Table 3.1). Other workers (e.g., Worsley et al., 1984; Krapez, 1993) favour an essentially uniform supercontinental cycle length of c. 330–440 My.

Second-order (10–80 My, Vail et al., 1977; 10–100 My, Miall, 1997) cycles of sea level change reflect