Improved integration and discoverability of tephra data for multidisciplinary applications

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1. Abstract

Tephra deposits form a common thread which connects diverse, multidisciplinary research directions that share overlapping data needs. Tephra beds reflect the magmatic, eruptive, dispersal, and depositional processes involved in their generation as well as the tectonic environment from which they originate. Therefore, they are globally important for examining links between tectonics, magma chemistry, volcano behavior, and environmental effects. They are fundamental for understanding past eruptions and future hazards, and they are key for dating both geologic and prehistoric events. It is, perhaps, in tephrochronology that tephra beds find their most diverse applications: providing isochrons of nearly unmatched temporal precision across regional to continental and even inter-continental distances; tying together glacial, marine, lacustrine, and terrestrial records; and helping to answer major questions in climate change, archaeology, paleontology, paleoecology, paleolimnology, paleoseismology, and geomorphology, among others.

Tephra data include physical (particle size, bed thickness), mineralogical, geographic, time-stratigraphic, geochemical, and interpretive information. Data collected over decades currently exist largely in disparate, disconnected, and commonly offline datasets, and this severely limits discovery and accessibility. The integration of such data along with eruption catalogs into unified or interoperable databases linked at the eruption scale is a critical need. The need is especially acute for tephrochronology, which is by its very nature a comparative technique requiring access to ideally comprehensive, multiparameter datasets for the identification and correlation of tephra beds.

To meet the needs of this large research community, we envision (1) the integration of decades of tephra data and available metadata into a system with a single point of access for all data types, (2) development of an interface and mechanism for multiparameter searching, (3) development of protocols for more routine collection and reporting of physical data for tephrochronology samples and better collection and reporting of metadata, (4) simplification of data entry to encourage routine submission of new data. Doing so will substantially enhance progress on fundamental questions in volcanology and petrology, facilitate progress toward integrated tephrochronologic frameworks for North America and other regions (and/or a global framework), and increase efficacy and confidence in tephra correlation for the numerous studies that depend on it.

As a first step, we are currently planning a workshop in cooperation with the IAVCEI commission on tephra hazard modeling, VHub, AMQUA, INTAV, and others. We anticipate community-wide involvement (introducing the volcanologists to the Quaternary scientists, for example) resulting in enhanced cooperation that benefits all tephra researchers and fostering the development of new collaborative studies. We plan to discuss the state of the art in tephra studies and community-wide data needs with the goal of formulating a path forward.

2. Tephra Applications & Data Needs

Applications	Data needs
Tephrochronology: Age control, tie points, and distributions for Archaeology & Paleoanthropology; Atmospheric circulation; Basin stratigraphy; Environmental, Ecological, & Climate Change; Fire histories; Geomorphology; Glaciology; Paleontology; Paleoseismology/ Neotectonics; Paleolimnology & Paleoceanography; Soil science; Storm frequencies	Utilizes most data types, especially location, stratigraphy, age, and geochemistry
CO_2, Sulfate, Cl, F, and particulate input into the atmosphere for atmospheric processes and climate studies	Eruption volumes, fine particle production, magmatic volatile contents, gas emission measurements, ages
Magmatic processes/igneous petrology	Mineralogy, geochemistry, volatiles, eruption volumes, ages, mineral imagery (SEM, X-ray compositional, CL)
Processes of eruption, tephra dispersal (including modeling), and deposition	Particle size & thickness distributions, bedding, volatile contents, crystal contents, eruption rates, eruption styles, atmospheric parameters, satellite imagery, eruption video
Volcanic hazards	Eruption types/processes, magnitudes, frequencies, affected locations
Volcano-tectonic processes, crustal evolution	Geochemistry, plate convergence rates, eruptive parameters, eruption frequencies
Dating methods: ^{14}C marine reservoir corrections; Multi-method dating to test radiometric methods	Ages, stratigraphy

3. Types of Tephra Data

Data categories	Specific data types
Geographic location	Latitude, longitude, elevation, political jurisdiction
Stratigraphy	Position in a sequence, bedding
Layer thickness	Minimum, maximum, average/typical, layer continuity, primary vs. redeposited
Color, Weathering	
Particle types and abundances	Pumice, scoria, lithics, free crystals
Particle size	Largest clasts, overall article size distributions, grading
Particle morphology	Shape, vesicularity
Mineralogy	Minerals present, mineral abundances, crystal sizes and texture/morphology (euhedral, resorbed, skeletal, etc.)
Geochemistry – bulk, minerals, glass	Major-elements, trace-elements, isotopes, volatiles, multiple populations, mineral zoning, whole rock vs. microanalytical
Age control	Historical (date, time), radiometric, dendrochronology, varves, ice core layering, paleomagnetic correlation
Imagery	Eruption photos/video, satellite images, deposit photographs, sample photographs, mineral and shard SEM images, mineral cathodoluminescence images, X-ray compositional maps
Source and Name	Source volcano, source eruption, tephra name
Interpretive , integrative, and model results	Eruption type (Plinian, phreatomagmatic, etc.), column height, mass eruption rate, VEI, isopachs, isopleths, volume, recognized distribution area, wind speed
Others	Publication & data source references; Data ownership; Sample curation

4. Databases

Some Existing Databases	
Smithsonian VGP	Public & online; Eruption catalog, volcano and event descriptions
Alaska Volcano Observatory	Public & online; Eruption catalog, volcano and event descriptions
Tephrabase	Public & online; Mainly tephra glass geochemistry for Europe/Iceland
RESET	Online but not yet public; Mainly tephra glass geochemistry from archaeological contexts in Europe
EarthChem	Public & online; Limited tephra glass geochemistry so far
Individual labs and research groups	Numerous!; Typically not public or online; Some published, some not; All data types possible

Common search terms to find eruptions/deposits of interest
Geographic location
Eruption size (e.g. VEI)
Mineralogy
Geochemistry (potentially using statistical methods to determine the closest match to a given analysis)
Age
Combinations of the above (multiparameter)

Scientific data effectively does not exist or is unusable if it is not discoverable, accessible, and sufficiently documented (metadata).

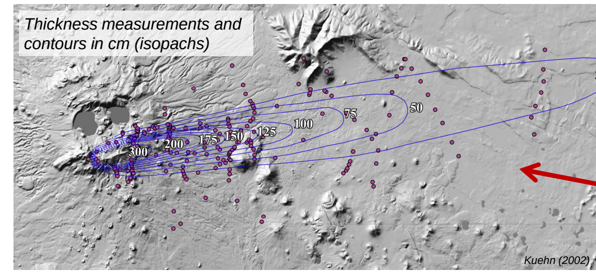
Data may be freely available and in an accessible digital format. Data may be freely available, but not digitized. Or, data may be proprietary and inaccessible without authorization or purchase.

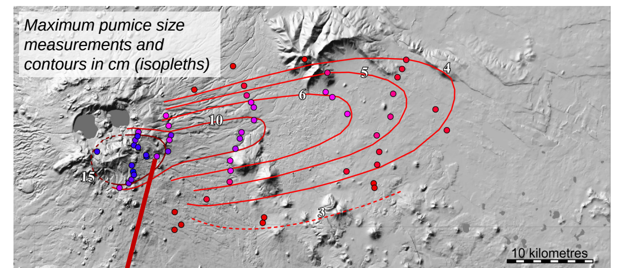
Even when data is discoverable and available, it may be scattered throughout multiple disconnected systems making access inefficient and time-consuming.

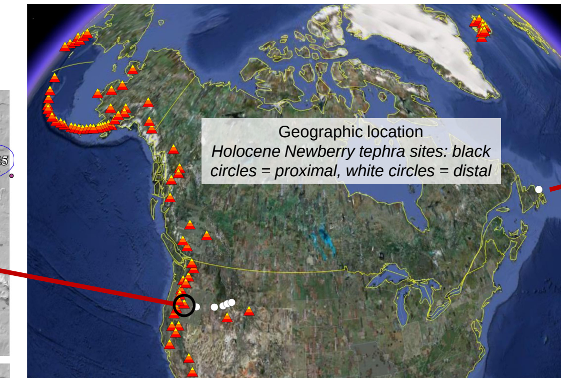
Linking global records including Smithsonian GVP descriptions, SESAR sample catalogs, EarthChem geochemistry, etc. at the scale of individual eruptions and assimilating large volumes of existing data into these systems would remove major barriers to scientific progress.

5. Data Examples

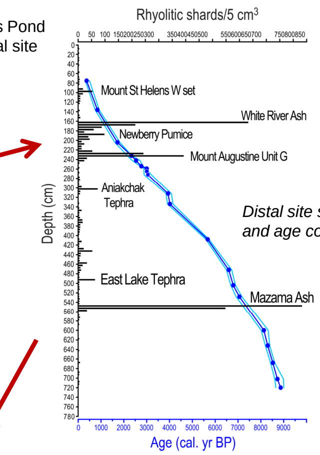
Newberry volcano proximal







Nordan's Pond bog distal site



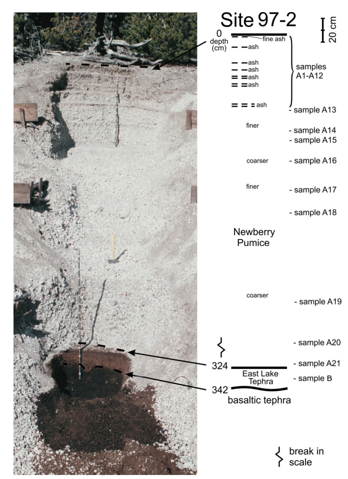
Major-element glass geochemistry for proximal and distal samples by EPMA

Sample		SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Total
Newberry Pumice proximal										
	Mean	71.62	0.22	14.06	1.91	0.17	0.84	5.21	4.05	98.30
	1SD	0.54	0.12	0.72	0.33	0.14	0.13	0.22	0.50	0.77
NDN-185: Newberry Pumice distal										
	Mean	71.84	0.20	14.16	1.82	0.16	0.83	4.89	4.01	98.00
	1SD	1.29	0.04	0.68	0.34	0.04	0.09	0.40	0.20	1.68
East Lake tephra proximal										
	Mean	71.89	0.24	13.81	1.75	0.24	1.00	4.79	4.01	97.77
	1SD	1.08	0.20	0.99	0.48	0.22	0.28	0.30	0.50	2.12
NDN-490: East Lake tephra distal										
	Mean	71.27	0.22	13.67	1.62	0.23	0.98	4.47	4.00	96.54
	1SD	0.85	0.05	0.58	0.26	0.05	0.20	0.38	0.39	1.17

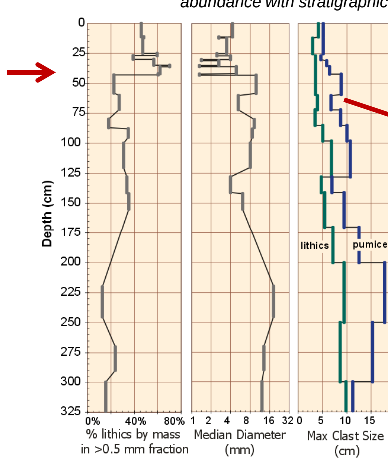
Pyne-O'Donnell et al. (2012)

These tephras have been ccorrelated across a distance of 5,000 km using a combination of geochemistry, stratigraphy, and age control. The presence of East Lake tephra at Nordan's Pond demonstrates that even relatively modest eruptions can result in detectable glass shards at great distances.

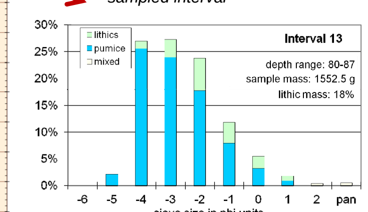
Proximal site photographs, stratigraphy, sampling intervals, color, weathering



Proximal site particle size, type, and abundance with stratigraphic context

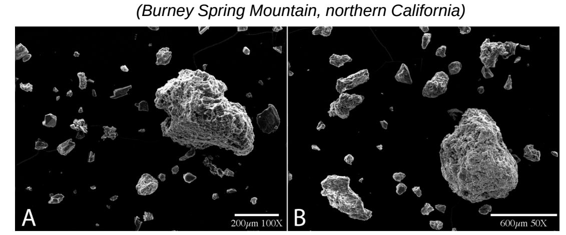


Sieve data for a specific sampled interval

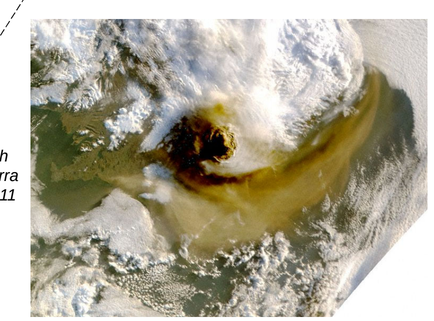


Grimsvotn ash cloud ground-based photo 21-May-2011 (Photo: AFP)

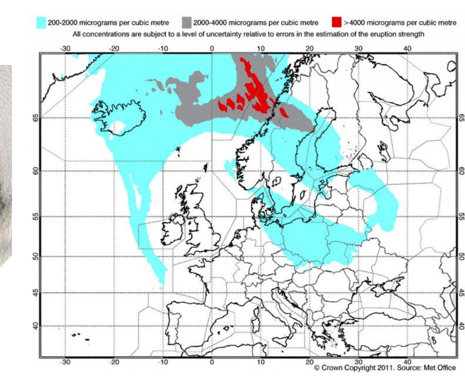
SEM images, particle size, particle shape, particle type & abundance (Burney Spring Mountain, northern California)



Pouget et al (2013)



Grimsvotn initial ash plume image by Terra satellite 22-May-2011 (NASA/Terra)



Ash dispersal model forecast for 26-May-2011 (UK Met Office)

6. A Few Research/Collaboration Scenarios

A Real World Scenario

A researcher working on Greenland ice cores finds glass shards. Using glass geochemistry and age information, the researcher needs to identify the source volcano and eruption and hopefully identify the same tephra in marine or lacustrine records to establish precise tie points. This begins a time-consuming and inefficient process of separately searching eruption catalogs; searching limited and incomplete public geochemical databases; contacting colleagues in Europe, USA, Canada, Russia, Japan, etc. ("Does anyone out there have a match to my tephra??" Response: "I'm busy. Let me get back to you in a couple of months."); and searching numerous publications for tephra data and potentially correlative sequences.

Some Collaborative Opportunities

Collaboration between dispersal modelers, tephrochronologists, and Quaternary scientists to apply dispersal modeling to better understanding past eruptions. This uses data accumulated by volcanologists, tephrochronologists, and Quaternary scientists from proximal and distal locations.

Collaboration between volcanologists, tephrochronologists, and Quaternary scientists for volcanic hazards assessment and perhaps with petrologists for long-term evolution of magma systems. Proximal records of pyroclastic eruptions are often incomplete. Being favorable depositional settings, lakes in volcanic regions offer the opportunity to produce much more complete eruption records including size and frequency information. A lot of lakes are cored by Quaternary scientists. Some (not all) of the tephras in those cores are sampled and submitted to tephrochronologists to be identified to volcano or eruption.

Tephrochronologists trying to source distal deposits benefit from proximal studies by volcanologists. Proximal samples provide the material to which distal samples can be correlated.

Tephra 2014 workshop

4-7 August, 2014
Portland State University
Portland, Oregon, USA

Immediately prior to the 2014 AMQUA biennial meeting in nearby Seattle, WA