Crossing new frontiers: extending tephrochronology as a global geoscientific research tool

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Introduction: tephrochronology as a global geoscientific research tool

Tephrochronology is a unique stratigraphic tool for linking, dating, and synchronising geological, palaeoenvironmental, or archaeological sequences and events (Lowe, 2011; Alloway et al., 2013). It relies on the identification and tracing of tephra or cryptotephra horizons spatially between various depositional sequences. These horizons can provide stratigraphic event layers (tephrostratigraphy) and, when dated, isochronous age markers – since most tephra are deposited on a scale of days to weeks – that can be transferred from site to site (tephrochronology) (Lane et al., 2017b). The correlation of horizons between different sequences is reliant on matching the physical characteristics, mineralogical assemblages, and geochemical compositions of minerals and/or glass shards in tephra deposits using a range of analytical methods and visual and statistical approaches (e.g. Lowe et al., 2017). Correlating tephra deposits back to their volcanic source allows tephrochronological studies to provide information on the eruption frequency and geochemical evolution of volcanic regions and individual volcanoes.

Tephrochronology is one of the most versatile techniques available to geoscientists. It can be applied over timescales from years to millions of years, it has the potential to correlate sequences over scales of centimetres to thousands of kilometres, and the capability to link proximal deposits up to metres thick to diminutive distal layers that have no visible expression (i.e. cryptotephras), which may only be composed of a handful of glass shards. Applications of tephrochronology are equally varied and include building chronostratigraphic frameworks, assessing leads and lags in the paleoclimate system, quantifying radiocarbon reservoir offsets, dating archaeological sequences, human activities and colonisation, assessing the impact of volcanic eruptions on climate and society, understanding landscape development, and reconstructing eruptive histories and assessing volcanic hazards. Several recent articles provide comprehensive reviews of the history, application and current status of tephrochronology, and are key references for anybody looking to learn more about the technique. Lowe (2011) and Alloway et al. (2013) are key primers on the theory and application of tephrochronology, Davies (2015) outlines the recent revolution in tephrochronology driven by cryptotephra studies, Lowe and Alloway (2015) focus on tephra dating techniques, Lowe et al. (2017) review the methods and best practices for chemically characterising glass shards from tephras and cryptotephras and correlating deposits, and Lane et al. (2017b) provide a useful update on various more recent advances.

The advent of 'modern' tephra studies began in the 1920s and 1930s in New Zealand, Japan, Iceland, South America, and USA (Alloway et al., 2013), although mapping of tephra deposits from historical eruptions had been undertaken much earlier (e.g. Thomas, 1888). It is now 75 years since the terms 'tephra' and 'tephrochronology' were added to the scientific nomenclature by Thórarinsson (1944). Based on his work using tephras to provide chronological control for pollen records and to constrain human occupation and abandonment, Thórarinsson (1944) suggested 'tephrochronology' to be used as an "international term to designate a geological chronology based on the measuring, interconnecting, and dating of volcanic ash layers in soil profiles". Since then the scope of the technique has been extended to many other depositional environments and expanded beyond those areas proximal to volcanoes to many locations across the globe. There has been a continued rise in the number of publications utilising tephra and, since pioneering work in the late 1980s and early 1990s (e.g. Dugmore, 1989; Pilcher and Hall, 1992), that rise has been matched by the rise in studies utilising cryptotephra deposits (Figure 1). This special issue on tephrochronology adds to the growing literature by drawing together a set of articles addressing varied aspects of the wide spectrum of the technique – reflecting, in many ways, the fact that tephra studies have never been stronger than now.

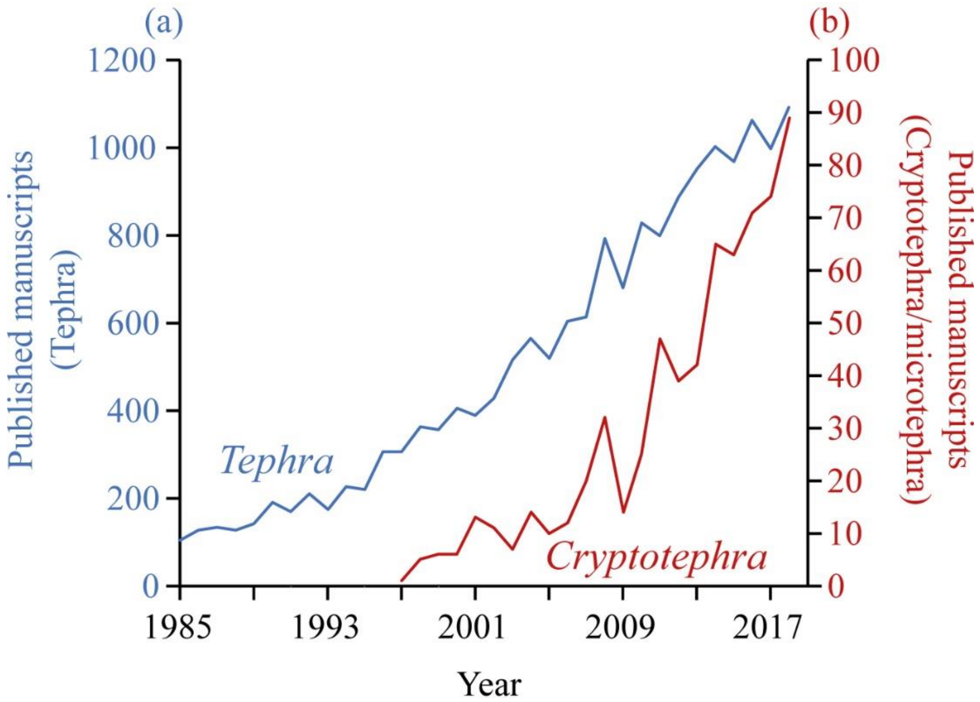

Figure 1: Numbers of papers published between 1985 and 2018 that include the terms (a) tephra, and (b) cryptotephra/microtephra. The numbers relate to searches on Scopus using 'tephra', 'cryptotephra' or 'microtephra' in 'all fields' (i.e. including title, keywords, and abstract). Note that the term 'cryptotephra', first introduced in 2001, has now replaced 'microtephra' (Lowe and Hunt, 2001; Lowe, 2011).

This special issue has arisen from the work of the International Focus Group on Tephrochronology and Volcanism (INTAV), and the most recent INTAV field conference on tephrochronology held in Romania during June 2018 (Figure 2; Karátson et al., 2018; Lowe, 2018). Its central theme is 'Crossing New Frontiers: Extending Tephrochronology as a Global Geoscientific Research Tool', which was chosen for several reasons. Firstly, INTAV, the field conferences and the conferences sessions it helps to organise, encourage both established and emerging tephrochronologists from many countries to cross borders to experience and learn from multiple points of view, and to network with the global community. Secondly, the geographical frontiers of tephrochronology are constantly being extended, in part by modern, systematic cryptotephra studies. Such studies are continually highlighting the revelation that tephras can be traced over much larger areas than previously demonstrated, elevating tephrochronology from a local- or regional-scale to a hemispheric-scale tool (Jensen et al., 2014; Davies, 2015; Ponomareva et al., 2015). Thirdly, the ever-increasing number of research studies using tephrochronology, the variety of differing applications, and the new studies in this special issue allow us to cross new frontiers in knowledge and understanding.

Figure 2: Participants of the field conference entitled 'Crossing New Frontiers: Tephra Hunt in Transylvania' standing in front of columnar basalt in the Perșani volcanic field (active 1.2–0.6 Ma) in the southern Carpathians, Romania, during the mid-conference field trip. Photo credit: Pierre Oesterle.

Themes of the special issue

This special issue presents 27 research articles dealing with varied aspects and applications of tephrochronology. Three key themes are identified and have been used to arrange the articles in the volume. Firstly, an initial set of three papers provides perspectives and reviews of differing aspects of tephrochronology. Secondly, three further papers outline the development of new analytical tools and approaches to data analysis that can be added to the tephrochronological toolbox. Thirdly, the final set of 21 papers take us on a global tour of research sites and volcanoes, providing examples of a diverse range of applications of tephrochronology in a variety of depositional settings.

Theme 1: Tephrochronological perspectives

The first two papers in the volume provide perspectives on the current status of two developing applications of tephrochronology and synergies with different fields of study. Firstly, Cashman and Rust (2020) highlight the role that cryptotephra data can play in volcanological studies. Tephra thicknesses can be used in physical volcanology to reconstruct eruption parameters and predict ash hazards. However, the far-travelled ash component is often 'missing' as a thickness cannot be determined. Cashman and Rust (2020) outline how the study of cryptotephras can fill this gap, but more data, not typically recorded for these deposits (such as particle size and shape), are required. Secondly, Dugmore et al. (2020) discuss how tephra deposits can be used to reconstruct past surface environments and subsurface processes, i.e. deriving paleoenvironmental information beyond using tephra deposits as chronostratigraphic markers. Following deposition and integration in the stratigraphic record, tephra deposits can undergo changes in thickness, morphology, and definition that can be used as proxies to reconstruct the interplay between a range of drivers such as climate, surface processes, vegetation, and human activity.

Bösken and Schmidt (2020) provide a useful review of the dating of tephras using luminescence methods. Using tephras as isochronous age markers relies on the dating of at least one occurrence of the tephra that can then be transferred between sites, and luminescence dating is one technique that can be utilised for this. It is a versatile but complex technique because different methods can be used to both directly date tephras using glass shards, volcanic minerals and/or country rock, or provide indirect age brackets through the dating of sediments or volcanic deposits encapsulating tephras.

Bösken and Schmidt (2020) review past studies of both direct and indirect dating approaches, highlighting the potential demonstrated by different methods and challenges encountered, before providing key recommendations for future studies.

Theme 2: Innovative tools for the tephrochronological toolbox

The tools available to tephrochronologists are constantly advancing and, alongside studies focussed on the varied applications of tephrochronology, this special issue also showcases a number of newly developed analytical and interpretative tools. Peti et al. (2020) highlight the potential of using Itrax micro X-ray fluorescence (µ-XRF) as a fast, non-invasive method to chemically characterise tephra layers, and trial the technique on rhyolitic tephras in sediment cores from maar lakes in the Auckland Volcanic Field, New Zealand. They show that element ratios from the µ-XRF data, such as Sr/Rb and Si/K, can be used to distinguish between different rhyolitic tephra layers from New Zealand (within the skope of the study). Experimentation with a range of scanning parameters allowed them to make recommendations for optimising the scanning protocol for data collection in future studies. Maruyama et al. (2020) also focus on testing a recently developed geochemical characterisation technique. They used femtosecond laser ablation-inductively couple plasma-mass spectrometry (fs LA-ICP-MS) (e.g. Maruyama et al., 2016) to characterise and correlate tephras from two cores from Lake Suigetsu, Japan. Fs LA-ICP-MS has the key advantage that 58 major, minor, and trace elements in individual glass shards can be measured simultaneously. Using these data, the source volcanoes of many of the tephras have been determined and hierarchical cluster analysis was used to statistically evaluate the relationships between the tephras.

The recent proliferation of tephra studies has been accompanied by a similarly expansive increase in the glass compositional data available to test correlations between deposits. This expansion has shown that geochemical differences between some eruptives and volcanoes can be very subtle, making it harder to test correlations using traditional manual plotting techniques. Several statistical approaches are already available for assessing correlations (see Lowe et al., 2017), but Bolton et al. (2020) evaluate a new tool utilising machine learning classifiers. Several classification algorithms were evaluated by training and testing them using data from ten Alaska volcanic sources. It was shown that the methods can be used to discern the sources of tephra and hence they have the potential to speed up correlations in comparison to traditional methods.

Theme 3: Applications of tephrochronology around the globe

This final theme draws together studies applying tephrochronology at a range of locations around the globe and the breadth of the applications makes them hard to classify; therefore, the papers are presented in geographical order from west to east starting off the coast of North America (Figure 3). In the first paper, Aoki (2020) reports the discovery of the ~29 ka Dawson tephra in a marine core from the Patton Seamount off the Alaskan Peninsula. Geochemical and chronological data for a normally-graded tephra identified in the SO202-27-6 marine core confirm a correlation to the Dawson tephra, a widespread age marker for Alaska and the Yukon (e.g. Froese et al., 2002). Using climatostratigraphic evidence, Aoki (2020) postulates that it was deposited on the marine isotope stage 3/2 transition and just prior to Greenland Interstadial 4. Further tracing of this horizon in marine records will allow it to act as a key age marker for palaeoclimatic correlation and synchronisation.

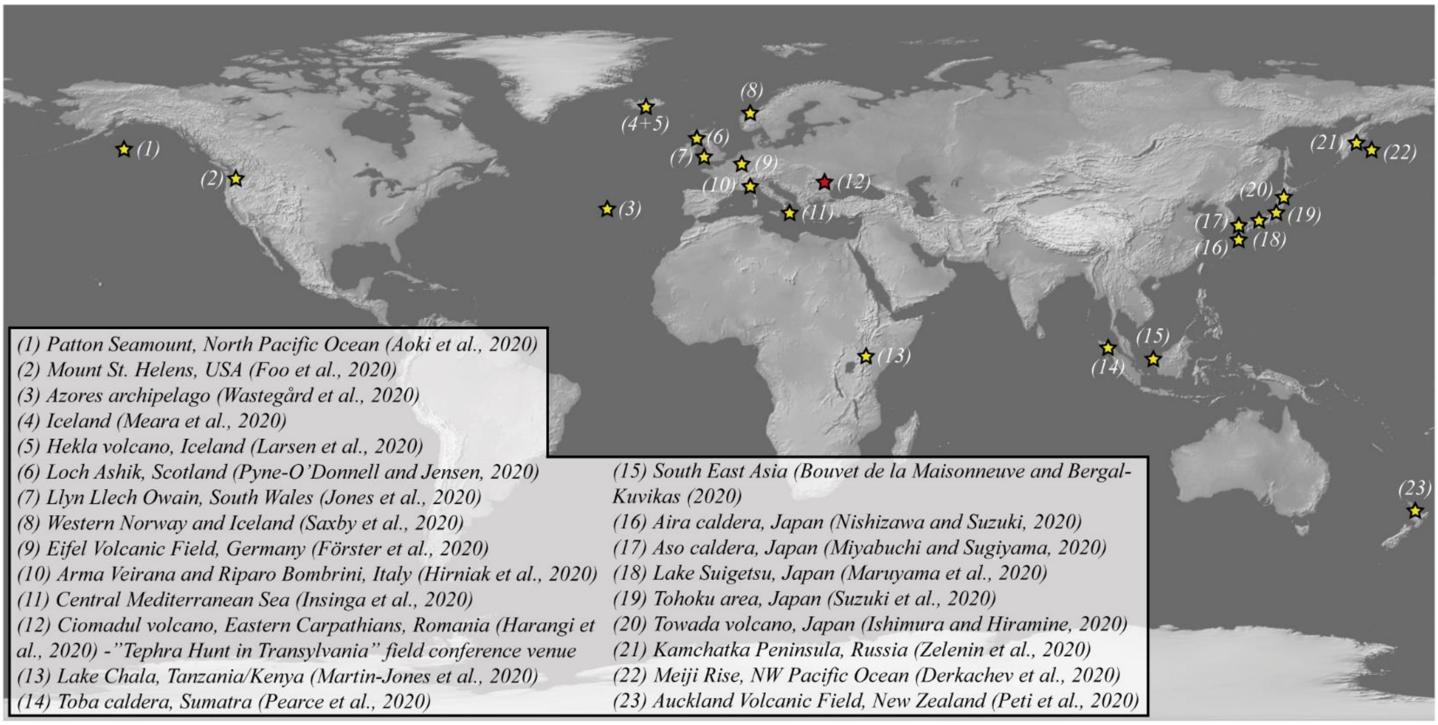

Figure 3: Map of sample locations or key volcanoes studied in many of the papers within this special issue. The red star also denotes the locality of the INTAV field conference 'Tephra Hunt in Transylvania'. Basemap from NaturalEarthData.com.

One of the best ways to attribute distal tephra horizons to source volcanoes or volcanic regions is to compare robust geochemical data from the same material, e.g. juvenile glass, but such data are not always available for proximal deposits (Lowe et al., 2017). The study of Foo et al. (2020) presents such a dataset by providing new glass geochemical characterisations of recent tephra layers from Mount St. Helens, deposited in the last 200 years. Radiocarbon dating is typically unreliable over this timeframe and so these are important regional chronostratigraphic markers for building chronologies for palaeoenvironmental sequences in the area. These new data show that the eruptives can be distinguished using their glass geochemistry, thereby providing a key reference dataset to aid the identification of distal deposits.

The next two papers focus on islands in the Atlantic also provide data from proximal deposits that, in these cases, will be highly useful for researchers focusing on distal localities in northern Europe. During the development of the northern European distal tephra framework, several enigmatic non-Icelandic trachytic tephras were identified and attributed to eruptions on Jan Mayen (e.g. Chambers et al., 2004). However, more recently, it has been suggested that the 'mystery' tephras could have been sourced from the Azores (e.g. Reilly and Mitchell, 2015). Building on the work of Johansson et al. (2017), Wastegård et al. (2020) present further proximal data for Azorean tephra deposits that strengthen the attribution of an Azorean source for some Irish cryptotephras and, furthermore, suggest that Azorean tephra may have also reached Sweden. Iceland has always been the key source of tephras in northern Europe, and Meara et al. (2020) presents a catalogue of new major and trace element characterisations of glass shards in proximal deposits from 19 Icelandic Holocene silicic tephra layers including important widespread markers such as Askja 1875 AD, Öræfajökull 1362 AD, the Landnám tephra, and Hekla 4. The Hekla volcano is the major producer of Holocene silicic and intermediate tephras in Iceland but, about 3000 years ago, the dominant eruption mode shifted to more frequent moderate eruptions with ≥ 26 eruptions occurring within 2000 years (Larsen et al., 2020). Larsen et al. (2020) provide a detailed summary of ten of the tephra layers from this period, the so-called two-coloured Hekla tephra series, outlining their dispersal, volumes, ages, and composition, and discuss their potential value as isochrons in distal settings.

Sparse, 'non-visible' occurrences of volcanic glass shards or crystals (minerals) in sedimentary deposits or soils had been documented in northwestern Europe/Scandinavia since the 1950s (Davies, 2015), in New Zealand from the early 1980s (Lowe, 2014), and Canada from the late 1980s (Zoltai, 1989). However, the rise in systematic, 'modern' cryptotephra studies began in the late 1980s, initially driven by research conducted on peat and lake sequences in the British Isles to identify Icelandic eruptives (e.g. Dugmore, 1989; Pilcher and Hall, 1992, 1996; Dugmore et al., 1995; Lowe and Turney, 1997; Turney et al., 1997). Over 30 years later a plethora of other potential sources for tephra/cryptotephra in these archives is now being considered (see Plunkett and Pilcher, 2018). Wastegård et al. (2020) have already shown that the Azores can be a source, and two further papers show that even more distant volcanic regions have contributed tephras to the British Isles tephra framework. Firstly, Pyne-O'Donnell and Jensen (2020) re-examine cores from Loch Ashik, Scotland, first investigated by Pyne-O'Donnell (2004, 2006), at a high-resolution, and uncover evidence for North American tephra deposition (Glacier Peak G) at this site during the Lateglacial Interstadial. Secondly, through their investigation of early- to mid-Holocene sediments from Llyn Llech Owain, Wales, Jones et al. (2020) tentatively report the discovery of North American tephra in the British Isles and provisionally propose only the second discovery of Mediterranean-derived tephra in the British Isles. Seven cryptotephras were isolated in the sequence with one possibly correlated to the Aniakchak caldera-forming eruption in Alaska, and another to the Fondi di Baia tephra from the Campi Flegrei, Italy. Although one other cryptotephra can be correlated to a known Icelandic eruption, the source of the remaining four has yet to be established, highlighting that, despite already being intensively studied, our current understanding of volcanic history and the widespread dispersion of ash in the Holocene is still substantially incomplete.

A common observation of cryptotephra studies in northern Europe is that distal deposits often contain glass shards larger than predicted by dispersal models and satellite observations (e.g. Stevenson et al., 2015; Watson et al., 2016). Saxby et al. (2020) explore this issue using deposits of the Vedde ash in Iceland and Norway and an atmospheric dispersion model. Typically, cryptotephra studies report only the maximum and/or modal grain length for glass shards in deposits. However, through more detailed acquisition of shape parameters for the glass shards, Saxby et al. (2020) show that particle size and shape are key factors in the transport of shards to distal sites and help explain the discrepancy between observed and modelled distances. They also recommend key parameters that could be measured when cryptotephras are discovered that would provide useful data for volcanological studies.

Farther from Iceland, another potential volcanic source for tephra deposits in northern Europe is the Eifel Volcanic Field, Germany. The most well-known eruptive is the Laacher See Tephra (Bogaard and Schmincke, 1985), but maar lake sediments in the Eifel region record several other prominent tephra layers deposited during the last 140 ka (e.g. Sirocko et al., 2013; Förster and Sirocko, 2016). Until now, from these deposits a source volcano has only been identified for the Laacher See Tephra. However, Förster et al. (2020) provide new glass and clinopyroxene geochemistry to link the remaining tephras to other centres within the Eifel Volcanic Field. This work provides insights into the eruptive history of the region and emphasises that these tephra layers could be important geochronological markers for central Europe.

The potential for multiple volcanic regions to contribute tephras to the European tephra framework, and the issues this complexity can cause when attempts are made to identify sources for new deposits (e.g. Kearney et al., 2018), are highlighted by Hirniak et al. (2020) in their cryptotephra study of deposits in two caves in northwest Italy. There has been an increasing interest in the use of cryptotephras to provide stratigraphic and chronological control in archaeological studies (e.g. Lane et al., 2014; Lowe et al., 2015), particularly in cave sites (e.g. Douka et al., 2014; Barton et al., 2015). Hirniak et al. (2020) identify rhyolitic cryptotephra in both sites, including one common geochemical population that can link the cave records. A wide search for potential correlatives, incorporating data from several volcanic regions that have generated deposits with broad geochemical similarities, included analyses from Italy, Iceland, Turkey, the Aegean Sea, and central Europe. Eventually, the search for a match showed that the cryptotephra was most likely derived from Lipari Island or

Iceland. In the final paper from Europe, Insinga et al. (2020) improve the tephrochronological framework for the central Mediterranean Sea between 4.4 and 2.0 cal ka through their study of cores from the Tyrrhenian and Ionian seas. A series of tephras from Italian sources can link these new cores to previously studied records, defining a framework of regional and local chronostratigraphic markers that can provide new chronological control for palaeoclimatic research.

Petrological and geochemical fingerprinting of volcanic products can provide valuable data for characterising the distinctive features of a volcanic eruption, and more securely pinpoint the source of distal tephras, and this is demonstrated by Harangi et al. (2020). The approach has been applied to some eruptive products of the dacitic Ciomadul lava dome complex in the Eastern Carpathians (Romania), the site of several significant Late Pleistocene eruptions with rather similar glass-shard chemical compositions (see Karátson et al., 2016). Harangi et al. (2020) underline that the petrological characteristics, such as ash texture and the occurrence of plagioclase and amphibole phenocrysts and their composition, alongside major element composition, and particularly the distinct trace element characteristics, provide strong fingerprints of eruptive products from Ciomadul volcano. These data can then be used for correlating tephra and cryptotephra occurrences. It is expected that further research into the distal and proximal volcanic products of Ciomadul, and their relation to other eruptives from geochemically similar volcanic fields, could considerably improve the central-eastern European tephrostratigraphic record.

Beyond the well-studied European region, Martin-Jones et al. (2020) demonstrate how long-lake sequences can be used to reconstruct the timing and frequency of volcanism in the East African Rift, an emerging ‘hot-spot’ for tephra studies with volcanological, archaeological, and palaeoenvironmental focusses (e.g. Poppe et al., 2016; Campisano et al., 2018; Fontijn et al., 2018). Martin-Jones et al. (2020) identified nine visible or cryptotephra deposits in sediments from Lake Chala that can be linked to volcanic activity in the Mt Kilamanjaro (Tanzania) and the Chyulu Hills (Kenya) volcanic fields. These correlations support documented evidence for recent volcanism and provide an insight into the timing and frequency of volcanic activity in the region that can now be used to assess the potential future hazard to local populations.

Another application of tephrochronology is addressed by Pearce et al. (2020), who demonstrate through an analysis of tephra-derived glass compositional data that it is possible to reconstruct magma volume estimates and describe aspects of magma storage and eruption dynamics. Pearce et al. (2020) used the Youngest Toba Tuff (YTT), produced during the largest known eruption in the Quaternary from the Toba caldera (Sumatra), as an example of how this can be achieved. They collated published (e.g. Westgate et al., 2013; Pearce et al., 2014) and previously unpublished glass trace element compositional data, both proximal and distal, from which five distinct populations could be identified in the YTT representing five discrete magma compositions. From these data and the stratigraphic relationships of the deposits, it was possible for Pearce et al. (2020) to reconstruct the crustal level of the magma reservoirs, their order of eruption, and their dispersal. Also focusing on Southeast Asia, Bouvet de la Maisonneuve and Bergal-Kuvikas (2020) provide a review of the present knowledge of the volcanic history and tephrochronological potential of the region. Regionally, there are over 750 volcanoes and 41 calderas thought to have been formed by VEI 6-8 eruptions. Understanding their history is highly important as they can pose a significant hazard to the ~600 million people who live in the region and, because it lies close to the equator, large eruptions can have a significant impact on global climate (Bouvet de la Maisonneuve and Bergal-Kuvikas, 2020). This review compiles published data on the timing, magnitude, geochemistry, and mineralogy of the Quaternary volcanic deposits studied to date. The article provides a useful resource for future tephrochronological studies in an area where this technique is relatively underutilised, but the vast future potential is also highlighted as many of the large calderas are undated and their eruptives poorly characterised.

Alongside Southeast Asia, Japan is another of the most volcanically active areas of the world, with over 100 active volcanoes. It is no surprise that tephrochronology is a key field of research in the country, as highlighted by the next four papers all focusing on Japanese tephras. The first two papers focus on tephra produced by two volcanoes on the island of Kyushu. Firstly, Nishizawa and Suzuki

(2020) report the recognition of a widespread Middle Pleistocene tephra layer, the Hegawa-Kasamori 5 Tephra. This tephra layer has an eruptive age between 458 and 434 ka (MIS 12) and was produced by a VEI 7 eruption. Using petrographic and geochemical analysis, Nishizawa and Suzuki (2020) correlated the newly recognised Hegawa pyroclastic flow deposits, proximal to the Aira caldera, to the distal Kasamori 5 deposit, spread over 1000 km from the source. The occurrence of this tephra layer in deep-sea sediments could provide an age for the eruption and, overall, a key regional chronological marker for the Middle Pleistocene could be defined. In the second paper, Miyabuchi and Sugiyama (2020) reconstruct vegetation history within the Aso caldera using phytoliths. Three sections, from after the late period of the Last Glacial Age, were studied with dating control provided by tephra layers, with notably the K-Ah tephra present in all sites. The influence of volcanic and human activity on the vegetation record is also considered. The second two papers focus on tephra from volcanoes situated in the north of Honshu. Suzuki et al. (2020) re-examine four lower Pleistocene tephras from northeast Japan erupted between 2 and 1 Ma, analysing proximal and distal glass shards using the fs LA-ICP-MS approach described by Maruyama et al. (2020) in this volume. The trace element analyses showed a pattern characteristic of tephras from the Hokkaido-Tohoku area, with two sourced from the Sengan geothermal region and two from the Aizu volcanic region. The proximal-distal correlations permitted the assessment of magnitudes of the eruptions depositing the tephras, with evidence provided for two closely-spaced VEI 7 eruptions, within less than 200 kyrs, from the Sengan geothermal region. Ishimura and Hiramine (2020) also focusses on the proximal-distal correlation of a tephra from northeast Japan, but for a more recent eruption, the Mid-Holocene Towada-Chuseri (To-Cu) tephra that has recently been dated to 5986–5899 cal a BP based on its distal occurrence in Lake Suigetsu (Mclean et al., 2018). Through the acquisition of glass morphology, refractive index, and major element compositional data from a large number of distal deposits, three members could be correlated to the proximal To-Cu tephra. As such, this well-dated layer could be an important Mid-Holocene age marker for northeast Japan, the Japan Sea, and the Pacific Ocean.

Another of the varied applications of tephrochronology is provided by Zelenin et al. (2020). Investigation of active faults is crucial for assessing the seismic hazard assessment and for exploring the interactions between volcanism and tectonic faulting. Zelenin et al. (2020) report on paleoseismological and tephrochronological investigations of Holocene faulting in Kamchatka's Eastern Volcanic Front. For the first time in Kamchatka, Holocene seismic events within the volcanic belt have been characterised and dated with the help of 18 Holocene tephra layers identified within the studied profiles and linked to the eruptive centers Shiveluch, Kizimen, Avachinsky, Opala, Khangar, and Ksudach volcanoes, and the Karymsky and Kurile Lake calderas. Zelenin et al. (2020) show that scaling of the surface ruptures in the studied area are related to earthquakes with a magnitude of 3.7–4.7 with recurrence intervals in the order of 1 ka, which agrees well with tephrochronological constraints. It thus appears that Holocene crustal seismicity of the Eastern Volcanic Front is temporally clustered rather than a uniform flux of events. However, no correlation was found between the dated seismic events and the larger eruptions of local volcanoes.

Zelenin et al. (2020) exploited the well-defined Holocene Kamchatkan tephrostratigraphy in their study. Nevertheless, reconstructing the pre-Holocene volcanic history is more complex as older sequences are rare and can be affected by erosion by glaciers and meltwater, or burial by subsequent eruptives. Derkachev et al. (2020) address this issue within the final paper of the volume by identifying and assessing pre-Holocene eruptives within a marine core retrieved from the Meiji Rise, northwest Pacific, ~400 km downwind from the Kamchatkan volcanic arc, because marine records can provide the most complete and long-term tephra records for this period. Derkachev et al. (2020) identify 25 tephras deposited within the past 215 ka. The geochemical characterisation of glass shards allowed these tephras to be linked to specific Kamchatkan volcanic centres, and a new age model could be used to provide ages for the eruptions. Only three of the tephras could be correlated to previously known eruptives, but, generally, a tephra framework is presented that could be useful in future palaeovolcanological and palaeoclimatic studies.

Role and future of the International Focus Group on Tephrochronology and Volcanism (INTAV)

INTAV has been supported as a focus group within the Stratigraphy and Chronology Commission (SACCOM) of the International Union for Quaternary Research (INQUA) since its reorganisation into five commissions in 2007 through two overarching projects: (1) INTREPID I and II (Enhancing tephrochronology as a global research tool through improved fingerprinting and correlation techniques and uncertainty modelling – INQUA projects 0907 and 1307s, 2009–2015); and, since 2015, (2) EXTRAS (EXTending tephRAS as a global geoscientific research tool stratigraphically, spatially, analytically and temporally within the Quaternary – INQUA projects 1307s and 1710P, 2015-2019). INTAV has provided a forum for discussion and collaboration between tephrochronologists through the organisation and support of field conferences, focused meetings including a number of skills-based workshops, conference sessions, and special issues of journals (e.g. Froese et al., 2008; Lowe et al., 2011; Lane et al., 2017a). There has been a special focus on supporting the activities of early career researchers (ECRs) (including students). For the 10-year period 2009-2018, the INTAV committee was successful in applying for a total of €34,100 in grants from INQUA, together with €2400 from PAGES, as well as obtaining various grants and in-kind support from local organisations where the meetings were held. These grants helped support dozens of ECRs since 2010 to participate in two tephra field conferences (Japan, 2010; Romania, 2018); a Bayesian age-modelling workshop (Mexico, 2010); a workshop on the Eyjafjallajökull eruption and its implications (Scotland, UK, 2011); and two tephra-skills workshops (Oregon, USA, 2014, 2017). The key role of leaders in the field has also been recognised through the granting of honorary life memberships and the celebration of important milestones, such as recent 50th anniversary of the pioneering publication of Smith and Westgate (1969). Smith and Westgate (1969) were the first to use electron microprobe analyses of glass shards to characterise and hence correlate tephras over long distances, and their legacy lives on to this day because this technique is the keystone of the overwhelming majority of tephra correlation studies.

INTAV is the most recent incarnation of a series of tephra-related international groups, including the Commission on Tephrochronology, Inter-congress Committee on Tephrochronology (ICCT), and the Subcommission on Tephrochronology and Volcanism (SCOTAV), that have evolved under the umbrella of INQUA since 1961 (Kobayashi, 1965; Suzuki et al., 2011; see Smalley, 2011, for a history of INQUA). However, for a brief period between 1982-1987, the collective was temporarily housed within the International Association of Volcanology and Chemistry of the Earth’s Interior (IAVCEI) (see Cas, 2019, for a history of IAVCEI). A new evolution occurred in 2019 as INTAV transitioned back to being called the Commission on Tephrochronology (COT) title and back under the auspices of IAVCEI, a move endorsed almost unanimously at the 100-strong tephra meeting held in Romania in 2018. This change does not represent a shift in the focus of the organisation but provides stability and the long-term continuation of an international tephra-related focus group. INTAV and its past forms have always had connections with IAVCEI and, following the transition, will maintain strong links with INQUA (such as through working groups). The success of two full sessions on tephrochronology at the recent 20th INQUA Congress in Dublin in 2019, with a total of 60 papers being presented, demonstrates the current importance of tephrochronology within Quaternary research. The ability of INTAV/COT to seamlessly move between these scientific organisations highlights the multidisciplinary nature of the technique and acknowledges the increasing role tephrochronology can play in volcanic studies (see Cashman and Rust, 2020, in this volume).

The main aim of the original COT was expressed simply in 1961 by Kobayashi (1965): ‘to advance the progress to the method [i.e. to develop the method] of tephrochronology and Quaternary research based on tephrochronology’, and to achieve this through gathering and exchanging information on tephra studies in different countries and reporting on these results (Kobayashi, 1965). While the aim of COT in 2019 can now be expanded to include an enhanced focus on volcanic studies, the means to achieve this remain the same. COT will continue to help organise field conferences, convene sessions at large-scale meetings such as the IAVCEI Scientific Assemblies (including the next being held in Rotorua, New Zealand, in February 2021) and INQUA congresses, support smaller meetings and workshops, and facilitate special issues of journals to report the results of tephrochronological studies. One objective of this broad aim – supporting and encouraging the emerging and early-career researchers – remains paramount. The number, diversity of applications, and geographical scope of the studies within this special issue emphasises the current strength and breath of the discipline and the need for the continuation of a thriving international tephra-related group.

In memoriam and dedication

With sadness we record the death (in May 2019) of Dr Richard J. Payne, a highly regarded peatland researcher and tephrochronologist. Richard's influence was twofold: (1) through his research and (2) as an inspirational colleague and mentor. To mark the deep respect held for Richard, to recognize his innovative contributions to tephrochronology and palaeoenvironmental research, and for the selfless support he provided to numerous collaborators and students, we have dedicated this special volume to his memory (see *In Memoriam* article by Bunting et al., 2020).

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