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A summary of terminology used in tephra-related studies

Un résumé de la terminologie d'usage dans l'étude des téphras

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Abstract: *the word 'tephra', derived from a Greek word for ash, is a collective term for all the unconsolidated, primary pyroclastic products of a volcanic eruption. We summarise here (in English) the meanings and applicability of this and related terms, including tephrostratigraphy, tephrochronology, tephrochronometry, tephrology, and cryptotephra. These and other tephra-based terms, some of which are erroneous or unnecessary, have been used in a wide range of stratigraphic and palaeoenvironmental disciplines and in archaeology.*

Keywords*: Tephra, tephrochronology, tephrostratigraphy, tephrology, nomenclature, pyroclastic deposits, volcanology, stratigraphy, archaeology, Quaternary.*

Résumé : *le terme "téphra" est dérivé d'un mot grec qui signifie "cendre". Il est utilisé en téphrologie comme un substantif collectif pour désigner tous les produits primaires non consolidés d'une éruption volcanique. On résume ici (en anglais) la signification et le champ d'application de ce terme et de ses dérivés comme téphrostratigraphie, téphrochronologie, téphrochronométrie, téphrologie et cryptotéphra. Ceux-ci et d'autres comprenant la racine "téphra" – dont certains sont erronés ou inutiles – ont été largement utilisés en stratigraphie, en paléoenvironnement et en archéologie.*

Mots-clés *: Téphra, téphrochronologie, téphrostratigraphie, téphrologie, nomenclature, dépôts pyroclastiques, volcanologie, stratigraphie, archéologie, Quaternaire.*

1. Introduction

The science of tephra studies, or tephrology (Froggatt & Lowe, 1990), is applicable to a wide range of geoscientific disciplines, especially volcanology and Quaternary stratigraphic and palaeoenvironmental research, archaeology and soil science (Fig. 1). This is because tephra deposits, uniquely, provide: (1) isochronous stratigraphic marker beds that assist in correlating sequences in terrestrial (including ice cap) and marine environments, and in linking these; (2) mineral and glass components for numerical dating; (3) a comprehensive record of volcanism, especially in distal environments (e.g., see Self & Sparks, 1981; Fisher & Schmincke, 1984; Sarna-Wojcicki & Davis, 1991; Westgate *et al.*, 1992; Knox, 1993; Lowe, 1996; Firth & McGuire, 1999; Hunt, 1999; Newnham *et al.*, 1999; Shane, 2000). The term 'tephra' was (re)introduced into the literature in 1944 by Sigurdur Thorarinsson (Thorarinsson, 1981). Since then, the rapid and worldwide growth in the application of tephra deposits to geoscientific and other environmental research has generated a new terminology. The historical background, rationale and etymology of this terminology, examples of usage, and applications to stratigraphic nomenclature have been reviewed in detail by Hunt & Lowe (in press). In this paper, therefore, we

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provide for English speakers a short summary of our view of the meaning and applicability of terms currently used in tephra-based studies (Table 1). Although around twenty terms are described, we suggest that the commonly used ones (Table 1) are adequate to cover most studies involving tephra deposits. A companion paper (Juvigné *et al.*, 2001) provides a review from a French-language perspective.

Commonly used terms	Less-commonly used terms
Tephra	Tephropetrology
Tephric	Tephrogenesis
Pyroclastic	Tephrogeodynamics
Microtephra	Tephrovolcanology
Cryptotephra	Tephrofacies
Tephrochronology (*sensu lato, sensu stricto*)	Tephrobiology
Tephrostratigraphy	Tephropalynology
Tephrochronometry	Tephropalaeoclimatology
Tephrology	(Tephrofact) [1]
	(Tephrite) [2]

1. This term is inappropriate and should be dropped (see text).
2. This and related terms have no relevance here. Although 'tephra' is their root, the terms pertain to non-pyroclastic rocks or minerals that are dominantly *ash-grey* in colour (tephrite is an alkali basalt, tephroite is a member of the olivine group of minerals).

***Table 1.** Tephra-related terms referred to in this paper.*

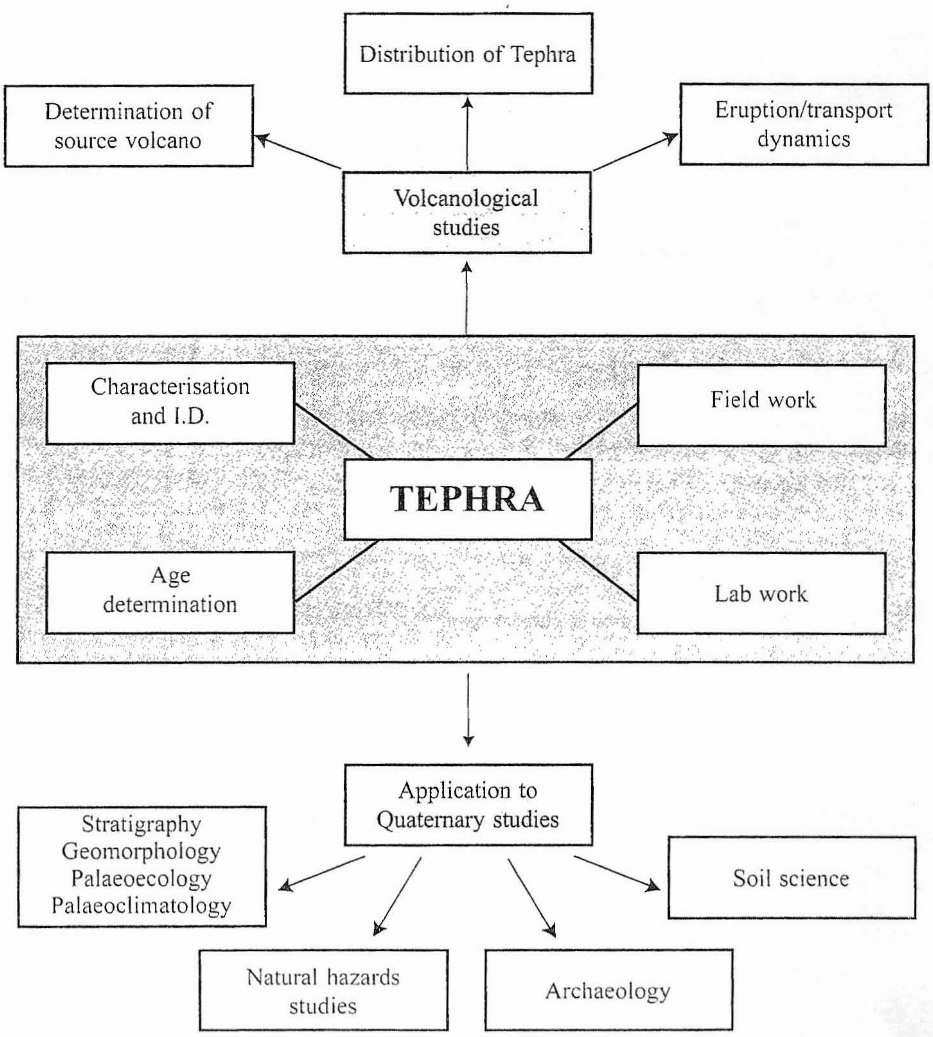

***Figure 1.** The study of tephra and its central role in volcanological and Quaternary stratigraphical and palaeoenvironmental studies, archaeology, and soil science (based on a figure by Hiroshi Machida, Japan). I.D. = identification.*

2. Common terms

2.1. Tephra

The word 'tephra' is derived from the Greek *tephra* (*τεφρα*), meaning ash, and is a collective term for all the unconsolidated, primary pyroclastic products of a volcanic eruption (Froggatt & Lowe, 1990). It is inclusive of all grain sizes, including very fine ash (dust) (<0.06 mm), medium ash (0.06–0.5 mm), coarse ash (0.5–2 mm), lapillus/i (2–64 mm), and block/s or bomb/s (>64 mm). Strictly, 'tephra' is singular (it does not seem to occur in Greek in the plural form) and hence it is used as a collective with singular verb forms. However, Froggatt & Lowe (1990) recommended that appending 's' to form the plural 'tephras' may reduce ambiguity. Note that in compound words in English based on Greek roots, the original final vowel ('a') is always replaced with 'o' to form derivatives such as tephrostratigraphy (Froggatt & Lowe, 1990; see also Juvigné, 1990).

The term originally encompassed the clastic material transported through the air during an eruption but this 'airborne' connotation has been modified to include all explosively ejected deposits irrespective of their specific origin or mode of emplacement (Fisher & Schmincke, 1984; Froggatt & Lowe, 1990). That is, 'tephra' may include fall deposits and those from pyroclastic flows (ignimbrite) or surges, or co-ignimbrite ash, provided they are essentially unconsolidated. The term also encompasses loose pyroclastic deposits generated or emplaced subaqueously or subglacially, and those generated from explosions through the interaction of lava with groundwater or seawater at rootless vents.

The 'morphological' definition of tephra given above is preferable in many stratigraphic applications because it eliminates the need to identify the mode of emplacement or environment of deposition. Where an indication of genesis is required, a modifying term is introduced. In this regard the widely-used qualifier 'airfall' is now less favoured and instead terms such as 'tephra-fall' deposits or 'fallout tephra' are being used.

2.2. Tephric

The adjective 'tephric' means 'related to' or 'of tephra' and is useful for denoting deposits reworked or weathered from antecedent tephra deposits (e.g., tephric alluvium).

2.3. Pyroclastic

The adjective 'pyroclastic' is derived from the Greek *pur*, fire, and *klastos*, broken in pieces, and is a collective term for clastic or fragmentary material, welded to non-welded, explosively ejected from a volcanic vent (Froggatt & Lowe, 1990). Except where welded or hardened, therefore, pyroclastic deposits are normally able to be described also as tephra deposits.

2.4. Microtephra, cryptotephra

Distal tephra deposits, preserved in peat bogs or lacustrine or marine sediments for example, may be invisible to the naked eye (e.g., Dugmore *et al.*, 1995; Pilcher *et al.*, 1996; Turney *et al.*, 1997; Hall, 1998; Newnham *et al.*, 1998). Increasingly, such deposits are referred to as 'microtephras', especially in northwestern Europe where tephra studies have expanded rapidly in the past decade. This term is appropriate to the extent that the deposits require analysis by microscopy to identify their occurrence. However, the term does not differentiate between the size of constituent particles, typically in the form of ash-sized glass shards, and the thickness of the deposit. Consequently, Hunt & Lowe (in press) recommended that the term 'cryptotephras', from the Greek *kryptein*, to hide, is more appropriate to convey the hidden or concealed nature of these deposits. Possible derivative terms such as 'cryptotephrostratigraphy' aptly describe the 'hidden' sequences of tephra deposits of Great Britain and Ireland. Similarly, 'cryptotephrochronology' may be useful in describing the application of such deposits as a dating tool.

2.5. *Tephrochronology* (sensu lato)

'Tephrochronology'(*sensu lato*) has effectively become the 'stand-alone' term for all chronological and related aspects of tephra studies including the characterization of tephra layers and their use as a dating tool (e.g., as used in Sarna-Wojcicki & Davis, 1991; Westgate *et al.*, 1992; Shane, 2000). More strictly, however, three separate components comprise this broad definition: tephrochronology (*sensu stricto*), tephrostratigraphy, and tephrochronometry, as discussed below.

2.6. *Tephrochronology* (sensu stricto)

'Tephrochronology' (*sensu stricto*) was defined as a dating method based on the "identification, correlation and dating of tephra layers" (Thorarinsson, 1981) – that is, essentially using tephra deposits as time-stratigraphic marker beds to establish numerical or relative ages.

When tephra studies began, age control was obtained for the youngest tephras principally using historical data (e.g., Christian documents, Icelandic sagas). Subsequently, radiocarbon assays of charcoal or wood entrained within tephra layers, or from organic sediments encasing them, expanded the age range of dateable tephra layers. In both instances the chronology was transferred from site to site using the stratigraphy of the tephras – depositional sequences, landscapes, or geomorphological or archaeological events, for example, were dated using the stratigraphic relationships of such features with respect to the characterised tephra deposit of known age. As tephras are increasingly investigated in diverse environments, so a greater range of dating methods can be applied to the tephra-hosting sediments (e.g., magnetostratigraphy, oxygen-isotope stratigraphy, ice-layer and varve counting). This conjunction of tephrostratigraphy and chronology defines tephrochronology *sensu stricto*. The differences between tephrostratigraphy and tephrochronology are, therefore, identical to the broader differences between stratigraphy and chronostratigraphy (e.g., Boggs, 1995).

2.7. *Tephrostratigraphy*

'Tephrostratigraphy' is the study of sequences of tephra layers and related deposits and their relative ages. It involves definition, description and the identification and characterization ('fingerprinting') of tephras or tephra sequences using their physical, mineralogical, or geochemical (including isotopic) properties (Fig. 1). Multiple criteria are needed to ensure confidence in most tephra correlations: (1) stratigraphic position (providing relative age); (2) intrinsic compositional properties that are diagnostic and persistent; and (3) numerical age (based on radiometric or other dating techniques).

Proximal tephra deposits and regionally continuous tephra marker beds may be correlated between exposures using stratigraphy in combination with lithology and other physical (field) properties. Such 'hand-over-hand' mapping techniques have been used, for example, in New Zealand (Lowe, 1990) and Japan (Machida, 1991, 1999). As tephra layers become less distinct away from source, then field methods must be supplemented by laboratory analyses. These usually include examination of mineral assemblages by petrological microscope or analysis of the elemental composition of glass shards, Fe-Ti oxides or various other minerals using, for example, the electron microprobe or laser-ablation inductively-coupled plasma mass spectrometry (e.g., Sarna-Wojcicki & Davis, 1991; Froggatt, 1992; Hunt & Hill, 1993; Westgate *et al.*, 1994; Hunt *et al.*, 1998; Pierce *et al.*, 1999; Lowe *et al.*, 1999; Shane, 1998, 2000). Numerical classification techniques, including discriminant function analysis, have been used to help distinguish geochemically between tephra source volcanoes or individual tephra layers (e.g., Stokes & Lowe, 1988; Stokes *et al.*, 1992; Shane & Froggatt, 1994; Cronin *et al.*, 1996, 1997; Charman & Grattan, 1999).

2.8. Tephrochronometry

Although frequently described as a dating technique, tephrochronology is in reality a highly effective means of transferring chronologies obtained independently of, but associated with, a tephra deposit. That is, identified tephras provide age-equivalent horizons or isochronous marker beds ('isochrons'). The term 'tephrochronometry' was first used by Berger (1985) and by John Westgate in 1990 (Sarna-Wojcicki & Davis, 1991). It is the determination of a numerical age of a tephra deposit. Dating techniques may be applied both directly to the mineralogical or glass components of the tephras themselves or indirectly to closely associated (contiguous or entrained) contemporaneous material. They include radiometric and non-radiometric techniques such as fission-track, K-Ar or single-crystal laser Ar-Ar, U-series, radiocarbon and luminescence dating, and orbitally-tuned marine oxygen-isotope stratigraphy, ice-core records and dendrochronology (e.g., see Lowe & Newnham, 1999; Shane, 2000).

2.9. Tephrology

The term 'tephrology' was proposed by Froggatt & Lowe (1990) as a single, harmonious term for the science encompassing all aspects of the study of tephras – that is, including their stratigraphy, chronology, correlation, and petrology.

3. Less-common terms

3.1. Tephropetrology, tephrogenesis

'Tephropetrology' is the study of the mineral and geochemical properties of tephra deposists and their petrological interpretation. The term is closely related to 'tephrogenesis' which describes and interprets magmatic factors (e.g., magma viscosity, volatile content) pertaining to tephra eruptions (Schmincke & van den Bogaard, 1991).

3.2. Tephrogeodynamics

This term describes large-scale geological processes that control tephrogenesis and thereby the frequency of preservation of tephra layers within long-term sedimentary records (Schmincke & van den Bogaard, 1991).

3.3. Tephrovolcanology

This is the application of tephra studies, especially those relating to distal environments, in documenting the history of a volcanic centre (Schmincke & van den Bogaard, 1991).

3.4. Tephrofacies

These describe different facies of unconsolidated pyroclastic deposits petaining to a single eruptive episode (e.g., Wilson & Walker, 1982; Schmincke & van den Bogaard, 1991).

3.5. Tephrobiology

This is the study of fauna and flora preserved within tephra deposits to obtain time-slice palaeoenvironmental information (e.g., Clarkson *et al.*, 1995; Waldmann, 1996).

3.6. Tephropalynology

This is essentially the joint application of tephrochronology and palynology, which involves the correlation and dating of pollen-based palaeoenvironmental reconstructions using tephra layers as the linkage (e.g., Newnham & Lowe, 1999). It also encompasses pollen-based studies of the impacts of tephra fall in various environments (e.g., Charman *et al.*, 1995; Giles *et al.*, 1999). The term was first used by Edwards (1996).

3.7. Tephropalaeoclimatology

In its original sense, this simply involved mapping tephra isopachs to produce palaeowind directions (e.g., Eaton, 1964; Larsen & Thorarinsson, 1977; Schmincke & van den Bogaard, 1991). However, more recent applications include linking acid layers (and related palaeoclimatic effects) in ice cores to specific eruptions by identifying coeval volcanic glass in the cores (e.g., Zielinski *et al.*, 1997). Studies of palaeoclimate using tephra deposits directly, such as analysing the deuterium content of water in tephra-derived volcanic glass (Friedman *et al.*, 1992), or deriving palaeo-rainfall trends from analyses of clay minerals or phytoliths in paleosols associated with tephras (Newnham *et al.*, 1999), may also be described as tephropalaeoclimatology.

3.8. Tephrofact

This term was used erroneously in archaeology to describe natural, tool-shaped lithic fragments (generically termed 'geofacts') that were produced by volcanism (Raynal *et al.*, 1995). Such geofacts included a range of lithologies, all unrelated to tephra deposits, and hence Hunt & Lowe (in press) recommended that the term be abandoned.

3.9. *Tephrite*

This and related terms (e.g., tephriphonolite, tephritoid) are etymological relatives of 'tephra' in that they are derived from the same root. However, they are irrelevant in a geological sense to tephra studies because they apply to lithified rocks, not unconsolidated pyroclastic deposits (e.g., 'tephrite' is a type of alkali basaltic rock). This missassociation arose through erroneous historical links (Hunt & Lowe, in press).

4. Conclusions

Tephra studies have grown dramatically in the late 20th Century and they have been applied across a widening range of scientific disciplines and environments. It is therefore appropriate to re-assess and redefine, as necessary, the evolving nomenclature relating to the central term 'tephra' and its derivatives. Although around twenty terms have been described, we suggest that the common ones (Table 1) adequately cover most studies involving tephra deposits. Others may be useful in some circumstances but erroneous or irrelevant terms should be discarded (Hunt & Lowe, in press).

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