Low frequency cycles through space and time

Robert Georgi

TU Bergakademie Freiberg

Abstract. Many different types of cycles were dominant in earth’s history. The fragmentation and defragmentation of super continents, epeirogeny, orogeny, earth magnetic field polarisation and many other cycles are controlling the sea level. Rise and fall of the sea level is directly linked with the sediment patterns, biosphere, ocean circulation and of course the global and regional climate. Most of the processes controlling the sea level fall and rise is shown in Table 1.

Table 1: Overview of processes generating sea-level changes [Miall, 1997]

<table>
<thead>
<tr>
<th>Process</th>
<th>Region affected</th>
<th>Type of result</th>
<th>Rate (m/ka)</th>
<th>Duration (m.y.)</th>
<th>Total possible change (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eustatic process</td>
<td>Global</td>
<td>Eustasy</td>
<td>0.001</td>
<td>100-100</td>
<td>100</td>
</tr>
<tr>
<td>Age distribution of earth’s oceanic crust</td>
<td>Global</td>
<td>Eustasy</td>
<td>0.002-0.01</td>
<td>50-100</td>
<td>50</td>
</tr>
<tr>
<td>Sea-floor ridge volume changes</td>
<td>Global</td>
<td>Eustasy</td>
<td>1</td>
<td>0.05</td>
<td>50</td>
</tr>
<tr>
<td>Density changes associated with intraplume stress</td>
<td>Global</td>
<td>Eustasy</td>
<td>1.5</td>
<td>0.1</td>
<td>150</td>
</tr>
<tr>
<td>Continental ice formation</td>
<td>Global</td>
<td>Eustatic fall</td>
<td>4-10</td>
<td>0.02-0.04</td>
<td>80-400</td>
</tr>
<tr>
<td>Continental ice melting</td>
<td>Global</td>
<td>Eustatic rise</td>
<td>30-50</td>
<td>0.002</td>
<td>6-100</td>
</tr>
<tr>
<td>Marine ice-sheet decoupling</td>
<td>Global</td>
<td>Eustatic rise</td>
<td>30-50</td>
<td>0.002</td>
<td>6-100</td>
</tr>
<tr>
<td>Processes leading to uplift of the continental crust</td>
<td>Hemisphere</td>
<td>Uplift of crust</td>
<td>0.005-0.01</td>
<td>100</td>
<td>500-1000</td>
</tr>
<tr>
<td>Thermal doming accompanying rifting</td>
<td>Rift flanks</td>
<td>Thermal bulge</td>
<td>0.012</td>
<td>16</td>
<td>250</td>
</tr>
<tr>
<td>Convergent tectonism</td>
<td>Collision zone</td>
<td>Uplift of fault blocks, nappes</td>
<td>10^6</td>
<td>0.3</td>
<td>2000</td>
</tr>
<tr>
<td>Intraplate stress</td>
<td>Entire plates</td>
<td>Modification of flexural deflections</td>
<td>0.01-0.1</td>
<td>1-10</td>
<td>100</td>
</tr>
<tr>
<td>Unsteadiness in mantle convection</td>
<td>Areas of 10^8-10^9 km^2</td>
<td>Regional warping</td>
<td>1-10</td>
<td>0.01-0.1</td>
<td>100</td>
</tr>
<tr>
<td>Processes leading to subsidence of the continental crust</td>
<td>Continental margin</td>
<td>Subsidence</td>
<td>0.003-0.005</td>
<td>20</td>
<td>600-1400</td>
</tr>
<tr>
<td>Post-rift thermal subsidence of cont. margin</td>
<td>Continental margin</td>
<td>Subsidence</td>
<td>0.003-0.005</td>
<td>20</td>
<td>2000-4000</td>
</tr>
<tr>
<td>Flexural loading</td>
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<td>Basin subsidence</td>
<td>0.08-1.0</td>
<td>2-15</td>
<td>1000-4000</td>
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Introduction

Many authors were busy in cyclostratigraphy in the last decades, like Vail et al. (1977) or Einsele et al. (1991b). The basement work of Vail et al. (1977) subdivided this topic into 5 order cycles, whereas this paper occupies the first 3 order cycles with a frequency of more then 1 m.y. The Global supercontinent cycle (200 – 500 m.y.), the cycles with a frequency of tens to hundreds of million years and cycles with frequencies of million years are these 3 cycles. All of them are generally controlled by eustatic sea level fall or rise, but the causes of the changes are very different. The most necessary cause for eustatic sea level changes are the spreading rates on mid – ocean rift systems. During high spreading rates, the doming of oceanic crust is controlling the emplacement of ocean water. While low spreading rates, the sea level falls.

1st order – super continent cycles

In earth’s history, numerous super continents (SC) are known, for example, the Rhodinia – SC during the period of 1100 – 800 m.y. or the Pangea – SC from 300 – 150 m.y.. During space and time, there also did exists giant continent assemblies over more then 800 m.y., like Gondwana, which built up the southern part of Pangea. After Miall et al. (1991) the formation and break up of such SC’s are dividable in four phases. The first phase can be described as a phase of fragmentation. During a period of more then 150 m.y. rifting and dispersion of continental crust are dominating, controlled by high spreading rates. The spreading rate of oceanic crust rises enormous, so the eustatic sea level increases to a maximum. The maximum dispersal phase is controlled by the beginning of oceanic crust subduction on active continental margins. Today, we live in this phase. The third phase is the assembly phase, which is dominated by
closing old Atlantic-type oceans. The sea level begins to fall. The super continent stasis phase is the 4th phase of the SC – cycle, whereas the continent is constant, the eustatic sea level gets to a minimum. The assembly of SC’s is directly linked with changes in global climate. Fig.1 shows the linkage between the sea level, caused by SC – assembly and the climate (I-icehouse, G-greenhouse).

![Fig. 1: SC-cycles during Phanerozoic, including sea-level change and fluctuation in global climate (modified, Worsley et al. (1984))](image)

2nd order – Cycles with Episodicities of Tens to Hundred of Millions of Years

In comparison with 1st order cycles, super cycles have periodicities of 10 – 100 m.y. These cycles can not be described only by eustatic sea-level rise and fall. For example, some sequences have huge horizons of continental deposits, so there have to be another explanation for the 2nd order – cycles. Other statements must be considered. Thermal changes, crustal thickening
and thinning or sediment loading yields to this cyclicity. All these facts were termed as *dynamic topography*.

Soares et al. (1978) described a epeirogenic cycle of three basins in Brazil, the Amazon Basin, the Parnaiba Basin and the Parana Basin (Fig. 2). In his correlation, he holds out 5 phases of epeirogeny.

(1) Basins plunged very fast with a development of nonmarine facies. (2) The subsidence slowed down. The basin center is geographical deeper, so the development of this region is marine. Only in marginal areas, the nonmarine facies occurs. (3) In this phase of basin development, the intrabasin will be elevated, resulting in a wide spectrum of facies. (4) After, the subsidence recurs basinwide, the progress of transgression is on the highest level in the basin development. (5) After the phase of subsidence, the phase of uplifts following, resulting a nonmarine facies. It is known, that these effects are associated with large- or small-scale convection cells, that establishing geoid anomalies, subsidence or uplift of continental crust or the evolution of cratonic basins.
One type of the 2\textsuperscript{nd} order-cycles is caused by orogeny. When continental fragments collides, the thickness of the crust increases, meanwhile the area of the collision decreases. So the ocean - plain become wider and the sea level begins to fall. The collision of Asia and India is an example for this 2\textsuperscript{nd} order-cycle. The duration of this process is not good determined, many authors have different opinions about the frequency. Durations between 40 m.y. and 80 m.y. are described (Soreghan et al., 1994).

With a cyclicity of about 80 m.y., the polarization induced spreading rate is also a cycle of the 2\textsuperscript{nd} order (Sheridan, 1987). Trough break up of continental crust, a cyclic eruption at the core – mantle – boundary will be established. The resulting mantle plume creates a turbulent regime (Fig. 3),
so the magnetic fields reverse more frequently. In time of low fluctuation, termed as a quiet zone, the spreading rates are higher and as a result, the sea level rises. The opposite is called as mixed polarity zone, selected by low spreading rates and low sea levels. The rates of rising and falling of the sea level are not known. So, there have to be done a lot research to answer this question.

![Fig. 3: magnetic-field changes during Paleozoic, correlated with sea level (modified after Sheridan, 1987)](image)

It exist also other processes, which initiates 2nd order-sequences. One process is the changing of ocean water temperature. Fairbridge (1961) calculated that the 1° rise of the mean ocean temperature would have a result of a 2 m-rise of the sea level. Fairbridge (1961) explained this process by changing the global climate, for example the changing from icehouse- to a warmhouse – climate trough rising spreading rates. Ridgwell and Zeebe (2005) determined the role of the global carbonate cycle (Fig. 4). They described three significant cycle modes, the Strangelove, the Neritan and the Cretan ocean mode. All these periods were different in their geochemistry. The Strangelove ocean mode is characterized by generally inorganic carbonate formations during the Precambrian. With the first biomineralization in the Cambrian-
of carbonate sedimentation was changed. The carbonate precipitation was controlled biologically in a shallow – water (neritic) regime. The 3rd mode is the Cretan mode, which is characterized by a pelagic biomineralization, also by a stabilization of the marine CaCO$_3$ saturation. Ridgwell and Zeebe (2005) explain the changing ocean mode with catastrophic disasters, like the event at the Cretaceous – Tertiary boundary.

Fig. 4: global carbon cycles, a) passive continental margin, b) active continental margin (Ridgwell and Zeebe, 2005)

3rd order – cycles with Million – Year Episodicities

In the cyclostratigraphy, there do exist many well-known examples of structurgeoetical cycles. These cycles are divided in there kind of evolution. So, there exist extensional and rifted clastic continental margin cycles, Foreland – Basin – cycles, Forearc – Basin – cycles and Backarc – Basin – cycles.

The Sverdrup – Basin, the Svalbard – Basin, the northern Greenland-Basin, the northern Norway – Basin and some Russian Basins are well investigated extensional margins. The Triassic sections were correlated by
Mork et al. (1989) in all these basins. In his work, he concentrated himself on prominent erosion surfaces as sequence boundaries. It was transcribed into transgression sequences, which were controlled by a balance of subsidence, sediment supply and sea level change. In his work, the precision of the correlation was within \( \pm 1 \) m.y.

Hotly discussed 3\textsuperscript{rd} order – cycles are described in the theory of the *cyclothem* and *mesothem*. Ramsbottom (1979) described extensive regressive and transgressive beds, which group multiple cyclothems to a mesothem. That means, a mesothem is build by multiple cyclothems. Only the mesothems can be described as 3\textsuperscript{rd} order – cycles, because there have durations of between 1.1 m.y. and 3.6 m.y. They are characterized by a muddy transgressive base, followed by several deltaic sandy cyclothems. On top, they can be capped by coal. The evolution always took place from the basin to the shelf.

Handoh and Lenton (2003) described mid – Cretaceous oceanic anoxic events (OAE) and plotted the positive and negative feedbacks of the Phosphorus burial (Fig. 5). These OAE’s were linked with the fluctuation in phosphorus and oxygen biogeochemistry. These events offer periodicities of 5 – 6 m.y. In general, OAE’s are linked with the increasing burial of organic carbon, the phosphorus recycling of marine sediments becomes more efficient by anoxic conditions. So, Handoh and Lenton (2003) correlated the phosphorus concentration and the OAE’s.
Errors in Stratigraphic Sequences

Miall and Miall (2002) described the *Exxon factor*, based on the Exxon global cycle chart, which was established by Peter Vail [Vail et al., 1977]. With geophysical reflection – seismic, he interpreted global unconformities as cyclic rising and falling sea levels with frequencies of few millions of years. But there was no appropriate explanation – mechanism for the changes in sea level, for example, chronostratigraphic methods are not accurate enough asserting the global correlation of Vail. Now, the scientific community is shared through two paradigms, the global – eustasy paradigm (Miall and Miall, 2002) and the complexity paradigm, controlled by local to regional controls with the factor of low – to high – frequency tectonic movements.
Conclusions

In many stratigraphic works, the scientists detected frequencies or periodicities in sedimentation patterns. In sequence stratigraphy, it is very difficult to classify the results, which means, the duration of the detected cycles. So, in future, it will be necessary to develop more exact methods to date these sediments. After that, it will be easier to get a stratigraphic conclusion.

The chapter shows, that every scientist has to be careful to correlate local or regional studies into a global context. Of course, it is possible to correlate facts of a super – continent in a global way, the correlation of 2nd or 3rd order – cycles is still very complex.

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