Challenges in ascertaining the late Quaternary tephrostratigraphy of southernmost Chile and Argentina

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Overview

- The explosive eruption history and tephrostratigraphy in southernmost Chile/Argentina is significant for volcanic hazard assessment and as a tool to correlate and date reliably the many palaeoenvironmental archives here, but is currently poorly constrained.
- We have reviewed the existing late Quaternary tephrostratigraphic record, and here summarise the challenges in further constraining the record (i.e., in finding and accurately characterising, correlating, and dating tephra and eruptions) in this region.
- We note that rigorous geochemical, mineralogical, and physical characterisation of the tephra deposits reported in palaeoenvironmental archives is uncommon, and present a case study that exemplifies some of the errors that can result from its absence.
- It is important to understand the limitations of using tephra from palaeoenvironmental archives to ascertain the eruptive history, and the necessity of detailed tephra characterisation (particularly glass or mineral chemical analysis) to overcome these.

Tephra preservation in terrestrial sections

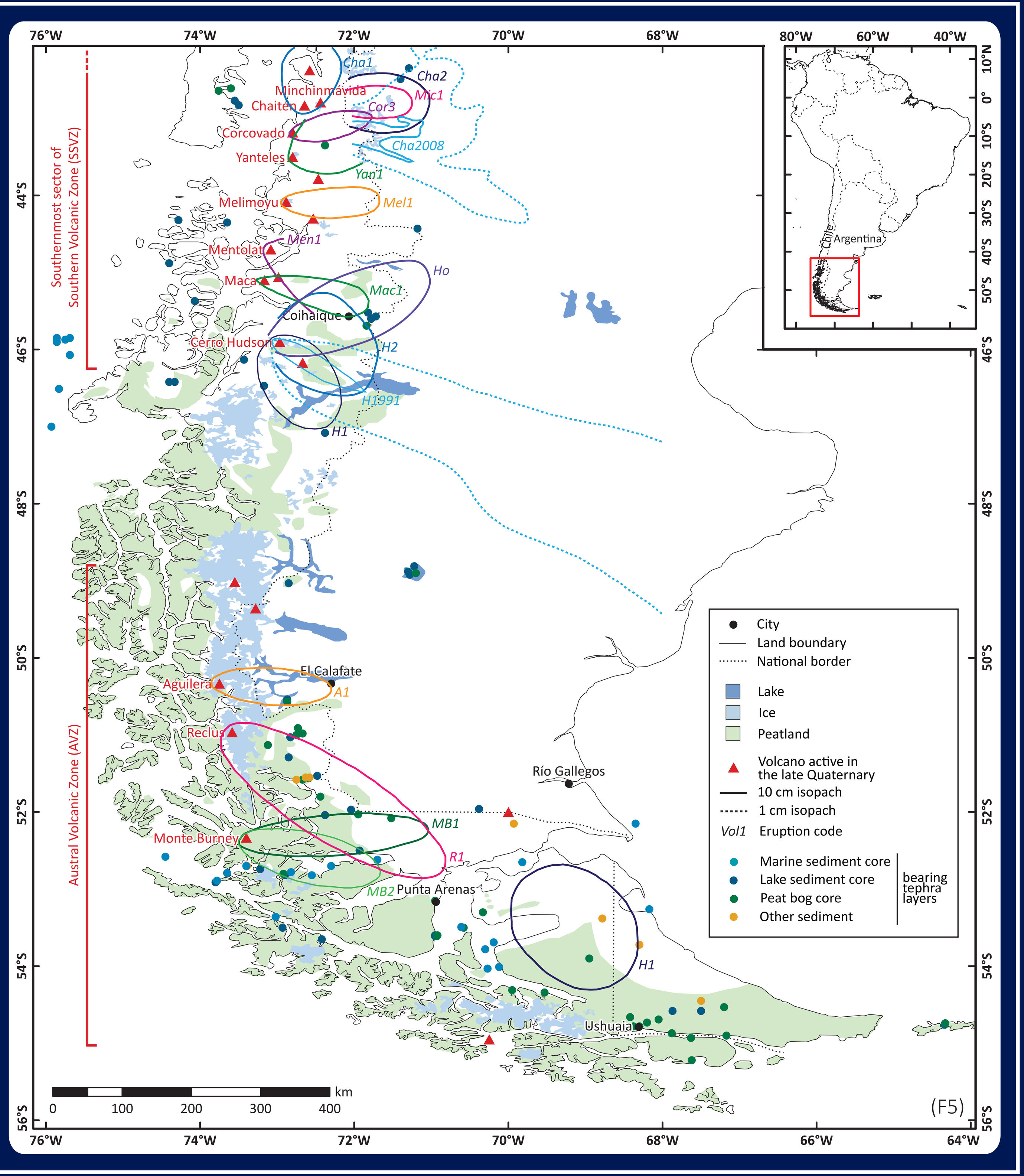
- East of the Andes, terrestrial sections are rare due to strong wind erosion preventing soil (and tephra[1]) accumulation (F1 and F2). The few sections present comprise fluvio-glacial (F3) or aeolian (F4) deposits, in which discrete tephra layers are not typically preserved.
- In the Andes, the topography means that tephra is only sporadically preserved and is sometimes remobilised, and sections are difficult to access (especially close to the AVZ). Moreover, glass is prone to leaching or alteration[2] and only post-glacial tephras are preserved[3].

Environmental conditions prevalent east of the Andes. Minimal soil or vegetation (F1) due to wind erosion (F2).

Typical sections east of the Andes: fluvio-glacial (F3) or aeolian (F4) deposits. Tephra layers are rare.

Palaeoenvironmental archives and explosive eruption history

- 19 volcanic centres are thought to have been active in post-glacial times in southernmost Chile and Argentina (>42.5 °S), 12 of which have had a total of at least 18 large (>1 km³ of tephra) explosive eruptions in the past 20 kyr.
- Many palaeoenvironmental archives (i.e., ice, peat, and cave, lacustrine, and marine sediment cores or sections) have been sought in this region, due to its unique location across the southern westerly wind belt[4].
- We have compiled a dataset of all the tephra deposits reported in palaeoenvironmental archives, and found that:
  - The majority of cores are reported to contain discrete tephra layers (F5), so there is significant potential to use tephra to correlate and date these archives
  - There are several additional moderate-size eruptions (reported in multiple cores) that have not previously been widely recognised
  - Cryptotephra units have only rarely been searched for, despite their potential to expand the tephrostratigraphic record
  - Most of the tephra units found are poorly characterised and attributed to an eruption using only tenuous constraints.



Map of southernmost Chile and Argentina, showing the volcanic centres active in the past 20 kyr with approximate isopachs for their largest eruptions, and the location of palaeoenvironmental archives containing tephra layers.

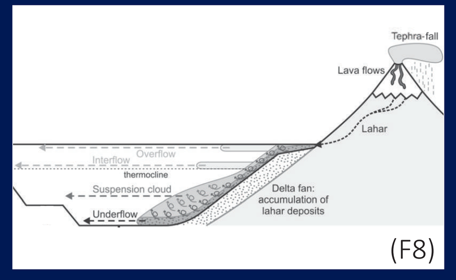
Tephra preservation in palaeoenvironmental records

Issues with using tephra in palaeoenvironmental archives in this region to correlate records and constrain eruption parameters:

Environment	Physical preservation	Chemical preservation	Dating and record bias issues
Peat	- Spatially and temporally variable accumulation rates (F6, F7) cause depth and thickness variations in tephra layers[5] - Tephra layers dispersed by root growth[6], so precise thickness measurement is difficult - Cryptotephra layers may be reworked[7]	- Al, Fe, alkali and alkali earth metals are all readily leached from glass[14] - Rapid dissolution of Fe-Mg minerals in tephra is possible if the pH <4[15] - Complete alteration of tephra (e.g., glass to siderite) is possible[6]	- Tephra layers are dispersed by root growth, so their position and hence age is uncertain[6] - Humic acid and humin fractions of peat may give different radiocarbon dates[16] - Typically only preserve postglacial tephra
Lake and marine sediment	- Influx of reworked tephra[26] (F8) and/or pumice rafting may cause the thickness and grain size distribution to not reflect fallout[8] - Remobilisation by turbidites is common[9] - Tephra layer dispersal is possible without textural indications (e.g., sediment mixing)[10]	- Alkali and alkali earth metals can be leached from glass[2] - Glass can be altered to clay	- Prone to anomalous and/or offset radiocarbon ages due to a reservoir effect[17] or deep water ventilation[18] - Fjords and Andean lakes usually only preserve postglacial tephra
Caves	- Most tephra present in cave sediment is likely to have been remobilised[11] - Cryptotephra layers have been found in stalagmites in proximal open caves[12]	- Relatively well-preserved	- Material from which reliable precise dates can be obtained is often rare - Bias in tephra preservation from cave orientation and prevailing wind direction[19]
Ice	- Potentially preserved in local ice caps, but may be reworked by meltwater or wind (F9) - Southern Andean cryptotephra layers have been found in Antarctic ice cores[13]	- Relatively well-preserved	- May be difficult to date precisely in the absence of resolvable annual layers[13] - Possible seasonal bias to preservation in temperate ice

Typical bog surface, which encourages depth and thickness variations in tephra deposition.

Bog core showing temporal variation in accumulation rate and extent of root growth.

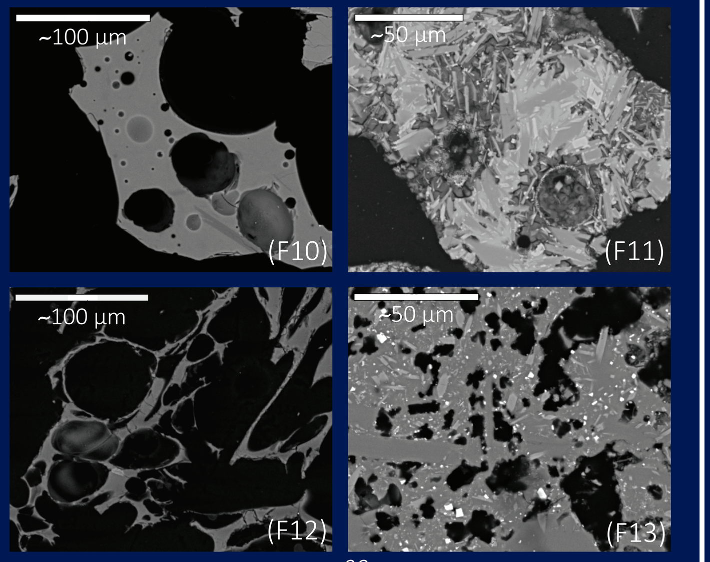


Schematic illustration of the size-dependent processes of reworking of volcanic deposits into lakes[8].

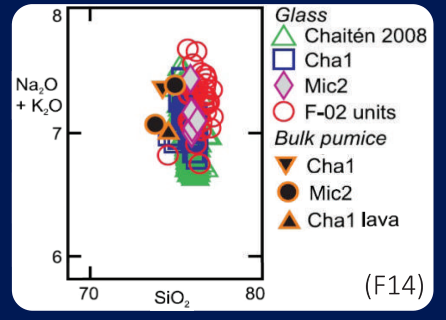
Tephra-bearing layers in intra-caldera ice due to seasonal melting concentrating aeolian deposits.

Chemical characterisation and correlation

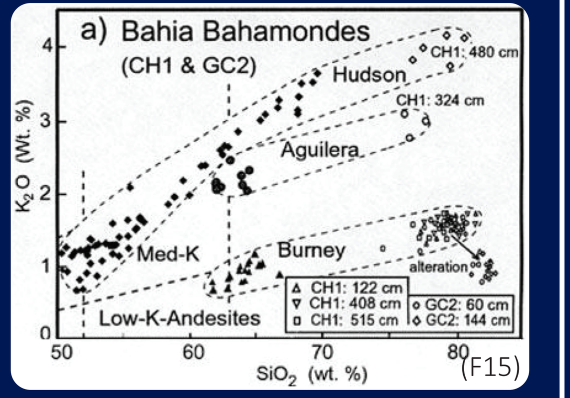
- Accurate chemical analysis of tephra samples is often difficult:
  - Tephra of basaltic to andesitic composition often contains abundant micro-phenocrysts (F13)
  - Tephra of dacitic to rhyolitic composition is often skeletal, with glass patches rarely >5 μm (F12)
  - Physical and chemical alteration of tephra is common (F11).
- The major-element glass composition of some tephras can be almost indistinguishable from those from previous eruptions of the source volcano, e.g. Chaitén (F14).
- Little reliable lava and tephra composition data are available for reference:
  - The only data for northern AVZ volcanoes are the bulk compositions of tephra and lava fragments collected from glacial moraine[25]
  - Bulk lava composition is sometimes used to attribute distal tephra to a source (F15)
  - EPMA of glass is often done with inappropriate beam parameters and/or without using secondary standards.
- Some tephra layers have been correlated using radiocarbon dates alone, or only a small amount of glass (F15) or bulk pumice[18] major-element composition data, or even the trace-element composition of bulk distal ash[10].



BSE images of Andean tephra[20]: examples of 'ideal' (F10), microlite-rich (F11), 'skeletal' (F12), and altered (F13) shards.



Near-identical composition of glass and bulk pumice from eruptions of Chaitén[21].



Tephra layers in peat cores attributed to a source volcano by extrapolation of trends in bulk lava and pumice (closed symbols) to glass compositions (open symbols)[6].

Case study: Correlating tephra layers in sections and cores near Cerro Hudson

Section redacted as it comprises unpublished data

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