Flood Basalts and Continental Rifts
Wilson Ch 10, p. 287-323 and Ch 11, p. 325-374

- In this lecture:
  Flood basalts
    - What?
    - Where?
    - When?
    - Geochemistry
    - Isotopic composition
    - Origin of Flood basalts

Continental rifting
- What?
- Where?
- When?
- Geochemistry
- Isotopic composition of magmas
- Origin

Flood Basalt
- Massive eruptions
- Short-lived
- Intracratonic
- Initiation of rifting
- Opening of ocean basins
- Plume-related
- Relation to mass extinctions

<table>
<thead>
<tr>
<th>Province</th>
<th>Age (Myr)</th>
<th>Volume (10^6 km^3)</th>
<th>Paleolatitude</th>
<th>Duration (Myr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia River</td>
<td>16 ± 1</td>
<td>0.25</td>
<td>45N</td>
<td>~ 1 (for 90%)</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>31 ± 1</td>
<td>~ 1.0</td>
<td>19N</td>
<td>~ 1</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>57 ± 1</td>
<td>~1.0</td>
<td>65N</td>
<td>~ 1</td>
</tr>
<tr>
<td>Deccan</td>
<td>66 ± 1</td>
<td>&gt;2.0</td>
<td>30S</td>
<td>~ 1</td>
</tr>
<tr>
<td>Madagascar</td>
<td>88 ± 1</td>
<td>7</td>
<td>40S</td>
<td>~ 2</td>
</tr>
<tr>
<td>Rajmahal</td>
<td>116 ± 1</td>
<td>7</td>
<td>50S</td>
<td>~ 1 or ~ 57</td>
</tr>
<tr>
<td>Serra Geral/ Etendeka</td>
<td>132 ± 1</td>
<td>&gt;1.0</td>
<td>40S</td>
<td>~ 1 or ~ 57</td>
</tr>
<tr>
<td>Antarctica</td>
<td>176 ± 1</td>
<td>~0.5</td>
<td>50-85S</td>
<td>~ 17</td>
</tr>
<tr>
<td>Karoo</td>
<td>163 ± 1</td>
<td>&gt;2.0</td>
<td>45S</td>
<td>~ 1</td>
</tr>
<tr>
<td>Newark</td>
<td>201 ± 1</td>
<td>&gt;1.0?</td>
<td>30N</td>
<td>~ 0.6</td>
</tr>
<tr>
<td>Siberian</td>
<td>249 ± 1</td>
<td>&gt;2.0</td>
<td>45N</td>
<td>~ 1</td>
</tr>
</tbody>
</table>
Flood Basalt

- Massive eruptions
- Short-lived
- Intracratonic rifts
  - Keweenawan
- Initiation of rifting
- Opening of ocean basins
  - Atlantic & Indian oceans
  - Parana-Etendeka-Karoo-Antarctica
    - Break-up of Gondwanaland supercontinent
    - Jurassic - Cretaceous
- Plume-related
- Relation to mass extinctions
Flood Basalts

The cause of mass extinctions?
poisoning atmosphere with CO₂ and SO₄

Table 2 compares the LIP ages given in Table 1 with the estimated ages of stratigraphic boundaries involving significant biotic changes, dated according to the most recent geological time scale. In at least three cases (the Deccan, Newark, and Siberian flood basalts), a direct measure of correlation with major extinction events is possible. The probability that three major volcanic events that typically last ~1 Myr should occur within 1 Myr of major extinction events during the last 250 Myr (of which there are ~12) is about 10⁻⁴. Thinking about the ways in which these two types of global event might be causally linked is a worthy scientific challenge.

<table>
<thead>
<tr>
<th>Flood Basalt Episode</th>
<th>Age</th>
<th>Stratigraphic Boundary</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia River</td>
<td>16 ± 1</td>
<td>Early/Mid-Miocene</td>
<td>16.4</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>31 ± 1</td>
<td>Early/Late Oligocene</td>
<td>30</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>57 ± 1</td>
<td>Paleocene/Eocene</td>
<td>54.8</td>
</tr>
<tr>
<td>(Transitional/Theropods)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deccan</td>
<td>66 ± 1</td>
<td>Oligocene/Tertiary</td>
<td>66.0 ± 0.1</td>
</tr>
<tr>
<td>Madagascar</td>
<td>88 ± 1</td>
<td>Cenoman/Turonian</td>
<td>93.5 ± 0.2</td>
</tr>
<tr>
<td>(Turonian/Carnian)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newark</td>
<td>118 ± 1</td>
<td>Aptian/Aptian</td>
<td>112 ± 1</td>
</tr>
<tr>
<td>Serra Geral/Elenekia</td>
<td>132 ± 1</td>
<td>Jurassic/Cretaceous</td>
<td>143 ± 2.6</td>
</tr>
<tr>
<td>(Wealden/Valanginian)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antarctica</td>
<td>176 ± 1 or 183 ± 1</td>
<td>Jurassic/Cretaceous (Liasian/Wealden)</td>
<td>176 ± 1 or 183 ± 1</td>
</tr>
<tr>
<td>Kansas</td>
<td>183 ± 1</td>
<td>Early/Middle Jurassic</td>
<td>176 ± 1</td>
</tr>
<tr>
<td>Newark</td>
<td>261 ± 1</td>
<td>Triassic/Jurassic</td>
<td>205 ± 1</td>
</tr>
<tr>
<td>Siberian</td>
<td>248 ± 1</td>
<td>Permian/Triassic</td>
<td>248 ± 4.8</td>
</tr>
</tbody>
</table>

Table 2 compares the LIP ages given in Table 1 with the estimated ages of stratigraphic boundaries involving significant biotic changes, dated according to the most recent geological time scale. In at least three cases (the Deccan, Newark, and Siberian flood basalts), a direct measure of correlation with major extinction events is possible. The probability that three major volcanic events that typically last ~1 Myr should occur within 1 Myr of major extinction events during the last 250 Myr (of which there are ~12) is about 10⁻⁴. Thinking about the ways in which these two types of global event might be causally linked is a worthy scientific challenge.
Flood Basalt

Columbia River Basalt
- 170,000 km² erupted in < 2 myr
- Ensilic Back arc basin?
- Relation to Yellowstone hot spot?

Chemical composition
- Subalkaline, tholeiitic
- Scatter in ME compositions
- TE enrichments relative to MORB, OIB

Suggest:
- Polybaric crystallization?
- Mantle source heterogeneity?
  - Subcontinental lithosphere?
- Crustal contamination?
Flood Basalt

Isotopic composition
Nd-Sr variations
Mantle is isotopically heterogenous

Some flood basalts in “mantle array”
Others more “crustal”

Columbia River basalt
Mixing array
MORB source mantle + upper crust

Parana-Etendeka basalt
Mixing
OIB mantle + crustal components

Figure 10.22 Nd-Sr isotope diagrams to show the range of variation displayed by (a) basaltic varieties from the flood basalts in the Klamath Block of Oregon, (b) flood basalts from the Deccan Traps Province of India, (c) basaltic varieties from the Columbia River (1420 Ma) placers of the western U.S. (Stolper and dozens of others, Field Project, 1981), (d) Paraná Etendeka basalts from the Paraná province of Brazil and basaltic rocks from the Kimberley province of Namibia (Whitaker et al., 1986; Peters at al., 1980).

Flood Basalt

Genesis is complex
1. crustal contamination of MORB-like melts
2. melting of enriched lithospheric mantle
3. mixing depeleted+enriched mantle
4. mixing enriched mantle melts and crust
Continental rifts

Regions of localized lithospheric extension
- 10-100 km wide
- 100-1000 km long
- Central depression
- Uplifted flanks
- Crustal thinning
- Sites of incipient continental fragmentation
  - Precedes ocean basin development

Classic examples
- East African rift
- Rio Grande rift
Continental rifts

Fundamentally basaltic volcanism
Smaller volumes of highly potassic or evolved magmas

Lithospheric extension+thinning
Compression of isotherms
Upwelling asthenosphere
High heat flow

Active vs. Passive rifting?
Continental rifts

- Lithospheric extension and thinning
- Compression of isotherms
- Upwelling asthenosphere
- High heat flow

Active vs. Passive rifting?

Subalkaline to alkaline magmas
Fractional crystallization control on chemical variations
Continental rifts

Trace element patterns
Similar to flood basalts

Isotopic compositions
Nd-Sr variations

Most basalts
MORB-OIB field

Some basalts
Enriched lithospheric mantle?

Or
Crustal contamination?

Figure 11.27: Variation of \(^{147}Sm\) vs \(^{143}Nd\) for volcanic rocks from continental rift zones. a) The volcanic rocks of the East African Rift Zone (EARS) (data from Sisson et al. 1993). b) The volcanic rocks of the Central European Volcanic Province (CEVP) (data from Sisson et al. 1993). c) The volcanic rocks of the Rio Grande Rift (data from Sisson et al. 1993).
Continental rifts

Petrogenesis complex
Compare to processes at oceanic hot spots

Much larger possibility for magmas to be generated within or interact with lithospheric mantle or old, evolved continental crust

Figure 11.32 Comparison of the Nd–Sr isotope characteristics of the different mantle reservoirs involved in the petrogenesis of (a) oceanic island and (b) active continental rift basalt. (After McDermitt et al. 1985, Fig. 7, p. 2063).