Volcanology

Tephra and Tephrochronology

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What is tephra?

- Any silicate material explosively erupted from a volcano
  - glass, crystals and lithics

- Chemical composition of glass is unique to a volcano and specific eruption- “fingerprint”

- Key to understanding past eruptions
  – Eruption (size and explosivity) and deposition dynamics
  – Volcano Evolution
  – Geochronology
  – Hazards
- Isochron for correlating and understanding other earth processes

Tephra Classification

TABLE 1. GRANULOMETRIC CLASSIFICATION OF PYROCLASTS AND OF UNIMODAL, WELL-SORTED PYROCLASTIC DEPOSITS

Clast size (mm)	Pyroclast	Pyroclastic deposit	
		Mainly unconsolidated: tephra	Mainly consolidated: pyroclastic rock
	Bomb, block	Agglomerate, bed of blocks or bomb, block tephra	Agglomerate, pyroclastic breccia
64 mm			
	Lapillus	Layer, bed of lapilli or lapilli tephra	Lapilli tuff
2 mm			
	Coarse ash grain	Coarse ash	Coarse (ash) tuff
1/16 mm			
	Fine ash grain (dust grain)	Fine ash (dust)	Fine (ash) tuff (dust tuff)

Schmid, 1981- Recommendations for IUGS tephra classification

Updated grain-size classification

TABLE 1. GRAIN-SIZE TERMS FOR PRIMARY VOLCANICLASTIC ROCKS

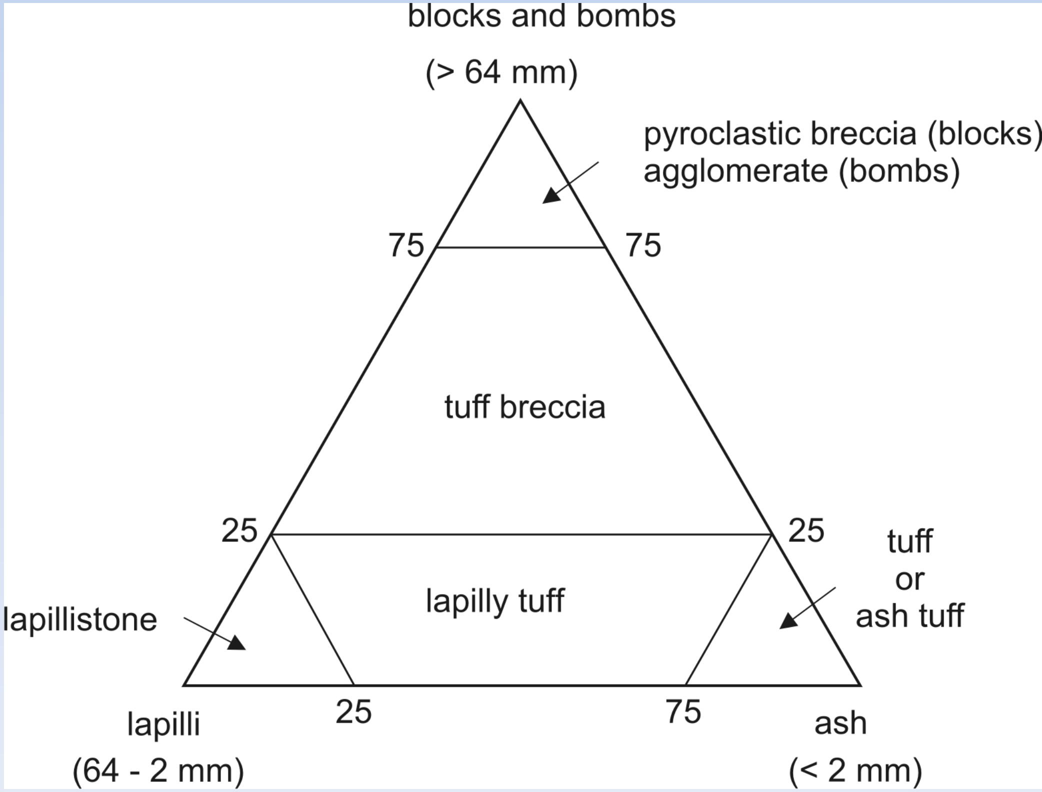
Grain size		Primary volcaniclastic deposit		Sedimentary deposit (rock name)	
(phi)	(mm)	Unconsolidated	Lithified	Unconsolidated	Lithified
>4	<1/16	Extremely fine ash	Extremely fine tuff	Clay	Mudrock, shale
3–4	1/16–1/8	Very fine ash	Very fine tuff	Very fine sand	Very fine sandstone
2–3	1/8–1/4	Fine ash	Fine tuff	Fine sand	Fine sandstone
1–2	1/4–1/2	Medium ash	Medium tuff	Medium sand	Medium sandstone
0–1	1/2–1	Coarse ash	Coarse tuff	Coarse sand	Coarse sandstone
−1 to 0	1–2	Very coarse ash	Very coarse tuff	Coarse sand	Coarse sandstone
−2 to −1	2–4	Fine lapilli	Fine lapilli-tuff	Granule	Grit, granule congl.
−4 to −2	4–16	Medium lapilli	Medium lapilli-tuff	Pebble	Pebble conglomerate
−6 to −4	16–64	Coarse lapilli	Coarse lapilli-tuff	Cobble	Cobble conglomerate
<−6	>64	Block/bomb	Breccia	Boulder	Boulder congl.

Note: The ash and lapilli grain-size ranges have been modified from that given by Fisher (1961) and derivative classifications to match and include the subdivisions within the sand and gravel ranges given by Wentworth (1922). "Extremely fine" ash replaced "fine ash" for particles finer than 4 phi (1/16 mm). Lithified sedimentary deposits with angular grains coarser than 2 mm are commonly termed "breccia."

White and Houghton, 2004

Confusing Nomenclature

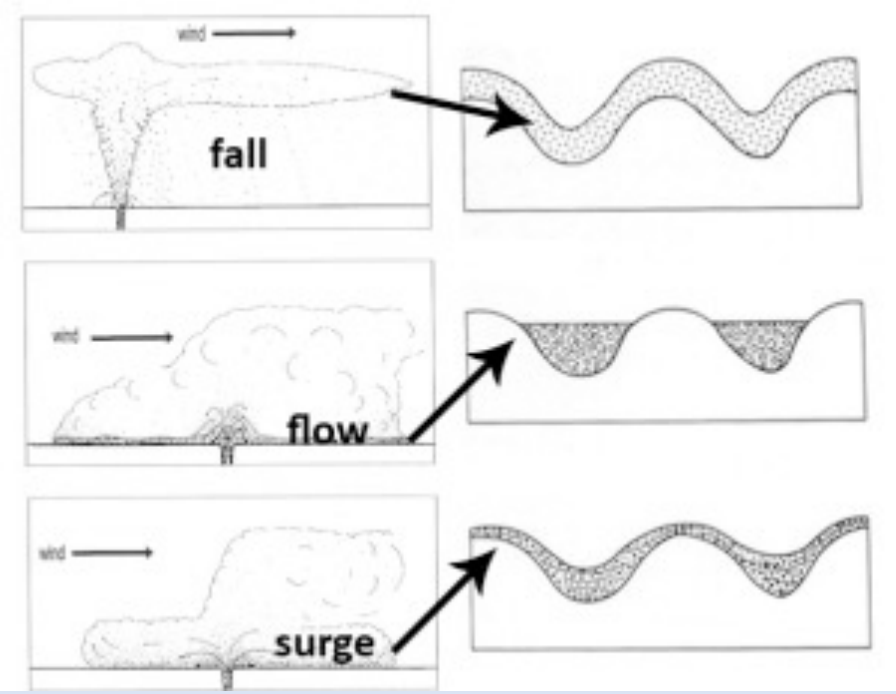
- Tephra
- Pyroclast
  - Pyroclastic deposit
- Ejecta
  - Not common



Fisher, 1966

Proximal tephra Deposits

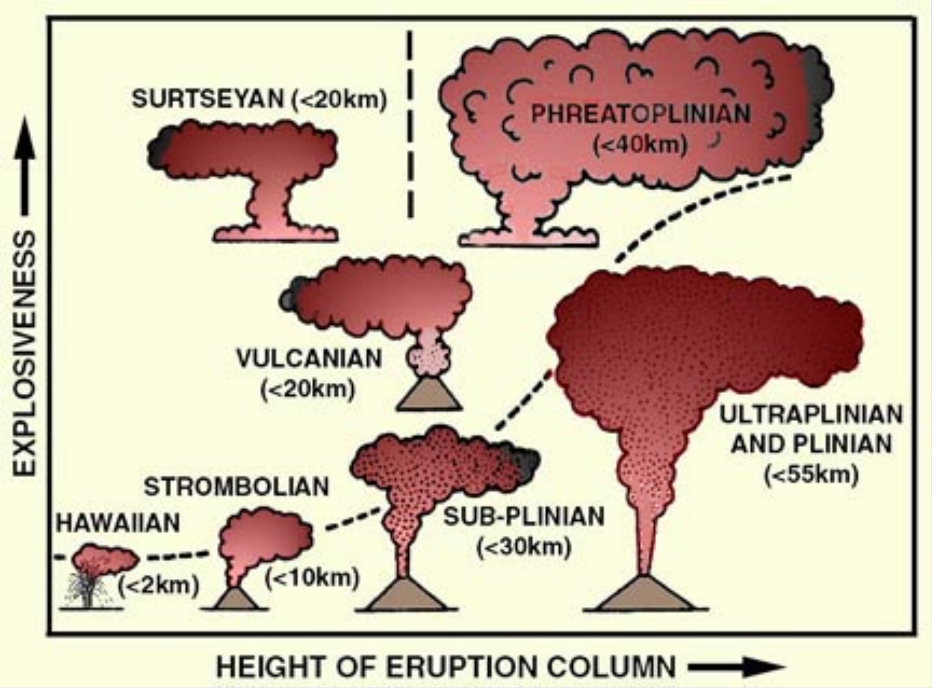
- Fall
  - Mantle topography
- Surge
  - Dilute, turbulent flow
- Flow
  - Dense, ~laminar flow
- *Epiclastic
  - Reworked pyroclasts (water or air)



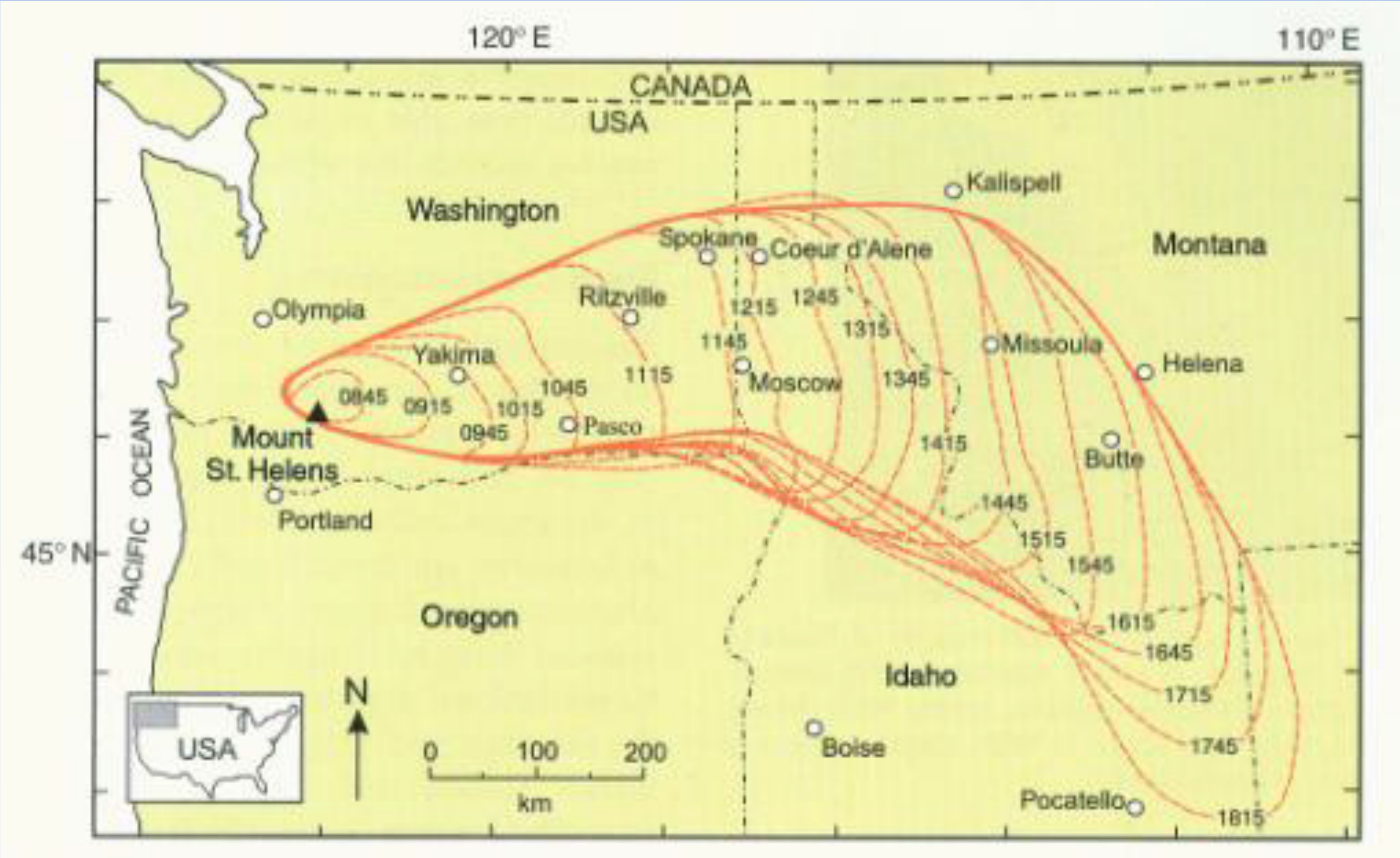
http://www.luckysci.com/2014/08/types-of-volcanic-rocks-and-deposits/

Ash Dispersion

- Eruption Height
- Angle of injection
- Wind strength
- Terminal Fall Velocity
  - Particle Size and Shape

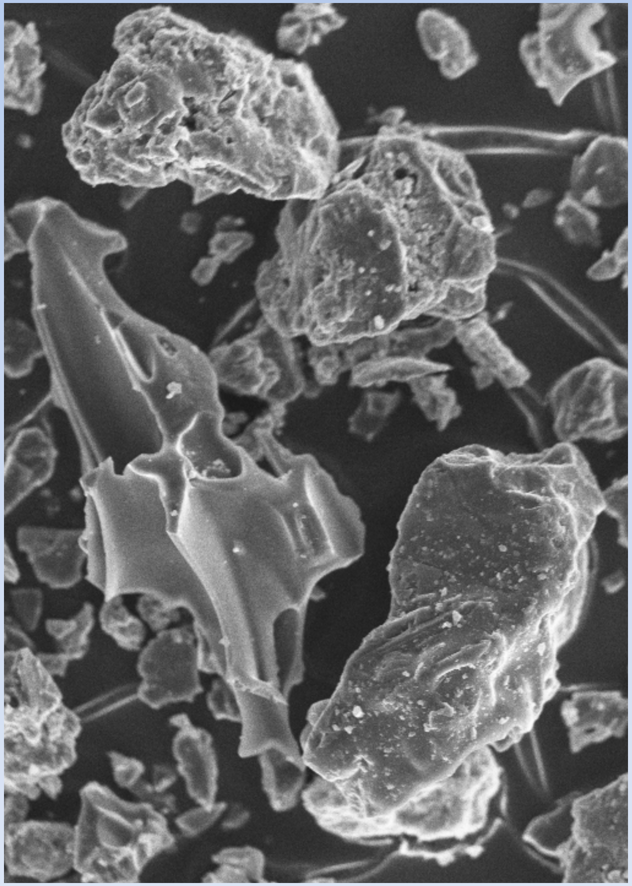


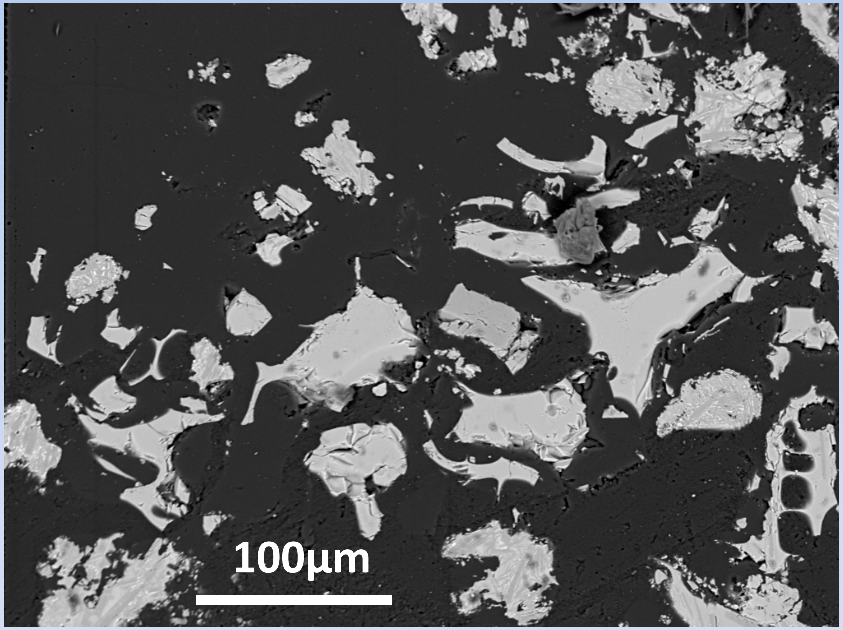
Tephra Distribution

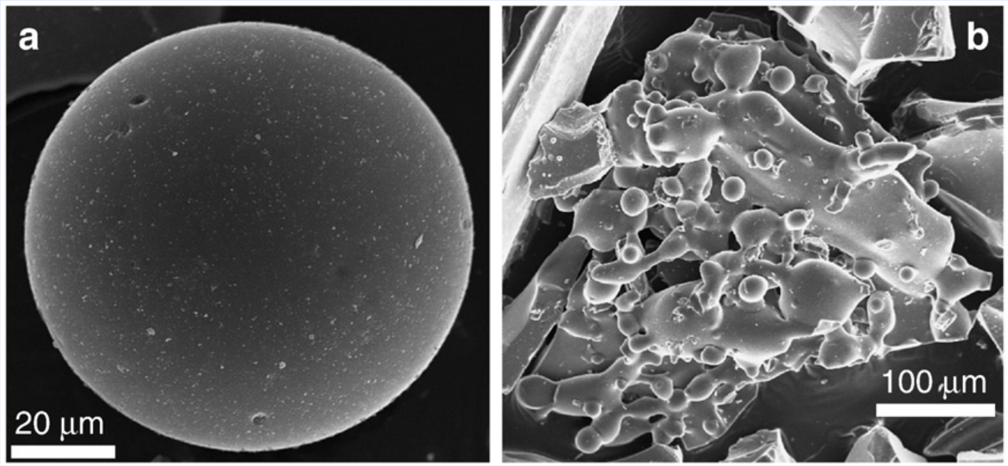


Alloway, 2006

Tephra morphology







What goes up, must come down?

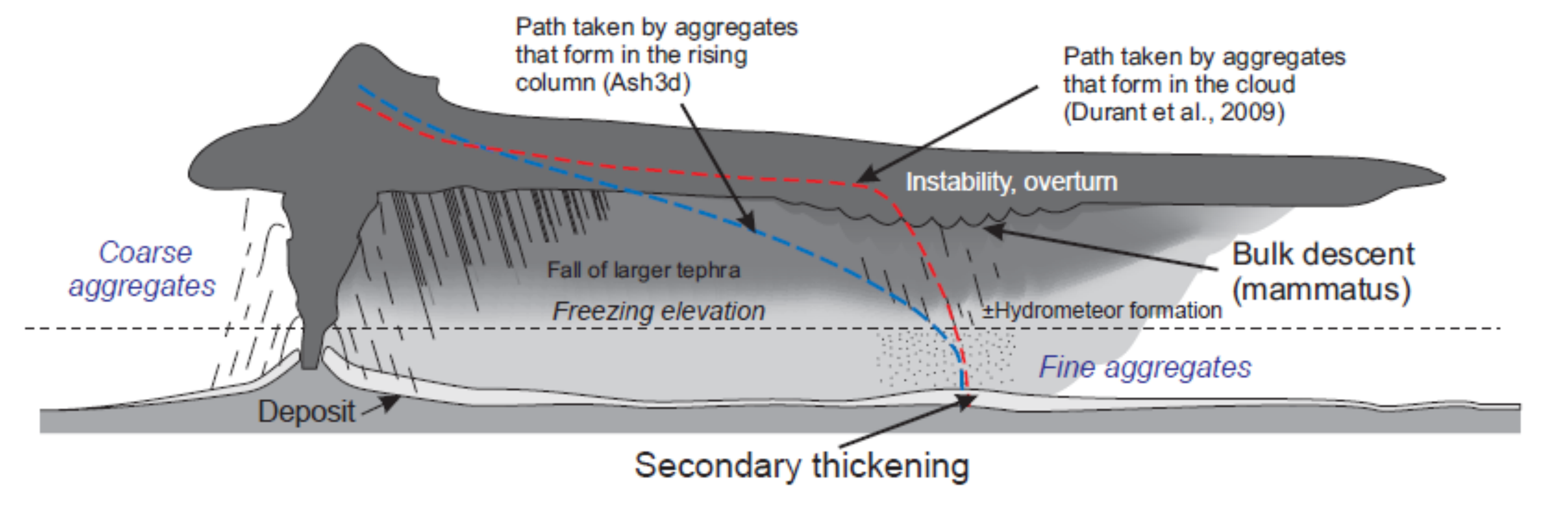


Figure 2. Illustration of the path taken by coarse aggregates that fallout in proximal sections, less than a few plume heights from the source (left), and fine aggregates that fall out in distal sections (right). Among distal fine aggregates, we show the path taken by those that might have formed within or below the downwind cloud as hypothesized by Durant et al. (2009) (red dashed line), and those that were transported downwind without changing size, as calculated by Ash3d (blue dashed line). Also illustrated are some key processes that might influence the distribution of fine, distal ash, including development of gravitational instability and overturn within the downwind cloud (Carazzo and Jellinek, 2012), and the development of hydrometeors as descending ash approaches the freezing elevation (Durant et al., 2009).

Mastin et al., 2016

Ash Aggregation

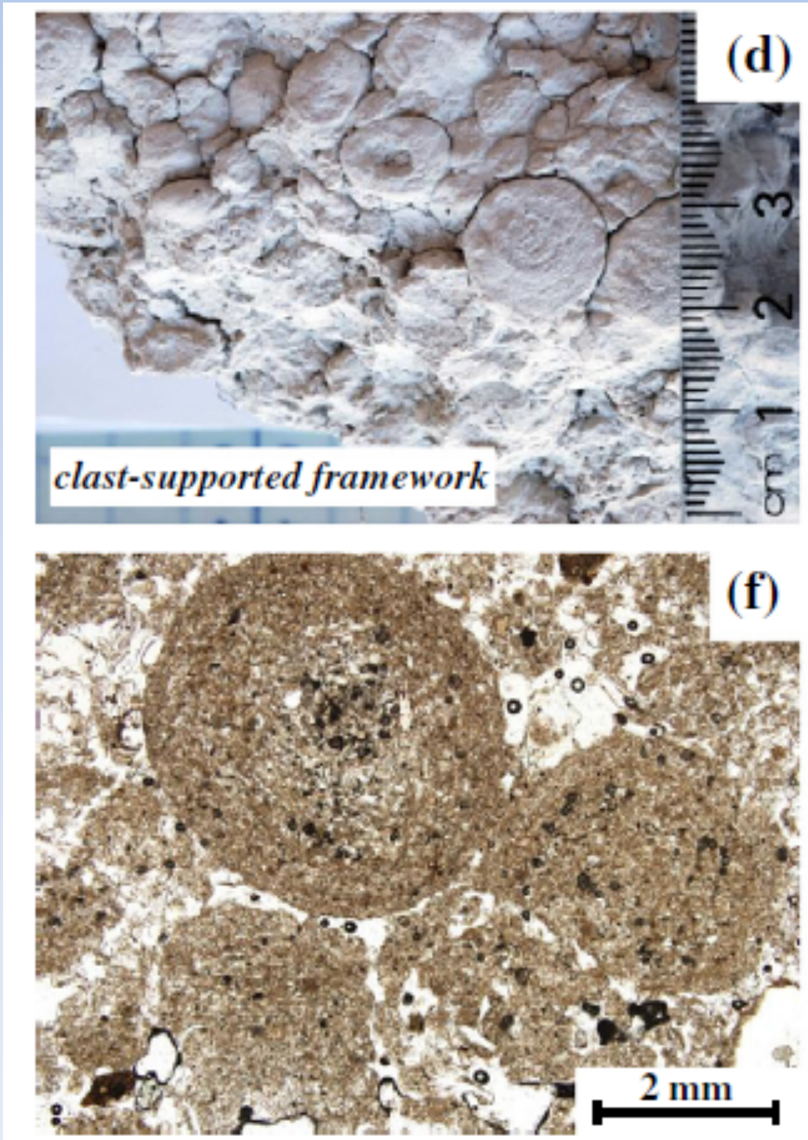
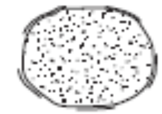
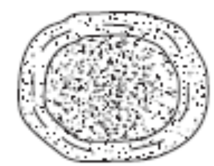
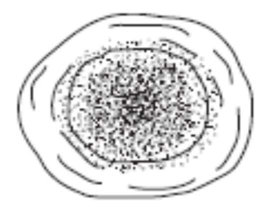
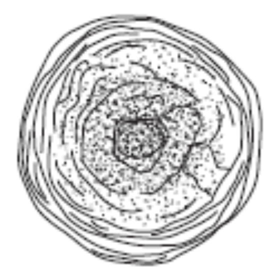


Table 1
Categories of aggregate types identified in the C
refer to the weight percent in aggregates based

Appearance	Name
	Particle clusters
	Massive ash pellets
	Coalesced ash pellets
	Layered accretionary lapilli
	Ultrafine rim-type accretionary lapilli
	Complexly layered accretionary lapilli

Van Eaton and Wilson 2013

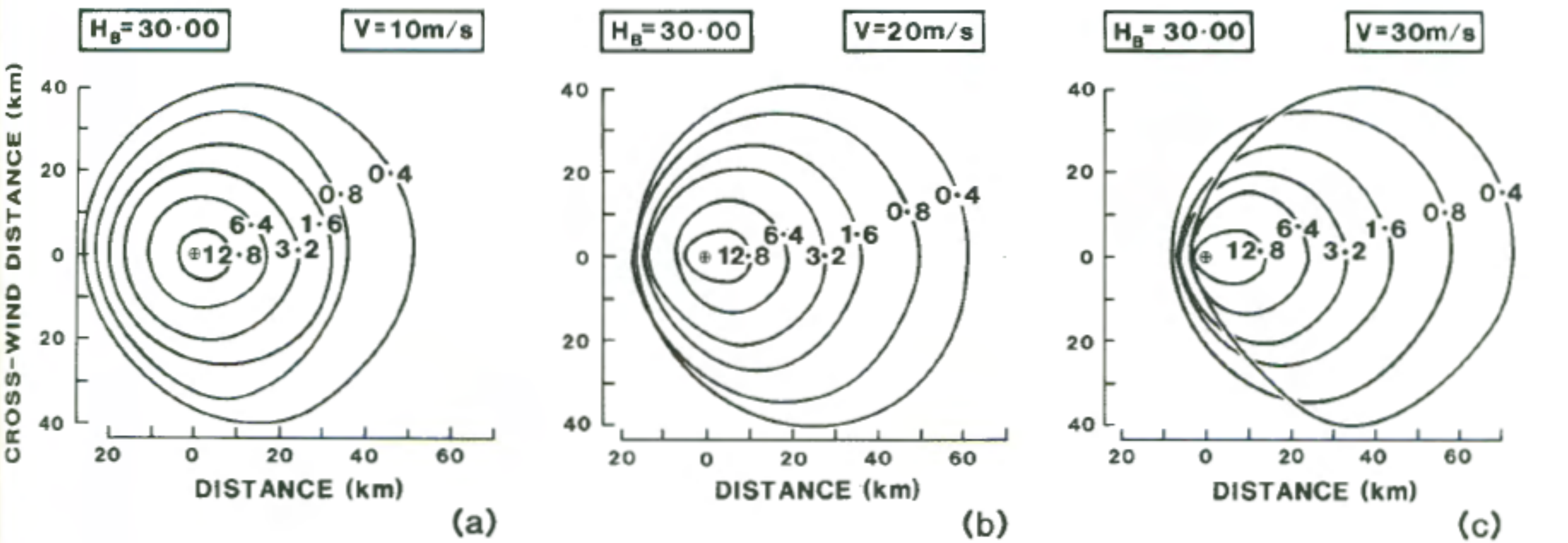
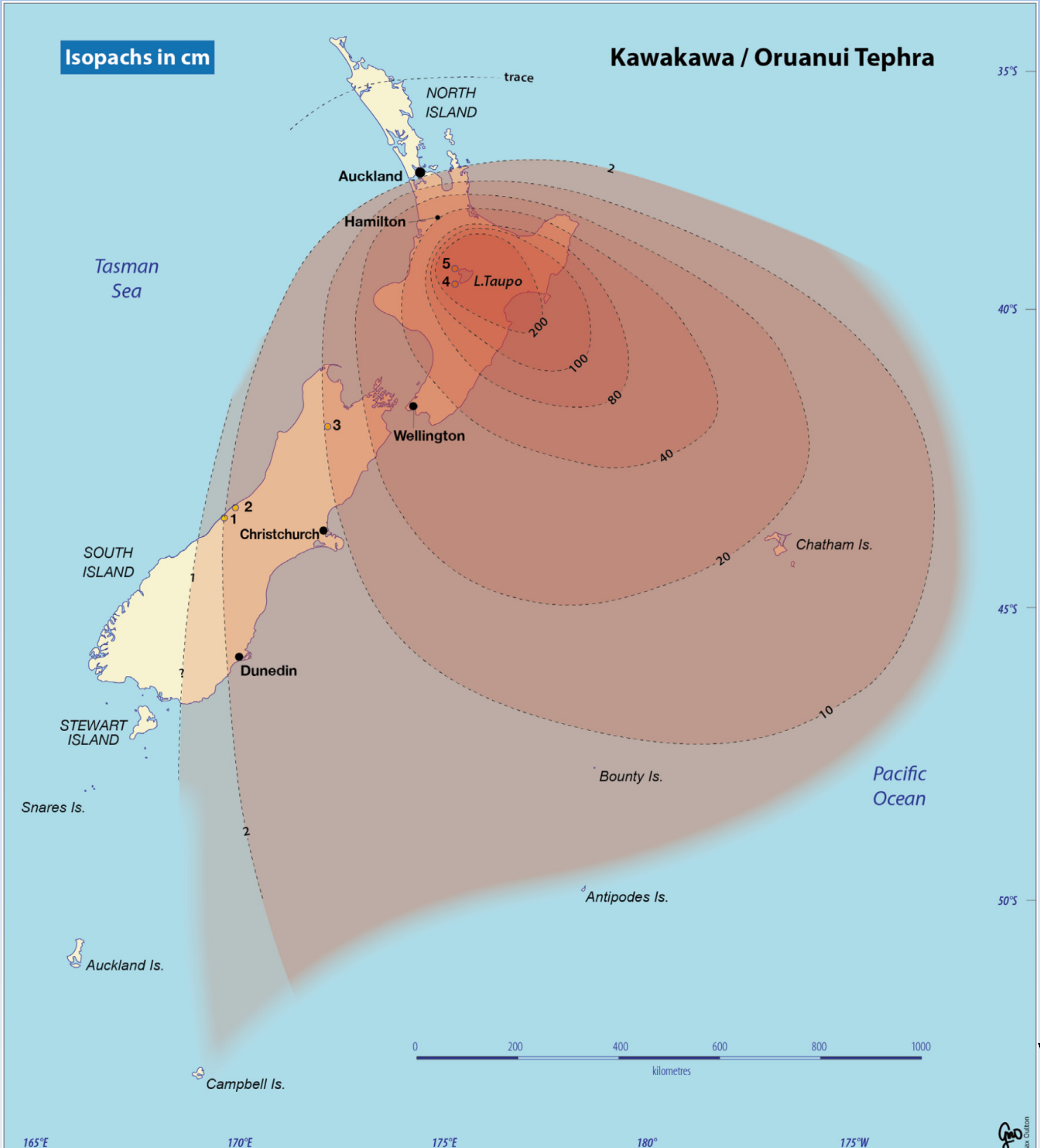


Fig. 12. **a** Geometry of clast isopleths from an eruption column of 43 km height with a maximum crosswind velocity at the tropopause of 10 m/s. Isopleth contours are for clast diameters in centimetres with a density of 2500 kg/m^3. **b** Geometry of clast isopleths from an eruption column of 43 km height with a maximum crosswind velocity of 20 m/s. **c** Geometry of clast isopleths from an eruption column of 43 km height with a maximum crosswind velocity of 30 m/s. Note the high degree of circular symmetry retained even at high wind speeds

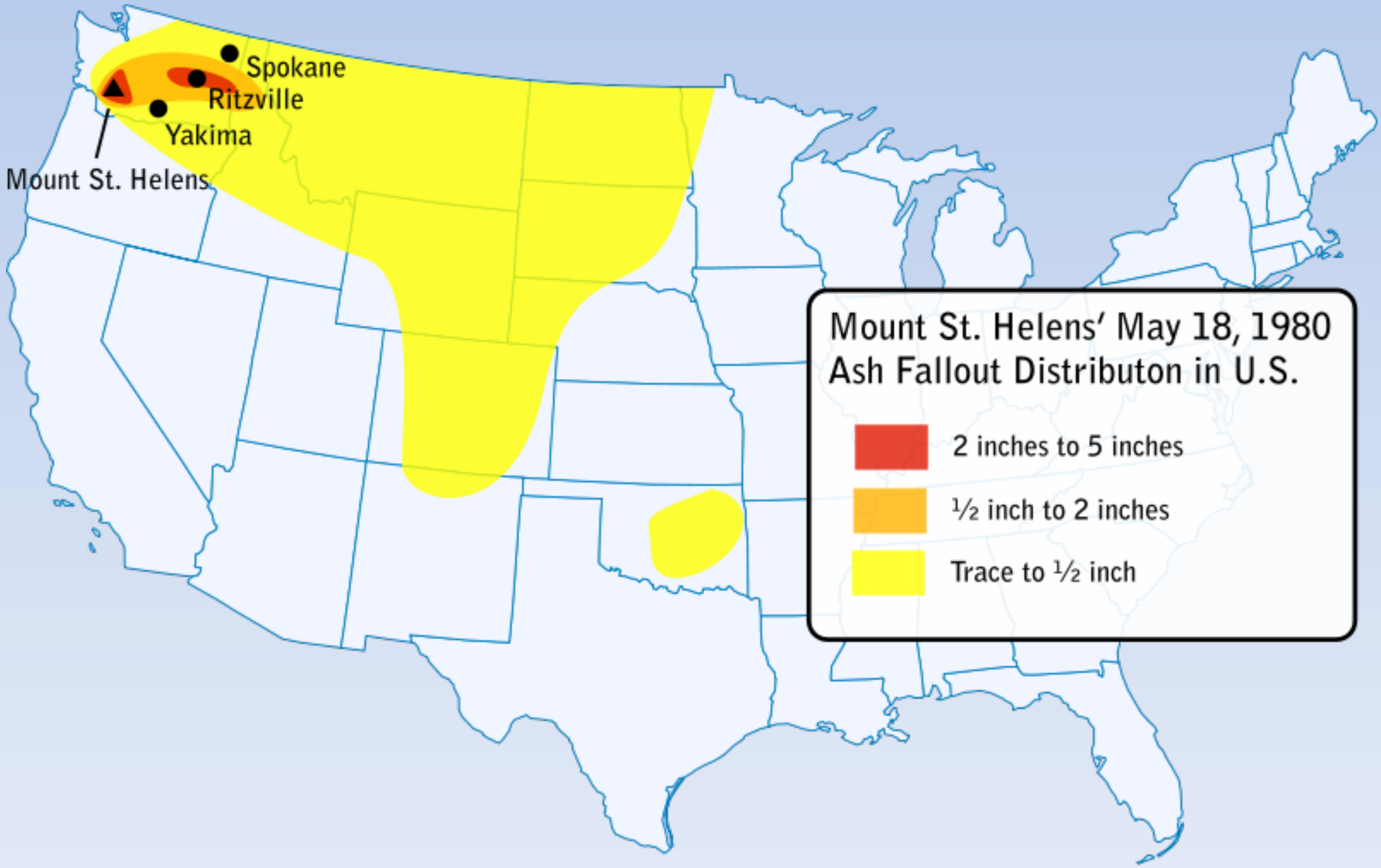
Carey and Sparks

Isopach Map



Vandergoes et al., 2013

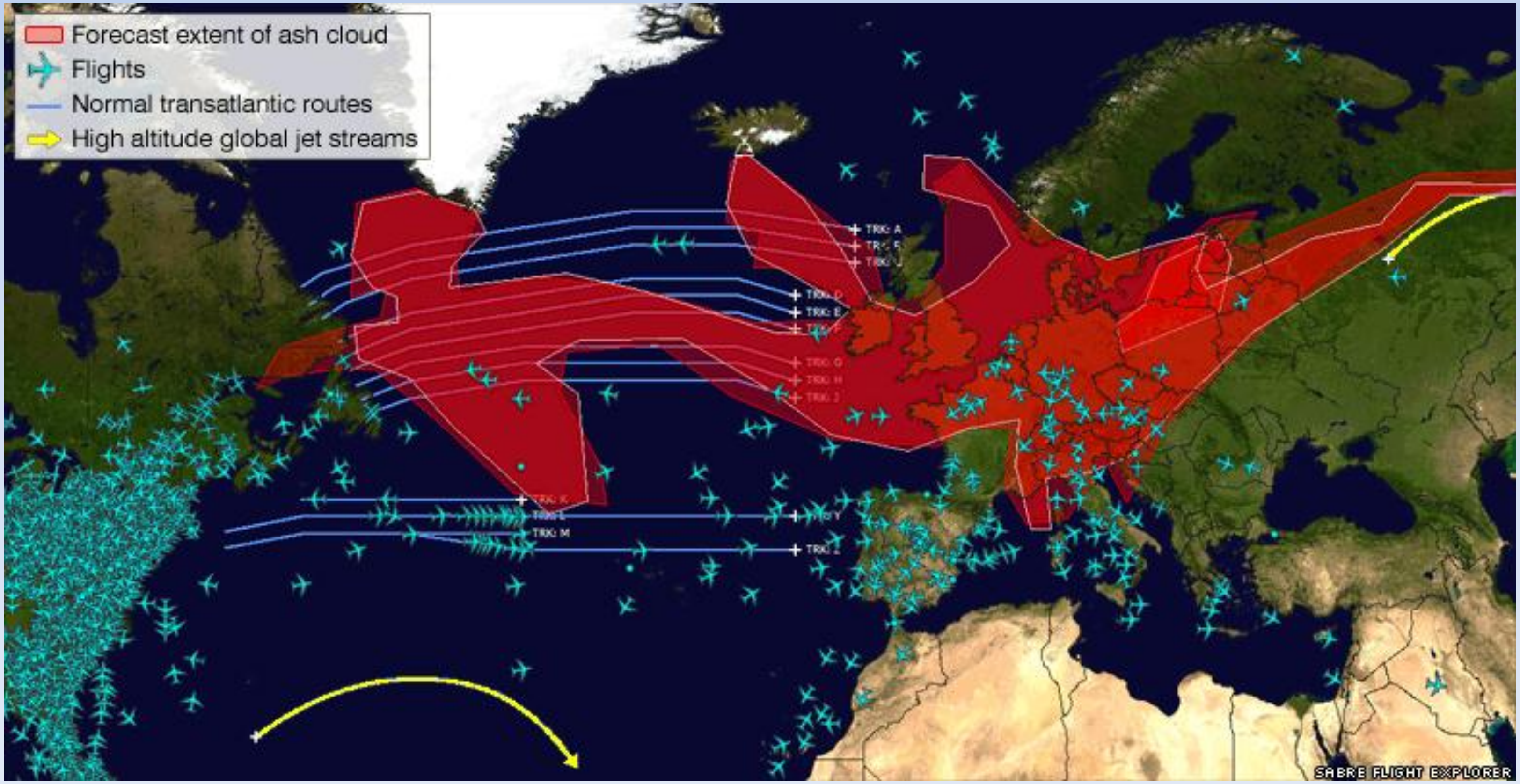
Ash Distribution



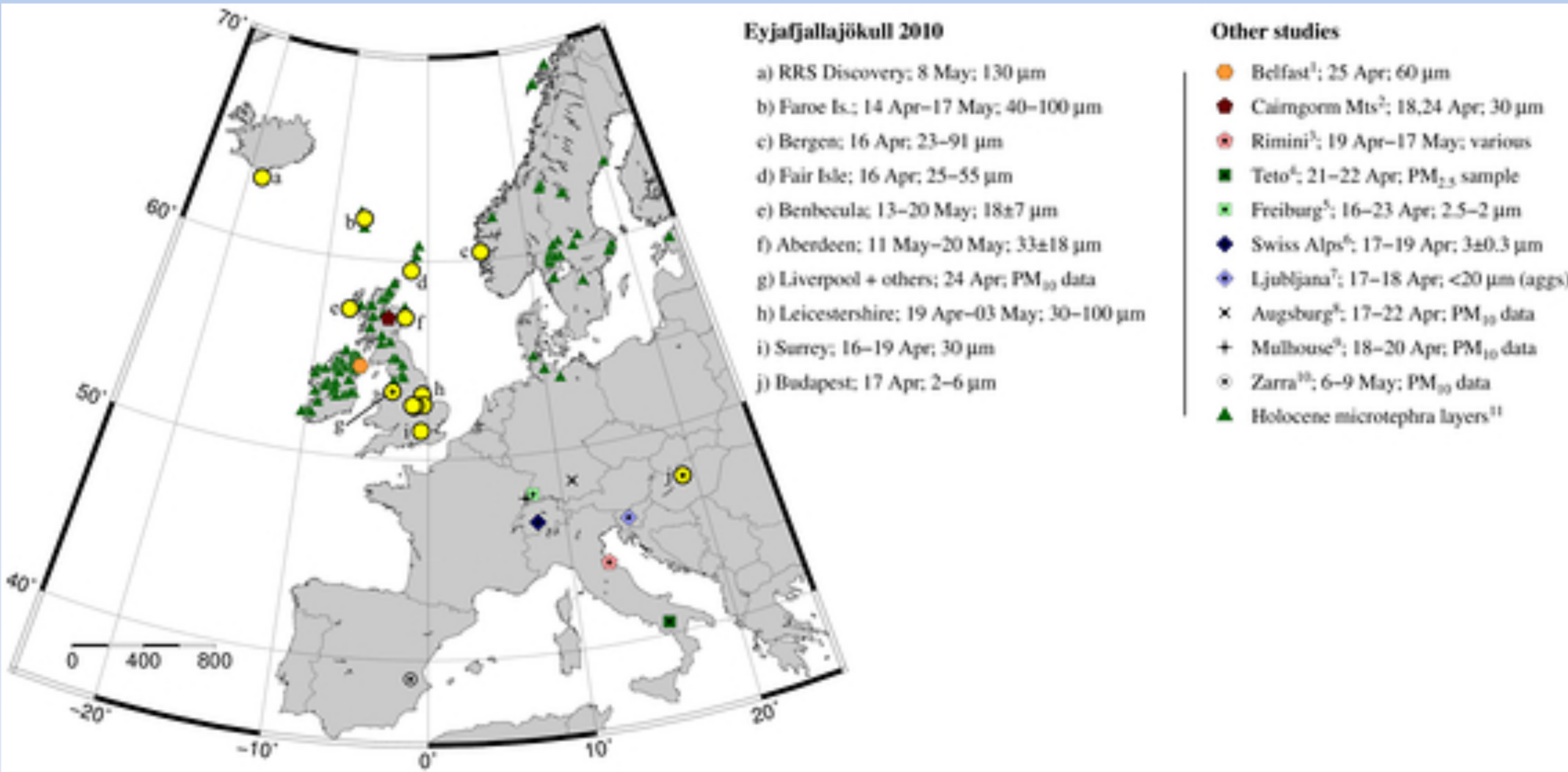
information from the USGS map of the same title.

Eyjafjallajökull Volcanic Ash Plume

Unpredictable Ash Clouds



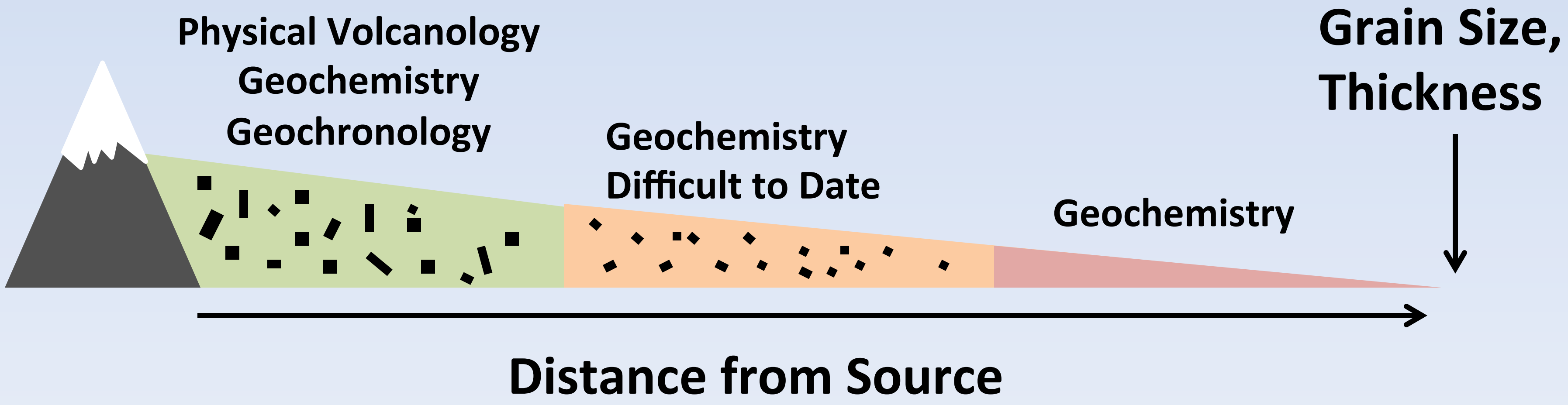
Distal deposition of tephra



Journal of Geophysical Research: Solid Earth
Volume 117, Issue B9, B00C10, 6 JUN 2012 DOI: 10.1029/2011JB008904
http://onlinelibrary.wiley.com/doi/10.1029/2011JB008904/full#jgrb17130-fig-0006

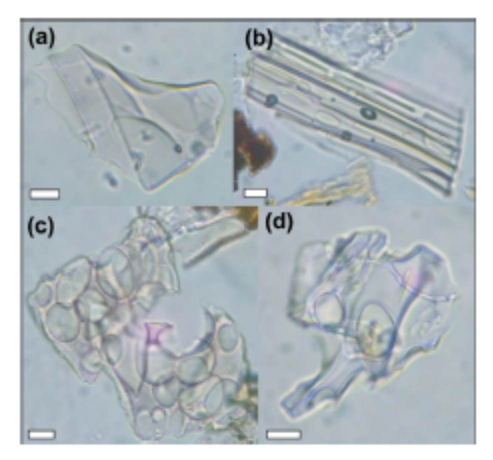
Tephra deposits and preservation

- Volcanoes eruptions
  - Proximal tephra
  - Distal tephra
  - Ultra-distal tephra
    - cryptotephra



Cryptotephra

- Distal tephra deposited that is essentially invisible to the naked eye in the field
- Usually found in marine/lake environments, ice cores, peat bogs and certain eolian seds



Stevenson, et al., 2015

Tephrostatigraphy vs. Tephrochonology

- Tephrostatigraphy- the study of sequences of tephra layers or stata and associated deposits and their relative ages. Involves defining, describing and characterizing tephra…underpins tehprochonology

- Teprhochronology- "the use of tephra as isochrons to link sequences in different places via precise tie-points and to establish relative or numerical ages"

Alloway, et al., 2006

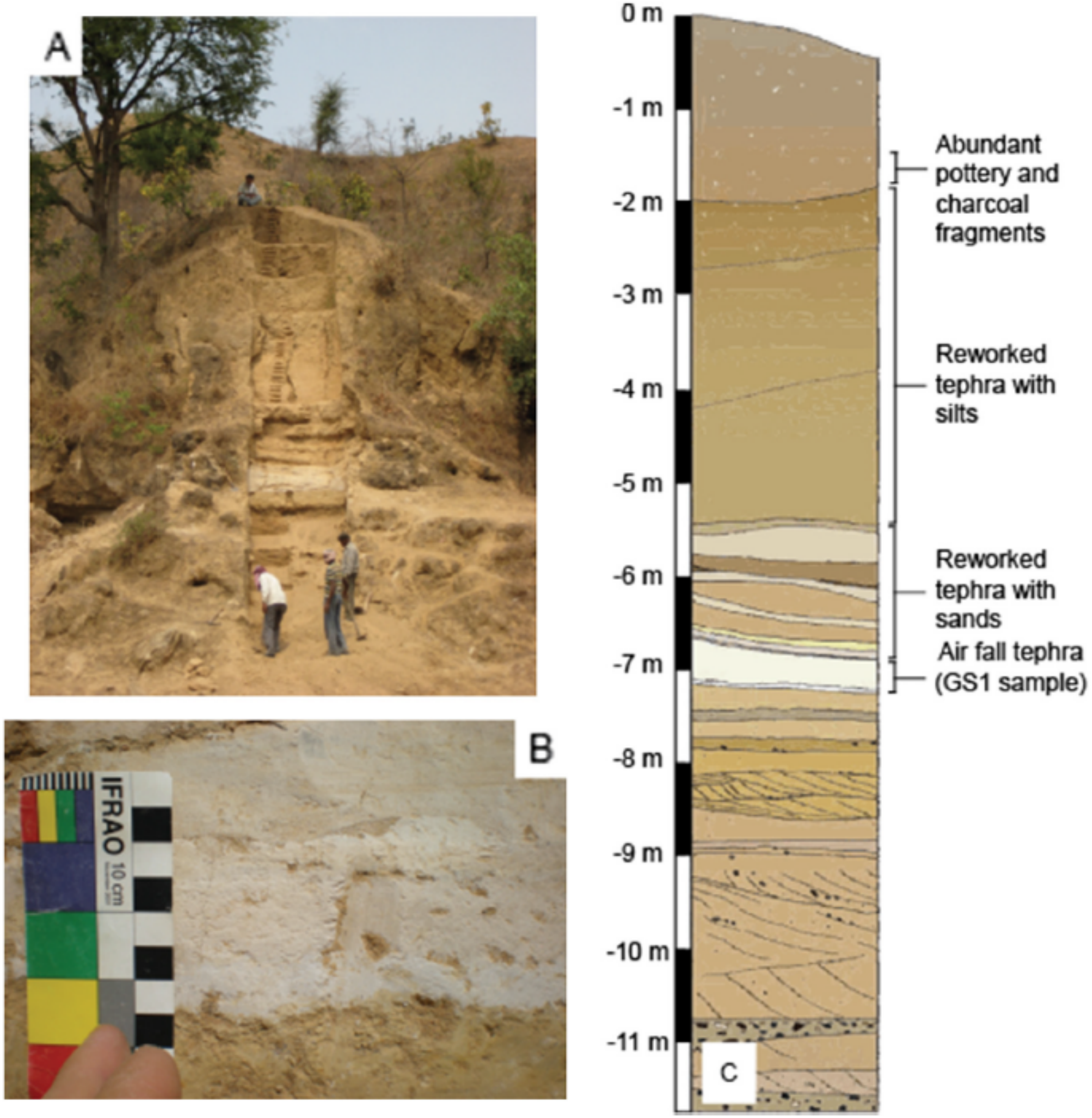
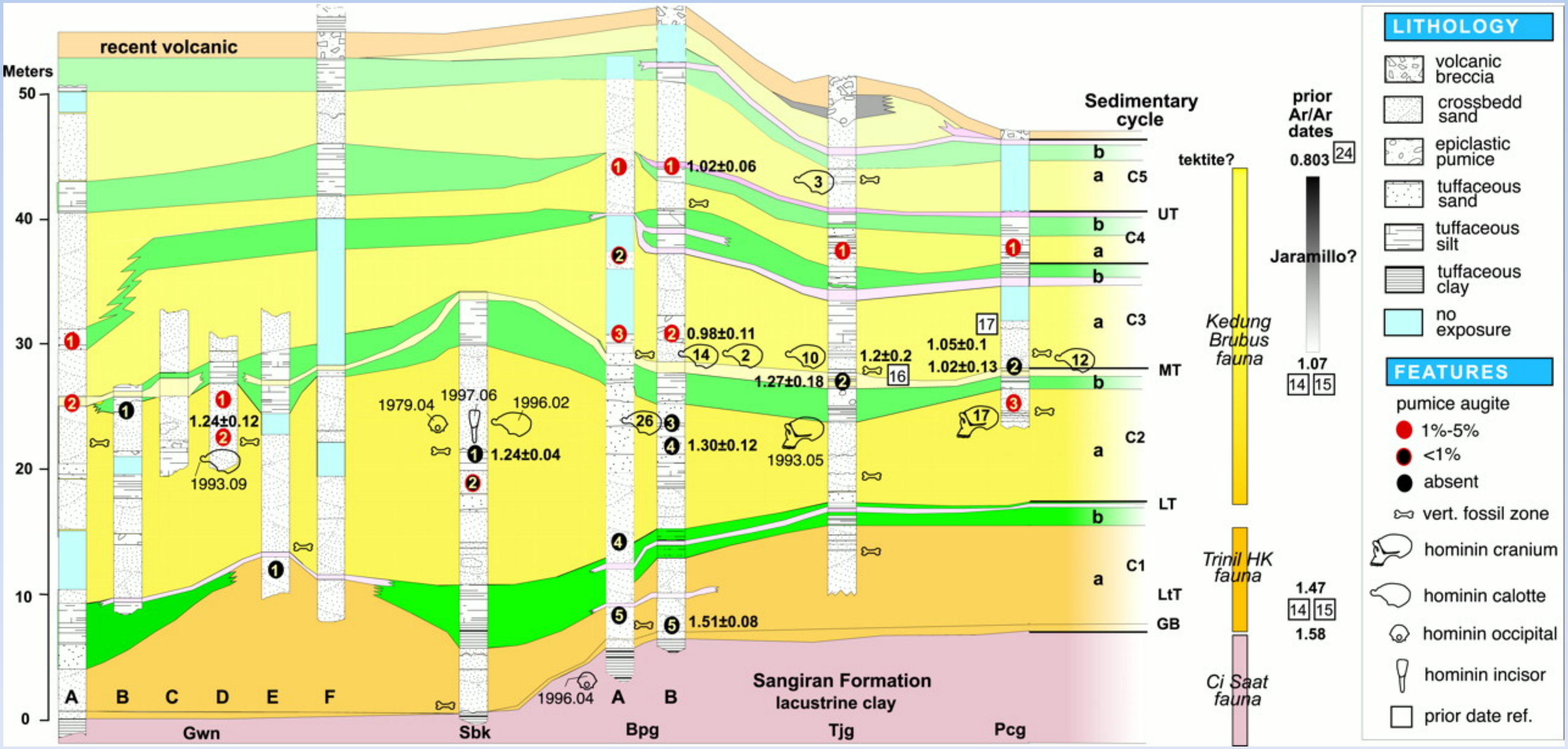


Fig. 4. Stratigraphy at the Middle Son Valley site, India. (A) Excavation at the Ghoghara locality. Note the white ash bed in section. (B) Basal ash layer at Ghoghara identified as an air-fall deposit (*c.* 5 cm thick), overlying the brown clay and underlying the medium to coarse grained reworked ash. Small bioturbation features are present (Lewis et al., 2012). (C) Stratigraphic log of the Ghoghara section. Note location of sample GS1. Photos P. Ditchfield.

Tephrostratigraphy



Larick et al., 2001

Applications of tephrochronology

- Anthropology applications- timing of hominid activities
- Chronostatigraphic boundries (i.e. Dansgaard-Oeschger events)
- Tectonic controls on landscape evolution (Basin and Range)
- Paleoseismicity
- Glacial process and ice sheet changes
- CO2 releases during deglaciation
- Paleoenvinronmental reconstructions
- Soil erosion
- Storm frequency and magnitude
- Marine/Ice core sychronization
- *Volcano evolution
- *Ice core synchronization
- *Past atmospheric circulation patterns
- …….

Tephrochronology

- How to directly date tephra?
  - $^{40}Ar/^{39}Ar$ geochronology (NMT)
  - Fission Track dating
  - Zircon Dating
    - U/Pb dating
  - ^{14}C
  - Layer counting
    - Dendrochronology
    - Ice cores
    - Varves

Taupo Ignembrite

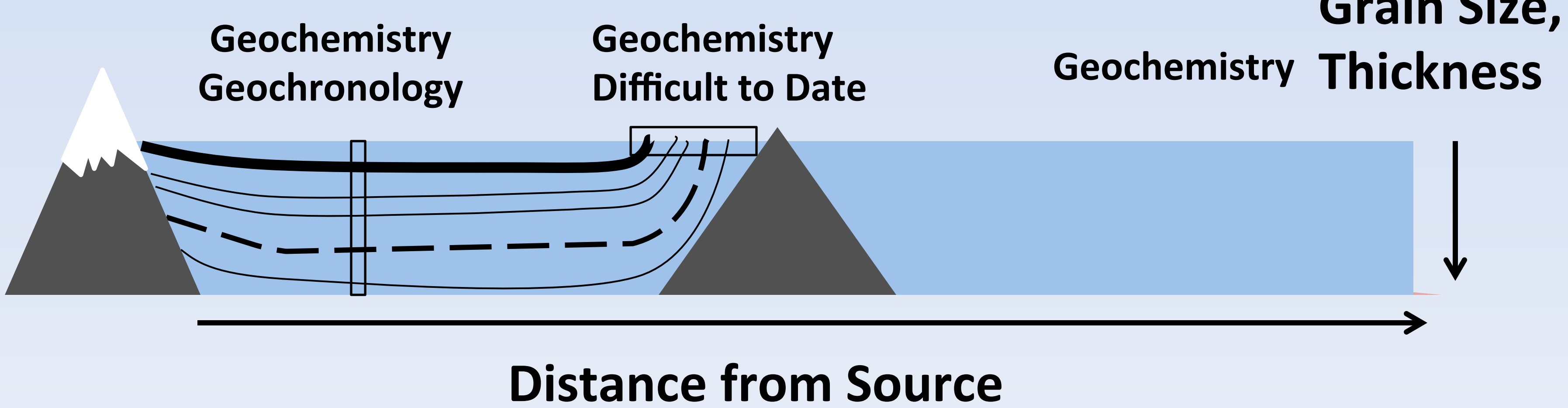
Tephrochronology

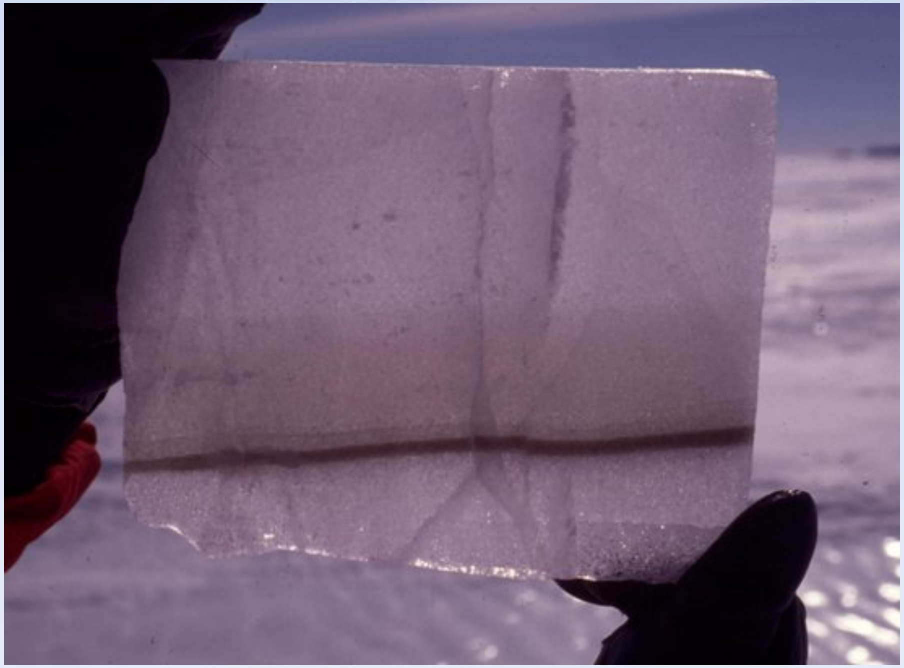
- How to indirectly date tephra?
  - Sediment record
    - Oxygen Isotope correlation (Wiggle matching)
  - Geochemical Correlations
    - Correlate to location that can be date by another technique
    - Isochron between multiple locations with no independent dates
  - Magnetostratigraphy

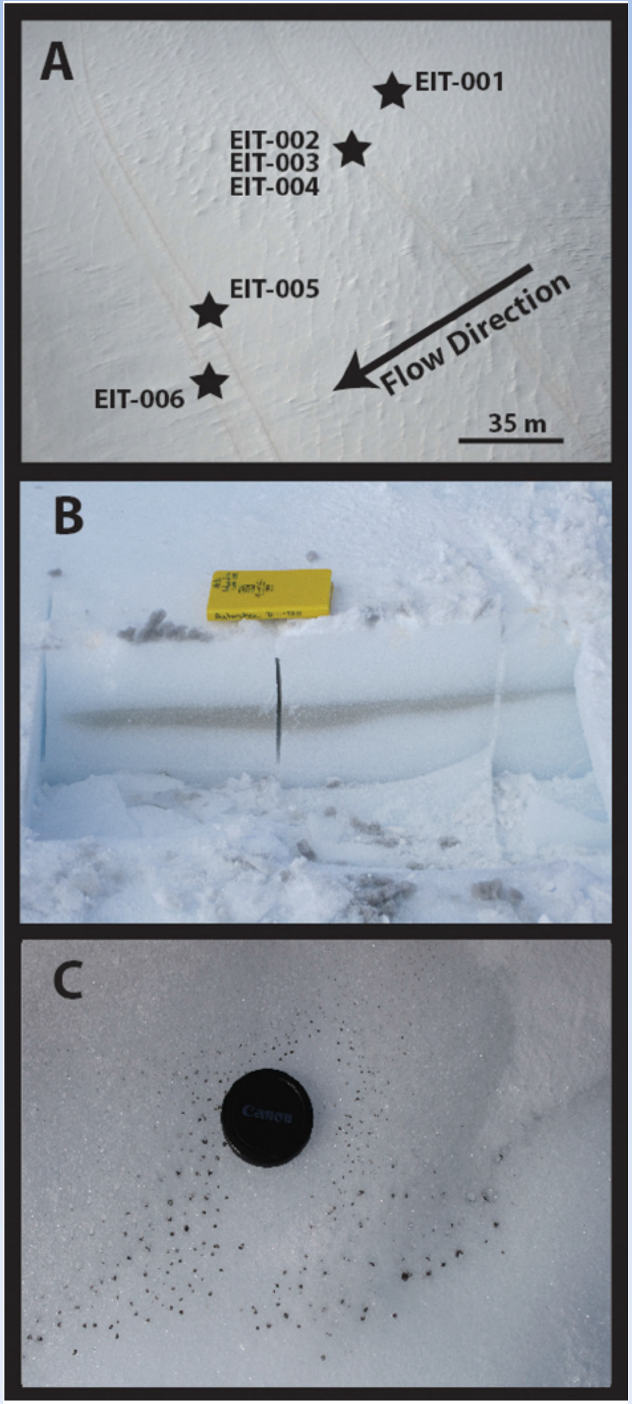
Taupo Ignembrite

Volcanoes on ice covered continents

- Volcanoes in Antarctica
  - Proximal tephra
    - Limited outcrops on edifice, Blue Ice area
  - Distal tephra (cryptotephra)
    - Blue Ice Areas, Ice cores, Marine cores
    - Great preservation with "no" contamination
    - Unparalleled sequences of volcanic activity






A
EIT-001
EIT-002
EIT-003
EIT-004
EIT-005
EIT-006
Flow Direction
35 m
B
C

Ash layers in multiple cores

- Same ash layer found in 5 cores

- Understand past wind patterns

- Size of volcanic eruptions