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Tracking Silurian eustasy: Alignment of empirical evidence or pursuit of deductive reasoning?

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ABSTRACT

Sea level is not static, but liable to fluctuations due to addition or subtraction of water in the world's oceans, as well as changes to the shape and holding capacity of ocean basins. Relative changes in sea level are well supported by the rock record on a regional scale. Whether or not global (eustatic) changes are evident and how frequently they occurred during any given interval of time is a matter of contention among stratigraphers. Opinions have evolved over the last century with arguments based on refinements in biostratigraphy, chemostratigraphy, radiometric dating, and conceptual advances in sequence stratigraphy derived from technological advances in seismic stratigraphy. The Pulsation Theory of A.W. Grabau (1936) attributed to Paleozoic strata a global history of 11 highstands distributed through a sequence with 21 subdivisions. In 1977, Peter Vail and associates from the Exxon Production Research Company independently interpreted a similar Paleozoic history showing 10 second-order highstands but distributed over 19 subdivisions. Vail's approach was model-based and followed a deductive path, while Grabau's was based on inductive reasoning. Recent refinements in a Paleozoic sea-level curve by Haq and Schutter (2008) are based on the same deductive approach taken by the Vail group, but pinned to patterns in sequence stratigraphy. Drawing on the Silurian System as a Paleozoic sample, the timing, frequency, and magnitude of sea-level highstands deduced by Haq and Schutter are compared with those promulgated by the author from the mid-1980s onward using empirical evidence more in line with Grabau's methodology. Both apply the concept of geographic reference areas, but Haq and Schutter identify 50% more Silurian highstands over an interval lasting 27.7 million years. Eight out of 10 Silurian highstands identified by this author match or overlap 8 out of 15 highstands recognized by Haq and Schutter. At issue is which, if any, qualify as eustatic signals with respect to current databases for biostratigraphic correlation. Evaluation is based on evidence reviewed from Iowa, New York, Norway, Estonia, and Austria in the paleogeographic context of three independent Silurian continents.

1. Introduction

The hypsographic curve is a graphical representation of the world's topographic highs and bathymetric lows arranged in a continuous line with variable slopes from the single highest point on the planet (Mt Everest) to the single deepest part of the ocean (Marianas Trench). Present-day sea level is the essential datum, separating all places above sea level (29%) from all shelf and abyssal areas below sea level (71%). Stretching from the outer margin of the world's continental shelves (commonly at −200 m) to the interior limits of coastal plains (around +250 m), the most level segment of the hypsographic curve represents an area of approximately 85 million km^2, or 16% of the planet's total surface area. Freeboard, a nautical term for the vertical distance between the deck of a ship and the level of the water, has been applied to this relatively flat-lying interval of the hypsographic curve (Wise, 1972). The implication is that shifts in the shoreline at any given time are accommodated within this space. The fact that marine strata are exposed at elevations high above continental plains, such as the Ordovician limestone found 70 m below the summit of Mt Everest (Myrow et al., 2009), clearly demands orogenic activity to account for significant uplift of ancient seabeds. Extensive marine strata also cover tectonically stable regions, as found around Chicago in northern Illinois where Ordovician and Silurian strata are situated less than 300 m above sea level but 1400 km from the nearest ocean. This fact still requires a large relative change in sea level to flood the epicontinental platform. Wise (1972) adopted a constant freeboard model in which deviations in the boundary between coastal plains and continental shelf remained within ±60 m of a normal value 20 m above present sea level through 80% of Phanerozoic time. Although his study collates data from other sources that find major rises in Ordovician and Silurian sea levels in North America, Wise (1972) concluded those events lie outside the

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expected norm. Back-stripping the more than 200-m thick package of Upper Ordovician and Silurian strata in northern Illinois means that the middle Paleozoic freeboard of North America was more vulnerable to sea-level changes at that time than today. Even so, more than one mechanism would be necessary to bring sea water to Chicago including both glacial melting and tectonic factors related to reduced ocean-basin volume.

Whether or not Ordovician and Silurian increases in global sea level can be identified as exceptional events coeval on multiple continents is further complicated by the fact that some continents today reflect the individual imprint of different hypsographic curves. Early on, Bond (1978) showed that Africa sits at a higher elevation overall than any other continent and Australia sits at a lower elevation. The hypsographic curves for these two continents are markedly astride the global average. In theory, the hypsometry of a supercontinent like Gondwana may have been more exaggerated than smaller continents such as Laurentia or Baltica. Another argument against eustasy relates to the uneven surface of the world's oceans due to the Earth's shifting shape as a geoid. Mörner (1976, p. 123) was among the earliest to insist that “because of geoid changes, eustasy is not globally valid.” More than two decades later, Dewey and Pitman (1998, p. 14) took care to evaluate the possible glacio-eustatic, sedimento-eustatic, and tectono-eustatic sources and ranges of sea-level change, but still concluded “most sequences and third-order cycles are controlled tectonically on a local and regional scale rather than being global-eustatically controlled.”

Miall (2004) takes a skeptical view of studies claiming to find evidence of eustasy in the rock record. Stratigraphers, it is noted, are preconditioned with skills for pattern recognition in search of cyclicity. It is appealing to our psychological makeup to seek order in chaos. Miall (2004) warns that stratigraphers are capable of finding patterns where none exist. His analysis divides all stratigraphical research into two camps: those driven by empirical observations in search of a theory through inductive logic and those propelled by pre-existing models in search of data through deductive logic. After looking at earlier contributions, Miall (2004, p. 20) points to work by Vail et al. (1977) from the Exxon Production Research Company as dependent on the preconditioned acceptance of patterns ascribed to cyclic events and essentially deductive in outlook. The 1977 Vail curve tracked discontinuities detected mainly through seismic stratigraphy and made assertions promoted as fully global and Phanerozoic in scope. More recently, Haq and Schutter (2008) proposed a Paleozoic sea-level curve derived from patterns in sequence stratigraphy. It is much advanced over the Paleozoic part of the original Vail curve. Progress in this area was a natural outgrowth of refinements in Mesozoic and Cenozoic sea-level curves made by Haq et al. (1987) with inspiration and collaboration from the original Exxon group.

The goals of this paper are two-fold: 1) to re-examine research by A.W. Grabau (1936, 1940) as the originator of a Paleozoic sea-level curve remarkably prescient to that of Vail et al. (1977) and 2) to focus on the Silurian System as an adequate Paleozoic sample, in which a detailed comparison of the sea-level curve by Haq and Schutter (2008) may be evaluated with respect to the timing, frequency, and magnitude of highstands previously advanced by the author (Johnson, 1987, 1996; Johnson et al., 1998; Johnson, 2006).

2. Comparison of Paleozoic curves by Grabau and Vail

Paleozoic sea-level curves formulated by Grabau (1936) and by Vail et al. (1977) share some striking similarities but differ in the technical style by which they were independently assembled. The Vail curve (Fig. 1a) depicts 10 second-order highstands separated through a sequence with 19 subdivisions. Grabau's curve (Fig. 1b) features 11 coarse highstands in sea level arrayed through a sequence with 21 subdivisions. For the most part, both schemes divide Paleozoic units into three intervals: early/lower, middle, and late/upper periods or

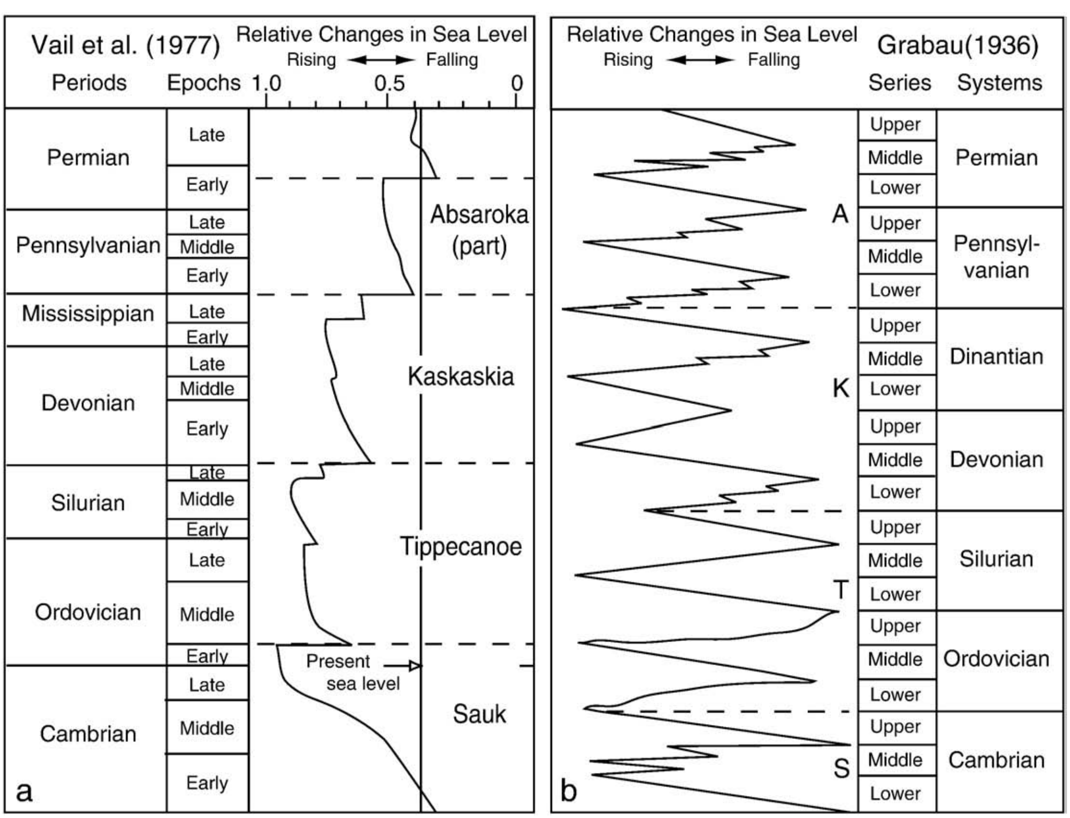

Fig. 1. Comparison of Paleozoic sea-level curves: (a) by Vail et al. (1977); and (b) by Grabau (1936).