TEPHROCHRONOLOGY BY MICROPROBE GLASS ANALYSIS

Gudrún Larsen

Nordic Volcanological Institute
University of Iceland, Reykjavik

ABSTRACT. Basaltic tephra layers form a considerable part of the postglacial tephra deposits in Iceland. They can be related to the volcanic systems that produced them by characteristics based on major and minor element chemistry. Microprobe analysis of volcanic glass shards have made it possible to relate even very thin (1-2 mm) basaltic tephra layers in distal areas outside the volcanic zones to their source.

1. INTRODUCTION

Most eruptions that occur in Iceland are dominantly effusive, basaltic fissure eruptions. In areas covered by ice, at sea and where ground water table is high, these eruptions are partly or wholly explosive due to interaction between water and magma. Widespread basaltic tephra layers are therefore common in Iceland. Silicic tephra layers form the framework of tephrochronology in Iceland (1,2) but basaltic tephras add considerable detail to the tephrochronological record. In soil sections in southern Iceland covering the last 11 centuries, between 30 and 80% of all tephra layers are basaltic.

2. CORRELATION PROBLEMS

Tephrochronological studies covering the period 900 AD to present in Iceland have so far mostly been based on field studies, combined with studies of old Icelandic literature, where descriptions of volcanic eruptions, their source and the year of eruption are recorded (1,2,3,4).

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In proximal areas, thickness and grain size variations of individual tephra layers are often sufficient criteria to relate the tephras to their source and to establish a dispersal pattern. In distal areas, however, chemical analysis may be the only way to relate a tephra layer to its source. There the thickness of the layers may be less than 1 cm and the samples that can be collected may be either too small for bulk chemical analysis, contaminated by soil or differentiated during transport and deposition.

The electron microprobe has greatly facilitated the use of chemical composition of tephras as a tool in tephrochronology. Volcanic glass and minerals can be analysed separately and the grains need only be a few microns in diameter. This method has proved especially promising for detailed chronological work on basaltic tephra layers. The relevant advantages are: (a) very small samples can be analysed, (b) rapidity of the method, and (c) favourable cost/efficiency ratio.

Basaltic tephra has a distribution pattern different from that of silicic tephra. The latter is generally erupted during a relatively short plinian phase forming a tephra layer with a distinct dispersal axis (2,5). Explosive basaltic eruptions produce moderate amounts of tephra for days or weeks, sometimes forming thin dispersed deposits, even near source (4). Correlating such deposits by field methods is both time consuming and unrewarding. A large number of soil profiles can, however, be efficiently studied by the microprobe technique in a relatively short time.

Each tephra layer, however insignificant, represents an eruption. If a tephra layer is omitted, information on an eruption can be lost, as it may not be recorded anywhere else. Detailed tephrochronology may be most useful to scientific studies such as archaeology in areas far outside the volcanic zones. In such cases the microprobe may often be the only way to relate thin basaltic tephra layers to their source.

3. CHEMICAL CHARACTERIZATION OF BASALTIC TEPHRA

In Iceland chemical "fingerprinting" of basaltic tephra is based on the fact that postglacial volcanic activity occurs along distinct volcanic fissure systems and on central volcanoes, collectively termed volcanic systems (6,7,8). Each system has chemical characteristics which in many cases can be used to identify its products.

The situation is especially favorable on the Eastern Volcanic Zone (Figure 1), where the volcanic systems are tholeiitic in the

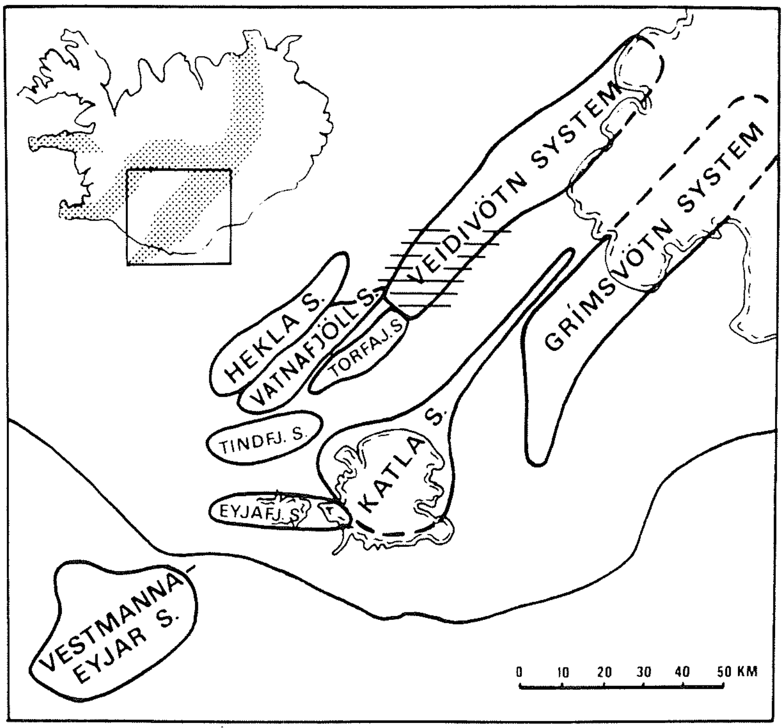

Fig. 1. The nine volcanic systems on the Eastern Volcanic Zone, after Jakobsson (7), and the areas covered by glaciers or affected by a high ground water table (shown by horizontal shading). Three have produced most of the basaltic tephra during the last 11 centuries: the Katla, the Grímsvötn and the Veidvötn systems. Those with names in small print have produced negligible amounts of basalts in postglacial times.

north but increasingly alkaline towards the south (7,8). This is important for tephra correlation work, since most of the postglacial tephra deposits in Iceland, both basaltic and silicic, originate from the Eastern Volcanic Zone. The compositional range of postglacial basalts in this region is well documented. During the timespan in question each volcanic system has produced basalts of relatively homogenous composition. The products of each system are chemically different from those of other systems, regardless of petrographic nomenclature (7,8).

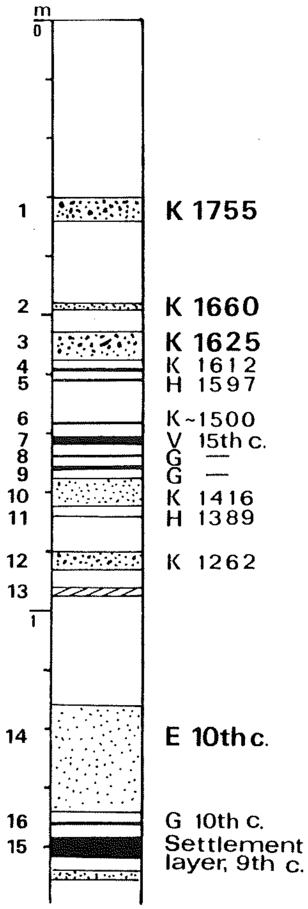

Fig. 2. Uppermost 1.5 m of a soil section from the Katla area, Southern Iceland. Origin and date of eruption of four layers (bold print) was known from previous studies (3,4). Eleven of the remaining layers have been related to their source by chemical characteristics (Figure 3) and given an absolute or approximate date of eruption (small print). G; eruptions within the ice covered part of the Grímsvötn system; H; eruptions of Hekla proper (intermediate to acid); K; eruptions within the ice covered Katla caldera; E; Eldgjá eruption (Katla system); V; Veidivötn eruption (Veidivötn system), Settlement layer: Vatnaöldur eruption (Veidivötn system).

The use of chemical characteristics of basaltic tephra for correlation purposes is demonstrated by a soil section from the Katla area in southern Iceland. The uppermost 1.5 m of the soil section (Figure 2), contains some 16 tephra layers erupted during the last 11 centuries. All the tephra layers except no. 13 are dark colored. The origin of four layers, no. 1, 2, 3, 14 is known through field studies. Most of the remaining tephra layers are thin and difficult to trace in the field. The origin of some of them was anticipated but awaited confirmation (3,4). Five to ten shards of glass from samples of each of the tephra layers in the above section were analysed on the microprobe.

The minor elements TiO_2 and K_2O have a larger compositional variation in basalts than most major elements and the difference between volcanic systems is pronounced on such a plot. Some other element ratio may resolve boundary cases and therefore a complete analysis of each tephra grain is performed. Figure 3 is a plot of K_2O against TiO_2 showing the average value and the range of these elements in postglacial basalts from six volcanic systems on the Eastern Volcanic Zone, based on bulk analyses from Jakobsson (7). Microprobe glass analyses of tephra are compared to this data. Each number represents a point analysis of a single glass shard and refers to a tephra layer in the soil section on Figure 2.

A clear separation between volcanic systems results from the plot in Figure 3. The fit is adequate given the fact that glass analyses are being compared to bulk analyses. The layers 4, 6, 10 and 12 originate within the ice covered Katla caldera; 8, 9, 16 and 7, 15 come from the Grímsvötn and Veidivötn systems, respectively. Three tephra layers were of silicic composition and are not plotted. Since all the tephra layers were deposited during historical times, the year of the eruption could be deduced from written sources in five cases and an approximate date could be assigned in six cases, see Figure 2.

The products of each volcanic system have a limited compositional range which is, however, considerably larger than that of individual eruptions from the same system (7,9). This is partly illustrated on Figure 3 by the analyses from layers 12 and 14 which form small groups within the field occupied by the Katla system. Another example is provided by tephra layers collected from soil sections 30 km apart in order to distinguish between and correlate individual layers using this difference in glass composition (Figure 4). The difference between the respective layers is small but distinct, although the number of grains so far analysed from each sample is too low to test conclusively the homogeneity of these layers.

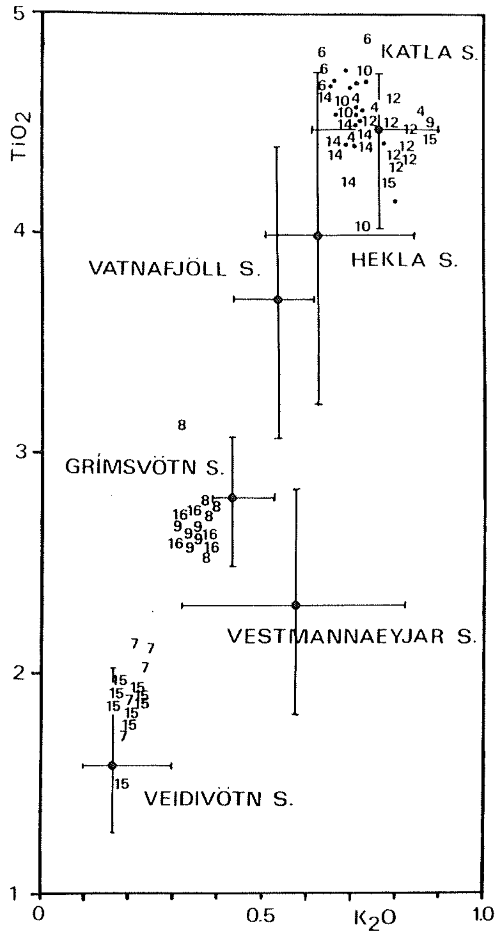

Fig. 3. Plot of K_2O against TiO_2 (wt%) showing the average value and range (filled circles and bars) of these elements in postglacial basalts from six volcanic systems on the Eastern Volcanic Zone (7) and corresponding values for basaltic tephra layers (numbers) from the soil section shown on Figure 2. Tephra layers 1-3 are represented by dots.

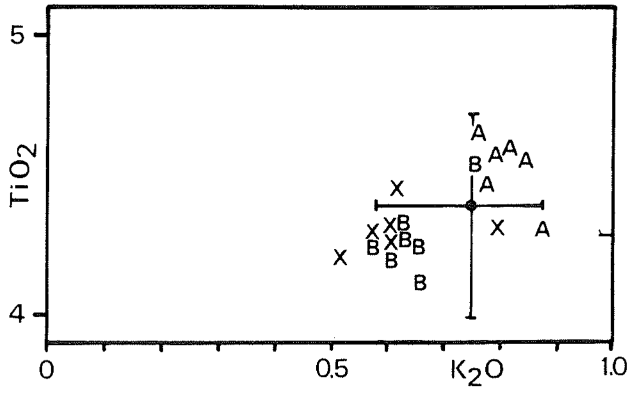

Fig. 4. Two Katla layers, A and B, from a known horizon in a soil section in the Katla area compared to Katla layer X in a soil section 30 km away, thought to correspond to one of them. Apparently X and B are the same layer.

Two tephra layers have been so tested for homogeneity; those from the 1918 eruption of Katla and the 9th century eruption from the basaltic part of Vatnaöldur fissure. The Katla tephra was found to be homogenous. A slight change in glass composition was observed along the eruptive fissure of the latter and minor amounts of glass with different chemical composition were found, corresponding to the glass of an underlying palagonite formation (9).

It should be emphasized that microprobe analyses of glass are directly comparable only with maximum precision. This is done by coating and analyzing the samples that are being compared in the same batch under the same conditions. The difference in chemical composition between eruptions from the same volcanic system are so small that they are easily obscured unless the above-mentioned conditions are fulfilled.

4. SUMMARY

Microprobe glass analysis of basaltic tephra layers have proved to be useful for correlation purposes in Iceland. Two levels of detail can be defined:

1) Basaltic tephra layers can be related to individual volcanic systems by their chemical characteristics, provided the composition of the system is well known.

2) A limited compositional range within each system offers the possibility of distinguishing between individual tephra layers from the same system by major and minor element chemistry alone. More data is, however, needed to firmly establish this and to what extent it needs to be supplemented by trace elements and mineral chemistry.

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