Abiotic Seawater Silicon Sources and the First Appearance of Siliceous Taxa in the Cretaceous
Abby Wyant

Abstract
Bioavailable seawater silica greatly influences siliceous biomineralizers, controlling reproduction in diatoms, spicule morphology in sponges, and skeletal robustness in radiolarians (Lazarus et al. 2009, Maldonado et al. 1999, Yool & Tyrell, 2003). The Cretaceous records an interesting time for siliceous organisms with the first appearance of several siliceous taxa and a radiation in radiolarians at the family level. Based upon these observations it is hypothesized that Cretaceous seawater may have had heightened seawater silica concentrations. To explore this possibility, data on silica sources from the past 200 million years were complied. A $^{87}$Sr/$^{86}$Sr curve indicates riverine and hydrothermal inputs. In addition, many oceanic plateaus were emplaced during the Cretaceous. Emplacement rates of large igneous provinces for the past 200 Ma were calculated and the possibility of oceanic plateaus contributing to seawater silica is explored. These data were then compared to the first appearance of all biomineralizers during this time and a diatom diversity curve at the genus level from their time of first appearance 130 million years ago. Future research aims to measure Ge/Si in marine diatoms from oceanic cores to test the hypothesis that Cretaceous seawater had relatively high silica concentrations.

Introduction
A biological role in the global silicon cycle began with the advent of silicon biomineralization, first seen in Early Cambrian siliceous sponges and radiolarians (Zhang & Pratt 1994; Braun et al. 2007; Cao et al. 2013). This biotic participation would further gain footing in the Early Cretaceous with the appearance of diatoms (Fig. 1b; Geroch, 1978), the most ecologically prominent siliceous taxon in the modern ocean. The remarkable extent to which siliceous taxa affect silicon cycling is seen with the Early Cambrian transition of peritidal to platform chert deposits, reflecting a transition from abiotic processes to siliceous sponges
dominating silicon removal (Maliva et al. 1989) In addition, subtidal deposits replaced sponge-derived chert during the Mid-Cretaceous due to the rise of radiolarians and diatoms (Maliva et al. 1989). Siliceous taxa not only control where silicon deposition occurs, they also influence each other by regulating the availability of seawater silicon. For example, the expansion of diatoms caused a decrease in the silicification of low-latitude radiolarians during the Cenozoic (Lazarus et al. 2009) and the virtual disappearance of desma-bearing sponges in neritic environments during the Cretaceous (Maldonado et al. 1999). Recent evidence has further emphasized a biological role in the silicon cycle, showing the appearance of grasses during the Eocene and their diversification during the Miocene increased the amount of marine silica in the form of opal phytoliths (Alayne Street-Perrott & Barker 2008; Falkowski et al. 2004). The evolution of land plants therefore may have greatly affected global silicon cycling throughout the mid to late Phanerozoic.

Research efforts have largely focused on the influence of diatoms on other siliceous taxa and how these organisms control chert deposition, while less attention has been paid to the abiotic sources of seawater silicon through time and how varying silicon inputs may have affected silicon biomineralizers. In the modern ocean silicic acid is a biolimiting nutrient for siliceous taxa. The amount of bioavailable silicon in seawater controls the success of siliceous populations, namely diatoms whose reproduction is impaired if silicon is too low (M. Brzezinski pers. comm., Oct. 2014, UCSB). Evidence for elevated silicon concentrations during the Middle-Late Cretaceous is based upon gross chert deposition (Hein & Parrish, 1987; Racki & Cordey 2000) and it is interesting to note that the first appearance of several siliceous taxa with a good fossil record occurs in the Cretaceous after over a 300 million year span of when radiolarians and siliceous sponges are first seen in the Cambrian (Porter, in prep). In addition, radiolarians greatly diversify at the family level in the Cretaceous (Casey et al. 1983). A hypothesized increase in dissolved silica during this time therefore may have caused the acquisition of a siliceous skeleton in several
clades and a radiation in radiolarians.

To determine whether silicon seawater input was heightened during the Cretaceous, data on the sources of silicon to seawater were compiled. A $^{87}\text{Sr}/^{86}\text{Sr}$ curve for the past 200 Ma was taken from (Prokopf et al. 2008) to show relative riverine flux and the amount of continental weathering versus how active hydrothermal sources were to marine waters. In addition, the emplacement of voluminous large igneous provinces (LIPs) in Cretaceous oceans is explored as a possible source of silicon to seawater. Emplacement rates for all large igneous provinces, which includes oceanic plateaus, continental flood basalts, and silicic LIPs over the past 200 Ma were calculated. The preliminary data suggest broad correspondence in time between oceanic plateau emplacement and the first appearance of several siliceous taxa (Fig. 1).

**Methods**

The total volume and total duration (the difference between the youngest and oldest age obtained) for all LIPs emplaced within the past 200 Ma were compiled from the literature. The types of LIPs include oceanic plateaus, continental floods basalts, and silicic large igneous provinces. Emplacement rates were then calculated in Excel for each LIP by dividing the total volume by the total duration in millions of years (Table 1).

\[
\text{Emplacement rate (10}^6 \text{ km}^3/\text{ Ma}) = \frac{\text{total volume (10}^6 \text{ km}^3)}{\text{total duration (Ma)}}
\]

In addition, for those LIPs with available data on pronounced magmatic pulses in which a substantial amount of the LIP was emplaced within a relatively brief time compared to total duration, emplacement rates for the pulses were calculated in Excel. Data on magmatic pulses were available for ten large igneous provinces (Table 1; Fig. 1). When the estimated percentage of total volume emplaced during the pulse(s) was available the volume emplaced during the pulse(s) was then divided by the total duration of the pulse(s) in millions of years.
Pulse emplacement rate = \% of total volume emplaced during pulse \times total volume \left(10^6 \text{ km}^3\right) / duration of magmatic pulse (Ma)

When the percentage of the total LIP volume emplaced during the pulse was unknown, total volume was divided by the duration of the pulse(s).

Pulse emplacement rate = \frac{\text{total volume} \left(10^6 \text{ km}^3\right)}{\text{duration of magmatic pulse} (\text{Ma})}

A $^{87}\text{Sr}/^{86}\text{Sr}$ curve was taken from (Prokoph et al. 2008), a diatom diversity curve from the past 130 Ma was taken from Falkowski et al. 2004, and the first appearances of all biomineralizing taxa from the past 200 Ma was provided by Susannah Porter (Porter, in prep). These organisms represent de novo acquisition of silica biomineralization from non-mineralizing ancestors, representing independent acquisition of Si mineralization.

**Results**

Of the forty-one large igneous provinces emplaced during the past 200 Ma, total volume and total duration data were available for twenty-six. Eruptive fluxes were calculated for each of these in Microsoft Excel and subsequently graphed in Adobe Illustrator. Six of the LIPs are continental flood basalts, three are silicic large igneous provinces, and eighteen are oceanic plateaus. Total volume, duration, and calculated eruptive flux for each of these is shown below (Table 1). The remaining fifteen large igneous provinces were excluded from the calculations due to a lack of total duration, unknown volumes, or total volume was determined to be too small (Table 2).
Figure 1. a) Emplacement rates of twenty-six large igneous provinces over the past 200 Ma. Bars above plotted emplacement rates indicated known magmatic pulses of LIPs. Data is provided in Table 1. b) First appearances of all biomineralizing taxa for the past 200 Ma. Hollow stars indicate siliceous taxa without a good fossil record, thus the timing of their first appearance may significantly postdate their actual first appearance. c) Diatom diversity curve for the past 130 Ma at the genus level taken from Falkowski et al. 2004. d) $^{87}\text{Sr}/^{86}\text{Sr}$ isotope curve for the past 200 Ma taken from Prokoph et al. 2008.
<table>
<thead>
<tr>
<th>Name</th>
<th>Type of LIP</th>
<th>Total Volume (x10^6 km^3)</th>
<th>Total Duration (Ma)</th>
<th>Calculated non-pulse flux (10^6 km^3/Ma)</th>
<th>Pulse Volume Used</th>
<th>Pulse Duration (Ma)</th>
<th>Calculated Pulse Flux (10^6 km^3/Ma)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia Flood Basalts</td>
<td>CFB</td>
<td>1.3</td>
<td>17 – 6</td>
<td>0.12</td>
<td></td>
<td></td>
<td>16.6 – 15.3</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>95% of total volume = 1.235</td>
<td></td>
<td></td>
<td></td>
<td>Bryan &amp; Ernst 2008; Eldholm &amp; Coffin 2000; Courtillot &amp; Renne 2003</td>
</tr>
<tr>
<td>Afro-Arabia</td>
<td>CFB</td>
<td>1.2</td>
<td>31 – 14</td>
<td>0.07</td>
<td></td>
<td></td>
<td>31 – 29.5</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80% of total volume = 0.96</td>
<td></td>
<td></td>
<td></td>
<td>Bryan &amp; Ernst 2008; Courtillot &amp; Renne 2003; Rochette et al. 1998</td>
</tr>
<tr>
<td>Sierra Madre Occidental Northern Kerguelen</td>
<td>Si</td>
<td>0.39</td>
<td>38 - 20</td>
<td>0.02</td>
<td></td>
<td></td>
<td>32 – 28; 24 - 20</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100% 0.39</td>
<td></td>
<td></td>
<td></td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>CFB</td>
<td>2.3</td>
<td>40 - 35</td>
<td>0.46</td>
<td></td>
<td></td>
<td>62 – 58 ; 56 - 53</td>
<td>1.14</td>
</tr>
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<td></td>
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<td></td>
<td>100% 8</td>
<td></td>
<td></td>
<td></td>
<td>Bryan &amp; Ernst 2008</td>
</tr>
<tr>
<td>Deccan Traps</td>
<td>CFB</td>
<td>1.2</td>
<td>67 - 63</td>
<td>0.3</td>
<td></td>
<td></td>
<td>66 - 65</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90% = 1.08</td>
<td></td>
<td></td>
<td></td>
<td>Sen &amp; Chandrasekhar 2011; Owen-Smith et al. 2013; Coffin et al. 2002</td>
</tr>
<tr>
<td>Ninetyeast Ridge</td>
<td>OP</td>
<td>4.7</td>
<td>82 - 37</td>
<td>0.1</td>
<td></td>
<td></td>
<td>92 – 88; 76 - 72</td>
<td>0.56</td>
</tr>
<tr>
<td>Madagascar</td>
<td>OP</td>
<td>4.4</td>
<td>90 - 84</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
<td>Bryan &amp; Ernst 2008; Eldholm &amp; Coffin 2000; Bryan &amp; Ernst 2008; Eldholm &amp; Coffin 2000</td>
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<tr>
<td>Caribbean-Colombian</td>
<td>OP</td>
<td>4.5</td>
<td>95 - 69</td>
<td>0.17</td>
<td></td>
<td></td>
<td>92 – 88; 76 - 72</td>
<td>0.56</td>
</tr>
<tr>
<td>Agulhas + Maud Rise + Northeast Georgia Rise</td>
<td>OP</td>
<td>5.3</td>
<td>100 - 94</td>
<td>0.88</td>
<td></td>
<td></td>
<td></td>
<td>Parsiegla et al. 2008; Eldholm &amp; Coffin 2000</td>
</tr>
<tr>
<td>Broken Ridge</td>
<td>OP</td>
<td>4.1</td>
<td>100 - 95</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Central Kerguelen</td>
<td>OP</td>
<td>4.5</td>
<td>105 - 100</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Elan Bank</td>
<td>OP</td>
<td>0.3</td>
<td>110 - 105</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Hess Rise</td>
<td>OP</td>
<td>9.1</td>
<td>111 - 88</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td>Bryan &amp; Ernst 2008; Eldholm &amp; Coffin 2000</td>
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<tr>
<td>Hikurangi Plateau</td>
<td>OP</td>
<td>2.7</td>
<td>118 - 96</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td>Eldholm &amp; Coffin 2000</td>
</tr>
<tr>
<td>Province</td>
<td>Type</td>
<td>Age (Ma)</td>
<td>Volume (km³)</td>
<td>Percent</td>
<td>Duration (Ma)</td>
<td>Percent</td>
<td>Width (km)</td>
<td></td>
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<tr>
<td>Southern Kerguelen</td>
<td>OP</td>
<td>8.5</td>
<td>119 - 110</td>
<td>0.94</td>
<td>119 - 110</td>
<td>0.94</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Manihiki</td>
<td>OP</td>
<td>8.8</td>
<td>126 - 117</td>
<td>0.98</td>
<td>126 - 117</td>
<td>0.98</td>
<td>117</td>
<td></td>
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<tr>
<td>Ontong Java</td>
<td>OP</td>
<td>44.4</td>
<td>129 – 119 ; 90 - 86</td>
<td>3.17</td>
<td>100% 44.4</td>
<td>125 – 121; 90-86</td>
<td>5.55</td>
<td></td>
</tr>
<tr>
<td>Nauru Basin</td>
<td>OP</td>
<td>0.9</td>
<td>130 - 110</td>
<td>0.5</td>
<td>130 - 110</td>
<td>0.5</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Whitsunday</td>
<td>Si</td>
<td>2.5</td>
<td>132 - 95</td>
<td>0.07</td>
<td>132 - 95</td>
<td>0.07</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>Magellan Rise</td>
<td>OP</td>
<td>1.8</td>
<td>135 - 100</td>
<td>0.05</td>
<td>135 - 100</td>
<td>0.05</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Parana-Etendeka</td>
<td>OP</td>
<td>2.35</td>
<td>138 - 125</td>
<td>0.18</td>
<td>80% of 2.35</td>
<td>134 - 132</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 1.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shatsky Rise</td>
<td>OP</td>
<td>4.3</td>
<td>147 - 124</td>
<td>0.19</td>
<td>147 - 124</td>
<td>0.19</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Karoo-Ferrar</td>
<td>CFB</td>
<td>2.5</td>
<td>184 - 174</td>
<td>0.25</td>
<td>100% 2.5</td>
<td>184 - 179</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Chon Aike</td>
<td>Si</td>
<td>0.23</td>
<td>188 - 153</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Atlantic Magmatic Province</td>
<td>CFB</td>
<td>2</td>
<td>205 - 191</td>
<td>0.14</td>
<td>100% = 2</td>
<td>202 - 200</td>
<td>1</td>
<td></td>
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</table>

Table 1. Large igneous provinces used in the non-pulse and pulse calculations shown in Fig. 1. Types of LIPs: OP (oceanic plateau), CFB (continental flood basalt), Si (silicic large igneous province).
<table>
<thead>
<tr>
<th>Name</th>
<th>Volume (x 10^6 km^3)</th>
<th>Age (Ma)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seychelles</td>
<td>?</td>
<td>63.5 – 65</td>
<td>Owen-Smith 2013</td>
</tr>
<tr>
<td>Sierra Leone Rise</td>
<td>2.5</td>
<td>70</td>
<td>Bryan &amp; Ferrari 2013; Eldholm &amp; Coffin 2000</td>
</tr>
<tr>
<td>Wallaby Plateau</td>
<td>1.2</td>
<td>96</td>
<td>Ernst &amp; Buchan 2002</td>
</tr>
<tr>
<td>Marie Byrd Land</td>
<td>?</td>
<td>110</td>
<td>Ernst &amp; Buchan 2002</td>
</tr>
<tr>
<td>Sylhet Traps</td>
<td>?</td>
<td>117</td>
<td>Ghatak &amp; Basu 2011</td>
</tr>
<tr>
<td>Naturaliste Plateau</td>
<td>1.2</td>
<td>132</td>
<td>Direen et al. 2013</td>
</tr>
<tr>
<td>High Arctic</td>
<td>0.05</td>
<td>130-80 ; 85-60</td>
<td>Bryan &amp; Ernst 2008; Maher 2001</td>
</tr>
<tr>
<td>Bunbury Basalts</td>
<td>0.001</td>
<td>132 – 123</td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Rajmahal Traps</td>
<td>0.03</td>
<td>118 – 117</td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Skiff Bank</td>
<td>0.3</td>
<td>68</td>
<td>Coffin et al. 2002</td>
</tr>
<tr>
<td>Comei</td>
<td>?</td>
<td>132</td>
<td>Bryan &amp; Ferrari 2013</td>
</tr>
<tr>
<td>Exmounth Plateau</td>
<td>?</td>
<td>160</td>
<td>Bryan &amp; Ferrari 2013</td>
</tr>
<tr>
<td>Dronning Maud Landing</td>
<td>?</td>
<td>182</td>
<td>Bryan &amp; Ferrari 2013</td>
</tr>
<tr>
<td>Tasman</td>
<td>?</td>
<td>190</td>
<td>Bryan &amp; Ferrari 2013</td>
</tr>
</tbody>
</table>

Table 2. Large Igneous Provinces that were excluded from the calculations of emplacement rates over the past 200 Ma. LIPs were excluded if a total volume or total duration was unavailable.

First appearances of all biomineralizing taxa for the past 200 Ma were compiled from the literature.

<table>
<thead>
<tr>
<th>Name</th>
<th>First Appearance</th>
<th>Skeletal Mineralogy</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Didemnid ascidians</td>
<td>Early Jurassic; Upper Toarcian</td>
<td>Aragonite (suggestive, not convincing)</td>
<td>Buge &amp; Monniot 1972</td>
</tr>
<tr>
<td>Sabellid worms</td>
<td>Early Jurassic; Upper Sinemurian</td>
<td>Aragonite</td>
<td>Vinn et al. 2008; Taylor 1994</td>
</tr>
<tr>
<td>Cheilostome bryozaans</td>
<td>Early Jurassic</td>
<td>Aragonite</td>
<td>Bayer 1956; Loser 1993</td>
</tr>
<tr>
<td>Helioporacean octocorals</td>
<td>Early Cretaceous</td>
<td>Aragonite</td>
<td>Cairns 1984; Fischer et al. 2000</td>
</tr>
<tr>
<td>Stylasterid hydrozoans</td>
<td>Paleocene</td>
<td>Aragonite</td>
<td>Sims et al. 2006</td>
</tr>
<tr>
<td>Cirratulid worms</td>
<td>Oligocene</td>
<td>Unknown</td>
<td>McCartney et al. 2010; McCartney et al. 1990</td>
</tr>
<tr>
<td>Diatoms (marine)</td>
<td>Early Cretaceous</td>
<td>Silica</td>
<td>McCartney et al. 2010; McCartney et al. 1990</td>
</tr>
<tr>
<td>Silicoflagellates</td>
<td>Early Cretaceous</td>
<td>Silica</td>
<td>McCartney et al. 2010; McCartney et al. 1990</td>
</tr>
<tr>
<td>Chrysophytes</td>
<td>Middle Cretaceous</td>
<td>Silica</td>
<td>Moshkovitz et al. 1983</td>
</tr>
<tr>
<td>Ebridians</td>
<td>Late Cretaceous</td>
<td>Silica</td>
<td>Dumitrica 1973; Rai et al. 2008</td>
</tr>
<tr>
<td>Actiniscaceae</td>
<td>Late Cretaceous</td>
<td>Silica</td>
<td>Alves et al. 2010; Schmidt et. al. 2010</td>
</tr>
<tr>
<td>Euglyphids</td>
<td>Paleogene</td>
<td>Silica</td>
<td>Alves et al. 2010; Schmidt et. al. 2010</td>
</tr>
</tbody>
</table>

Table 3. First appearances of all biomineralizing taxa from the past 200 Ma.
Discussion

In the modern ocean, the greatest Si source is from rivers (5.8 Tmol yr\(^{-1}\)), with lesser amounts of Si contributed from seafloor weathering (1.9 Tmol yr\(^{-1}\)), hydrothermal sources (0.6 Tmol yr\(^{-1}\)), groundwater (0.6 Tmol yr\(^{-1}\)), and aeolian inputs (0.5 Tmol yr\(^{-1}\)) (Treguer & De La Rocha 2012). Though true of the modern ocean, dissolved silica sources have presumably varied throughout geologic time. Most of the silicon from riverine flux today is from lithogenic sources due to continental weathering (Treguer & De La Rocha 2012), yet continental weathering rates have varied greatly throughout time (Fig. 1d). A drastic increase in \(^{87}\text{Sr}/^{86}\text{Sr}\) began around 40 Ma and continues into the present, therefore continental weathering most likely increased and/or hydrothermal input decreased and the riverine silica input to the oceans may have relatively recently become a more important source of silicon than it was Mesozoic and Cenozoic. \(^{87}\text{Sr}/^{86}\text{Sr}\) values increase in the Cretaceous from those of the Jurassic and are relatively low compared to the other periods of the Phanerozoic. This could represent a decrease in riverine Sr input during the Cretaceous, for variations in the seawater Sr-curve are generally interpreted as changes in riverine flux for most of the Phanerozoic (Jones & Jenkyns 2001 and references therein), yet the Cretaceous and Jurassic are thought to be exceptions to this (Berner & Rye 1992; Francois et al. 1993) and instead hydrothermal sources may have largely controlled \(^{87}\text{Sr}/^{86}\text{Sr}\) variations (Ingram et al. 1994; Jones et al. 1994). With this in mind, the input of marine silica from continental weathering via rivers may have been substantially less than it is today or the hydrothermal input to Cretaceous oceans was substantially higher than during the rest of the Phanerozoic, causing the \(^{87}\text{Sr}/^{86}\text{Sr}\) to decrease.

Silica is released to seawater at mid ocean ridges from metasomatism of basalts, whereby hydrothermal waters (~300-400 \(^\circ\) C) alter the composition of basalts to greenschist, and silica-infused fluids are expelled through hydrothermal vents (F. Spera pers. comm., Oct.)
The amount of silica leached from basalts during this alteration may be modest though, for the bulk percent composition of Si in basalt is close to the amount in a greenschist (Dungan et al. 1983). Experimental results suggest that Si is leached from basalts to a much greater extent, however, when heated to 200° C at 500 bars pressure, though this release of silica is on ecological, not geologic time scales (Bischoff and Dickson, 1975). The emplacement of large igneous provinces in the ocean during the Cretaceous increased the volume of basalt extruded onto the ocean floor, adding to that created at mid-ocean ridges, though these volumes are rather small when compared to that created globally at mid-ocean ridges. The greatest volume of oceanic plateaus globally was calculated to be 5.19 x 10^6 km^3 at 119 Ma when five oceanic plateaus were being actively emplaced (Fig. 1), yet when using modern day spreading rates, a total of ~30 x 10^6 km^3 per Ma of oceanic crust of basaltic composition is created at mid-ocean ridges. Therefore, the contributions of silica from oceanic plateaus during the Cretaceous were most likely much smaller than that contributed to seawater from seafloor spreading (F. Spera pers. comm., Oct. 2014, UCSB).

The amount of Si released to seawater may vary based upon spreading rates at mid-ocean ridges. An increase in seawater Si is seen at slow spreading ridges along with an increase in Mg/Ca. This is due to hydrothermal fluids penetrating to greater depths in the lithosphere, interacting with peridotite which leaches more Si than basalts. There is a thicker veneer of basalt at fast-spreading ridges, thus not as much Si is released (Ligi et al. 2013). Some argue the Cretaceous had unusually fast spreading rates (e.g. Larson et al. 1991), though this is not widely accepted. One problem in determining spreading rates for the Cretaceous is the lack of magnetic anomalies (F. Spera pers. comm., Oct. 2014, UCSB) If spreading rates were high in the Cretaceous then based upon Ligi et al. 2013, the silica flux to seawater would have been lower than during periods of slow spreading.
The oceanic plateaus were on the whole rapidly emplaced and the effects of this on seawater Si are unknown. Their contributions may have been small, like that at fast-spreading ridges. In addition, there is no direct evidence on the geometry, extent, or even existence of ancient hydrothermal vents in oceanic plateaus (Jones & Jenkyns 2001), yet this may be because research of this nature is difficult considering their location and associated hydrothermal vents may remain unknown.

The picture of silicon contributions to Cretaceous oceans is still far from complete. It remains unknown whether there is a link between the oceanic plateaus emplaced during this time and the appearance of several siliceous taxa or the radiation of radiolarians, though based upon available evidence the Si contribution from these LIPs may not have been substantial. These trends in siliceous taxa during the Cretaceous may be more complex than simply changes in silicic acid concentrations, though to further explore whether seawater silicon was heightened during the Cretaceous, future research aims to answer this question by measuring Ge/Si in diatoms from ocean sediment cores.


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