Methods for Dating Ice Cores

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Basic Outline

- Ice Cores - Background
- Four Major Methods for Dating Ice Cores
  - General Background
  - Benefits
  - Problems
- Conclusions

Ice Cores - Background

- Layers of snow compact under own weight and become ice
  - Snow and ice builds up slowly each year

- Ice cores serve as:
  - Archives of atmospheric composition
  - Vertical timeline of past climates stored in ice sheets
  - Tools to analyze physical & chemical characteristics of paleoclimatic information

- Variation among ice cores:
  - Dependent on depth, surface temperature and accumulation rate
  - Geographical and temporal areas

(Hubbard and Glasser 2005; Riebeek 2005; ICR 2009; NICL 2009)

Ice Cores continued…

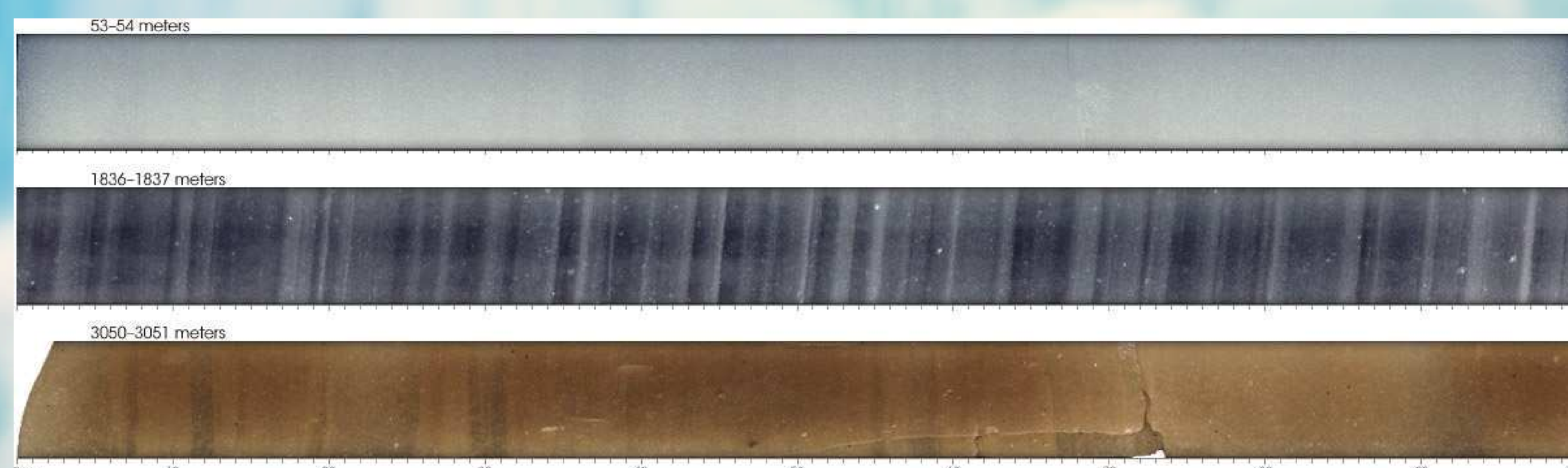
- Drilling for Ice Cores:
  - Ice core includes all layers of snow accumulated
  - Site choice based on:
    - Shape of underlying bedrock
    - Height of ice sheet
    - Areas where ice does not move
  - Procedure:
    - Mechanical drills penetrate ice sheet
    - 1 day to drill 50-70m
    - Cores usually ~10 cm in diameter

- Ice Core Locations:
  - Longest record (deepest ice) in Antarctica (Vostok samples)
  - Antarctica - Vostok core (400,000 years) & EPICA core (800,000 years)

(van Ommen 2003; ICR 2009; Landis and Hintz 2009)

Ice Cores continued…

- GISP2, Greenland project finished in 1990s
  - At least 110,000 years of the past.
  - First layer: 53 m deep
  - Second layer: 1836 m deep
  - Third layer: 3050 m deep



(Riebeek 2005)

Methods

1. Counting of Annual Layers

2. Pre-determined Ages Used as Markers

3. Radioactive Dating

4. Ice Flow Models

Method 1:
Counting of Annual Layers

- Procedure:
  - Count visual annual fluctuations in the ice core

- Usefulness:
  - Date shallow ice cores (e.g., GISP2)
  - Used to date other cores using ages from identifiable horizons
  - Each annual layer starts with rich $\varrho^{18}O$ and becomes $\varrho^{18}O$ poor
  - Can compare relative temperatures with paleoclimatic data

- Dependent upon:
  - Temperature: colder in winter and warmer in summer
  - Irradiance: less in winter and more in summer

(Brinkman 1995; Hubbard and Glassser 2005)

Method 1: Major Benefits

- Most precise dating method.
- Ice core locations with high accumulation rates more useful than low rates (e.g., Dye 3)

(Paterson 2002)

Method 1: Major Problems

- Deep and older layers become thin and stretched.
  - Molecular isotopes tend to diffuse over time
- Analysis is time-consuming
- Impractical below certain depths; layers become too thin for analysis
  - Must use other techniques below certain depth.
- Annual counts could lead to over and under counts.

(Brinkman 1995; Paterson 2002; van Ommen 2003; Hubbard and Glasser 2005)

Method 2:
Pre-determined Ages Used as Markers

- Method compares known ice-core characteristics with unknown or uncertain ice-cores; such as:
  - Volcanic Eruptions
  - Internal Reflecting Horizons
  - Paleoclimatic Comparisons
  - Atmospheric Fallout

(Brinkman 1995; Paterson 2002; van Ommen 2003; Hubbard and Glasser 2005)

Method 2:
Major Benefits

- Relatively quicker procedure than annual counting.

(Brinkman 1995)

Method 2: Major Problems

- Must:
  - Acquire a known age-dated ice core beforehand
  - Have knowledge of previous volcanic eruptions
  - Have knowledge of the different signals of climate change corresponding to same event
- Deformation of ice sheets as they move through their host ice mass
- Shape of bedrock can affect the ice bed
- If pre-determined age markers are incorrect, other ice cores incorrect

(Brinkman 1995; Hubbard and Glasser 2005; Readinger 2006)

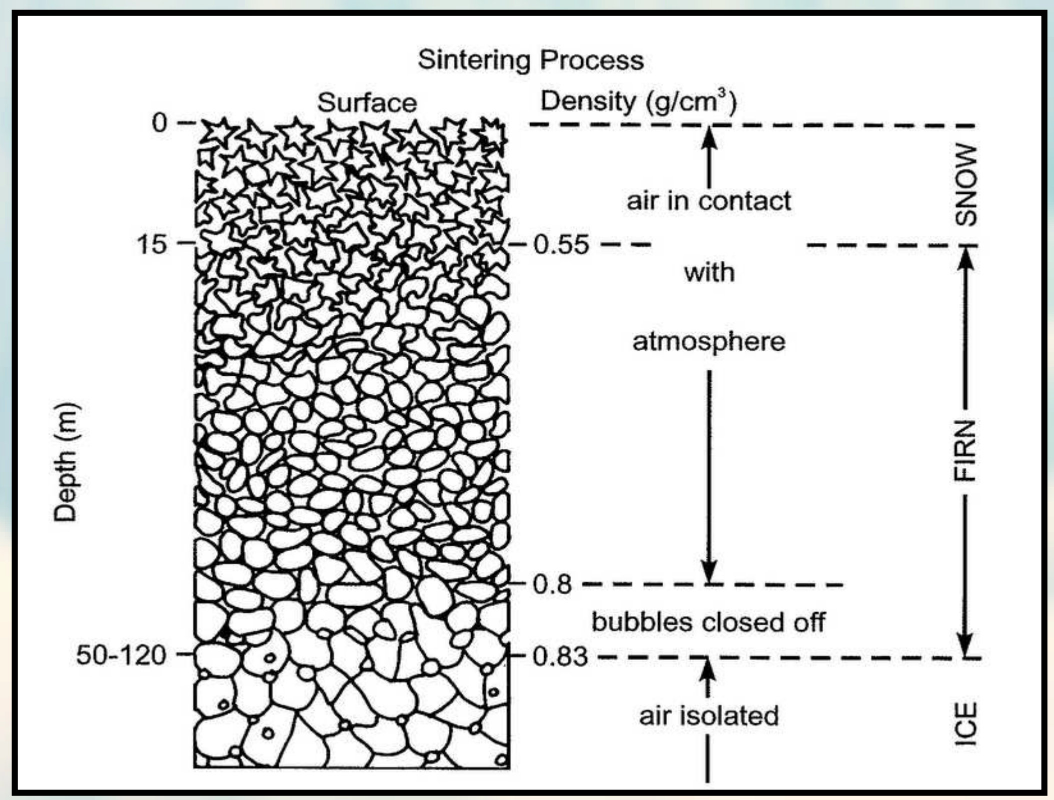
Method 3:
Radioactive Dating

- Dating CO^2 extracted from air bubbles in the ice
- When the snow turns to ice, tiny bubbles of air are trapped in the ice
- Procedure:
  - Melts a quantity of ice core from a given depth
  - Collects gases that trapped for standard ^{14}C dating

(Brinkman 1995; Paterson 2002; Landis and Hintz 2009)

Method 3: continued…

- Atmospheric composition from air bubbles trapped in ice sheets



(Readinger 2006)

Method 3:
Major Benefits

- Gain direct knowledge of gases accumulated over time for ice core locations either un-cored or uncertain

Method 3:
Major Problems

- Carbon dating is only useful for determining ages between 0 and 80,000 years

- Conversion from radiocarbon to true years uncertain

- Large amounts to be melted for analysis of gases present

- Cosmic rays strikes ice and converts some of the oxygen in core to ^{14}C

(Brinkman 1995; Paterson 2002)

Method 4: Ice Flow Models

- Theoretical ice-flow models to analyze ice-age depths
- Depends on past changes in:
  - Ice thickness
  - Temperature
  - Accumulation rates
  - Flow patterns
  - Ice rheology (deformation)
- Dansgaard-Johnsen model (commonly accepted)
  - Model varies with season and related parameters

(Paterson 2002)

Method 4:
Major Benefits

- Only method available for site selection and sampling method choice prior to ice core recovery.

- Useful when analyzing older, thin layers that cannot be counted or distinguished.

(Paterson 2002; van Ommen 2003)

Method 4: Major Problems

- Must use at least 2 variables to reduce uncertainty
- Molecular diffusion in ice smooths out variations and percolates (filter out) meltwater in firn
- Must make assumptions of:
  - Original thickness of the annual layer
  - Rate of formation at a particular thickness

(Brinkman 1995; Paterson 2002)

Conclusions

- Methods of dating ice cores dependent on characteristics of ice mass being sampled
- Seasonal variation hard to detect if accumulation rate is very slow; some annual layers may be missing
- Absolute dating restricted to upper, younger layers of ice cores; must rely on relative dating or ice flow models for lower, older layers

(Paterson 2002)


Questions?