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Episodic Tectonics in the Phanerozoic Succession of the North American Arctic and the "10 Million Year Flood"

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Introduction

The goal of this study is to catalogue all the large scale, tectonically-generated sequence boundaries which punctuate the Phanerozoic stratigraphy of the North American Arctic and to determine the frequency and possible origin of the interpreted tectonic episodes which gave rise to the boundaries. This study is feasible because, over the last 40 years, the Phanerozoic succession of the North American Arctic, both on the surface and in the subsurface, has been intensely studied in various sedimentary basins with modern basin analysis techniques including sedimentology, sequence stratigraphy and biostratigraphy.

Data Sources

Notably, the entire Phanerozoic succession is present in the NA Arctic although no single basin contains a complete column. The data for this study come mainly from three major basins: Franklinian Basin, Sverdrup Basin and Beaufort-Mackenzie Basin. Data from other basins in the NA Arctic such as the North Slope Basin of Alaska have been used to complement and refine the results obtained from the three main basins.

The Franklinian Basin of the Canadian Arctic Islands and adjacent northern Greenland provides an excellent record of the Cambrian to Devonian succession from basin margin to basin centre and the stratigraphy of the succession is detailed in numerous reports, including Mayr (1978), Thorsteinsson and Mayr (1987), Higgins et al. (1991), Trettin et al. (1991), Embry (1991a), Mayr et al (1994), Harrison (1995), Mayr et al. (1998), de Freitas et al. (1999), and Dewing et al. (2008). Relevant sequence stratigraphic data on the Cambrian-Devonian succession have also been gleaned from work done on the northern Canadian mainland where the strata are widely distributed (Fritz et al., 1992; Pyle and Jones, 2009).

Stratigraphic data for the Carboniferous through Cretaceous succession have been obtained primarily from the Sverdrup Basin of the Canadian Arctic Archipelago. The succession is very thick (12 km) and exquisitely exposed in the eastern part of the basin. In the west, ample well and seismic data supplement the surface exposures. The key references for the detailed stratigraphy of this succession are Balkwill (1978, 1983), Beauchamp and Henderson (1994), Beauchamp and Thériault (1994), Beauchamp (1995), Beauchamp et al. (2001, 2009), Beauchamp and Olchowy (2003), Embry (1991b, 1993, 1997, 2011) and Embry and Beauchamp (2008). Data for the Jurassic and Cretaceous succession were also acquired from studies in the Mackenzie Delta and adjacent areas (Dixon 1982, 1991, 1993; Poulton, 1982), offshore west Greenland (Schenk, 2011) and the North Slope Basin of Alaska (Houseknecht and Bird, 2004; Decker, 2007; Bird and Houseknecht, 2011).

Cenozoic stratigraphic data are most complete for the Beaufort–Mackenzie Basin on the northern continental margin. The succession is mainly in the subsurface and has been unraveled through the analysis of plentiful well and seismic information. Important references for the Cenozoic stratigraphy include Dixon et al (1992), Dixon (1996), Dixon et al. (2008) and Helwig et al (2011). Additional stratigraphic data were obtained from the outcropping Paleogene succession of the eastern Sverdrup Basin (Ricketts, 1991, 1994; Ricketts and Stephenson, 1994; Harrison et al., 1999).

Tectonic Episodes

These detailed and basin-wide stratigraphic studies in the various basins have revealed the presence of 56, large magnitude, sequence boundaries within the Phanerozoic succession of Arctic North America. These boundaries are distinguished by the presence of the following characteristics:

1) A widespread, often angular, unconformity on the basin margins and positive elements
2) A major change in depositional regime
3) A notable change in tectonic regime and subsidence pattern
4) A change in source region for siliciclastic sediments
5) A major back step of the carbonate platform edge for carbonate sediments
6) A widespread transgression with significant deepening directly following the boundary

The sequence boundary characteristics strongly indicate that the boundaries identified were generated primarily by tectonics and not by eustasy (Embry, 1990). Thus, each sequence boundary is interpreted to be generated by a tectonic episode which affected the entire region and which resulted in tectonic uplift and erosion on the margins of the basins. This uplift was accompanied by notable regression in the more central areas of the basins and was followed by a collapse and marine flooding of the basin margins and beyond. The sequence boundaries, which punctuate the Phanerozoic stratigraphy of the NA Arctic, occurred on average about every 10 million years (56 boundaries in 545 million years).

The maximum regressive surface portion of each sequence boundary has been dated on the basis of the available biostratigraphy which, in most cases, allows the boundary to be assigned to a specific biozone. The sequence boundaries were then assigned a numerical age through the correlation of the biozones with the 2012 geological time scale (Gradstein et al., 2012). The time intervals between the boundaries were no less than 5 and no more than 15 million years in almost all cases. It is clear that the tectonically generated boundaries were not strictly periodic but were chaotic and had a relatively high chance of reoccurring within 10 million years. Furthermore, there is no systematic change in boundary frequency throughout the entire Phanerozoic and an average frequency of about 10 million years occurs for any given 100 million year interval. Thus, the major transgression which follows each boundary could perhaps be referred to as a “10 million year flood”.

A given tectonic episode began with the initial uplift of the basin margin (start of base level fall) and ended with the collapse and marine flooding of the margin (maximum flooding surface). The sequence boundary was generated during the tectonic episode and represents the time of maximum uplift and basinward extent of the unconformity. It is estimated that the duration of each of the tectonic episodes was in the range of a few million years and was significantly shorter than the intervening times of tectonic quiescence.

Origin of Tectonic Episodes

The recognition of these tectonic episodes leads to questions such as “what is the primary cause of such repetitive episodes?” and “are they global in extent or just a characteristic of the North American Arctic?” It is postulated that such tectonic episodes are an expression of relatively rapid and substantial changes in the horizontal and vertical stress fields of the NA Arctic. Such stress changes would be possibly due to somewhat abrupt changes in the speed and/or direction of plate movements which affected the NA Arctic. Given there is a complex feedback between plate distribution and dynamics with mantle convection and heat release (Rolf et al., 2012), the recognized tectonic episodes would presumably reflect perturbations in mantle convection intermittently occurring every 5 -15 million years due to a gradual buildup and consequent, episodic release of stress and heat.

In terms of the possible global extent of the recognized events, it is worth noting that all of the 18 major, tectonic, sequence boundaries recognized by Sloss (1988) for the Phanerozoic of the North American continent are present in our compilation for the Arctic. Furthermore, a cursory literature survey has indicated most of the tectonic sequence boundaries we have recognized are present in basins on different continents. However, in many cases, the published data are not sufficient to document a tectonic origin for a given boundary in a given basin. A more detailed literature search for the Triassic (Embry, 1997) has revealed that all the Triassic, tectonically-generated sequence boundaries recognized in the NA Arctic are present in numerous basins in North America, Europe and Asia and were also tectonically generated in those areas.

It has also been determined that 16 of the18 Cambrian-Pliocene mass extinctions identified by Bambach (2006) coincide with an identified tectonic episode and that many of the tectonic episodes correlate with significant carbon isotope excursions (Saltzman and Thomas, 2012). Such correlations would imply that the episodes were the expression of a global phenomenon rather than one confined to the NA Arctic. Thus, it is quite possible that most, if not all, of the recognized, tectonically-generated, sequence boundaries of the NA Arctic represent episodic tectonics which occurred on a global scale. Given that all the tectonic plates are linked and a mantle-driven, major adjustment in the speed or direction of one plate would require compensatory movement changes in all the other plates, a phenomenon of episodic global tectonics occurring with a frequency of 5 -15 million years is a theoretical possibility.

Implications for Petroleum Exploration

These results have implications for petroleum exploration in that petroleum traps would have been formed, altered and sometimes breeched during the tectonic episodes. Also, the movement of subsurface fluids would have been greatly influenced by such intermittent convulsions of the sedimentary column. Finally the recognition and dating of these tectonically-generated sequence boundaries in combination with their potential global distribution allows their occurrence to be predicted in unexplored sedimentary basins.

Conclusions

Fifty-six, large magnitude sequence boundaries have been delineated in the Phanerozoic succession of Arctic North America. The characteristics of the boundaries indicate that they were primarily generated by tectonics. The boundaries occur with an approximate 10 million year frequency (9.8 +/- 3.1). Each boundary was generated during a tectonic episode interpreted to reflect a mantle-driven, plate tectonic reorganization and consequent changes in regional stress fields. Such episodes likely lasted for a few million years and were separated by longer intervals of relative tectonic quiescence. There are indications that the recognized tectonic episodes affected basins throughout the world.

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