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Dating the Cave? The Preliminary Tephra Stratigraphy at Kverkin, Seljaland

Abstract

Analysis of the sequence of volcanic airfall layers (tephra stratigraphy) at Kverkin, southern Iceland, shows the potential for dating environmental change and construction of Kverkarhellir-cave. This analysis suggests that putative spoil from the construction of the cave may be older than the Landnám ash of c. AD 870. Stratigraphic evidence is presented for the identification of tephra from the Landnám (V870) and later Katla R (KR920) eruptions. In close proximity to the cave, initial geochemical analyses identify the chemically distinctive Landnám tephra paired with a Katla tephra. Further stratigraphic data and geochemical analyses are required to confirm the identification of these volcanic ash layers.

Introduction and Background

In order to establish a chronological framework for archaeological and environmental investigations at the Seljaland site in southern Iceland (Ahronson *this volume*), a number of tephra samples were taken in September 2001 and geochemically analysed over the following months. The initial analysis of this material is presented here.[1]

Tephrochronology is a dating technique that uses tephra layers within the sedimentary record as time-parallel marker horizons, horizontally continuous units that represent an instance in time within the sedimentary record of a region. By

[1] Substantial tephrochronological fieldwork by the authors in 2002, after this article was submitted, has clarified the initial analysis presented here. The 2002 Seljaland Project field report (*in prep*) presents a new robust tephra stratigraphy for the site.

tracing these tephra layers across an area, a regional chronology can be developed. Using historical records, ice core data and radiometric dating techniques, independent ages can be obtained for these layers. This stratified sequence of dated tephra layers can then provide a chronological framework within which events recorded in the sedimentary record can be placed. Tephrochronology is a particularly useful chronological technique for studies of first Millennium AD environmental change in southern Iceland. In particular, the Seljaland region is well suited to the application of tephrochronology due to the very detailed and well-constrained record of tephra layers that has been developed for the region (Dugmore 1987, Larsen *et al.* 2001). Throughout the Holocene (approximately the last 10,000 years), a number of very active volcanic systems in close proximity to Seljaland have produced many visually and geochemically distinctive tephra layers. These layers are particularly suitable for stratigraphy-based tephrochronology.

Methods

Tephra layers were logged in two profiles from in front of Kverkarhellir-cave as part of the initial archaeological work carried out at this site (Ahronson *this volume*). Profile D1 was located 1.6 metres NE of the cave mouth and included putative construction spoil. A control trench, D3, was also excavated 14 metres ESE of D1 and a profile recorded. For trench D1, a 2 metre west-facing profile and a 1 metre north-facing profile were recorded to a maximum depth of 2 metres. For trench D3, a 1 metre north-facing profile was recorded to a depth of 2.2 metres. Layers were recorded according to the following system: trench number (D1 or D3) and layer (A, B, C, D, ...), thus D1G expresses trench D1 layer G.

For each profile, the sequence of sedimentary layers was recorded by scale diagram, based on measurements and observations of grain size, colour, layer thickness, continuity of units and layer composition. These scale diagrams have been summarised as a basic sedimentary log for comparison with reference profiles recorded at Seljaland by Dugmore (1987). This reference profile is a complete sequence of undisturbed tephra layers consistent with wider records in the Markarfljót, Seljaland and Sólheimar areas.

Preliminary geochemical analyses of samples of layers F and G[2] were carried out by electron microprobe analysis using a Microscan V instrument, following procedures summarised in Dugmore *et al* (1992).

Preliminary tephra stratigraphy and geochemical analysis

Figure 1 shows the Kverkarhellir and Seljalandsheiði tephra stratigraphies. The Seljalandsheiði profile shows that in this area very few black Katla tephra layers have been recorded in the soils during historic time. The distinctive key historical layers are predominantly from Hekla: H1947[3] (coarse grey-brown pumice), H1510 (coarse grey-brown pumice) and H1341 (fine blue-grey tephra). K1500 is a relatively coarse black tephra layer from Katla. A pair of distinctive tephra layers is found near to the time of Norse settlement of the island (Landnám). The V870 tephra layer (Landnám ash), a greenish brown tephra with a small pale silica-rich component, is from the Veiðivötn system. The Landnám, or 'settlement', of Iceland by the Norse is dated by historic accounts to AD 870 (ÍF 1968:4). The Landnám tephra, which is generally understood to seal the prehistoric sequence from the historic or Norse settlement period (Vésteinsson 1998:3-4), has been dated to AD 871±2 (Grönvald *et al.* 1995). Approximately 50 years later Katla erupted producing the black Katla-R (Reykjavík)[4] tephra in c. AD 920. Thick (often greater than 10 cm) coarse black tephra layers from the Katla volcano dominate the pre-settlement sequence, clearly distinguishable from the series of tephra deposits after Landnám.

[2] Layers F and G refer to layers D3F and D3G from the control trench, D3. In the field, a common sedimentary stratigraphy was noted between trenches D1 and D3. Thus layers D1E and D3F were interpreted to be stratigraphically the same, as were layers D1G and D3G. Layer D1E is a tephra layer above the tephra layer D1G.

[3] Tephra layers discussed in the text are referred to using a two-element system. The first element abbreviates the source volcanic system to one letter (H for Hekla, K for Katla, V for Veiðivötn), while the second element expresses the AD date (H 1947 for Hekla AD 1947).

[4] The black Katla-R (Reykjavík) tephra of c. AD 920 is so-named because the ash from the eruption was blown towards Reykjavik (Hafliðarson *et al.* 1992).

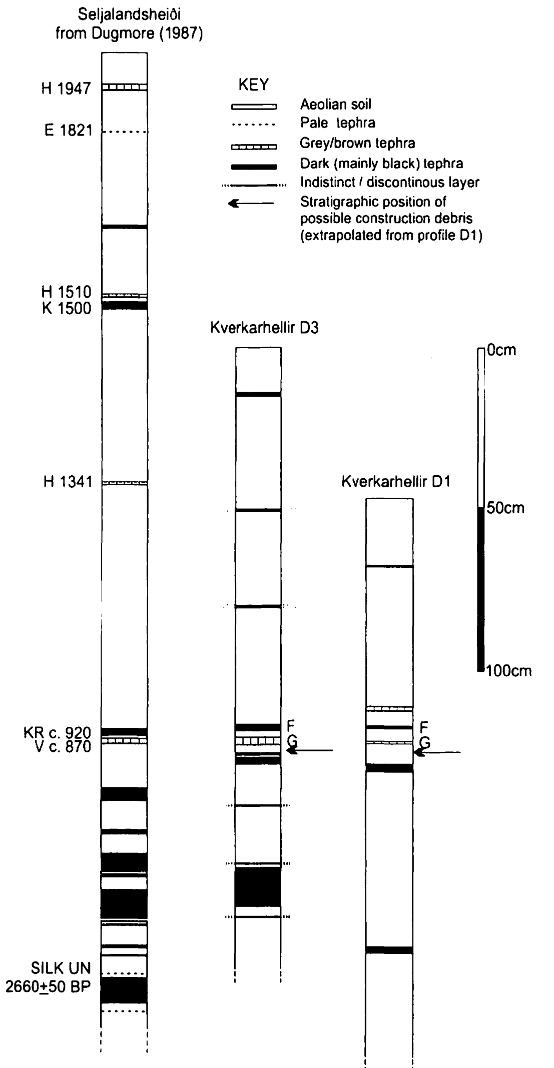

Figure 1. Preliminary stratigraphy from Kverkarhellir and a reference profile for Seljalandsheiði from Dugmore (1987). The tephra layers are labelled with a two-element system: volcanic system and date (H 1947 for Hekla AD 1947). Volcanic systems are abbreviated to K for Katla, H for Hekla, E for Eyjafjallajökull and V for Veiðivötn. The SILK prefix refers to a silicic tephra layer from Katla (Larsen *et al.* 2001). Tephra layers from historical time have calendar ages and prehistoric dates are stated in ^{14}C years BP (from Þórarinsson 1954, 1967, 1975, Dugmore 1987, Grönvold *et al.* 1995).

Field interpretation of the Kverkarhellir sequence suggested that both trenches share the same sedimentary and tephra stratigraphy with the exception of the putative construction material, found only in trench D1 at the cave mouth. Both profiles show a distinctive pair of tephra layers (F and G) provisionally identified from field observations and stratigraphy to be the KR920 / V870 couplet. Layer F is a fine black tephra and Layer G is a grey-brown unit with pale grains. Below this pair of tephra layers, there are a number of thick coarse black tephras likely to have been deposited prior to c. AD 870, based on comparisons with Dugmore's (1987) Seljaland profile. This interpretation of the Kverkarhellir stratigraphy depends upon removal of the upper part of the profile, that above K1500.

From 1872 to 1895, Kverkarhellir served alternatively as seasonal sheep house and local parliament site or Þingstaður for the hreppur, or district. During this period, shovelling and removal of the accumulated sheep dung for the local parliamentary meeting is recorded (Tómasson 1997:151). Furthermore, folk tradition describes the use of Kverkarhellir for human habitation in the 1500s (Árnason 1856:200-202). Additionally, the area of Kverkin, in which Kverkarhellir is found, was landscaped in the 1980s. This work included significant disturbance of the upper sediments for the laying of stone pathways and extensive tree planting (Hálfdan Ómar Hálfdanarson *pers. comm.*). As a consequence of this rich record of earth working at the site, removal or disturbance of the upper soil and tephra deposits above K1500 is easily envisaged.

The simplest stratigraphic interpretation correlates Kverkarhellir layers F and G with the KR920 and V870 couplet. This was tested by analysing the geochemistry of samples of these layers from both trenches (Tables 1 and 3). Initial geochemical analyses of layers F and G from trench D3 support the identification of the c. AD 920 Katla R and c. AD 870 Landnám tephras.

The tephra 'Layer F' in both trenches is attributed to an eruption within the caldera of the volcano Katla. This is based on comparisons of the Kverkarhellir geochemical data presented here (Table 1), with analyses of Katla R c. AD 920 from the nearby coastal plain of Landeyjar (Duncan *writt.*

comm.) and a typical basaltic Katla tephra discussed by Larsen (2000) (see Table 2). However, the basaltic tephras produced during intra-caldera eruptions of Katla are difficult to differentiate between using analysis of major element chemistry (Larsen 2000). Katla has erupted approximately every 47 years during the historic period. This means that the identification of a basaltic Katla tephra from geochemical analyses alone cannot allow us to allocate a date to Layer F. It is necessary to stratigraphically relate this layer to a chemically distinctive layer that can be more firmly identified using geochemical analysis.

Layer G from trench D3 (Table 3) has strong geochemical similarities to Landnám tephra analyses from Landeyjar (Duncan, *writt. comm.*) and those published in Larsen *et al* (1999) (see Table 4).

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
(D1)	47.73	4.76	12.59	14.27	0.24	4.79	9.61	3.16	0.77	97.91
	47.68	4.66	12.66	14.77	0.22	4.73	9.56	3.06	0.80	98.15
	47.54	4.77	12.66	14.78	0.23	4.86	9.60	3.09	0.82	98.35
	47.38	4.35	12.60	14.73	0.28	4.83	9.33	3.17	0.80	97.47
	47.30	4.80	12.63	14.63	0.29	4.86	9.61	3.22	0.80	98.14
	47.30	4.61	12.62	14.50	0.25	4.85	9.52	3.31	0.89	97.85
	47.29	4.85	12.63	14.46	0.25	4.82	9.44	3.21	0.87	97.83
	47.20	4.68	12.59	14.25	0.20	4.76	9.25	3.23	0.86	97.01
	47.16	4.57	12.53	14.42	0.26	4.84	9.43	3.25	0.75	97.21
	47.15	4.73	12.66	13.96	0.28	4.93	9.43	3.10	0.80	97.02
	47.09	4.70	12.57	14.59	0.22	4.96	9.22	3.18	0.74	97.28
	46.85	4.77	12.75	14.65	0.29	4.89	9.66	3.13	0.79	97.78
mean	*47.31*	*4.69*	*12.62*	*14.50*	*0.25*	*4.84*	*9.47*	*3.18*	*0.81*	*97.67*
(D3)	47.53	4.64	12.57	14.50	0.21	4.77	9.34	3.20	0.75	97.50
	47.31	4.72	12.50	14.40	0.23	4.81	9.38	3.15	0.81	97.29
	47.28	4.63	12.46	14.37	0.22	4.75	9.35	3.21	0.83	97.11
	47.24	4.59	12.46	14.55	0.27	4.82	9.26	3.25	0.78	97.22
	47.20	4.60	12.52	14.31	0.30	4.75	9.36	3.10	0.84	96.98
	47.19	4.51	12.40	14.54	0.27	4.78	9.45	3.20	0.82	97.16
	47.17	4.49	12.47	14.28	0.26	4.66	9.41	3.13	0.77	96.64
	47.09	4.65	12.62	14.61	0.23	4.83	9.31	3.29	0.81	97.44
	47.08	4.53	12.33	14.32	0.22	4.71	9.36	3.22	0.79	96.57
	46.96	4.58	12.47	14.49	0.27	4.65	9.13	3.16	0.81	96.52
mean	*47.21*	*4.59*	*12.48*	*14.44*	*0.25*	*4.75*	*9.34*	*3.19*	*0.80*	*97.04*

Table 1. Chemical analyses of Layer F in profiles D1 (selection from 14 analyses) and D3 (selection from 12 analyses) from Kverkin, Seljaland. Total iron is expressed as FeO.

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
(1)	47.70	4.58	12.41	14.82	0.21	4.68	9.36	3.10	0.89	97.75
	47.30	4.56	12.48	14.73	0.26	4.77	9.51	2.98	0.82	97.41
	47.23	4.70	12.59	14.49	0.22	4.75	9.41	3.16	0.78	97.33
	47.15	4.39	12.50	13.92	0.22	4.78	9.46	3.04	0.80	96.26
	47.12	4.72	12.39	13.43	0.24	4.84	9.35	3.21	0.74	96.04
	47.01	4.48	12.52	14.57	0.21	4.90	9.26	3.25	0.79	96.99
	46.81	4.52	12.61	14.31	0.19	4.78	9.63	3.21	0.84	96.90
	46.77	4.63	12.70	14.50	0.23	4.81	9.22	3.17	0.82	96.85
	46.75	4.55	12.15	14.32	0.17	4.98	9.51	3.12	0.79	96.34
	46.75	4.66	12.53	14.13	0.18	4.79	9.42	3.14	0.79	96.39
	46.74	4.62	12.66	14.43	0.21	4.77	9.47	3.16	0.89	96.95
mean	*47.03*	*4.58*	*12.50*	*14.33*	*0.21*	*4.80*	*9.42*	*3.14*	*0.81*	*96.84*
(2) *mean*	*46.28*	*4.56*	*12.62*	*14.75*	*0.23*	*4.89*	*9.97*	*2.72*	*0.71*	*97.44*

Table 2. Summary of published chemical analyses of basaltic tephra from Katla: (1) Katla R 920 analysis from Skíðbakkavatn, Landeyjar (selection from 13 analyses). Data from Duncan (*writt. comm.*); (2) Katla 1625 (mean of 7 analyses). Data from Larsen (2000:7). Total iron is expressed as FeO.

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
(a)	71.81	0.27	14.78	2.72	0.10	0.24	0.92	4.46	4.67	99.96
	71.60	0.35	13.16	3.58	0.17	0.16	1.08	4.31	3.95	98.36
	71.07	0.24	12.77	3.35	0.16	0.12	0.87	4.17	4.00	96.77
	70.85	0.24	12.47	3.06	0.12	0.12	0.88	4.00	4.06	95.80
	69.89	0.44	14.43	2.97	0.10	0.42	1.22	4.16	4.44	98.07
mean	*71.04*	*0.31*	*13.52*	*3.14*	*0.13*	*0.21*	*1.00*	*4.22*	*4.22*	*97.79*
(b)	49.64	1.75	13.32	12.35	0.24	6.55	11.40	2.50	0.20	97.95
	49.51	1.73	13.38	12.69	0.22	6.42	11.19	2.66	0.19	97.99
	49.45	1.81	13.23	12.63	0.24	6.52	11.38	2.56	0.19	98.03
	49.42	1.75	13.28	12.29	0.24	6.51	11.36	2.55	0.24	97.65
	49.29	1.85	13.15	12.74	0.23	6.39	11.16	2.51	0.27	97.60
	49.20	1.92	13.17	12.75	0.23	6.57	11.12	2.56	0.24	97.76
	49.17	1.87	13.08	12.52	0.25	6.29	11.11	2.56	0.25	97.10
	49.16	1.87	13.35	12.68	0.27	6.43	11.11	2.56	0.22	97.66
	49.05	1.90	13.25	12.68	0.22	6.34	11.17	2.56	0.21	97.37
	49.01	1.84	13.09	12.71	0.26	6.33	11.02	2.50	0.22	96.98
	48.80	1.90	13.23	12.50	0.28	6.43	11.17	2.50	0.22	97.03
mean	*49.25*	*1.84*	*13.23*	*12.60*	*0.24*	*6.43*	*11.20*	*2.55*	*0.22*	*97.56*
	47.49	4.30	12.09	14.46	0.25	4.57	9.34	3.14	0.83	96.46
	47.07	4.58	12.41	13.85	0.29	4.83	9.60	3.21	0.85	96.68
	46.86	4.37	12.45	14.57	0.24	4.84	9.43	3.18	0.83	96.76

Table 3. Chemical analyses of: (a) silicic part and (b) basaltic part of the D3G tephra layer from Kverkin, Seljaland (selection from 21 analyses). Three sporadic grains, which may be xeno-glasses (volcanic glass acquired from the walls of the eruption conduit) or contamination from surrounding tephra-rich soil, are shown at the base of the table. Total iron is expressed as FeO.

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
(1a)	71.93	0.24	14.53	2.52	0.10	0.21	0.90	4.27	4.90	99.60
	71.90	0.24	14.59	2.49	0.03	0.23	0.88	4.25	4.90	99.51
	71.58	0.26	14.62	2.31	0.01	0.21	0.80	4.23	5.06	99.08
	71.19	0.31	14.43	2.20	0.05	0.18	0.60	4.25	5.12	98.33
	71.16	0.31	14.68	2.56	0.05	0.27	0.90	4.19	4.95	99.07
	71.15	0.26	14.34	2.34	0.04	0.27	0.83	4.50	4.73	98.46
	71.12	0.32	14.44	2.44	0.03	0.23	0.79	4.76	4.66	98.79
	71.12	0.25	14.40	2.45	0.04	0.25	0.84	4.67	4.78	98.80
	71.11	0.35	14.37	2.46	0.08	0.28	0.84	4.90	4.74	99.13
	70.99	0.26	14.14	2.32	0.05	0.23	0.87	4.38	4.72	97.96
	70.74	0.32	14.35	2.43	0.04	0.28	0.92	4.45	4.73	98.26
	70.03	0.28	14.58	2.38	0.08	0.22	0.81	4.48	4.71	97.57
mean	*71.17*	*0.28*	*14.46*	*2.41*	*0.05*	*0.24*	*0.83*	*4.44*	*4.83*	*98.71*
(1b)	49.62	1.84	13.41	12.48	0.21	6.65	11.32	2.40	0.23	98.16
	49.23	1.79	13.24	12.35	0.19	6.46	11.19	2.41	0.21	97.07
	49.09	1.86	13.23	12.35	0.14	6.48	11.17	2.38	0.21	96.91
	49.01	1.96	13.10	12.48	0.18	6.47	11.29	2.48	0.27	97.24
	48.61	1.92	13.28	12.42	0.22	6.40	10.87	2.45	0.22	96.39
mean	*49.11*	*1.87*	*13.25*	*12.42*	*0.19*	*6.49*	*11.17*	*2.42*	*0.23*	*97.15*
(2a) *mean*	*70.97*	*0.25*	*14.46*	*2.32*	*0.09*	*0.24*	*0.89*	*4.78*	*4.64*	*98.63*
(2b) *mean*	*49.27*	*1.83*	*13.73*	*12.19*	*0.23*	*6.85*	*11.55*	*2.36*	*0.21*	*98.22*

Table 4. Summary of published analyses of the V870 Landnám tephra: (1a) silicic part of the Landnám tephra from Skíðbakkavatn, Landeyjar (selection from 14 analyses); (1b) basaltic part of the Landnám tephra from Skíðbakkavatn, Landeyjar (selection from 8 analyses). Data from Duncan (*writt. comm.*). (2a) lower silicic part of the Landnám tephra from Áfangagil (mean of 12 analyses); (2b) upper basaltic part of the Landnám tephra from Áfangagil (mean of 6 analyses). Data from Larsen *et al* (1999:468). Total iron is expressed as FeO.

The Landnám tephra has two components, one basaltic and the other silicic. Basalt, with SiO_2 content around 49% and low K_2O levels around 0.2%, is the main component of the Landnám tephra layer in Eyjafjöll and the sole component farther east (Guðrún Larsen *pers. comm.*). The silicic component is characterised by high levels of K_2O, typically greater than 4% where SiO_2 content is greater than 70% (Larsen *et al.* 1999). These traits make the Landnám tephra chemically distinctive. D3G, although difficult to analyse with few silicic grains in the sample, shows similar chemical characteristics to this pattern. The analyses in Table 3 show a distinct basalt component, similar to the published data, and a number of silicic grains with SiO_2 above 70% and K_20 around or above 4%. It should be noted that FeO content of the silicic component appears somewhat higher than in previously published data, particularly that of Larsen *et al* (1999). However, the similarities between this analysis of D3G and the data from Duncan (2001) and Larsen *e t al* (1999) suggest that this layer is likely to be the Landnám tephra (Guðrún Larsen *pers. comm.*).

The pairing of Layers F and G in trench D3 geochemically identified as a Katla tephra and the Landnám tephra confirms the stratigraphic interpretation that Kverkarhellir Layers D3F and D3G correlate with the KR920 and V870 couplet.

Turning to trench 1, analysis of Layer G proved inconclusive. The sample analysed lacked the characteristic basaltic component and FeO and Al_2O_3 contents differed from the published data on the Landnám tephra. However, the similarity of the stratigraphic sequence in the two trenches strongly suggests that Layer G is continuous between the two profiles and consistently paired with the Katla tephra, Layer F. Although the simplest interpretation of the stratigraphy suggests that the Kverkarhellir layers F and G correspond to the KR920 and V870 pair of tephras, the possibility remains that natural or human agents have reworked the primary airfall deposits, presenting a more complicated story than initially understood. Further work with re-sampling, wider-scale data collection and geochemical analyses is necessary for a conclusive identification.

Conclusion

Stratigraphic and geochemical evidence from trench D3 suggests that the putative construction spoil in trench D1, near the mouth of Kverkarhellir-cave, may have been deposited some time before AD 870. Thick, coarse black tephra layers below this pair of tephras and the lack of such layers above this couplet support the field identifications. Geochemical analyses present a good case for identification of the Landnám tephra (c. AD 870) paired with a Katla tephra in control trench D3. A limitation of the identification of the spoil deposit beneath the Landnám AD 870 tephra is that this interpretation depends upon initial fieldwork observations and interpretation of the tephra stratigraphy that need to be confirmed. This paper does not deal with the nature of the putative construction spoil. For discussion of this material, see Ahronson (*this volume*). Further data collection, sampling and conclusive geochemical evidence is required for a positive identification of these tephra layers and thus well-constrained dating of the sedimentary sequence at this location.

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