Mass Balance and Ice Flow Mechanisms

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Glacier accumulation and ablation curves (annual mass-balance)

After Bennett and Glasser, 2009
After Bennett and Glasser, 2009
Equilibrium line
Athabasca Glacier

Equilibrium line
Somewhere in the Swiss Alps

Equilibrium line
Glacier mass balance diagram

After Bennett and Glasser, 2009
Glacier Movement

- Internal deformation (ice deforms through much of its thickness by creep and by folding and faulting)

- Basal sliding
  - Sliding at the ice – bed interface
  - Enhanced basal creep (basal ice deforms around obstacles)
  - Regelation slip (thawing and freezing)

- Bed deformation (deformation of the sediments or rock beneath the glacier)
Internal flow only

After Bennett and Glasser, 2009
Internal flow and basal sliding

Internal flow

Basal sliding

Glacier bed

Bedrock

After Bennett and Glasser, 2009
Internal flow, basal sliding and bed deformation

After Bennett and Glasser, 2009
Deformed till
Factors that contribute to weakness in the material underlying a glacier

- **Temperature** (frozen sediments tend to be quite strong no matter what they’re made of)
- **Composition** (clay minerals tend to be much weaker than other silicates)
- **Degree of lithification** (lithified materials are obviously stronger than unlithified ones)
- **Water content** (most materials, especially clay-bearing materials, are weaker when they are wet)
After Bennett and Glasser, 2009
After Bennett and Glasser, 2009
Basal sliding

**Sliding at the ice – bed interface**
- Most effective on smooth hard rock
- Presence of water enhances sliding
- Stick-slip motion is likely

**Enhanced basal creep**
- Basal ice deforms around obstacles
- Stress is greatest on the up-ice side of an obstacle so there is a greater tendency for deformation near to an obstacle than where the base is flat

**Regelation slip**
- The greater P on the up-ice side of an obstacle may lead to melting
- The water then flows around to the low side (where the P is less) and refreezes

If the base of the ice-sheet is very cold then the likelihood of basal sliding is very low. The ice will likely be frozen to the substrate, and will not move.
## Controls on basal ice temperature

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
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<tbody>
<tr>
<td>Ice thickness</td>
<td>Provides insulation from the cold air above. The greater the thickness the warmer the base.</td>
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<tr>
<td>Accumulation rate</td>
<td>Rapid accumulation of cold snow leads to a cold base. Rapid accumulation of warm snow leads to a warm base.</td>
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<tr>
<td>Ice surface T (a function of the air T)</td>
<td>Cold surface contributes to a cold base (degree for degree)</td>
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<td>Melt water</td>
<td>Warm melt water warms the basal ice. Melt water that re-freezes at depth warms basal ice even more (1 g of water that re-freezes can raise the T of 160 g of ice by 1° C)</td>
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<td>Geothermal heat</td>
<td>Warms the basal ice – much greater in some areas than others.</td>
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<tr>
<td>Friction</td>
<td>Greater ice velocity contributes to a warmer base. (Ice velocity of 20 m/y is equivalent to the average geothermal heat flux)</td>
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</table>
Which conditions are likely to lead to the warmest basal ice, and which the coldest?
After Bennett and Glasser, 2009

Melting T of ice decreases with pressure. At 2000 m depth the melt T is -1.6°C
Boundary Conditions

- A – Net basal melting (more heat is generated at the base than can be conducted away)

- B – Equilibrium between melting and freezing

- C – Net basal freezing (Heat generated at the base of the glacier is removed efficiently and the ice remains frozen on the bed)

After Bennett and Glasser, 2009
After Bennett and Glasser, 2009

B2 is transitional between A and B
Continental/polar

Maritime/mid-latitude

Condition:

C  B  A  B  A

Deformable sediment, but no subglacial deformation

Deformable sediment and subglacial deformation

Condition:

C  A  C  B  A  B  A  A

After Bennett and Glasser, 2009