Comparison of meteoric and \textit{in situ}-produced $^{10}$Be depth profiles

Evaluating erosion rates, meteoric $^{10}$Be flux, and the steady state assumption

Clow, T.$^1$, Willenbring, J.K.$^{1,2}$, Schaller, M.$^3$, Blum, J.$^4$, von Blanckenburg, F.$^2$
**10Be nuclide production and depth profiles**

- Differences in production rate
- Delivery mechanism
- Environmental conditions

**Motivation**

- Meteoric 10Be easier to measure
- Applicable to a much wider range of environments than *in situ*
- Possibility of using archives to determine rates from the past

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Willenbring & von Blanckenburg (2014)
$^{10}$Be nuclide production and depth profiles

Constrain:
- depositional age
- rates of denudation/erosion
- evaluate steady-state conditions
- $^{10}$Be$_{\text{met}}$ flux

Top down (meteoric) vs. Bottom up (in situ)

Do they capture the same signal?

Schaller et al. (2009a)
An ideal situation for comparison

Pinedale & Bull Lake Terminal Moraines

Well characterized:
- Grain sizes
- Weathering indices
- Soil properties

Independently constrained:
- Landform ages
- Denudation rates

Clow et al. (almost submitted)
In situ $^{10}$Be depth profiles, rates

- Mixing depth -- Bull Lake incomplete?
- Ages comparable
- Constant or transient denudation
- Remove weathering component (Schaller et al. 2009b)

Recalculated average effective erosion rates (mm ky$^{-1}$)

<table>
<thead>
<tr>
<th></th>
<th>Pinedale</th>
<th>Bull Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>12.6</td>
<td>6</td>
</tr>
<tr>
<td>Transient</td>
<td>26.9</td>
<td>10</td>
</tr>
<tr>
<td>Average</td>
<td>19.7</td>
<td>8</td>
</tr>
</tbody>
</table>

Schaller et al. (2009a)
**Meteoric $^{10}\text{Be}$ depth profiles**

- Rapid exponential decay
- No correlation with clay content
- Inherited concentrations
  - Incomplete glacial resetting likely
- Lack of soil mixing signal
  - Differing diffusion coefficients?
  - Swamping due to advection?

Clow et al. (almost submitted)
Erosion rate calculations

We calculate the local erosion rate via two methods

\[ E = \frac{Q - (I \lambda)}{N_{\text{surf}} \rho} \]

'Inventory Method' (Brown, 1987)

\[ E = \frac{Q}{N_{\text{surf}} \rho} \]

'Nsrf Method' (Willenbring & von Blanckenburg, 2010)

However, an accurate estimation of \(^{10}\text{Be}_{\text{met}}\) flux is crucial for obtaining accurate erosion rates.
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Heikkila & von Blanckenburg (2015)

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However, an accurate estimation of \(^{10}\text{Be}_{\text{met}}\) flux is crucial for obtaining accurate erosion rates.

Heikkila & von Blanckenburg (2015)

\[= 1.5 \times 10^6 \text{ at/cm}^2/\text{yr}\]

Graly et al. (2011)

\[= 0.55 \times 10^6 \text{ at/cm}^2/\text{yr}\]
Factors influencing Graly flux estimate

Modeled precipitation rates ~200% higher during LGM (Birkel et al., 2012)

Relative paleointensity over last 140 ky was 20-40% of present, on average (Pigati and Lifton, 2004)

Flux rates 27% and 38% higher for Pinedale and Bull Lake, respectively.
Profiles have surficial pH of ~5.5; must consider retention of Be on calculated erosion rates using von Blanckenburg et al. (2012) equation:

\[
E_{\text{erosion}} = E_{\text{erosion}} - \frac{Q}{Kd}
\]

\[
Q = 0.283 \, \text{m/yr (modern precip. rate)}
\]

\[
Kd = \sim 1-100 \, \text{L/g (Boschi & Willenbring, 2016)}
\]

This leads to an erosion rate correction of **-0.7 to -1.8%**

Even if we double our estimate for Q, it is still < -3.5%
Flux and erosion rate comparison

From predicted flux of Graly et al. (2010)
- Pinedale: 16 mm ky$^{-1}$
- Bull Lake: 6.5 mm ky$^{-1}$

20% Off

From Heikkila & von Blanckenburg (2015)
- Pinedale: 43.8 mm ky$^{-1}$
- Bull Lake: 18 mm ky$^{-1}$

220% Off

From best-fit flux of $0.67 \times 10^6$ at/cm$^2$/yr
- Pinedale: 19.6 mm ky$^{-1}$
- Bull Lake: 8 mm ky$^{-1}$

Within 1%

Rates between $N_{surf}$ and Inventory method are virtually identical

Clow et al. (almost submitted)
The steady state assumption

Erosion rates from each method identical

Why would the rates match?

- Steady state has been achieved and $Kd$ does not have an appreciable effect

or

- $^{10}\text{Be}_{\text{met}}$ adsorption is affecting both the surface and the depth profile the same
The steady state assumption

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$^{10}\text{Be}_{\text{met}}$ adsorption is affecting both the surface and the depth profile the same
Conclusions

• Best-fit meteoric $^{10}\text{Be}$ flux of $0.67 \times 10^6$ at cm$^{-2}$ yr$^{-1}$
  • Falls within estimates of 0.5 and 1.5 $\times 10^6$ from other methods

• Meteoric $^{10}\text{Be}$ erosion rates of 19.6 mm ky$^{-1}$ and 8 mm ky$^{-1}$
  for the Pinedale and Bull Lake moraines, respectively
  • Agree remarkably well (±1%) with in situ-produced $^{10}\text{Be}$ erosion rates
  • Independent flux estimates lead to considerable range (-20% to +220%)

• No mixing signal observed in meteoric profiles

• Minimal (1-2%) loss of Be due to dissolution

• Steady state appears to have been achieved with this system
Acknowledgements

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References


Addi1onal Slides

Pigati and Lifton (2004)
Schaller et al. (2009)
Additional Slides

von Blanckenburg and Bouchez (2014)