1. What is tephrochronology?

2. How are tephras dated?
   - Bayesian improvements

3. Identifying uncertainties
   - Six steps to miscorrelation
1. What is tephrochronology?

- A stratigraphic linking, dating & synchronizing tool
  - for palaeoenvironmental, geological or archaeological sequences or events

- Linking/correlating tephras relies on:
  - Statigraphic position (law of superposition → relative age)
  - Characterisation using physical, mineralogical and geochemical properties = ‘fingerprinting’ (fingerprints must be diagnostic, ideally persistent)
  - Numerical age

- Hence unique power (advantages) of tephrochronology:
  - Deposits and palaeoarchival information positioned precisely on common time scale using tephra isochron as stratigraphically fixed tie-point – even if age unknown or imprecise
  - Numerical age acquired for tephra, or relative age, can be transferred from one site to next because tephra eruption age geologically ‘instantaneous’
  - Provides independent test of sequence chronology
Example 1: Fugloyarbanki tephra (Iceland)

Fugloyarbanki tephra

Ice-core age:
26,740 ± 390 yr before 2000 AD (1σ)

(from Siwan Davies et al. 2008 JQS)

Hence F tephra:
- Correlated ~3000 km
- NGRIP → age & environ. proxies
- Marine cores → environ. proxies
- Ice-core age vs marine 14C ages → correct marine reservoir effect LGM
Example 2: Kawakawa tephra (New Zealand)

Galway Tarn
Photo: M. Vandergoes

Correlated ~1000 km

Kohuora crater, Auckland
Kawakawa tephra

Links palaeoarchival records to common tie-point in Auckland (A) – Taranaki (B) – West Coast (C)

- Even though age imprecise $27,097 \pm 957$ cal yr BP (2σ)

(After Rewi Newnham et al. 2007 JQS)
2. How are tephras dated?

- **Historical**
- **Radiometric**
  - $^{14}\text{C}$
  - Fission track esp. isothermal plateau FTD on glass (also FTD on zircon)
  - $^{40}\text{Ar}/^{39}\text{Ar}$
  - Luminescence (TL, OSL)
- **Incremental**
  - Dendrochronology
  - Varved sediments
  - Ice-core layering
- **Age equivalent**
  - Palaeomagnetism
  - Correlation with marine oxygen isotope stages or biostratigraphy (e.g. palynostratigraphy)
NZ-INTIMATE records linked with tephra isochrons

→ Improve ages on tephras at Kaipo bog sequence using OxCal and Bpeat
Lower section
20 radiometric $^{14}$C ages from Waikato lab in red
- via Dr Alan Hogg

14 dates on tephras (via tephrochronology) in black (Froggatt & Lowe 1990, Lowe et al. 1999)

20 AMS $^{14}$C ages from ETH lab (Switzerland) in blue
- via Dr Irka Hajdas

Total of 51 independently dated points

(Lowe et al. 1999 NZJGG, Irka Hajdas et al. 2006 QR)
Kaipo bog sequence fitted to INTCAL04 using Bpeat & stratigraphic ordering (Dr Maarten Blaauw)

Interpolated dates via Bpeat - maximum posterior densities of chronological ordering-constrained calibration ranges (red = 100% outlier)
Tephra age models derived from Kaipo Bpeat analysis

Volcanic centres
- Red = Okataina
- Yellow = Taupo
- Green = Tong./Egmont
- Purple = Tuhua (Mayor Is)

Point age estimates from single-best Bpeat iteration
- Bpeat 95.4% HPD (2σ range)
- OxCal 95.4% HPD (2σ range)

(After Lowe et al. QSR 2008 with help of Dr Maarten Blaauw)
3. Identifying uncertainty

- Miscorrelation of tephra layer may →
  - Isochron drawn at incorrect position
  - Misassociation of palaeoclimatic or archaeologic events = incorrect linking/synchronization
  - Incorrect age transferred

- Six steps to uncertainty...
Uncertainty in tephrochronology

1. Faulty characterisation

– Analytical data compromised, e.g.
  - Unsuitable anal. method used
    (bulk sample vs. single grain)
  - Glass or crystals not polished
  - Appropriate standards not used
  - Incorrect probe conditions
    (e.g. glass needs de-focussed ~20-μm beam)
  - Grains weathered
2. Non-unique fingerprints

- Major element composition of glass can be identical for different tephras
  - e.g. Holocene Taupo tephras

- Need additional data
  - Trace element/rare earth data from single grain LA-ICPMS
  - Stratigraphic or chronological data
Uncertainty in tephrochronology

3. Multiple fingerprints

- Compositional heterogeneity
  - Some eruptions tapped 2–3 magmas simultaneously or sequentially

→ compositions vary in different fallout directions
→ inadequate to characterise few samples from limited dispersal directions
  - May have miscorrelated tephras in past
  - How many grains need we analyse?

- Wide variability andesitic glass composition from crystal inclusions (microlites)
  - Can now correct using petrologic method
4. Reworking to different stratigraphic position

- Results in wrong positioning of isochron
- Dissemination of grains through sediment
  - e.g. Shard concentration zone in peat: where is isochron ‘line’?
- Tephra sinking in v. soft lake sediments

How to recognise reworking?

- Grain character
- Stratigraphic/sedimentary context
- Multiple populations shown by single-grain analyses
- Reproducibility
Uncertainty in tephrochronology

5. Dating ‘errors’

- Wrong age transferred
  - Misassociation
  - Contamination
    - e.g. Old carbon in-wash in lakes; young carbon migration; in-built age; hard-water, marine reservoir effects
  - Large counting errors (low precision)
  - Annealing problem glass fission-track dating
    → age underestimated, now corrected ITPFT
6. Statistical misadventure

- Miscorrelation because database not comprehensive or poor quality data (etc)
  - e.g. DFA generally OK (provides probability of miscorrelation, Mahalanobis distance stat.) but dependent on quality & comprehensiveness of training sets

- Some tephras very similar compositionally, others separable, e.g. Kk vs Re vs O

Table 11: $D^2$ values and classification efficiencies of the discriminant model for the 22–65 ka tephras

<table>
<thead>
<tr>
<th></th>
<th>Kk</th>
<th>O</th>
<th>Om</th>
<th>Mg</th>
<th>Hu</th>
<th>T</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^2$ values between groups</td>
<td>7.3</td>
<td>25</td>
<td>77</td>
<td>98</td>
<td>45</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>18</td>
<td>59</td>
<td>106</td>
<td>40</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Om</td>
<td>30</td>
<td>123</td>
<td>50</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>126</td>
<td>118</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hu</td>
<td>262</td>
<td>245</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| % correctly reclassified by model | 93 | 100| 100| 100| 100| 100| 100

DFA from Shane Cronin et al. 1997 NZGG
Reducing uncertainty

- Need
  - Multiple criteria = safer correlation
  - Rigorous analyses, standards must be documented, uncertainty reported
  - Ideally use comprehensive sequences esp. with interfingering tephras from different sources
    - Distal can be best, e.g. lake sediments, marine cores, ice cores

- Even if age on tephra is imprecise, correct characterisation means isochron still transferrable
  - Effectively tephra tie-point fixed (stratigraphic position) on ‘elasticated’ chronology