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The supercontinent cycle: A retrospective essay

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ABSTRACT

The recognition that Earth history has been punctuated by supercontinents, the assembly and breakup of which have profoundly influenced the evolution of the geosphere, hydrosphere, atmosphere and biosphere, is arguably the most important development in Earth Science since the advent of plate tectonics. But whereas the widespread recognition of the importance of supercontinents is quite recent, the concept of a supercontinent cycle is not new and advocacy of episodicity in tectonic processes predates plate tectonics. In order to give current deliberations on the supercontinent cycle some historical perspective, we trace the development of ideas concerning long-term episodicity in tectonic processes from early views on episodic orogeny and continental crust formation, such as those embodied in the chelogenic cycle, through the first realization that such episodicity was the manifestation of the cyclic assembly and breakup of supercontinents, to the surge in interest in supercontinent reconstructions. We then chronicle some of the key contributions that led to the cycle's widespread recognition and the rapidly expanding developments of the past ten years.

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1. Introduction

Over the past two decades, data from a wide variety of sources have led to the general realization that Wegener's Pangea, rather than being the Earth's only supercontinent (Fig. 1), is simply the most recent in a series of supercontinents that have punctuated Earth history for billions of years (e.g., Rogers and Santosh, 2002, 2003, 2004; Murphy and Nance, 2003, 2012; Santosh and Zhao, 2009; Condie, 2011; Yoshida and Santosh, 2011a; Huston et al., 2012; Mitchell et al., 2012). This history of episodic supercontinent assembly and breakup, which constitutes the supercontinent cycle, is now recognized as having profoundly influenced the course of the Earth's geologic, climatic, and biological evolution (e.g., Hoffman et al., 1998; Hoffman and Schrag, 2002; Lindsay and Brasier, 2002; Dewey, 2007; Condie et al., 2009, 2011; Goldfarb et al., 2010; Hawkesworth et al., 2010; Santosh, 2010a, 2010b, 2010c; Bradley, 2011; Hannisdal and Peters, 2011; Strand, 2012; Young, 2012, 2013a, 2013b; Melezhik et al., 2013). Its existence documents a fundamental aspect of the Earth's dynamic system (e.g., Condie, 2003, 2011; Evans, 2003; Zhong et al., 2007; Santosh et al., 2009a; Zhang et al., 2009) and its recognition is arguably the most important development in Earth Science since the introduction of plate tectonics over 40 years ago.

Sometimes overlooked in the pursuit of this exciting realization is the long history that led to its development. Although the widespread recognition of the importance of supercontinents in Earth history is quite recent, the concept of a supercontinent cycle is not new and the notion of episodicity in tectonic processes predates plate tectonics. In this paper, we attempt to give the rapidly expanding recognition of the episodic recurrence of supercontinents some historical perspective. We do so by tracing the history of the supercontinent cycle from its controversial introduction in the early 1980s, through its increasing application in the 1990s, to its widespread acceptance in the first decade of the 21st century.

2. Early ideas

2.1. Tectonic episodicity

Advocacy of long-term episodicity in tectonic processes is by no means new and was being expressed long before plate tectonics and an understanding of mantle dynamics provided the potential for its explanation. One of the most prescient of these early advocates was Umbgrove (1940, 1947) who argued for the existence of a ~250 m.y. "pulse" in Phanerozoic orogeny, magmatism, sea level and climate (Fig. 2). The notion of episodic orogenic activity was subsequently advocated in several early treatments of Precambrian fold belts (e.g., Holmes, 1951; Wilson et al., 1960; Burwash, 1969), and the idea that continental crust formation was likewise episodic was proposed by Holmes (1954) and further developed by Gastil (1960), who argued on the basis of age data that the geologic record of granite production was intermittent rather than continuous. Episodicity in tectonic processes is also inherent in the cratonic sequences documented by Sloss (1963), it was recognized in early radiometric age compilations (e.g., Voitkevich, 1958; Vinogradov and Tugarinov, 1962; Runcorn, 1962, 1965; Dearnly, 1966; Fig. 3), and it lay at the center of Sutton's (1963) argument for the existence of "chelogenic cycles", or global-scale shield-forming events. It was also inherent in Wilson's (1966) case for the repeated opening and closure of ocean basins now known as "Wilson cycles". However, unlike the well-known Wilson cycle, which pertains to individual oceans, Sutton's now-largely forgotten chelogenic cycle called for the episodic clustering of continents through changes in the pattern of subcontinental mantle convection. Rather than producing a supercontinent, however, the chelogenic cycle resulted in the periodic recurrence of two antipodal continental clusters, the assembly and disruption of which were responsible for the record of orogenic episodicity. The cycle was thought to occur because small subcontinental convection cells first resulted in continental clustering and orogeny in continental interiors, but then coalesced into larger cells that fostered continental breakup, orogenic quiescence, and the later regrouping of the disrupted continental masses into two new antipodal clusters. According to Sutton, the chelogenic cycle had a periodicity of 750–1250 m.y. and had been repeated at least four times during the geologic history of the Earth.

Following the introduction of plate tectonics, recognition of the process of ocean closure by subduction provided an explanation for orogenesis and crustal growth (e.g., Dewey, 1969), the episodic natures of which were confirmed by increasingly precise radiometric ages (e.g., Condie, 1976, 1982; Fig. 4) (see also Fig. 3), the pattern of Phanerozoic sedimentary cycling (Mackenzie and Pigott, 1981), and the distribution of ore-forming processes through time (Meyer, 1981, 1988). The concept

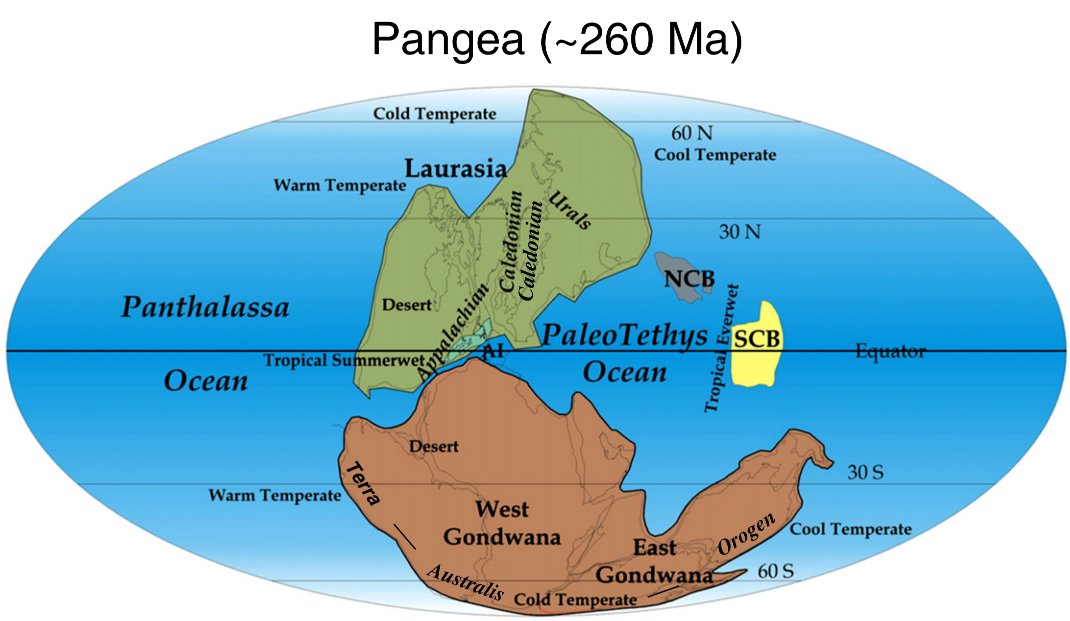

Fig. 1. The Late Paleozoic supercontinent Pangea at ca. 260 Ma, showing its two main components, Gondwana (south) and Laurasia (north), separated by the PaleoTethys ocean and surrounded by the Panthalassa. NCB = North China Block, SCB = South China Block, and AI = Armorica, Avalonia and Iberia. Modified from Meert (2012).