Abandoned Farms, Volcanic Impacts, and Woodland Management: Revisiting Þjórsárdalur, the "Pompeii Of Iceland"

Andrew J. Dugmore, Mike J. Church, Kerry-Anne Mairs, Thomas H. McGovern, Sophia Perdikaris, and Orri Vésteinsson

Abstract. Geomorphological maps and nine soil profiles containing 92 tephra layers have been examined to explore the nature of medieval environmental change in Þjórsárdalur, Iceland, where farms are thought to have been abandoned after the massive tephra fall from the eruption of Hekla in 1104 A.D. This paper presents evidence for continued human activity in the area in the two centuries following the 1104 A.D. eruption, indicating that continued utilization of the region changed after another major episode of volcanic fallout in 1300 A.D. The paper proposes that measures were taken in the fourteenth century to conserve woodland in Þjórsárdalur resulting in localized landscape stabilization that continued throughout the following Little Ice Age episodes of climate deterioration.

Introduction

The aim of this paper is to use tephrochronology to assess ideas of landscape change and settlement in Þjórsádalur, Iceland. This is important because it illustrates recent methodological developments in the application of tephrochronology to archaeological questions (Dugmore et al. 2000, 2006 Mairs et al. 2006, and contributes to the widening debate on human adaptation to landscape change in the North Atlantic (Dugmore et al. 2005; McGovern et al. in press). Also new evidence is brought to bear on a long-standing debate in Icelandic archaeology concerning the timing and causes of abandonment of Medieval settlement in the valley of Þjórsárdalur.

Þjórsárdalur in Icelandic Archaeology

The valley of Þjórsárdalur lies close to the foot of mount Hekla, an active volcano in southern Iceland (Fig. 1). In the valley 12–15 abandoned

Andrew J. Dugmore, Institute of Geography, School of GeoScience, University of Edinburgh, Edinburgh, EH8 9XP, UK
Mike J. Church, Department of Archaeology, Durham University, Durham, DH1 3LE, UK
Kerry-Anne Mairs, Institute of Geography, School of GeoScience, University of Edinburgh, Edinburgh, EH8 9XP, UK
Thomas H. McGovern, Hunter Bioarchaeology Laboratory, Department of Anthropology, Hunter College, City University of New York, 695 Park Ave, New York, New York 10021
Sophia Perdikaris, Department of Anthropology and Archaeology, Brooklyn College, City University of New York, 2900 Bedford Avenue, New York, NY 11210-2889
Orri Vésteinsson, Archaeology Programme University of Iceland, v/Suðurgötu, 101 Reykjavik, Iceland

ARCTIC ANTHROPOLOGY, Vol. 44, No. 1, pp. 1–11, 2007 ISSN 0066-6939

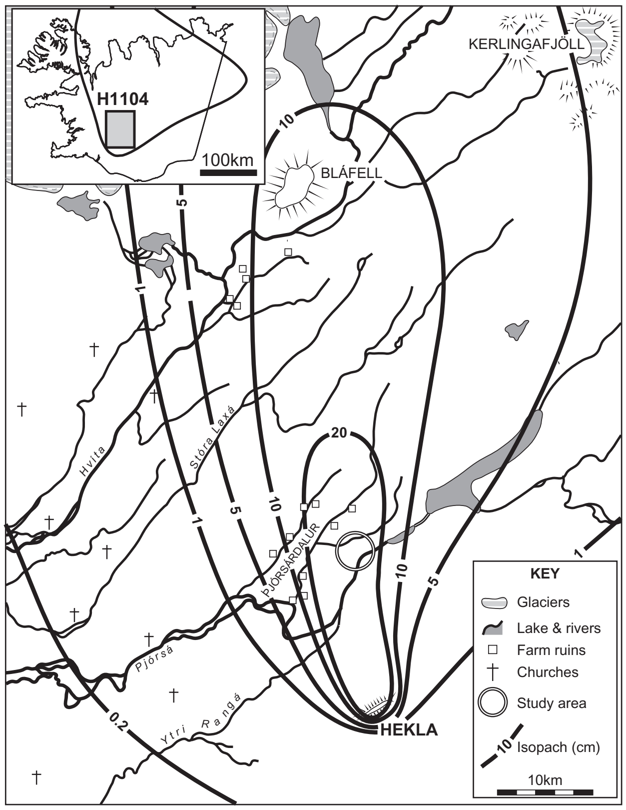

Figure 1. The location study area showing the fallout from Hekla 1104 (Þórarinsson 1967) and the location of abandoned farms.

medieval farm sites are known. One farm was abandoned in 1693 as a result of an eruption of Hekla (Þórarinsson 1951) and two farms, where the valley opens out into the lowlands, remained occupied into the twentieth century. In Icelandic archaeology Þjórsárdalur has long been considered as the prime example of the degeneration of once flowering settlements due to adverse environmental conditions and/or natural catastrophes. The valley was first surveyed in the 1860s by Brynjúlfur Jónsson (Jonsson 1885) who published a detailed site directory in 1885. As a direct result of Jónsson's publication, extensive examination of farm ruins and some excavation were carried out in the valley in the 1890s by Þorsteinn Erlingsson (1899) and Daniel Bruun (1897). It was the latter who invoked the idea of a catastrophic end to the settlement by calling Þjórsárdalur the "Pompeii of Iceland" (Bruun 1897:24), and it was he who brought Þjórsárdalur's archaeology to the attention of international scholarship. Local traditions had long held that Þjórsárdalur had been devastated in the early fourteenth century by a volcanic eruption in the valley itself. In his early work Brynjúlfur Jónsson demonstrated that there is no volcano within the valley, but it was geologist Þorvaldur Thoroddsen who suggested that the valley had been ruined by an eruption in neighboring Hekla, probably in 1341 (Thoroddsen 1889:70–76).

In 1939 an expedition of Nordic archaeologists came to Iceland and, concentrating their efforts on Þjórsárdalur, excavated six farmsites in the course of one summer (Stenberger 1943). Working with the group was geologist Sigurður Þórarinsson who was in the process of developing tephrochronology as a dating method (Þórarinsson 1944). Underneath most of the ruins he identified the Landnám tephra (vii a+b)—now dated to 871±2 B.P. through correlation of tephra shards in the GRIP Greenland ice core (Grönvold et al. 2005). A thick layer of pumice infilling most of the ruins, however, he initially identified as being the product of the eruption of Hekla in 1300 (Þórarinsson 1943, 1949). This accorded well with the traditional dating of Þjórsárdalur's abandonment and was also considered by the archaeologists to be in agreement with the structural and artifactual evidence unearthed by the project. These results came under heavy criticism in Iceland (e.g., Jón Steffensen 1943, 1950) and Þórarinsson subsequently changed his mind about the layer of pumice and suggested that it was in fact from the Hekla eruption of 1104, thus pushing the demise of the settlement back two centuries (Þórarinsson 1954). This identification has gained general acceptance and the results of later archaeological work in Þjórsárdalur (Eldjárn 1951, 1961; Rafnsson 1977) did not unearth evidence that contradicts it. On the basis of his excavation of Sámsstaðir Rafnsson even felt confident enough to speculate on the time of the year in which the 1104 A.D. eruption had taken place.

By the late 1970s Icelandic archaeologists were becoming critical of earlier simplistic models of settlement disruption. New historical and archaeological research into farm abandonment (e.g., Sveinbjarnardóttir 1992) was unable to find much correlation between farm abandonment and the favorite scapegoats of earlier scholarship—epidemics and volcanic eruptions, suggesting that abandonment was a more complex process than previously believed. It was also becoming increasingly clear from the study of historically recorded volcanic eruptions that their impact was rarely fatal to settlements, and if so only on a small scale and for a short period.

In 1982 Vilhjálmur Örn Vilhjálmsson started a re-excavation of Stöng, the most celebrated site from the 1939 expedition, with the aim to test Þórarinsson's dating of the site's abandonment. Vilhjálmsson felt that the artifactual evidence from Stöng—including a sherd of Grimston ware from the thirteenth century —did not accord well with the 1104 A.D. date. In his trenches Vilhjálmsson identified evidence of the Hekla 1104 eruption underneath archaeological deposits which were stratigraphically below the layers of pumice (identified by Þórarinsson as the 1104 A.D. tephra) removed in the 1939 excavation. Vilhjálmsson's explanation for this is that the pumice infilling the ruins and thus post-dating them was the 1104 A.D. tephra, but redeposited due to wind erosion long after the actual eruption. Vilhjálmsson's hypothesis (1989) is thus that Stöng—and by implication the other sites in the valley—was not ruined by the 1104 A.D. eruption but survived into the early or mid thirteenth century. Their abandonment at that date was however due to environmental degradation, to which the 1104 A.D. eruption, as well as subsequent Hekla eruptions in 1158 A.D., 1159 A.D., and 1206 A.D., had contributed in no small way. Vilhjálmsson's hypothesis has not gained general acceptance, no doubt primarily because he failed to have his tephra identifications ratified by geologists, and Icelandic scholars continue to attribute the abandonment of the valley to a catastrophic eruption of Hekla in 1104 A.D. (e.g., Karlsson 2000:45,192). A recent survey of artifacts from Þjórsárdalur—some 1,900 from 36 sites are known—concluded that the assemblage as a whole was Viking age with only a handful of finds attributable to the later middle ages (Gísladóttir 2004).

Research Questions

The dating of landscape change and settlement of Þjórsárdalur remains an important issue in Icelandic archaeology. Firstly, the valley contains a critical mass of archaeological sites, more than a third of all excavated Viking age sites in Iceland (Vésteinsson 2004), making the dating of these remains a critical issue for typological dating of structures and artifacts. Secondly, Þjórsárdalur has a central place in the debate about the nature of human-environmental interaction in Iceland. It is of crucial importance to understand the processes that led to settlement and landscape change in Þjórsárdalur, and fresh insights into this issue will have implications far outside the limits of the valley.

A key concept here is the notion of a "farm"; by this do we mean a set of buildings (a site of permanent occupation) or a discrete area of land? The distinction is important since although a building may be abandoned, the surrounding land may continue to be utilized in either a similar or different way than before. In Þjórsárdalur, several quite different situations may have developed. Across the valley as a whole, settlement sites may have been abandoned in the aftermath of the 1104 A.D. eruption and land use may also have changed, with a substantial reduction of grazing, the abandonment of home fields and other fodder producing areas, and a change in woodland utilization. Alternatively, although permanent occupation of farm houses may have ended, there could have been some continued episodic and casual occupation of the buildings until they fell into complete disrepair and collapsed. Land use may have continued essentially unaltered. Another possibility is that in addition to temporary use, some form of permanent occupation could have also continued. The important point is that between the extremes of continuity and abandonment, there are a number of different possibilities and key information exists in the landscape as well as on occupation sites that can be a used to address these questions.

The central issue we wish to explore concerns the nature of landscape change in the aftermath of the 1104 A.D. eruption of Hekla and we hope to establish the rate and extent of land surface stabilization after the tephra fall. In the absence of continued grazing pressure we could expect surface stabilization in areas with pre-existing soil and vegetation on timescales of years to decades, especially where the pre-existing vegetation included trees and shrubs. In contrast, long periods of surface instability are likely to indicate continued disturbance by animals.

Approaches And Methods

Tephrochronology has provided valuable–if at times debated–dating control for excavated sites in Þjórsádalur, but it has not been extended into the surrounding landscape to determine patterns of past environmental changes, even though this is one of the great strengths of tephrochronology originally highlighted by Þórarinsson (1961). Elsewhere in Iceland this development has provided key insights (e.g., Dugmore and Buckland 1991; Dugmore and Erskine 1994; Dugmore et al. 2000, 2006; Mairs et al. 2006, so the approach in this paper is to focus on landscape and use tephrochronology to assess changes in related parts of a landscape system. The immediate environs of Stöng have suffered extensive erosion leaving little environmental data in the form of soil profiles. Our study area lies about 3 km to the east of Stöng where a large bedrock gully system (about 1.5 km long) lies close to an ancient routeway through Þjórsádalur, on the edge of deflated areas of black sand and surrounded by surviving patches of soils, grasslands, and patches of scrub woodland. Geomorphological mapping provides the spatial context (Fig. 2).

Data from seven soil profiles were used that contained a total of 57 identified tephra deposits and were recorded at altitudes between 220–250 m asl around the gully system (Figs. 2 and 3). In addition an eighth reference profile at 235 m on the edge of nearby woodland was recorded that contains a further eleven identified tephras. Also a

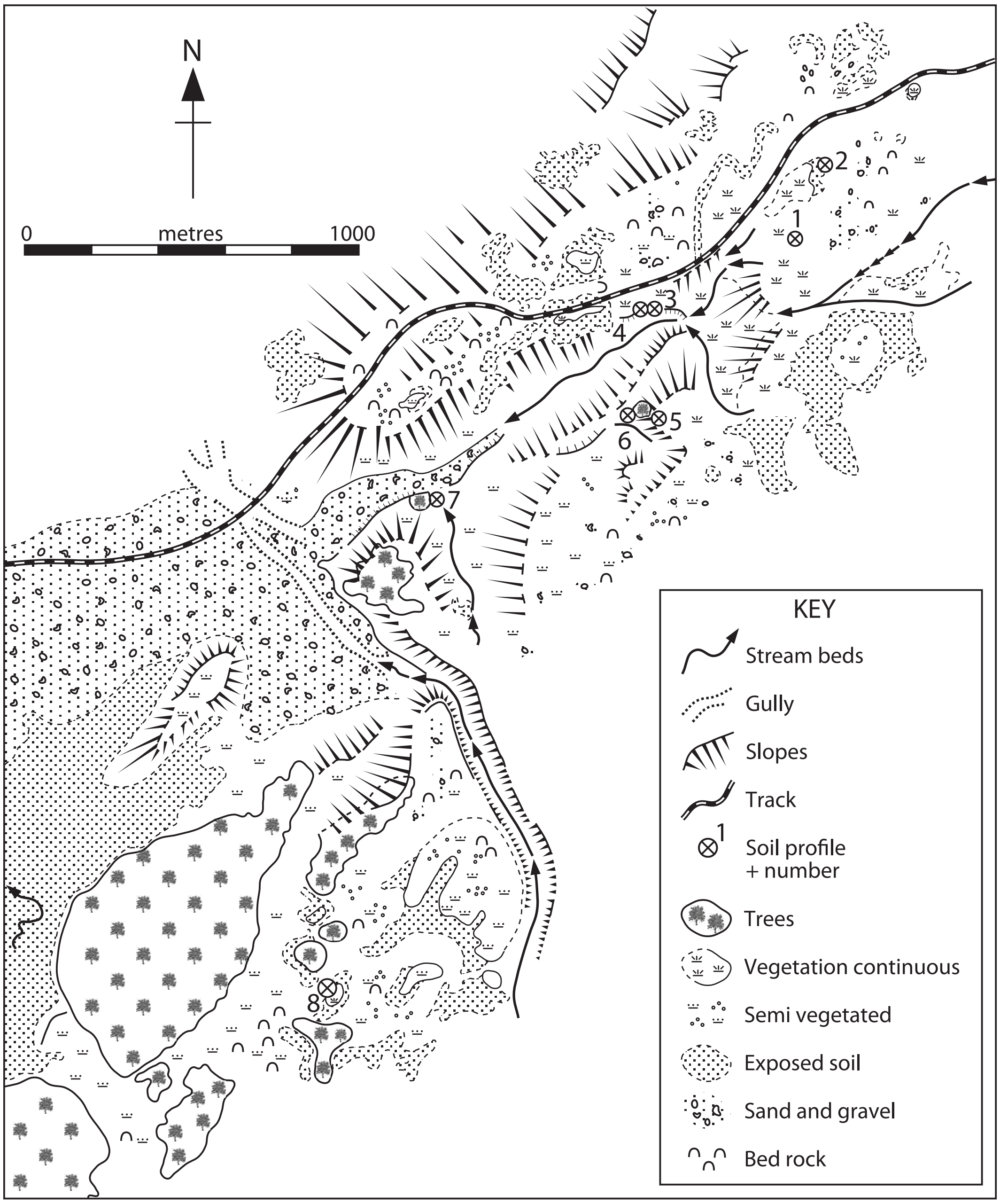

Figure 2. The topography and geomorphology of the study area showing the location of the soil profiles in Figure 3.

short sequence of ten tephras and related stratigraphy was recorded near to Stöng. Exposed sections of stratigraphy approximately 50 cm in width were created and layers were logged to a resolution of 5 mm with samples of key tephra layers collected for chemical analysis.

The tephrochronological framework is based on the work of Þórarinsson (1967) with some key revisions based on later studies by Grönvold et al. (1995), Halfliðason et al. (1992), Larsen (1984, 1996), Larsen and Þórarinsson (1977), Larsen, Dugmore, and Newton (1999) Zielinski et al. (1995).

Soil sections were chosen to assess change in specific parts of the landscape; individual tephra isochrones were traced across the area to consider land surfaces at particular times, with the 3-D geometry of layers used to infer the shape of past land surfaces. Multiple isochrones were considered in order to assess change during specific time intervals and determine rates of aeolian sediment accumulation (a proxy for aeolian erosion). Reworked tephras were assessed as tracers to constrain the nature and duration of past environmental processes. Erosional and depositional breaks,

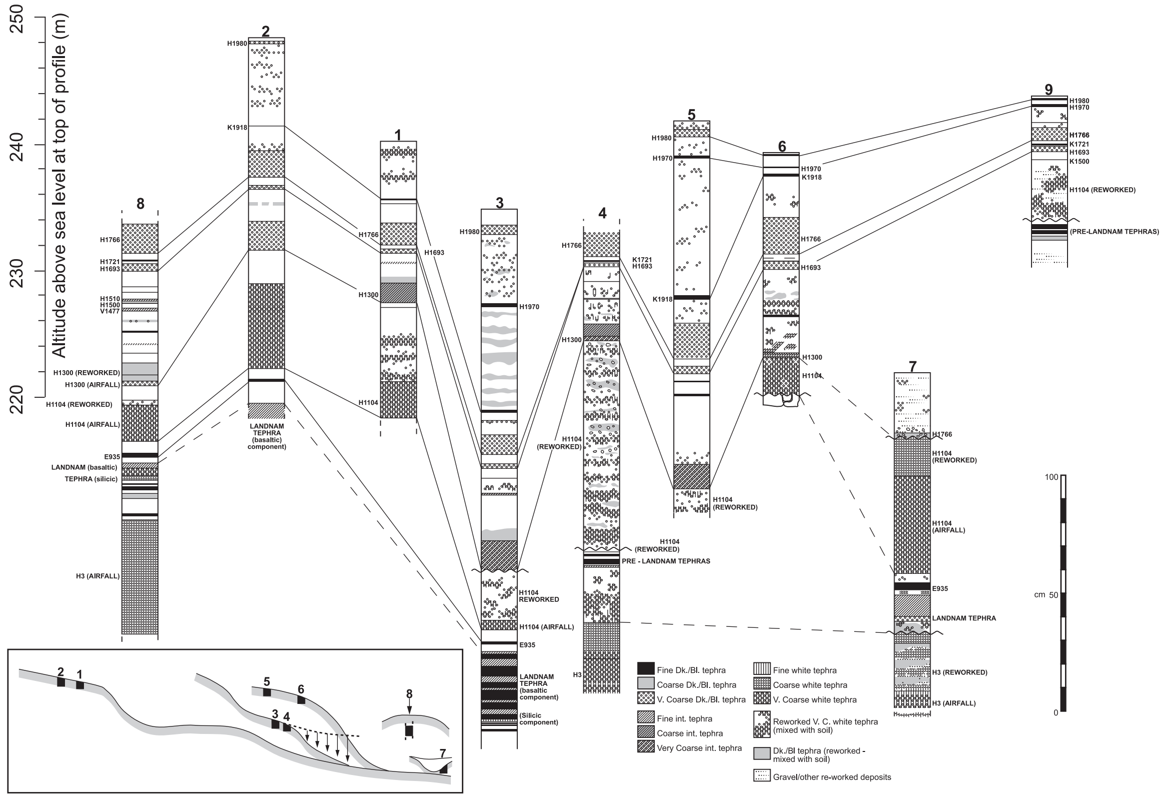

Figure 3. Tephrochronology of the gully system. Results of selected geochemical analysis are shown in Table 1.

highlighted by tephra stratigraphy, were also noted as another key indicator of change.

Results

The reference section, Profile 8, was located close to surviving woodland and outside the immediate gully system under consideration, but lying at a mid-range altitude in reference to the other profiles. Rates of aeolian sediment accumulation in pre-settlement times average hundredths of a millimeter per year with 105mm of accumulation between the Hekla3 tephra, dated to 2879±34 B.P. (Dugmore et al. 1995), and the Landnám tephra dated to 871±2 (Grönvold et al. 1995). After settlement this rate increases by an order of magnitude to average 0.38mm/yr in the period 870–935 A.D. Accumulation rates are similar, if somewhat lower, in the later tenth century and decline marginally after the 1104 A.D. eruption. Reworked tephra on top of the primary airfall deposits indicate periods of instability following both the 1104 A.D. and 1300 A.D. tephra falls. There are no major erosional or depositional unconformities in the recorded sequence.

Profiles 1 and 2 were sited to the east of the gully head. Profile 2 at 250 m asl preserves a similar environmental record to reference Profile 8 but with a rapid stabilization of both Hekla 1104 and Hekla1300 tephras. Accumulation rates peak in the settlement period 870–935 A.D., declining in the tenth century, to return to the higher early settlement period rate after 1104 A.D. Profile 1 was sited down slope. Here the 3° local slope was sufficient to delay the stabilization of both the 1104 A.D. and 1300 A.D. tephras. Overall tephra layer thicknesses for Hekla1104 and Hekla1300 are similar to Profile 2 but the upper parts are mixed with silt.

Profiles 5 and 6 were sited on the southern shoulder of the main gully on either side of a small patch of birch trees (*Betula pubescens*). Profile 5 was only excavated into the late thirteenth century strata below Hekla 1300, but it was apparent that Hekla 1104 tephra was being locally reworked until 1300 A.D. Profile 6 contained a truncated soil profile: after 1104 A.D. the site was stripped to bedrock. Pockets of soil within the rock surface contain reworked tephra from 1104 A.D. mixed with silt. This mix of pumice from Hekla 1104 and silt stabilized to permit deposition of lenses of Hekla 1300 and aggradation from the fourteenth century to now.

Gully-edge Profiles 3 and 4 were sited on the lip of a vegetated step on the northern side of the gully. Current erosion has created two large natural exposures with vertical faces over 2m high.

Table 1. Selected geochemical data on individual tephra grains from key tephra layers in the study area. Much data have already been published on key tephras such as H3, Landnám Tephra, and H1104 (e.g., Kirkbride and Dugmore 2001; Larsen et al. 1999). New data are shown here because of a previous lack of published geochemical data, for example in the case of Hekla 1693, or because they provide data on the geochemical range at a site close to source, for example Hekla 1300, or because they are data on a tephra at the margins of currently established distributions, for example Eldgjá 935.*

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
Profile 3 E935 glx	49.47	2.33	13.13	13.59	0.29	6.13	10.54	2.79	0.35	0.24	98.85
Profile 3 E935 glx	49.12	2.57	12.96	14.08	0.25	5.57	9.69	2.79	0.42	0.27	97.71
Profile 3 E935 glx	48.78	2.61	12.37	14.37	0.22	5.91	10.30	2.65	0.44	0.25	97.90
Mean (%)	**49.12**	**2.50**	**12.82**	**14.01**	**0.25**	**5.87**	**10.18**	**2.74**	**0.40**	**0.25**	**98.15**
Standard deviation	**0.35**	**0.15**	**0.40**	**0.39**	**0.04**	**0.28**	**0.44**	**0.08**	**0.05**	**0.02**	**0.61**
Profile 3 E935 glb	47.22	4.70	12.46	14.69	0.32	4.82	9.31	3.31	0.87	0.69	98.38
Profile 3 E935 glb	47.22	4.74	12.53	14.92	0.25	4.91	9.39	3.23	0.83	0.64	98.65
Profile 3 E935 glb	47.16	4.71	12.38	14.65	0.22	4.92	9.47	3.25	0.68	0.58	98.00
Profile 3 E935 glb	47.06	4.72	12.60	14.69	0.26	4.96	9.44	3.15	0.86	0.62	98.35
Profile 3 E935 glb	46.97	4.65	12.53	15.02	0.21	5.08	9.55	3.15	0.85	0.58	98.58
Profile 3 E935 glb	46.79	4.67	12.48	14.90	0.21	4.89	9.43	3.39	0.84	0.65	98.24
Mean (%)	**47.07**	**4.70**	**12.50**	**14.81**	**0.25**	**4.93**	**9.43**	**3.25**	**0.82**	**0.63**	**98.37**
Standard deviation	**0.17**	**0.03**	**0.08**	**0.15**	**0.04**	**0.09**	**0.08**	**0.09**	**0.07**	**0.04**	**0.24**
Profile 3 E935 gla	46.39	4.49	12.51	15.55	0.22	5.53	10.39	2.79	0.76	0.48	99.12
Profile 3 E935 gla	45.74	4.77	12.17	15.78	0.25	5.29	10.17	2.82	0.65	0.47	98.10
Profile 3 E935 gla	45.30	4.53	11.45	15.47	0.23	6.19	10.90	2.68	0.66	0.44	97.85
Mean (%)	**45.81**	**4.60**	**12.04**	**15.60**	**0.23**	**5.67**	**10.49**	**2.76**	**0.69**	**0.46**	**98.36**
Standard deviation	**0.55**	**0.15**	**0.54**	**0.16**	**0.02**	**0.47**	**0.37**	**0.07**	**0.06**	**0.02**	**0.67**
Profile 3 H1300	61.62	0.89	14.78	8.81	0.30	1.08	4.54	4.72	1.88	0.37	98.98
Profile 3 H1300	59.88	1.11	14.89	9.10	0.23	1.50	4.83	4.43	1.71	0.41	98.08
Profile 3 H1300	59.74	1.05	14.74	8.75	0.23	1.51	4.85	4.45	1.78	0.41	97.50
Profile 3 H1300	59.49	1.19	15.27	9.42	0.30	1.62	4.83	4.46	1.73	0.46	98.77
Profile 3 H1300	59.07	1.05	14.64	8.87	0.26	1.44	4.90	4.57	1.63	0.42	96.87
Profile 3 H1300	59.00	1.10	14.85	9.42	0.24	1.56	5.00	4.31	1.65	0.38	97.50
Mean (%)	**59.80**	**1.07**	**14.86**	**9.06**	**0.26**	**1.45**	**4.83**	**4.49**	**1.73**	**0.41**	**97.95**
Standard deviation	**0.96**	**0.10**	**0.22**	**0.30**	**0.03**	**0.19**	**0.15**	**0.14**	**0.09**	**0.03**	**0.82**
Profile 3 H1693	58.74	1.29	15.17	9.43	0.27	1.89	5.33	4.48	1.51	0.55	98.67
Profile 3 H1693	58.42	1.34	15.23	9.71	0.27	1.95	5.42	4.45	1.58	0.57	98.95
Profile 3 H1693	58.27	1.33	14.99	9.79	0.26	1.97	5.31	4.48	1.58	0.55	98.53
Profile 3 H1693	58.24	1.36	15.04	10.01	0.30	1.98	5.35	4.39	1.58	0.56	98.81
Profile 3 H1693	58.18	1.32	14.96	9.64	0.21	1.88	5.27	4.37	1.45	0.51	97.77
Profile 3 H1693	58.07	1.37	15.01	10.00	0.32	1.92	5.32	4.39	1.50	0.56	98.45
Profile 3 H1693	57.98	1.32	15.08	9.56	0.32	1.93	5.33	4.35	1.54	0.57	97.97
Profile 3 H1693	57.87	1.35	15.08	9.78	0.30	1.96	5.43	4.51	1.55	0.57	98.39
Profile 3 H1693	57.81	1.38	15.14	9.82	0.29	1.97	5.41	4.26	1.59	0.55	98.21
Profile 3 H1693	57.64	1.30	14.93	9.71	0.25	1.95	5.28	4.33	1.53	0.56	97.50
Mean (%)	**58.12**	**1.34**	**15.06**	**9.75**	**0.28**	**1.94**	**5.35**	**4.40**	**1.54**	**0.56**	**98.33**
Standard deviation	**0.32**	**0.03**	**0.10**	**0.18**	**0.03**	**0.03**	**0.06**	**0.08**	**0.04**	**0.02**	**0.46**

*Pre-treatments for microprobe analysis followed Dugmore *et al.* (1995). Tephra samples were mounted in resin and then ground, polished and carbon coated. Analyses were undertaken on a five spectrometer Cameca SX100 electron microprobe, using an accelerating voltage of 20 kV. A beam with a 4 nA current and a 10μm raster was used to reduce sodium migration found in the more silicic tephra layers. Peak count times were 10 seconds per suit of elements (total count time of 45 seconds). The instrument was calibrated using a mixture of pure metals and simple silica compounds and counter deadtime, fluorescence and atomic number effects were corrected using Cameca's PAP correction programme. Total iron is expressed as FeO. Further online information can be found at Tephrabase (http://www.tephrabase.org). The different components within the Eldgjá 935 tephra are differentiated following Larsen (2000).

Up slope of Profile 3 the Landnám tephra did not stabilize immediately after deposition: it was reworked downslope to create a layered unit at the site of Profile 3. The lack of admixed silt indicates that this process did not involve a breach of the contemporaneous vegetation cover, but this vegetation could not immediately stabilize the deposition of a 6cm tephra-fall. Aeolian sediment accumulation did resume quite soon afterwards as there is a 10 mm bed of silt separating the top of the reworked Landnám tephra deposit from the overlying Eldgjá 935 tephra, deposited some 65 years after the eruption of the Landnám tephra. After the deposition of Hekla 1104 the slope did not stabilize, and reworked layers are characterized by the mixtures of both the Hekla 1104 pumice and silt. The depth of the Hekla 1104 primary airfall deposit in the gully-edge Profile 3 is less than at the sites outside the gully (Profiles 8, 1, and 2) and depth overlying reworked layers are similar, indicating episodes of erosion at the gully-edge as well as deposition. Stabilization did, however occur with the deposition of the Hekla 1300 tephra. In contrast to Hekla 1104 the deposits of Hekla 1300 at gully-edge Profile 3 and outside-gully Profile 2 are very similar, suggesting both a rapid stabilization of the tephra at both sites and minimal post-depositional disturbance. Following the deposition of Hekla 1300 sedimentation on the gully-edge Profile 3 is represented by the accumulation of silt. This indicates a rapid contemporaneous change that results in the stabilization of the previously mobile Hekla 1104 tephra. Acceleration of sediment accumulation and a change to coarser sediments subsequently occurred in the twentieth century after 1918, an indication of renewed local slope instability. Profile 4, sited within a tributary gully a few meters from Profile 3, tells a similar story, though here there is an erosional unconformity that took out deposits from 1104 to immediately pre-Landnám. The thickness of reworked Hekla 1104 pumice is greater than at profile 3 but again a stabilization of the Hekla 1104 tephra begins after the deposition of Hekla 1300.

Bedding within the Hekl 1104 pumice in the gully-edge Profile 3 indicates that the gully below this point has deepened since the turn of the twelfth century A.D. because the slope of the bedding runs parallel to the orientation of the gully rather than intersecting it. One possibility is that an abrupt deepening of the gully could explain the switch in sedimentation after 1300 A.D., but this is unlikely as Profile 3 is recording change upslope, and this would not be affected by a deepening of the gully. Furthermore the change in sedimentation is also recorded on the opposite side of the gully in Profile 6.

Profile 7 was excavated where a small tributary gully meets the main gully just before it opens out onto the sandy plain to the west. This profile records a massive thickening of the Hekla 1104 deposit with a primary deposit 60 cm deep in contrast to thicknesses of 35 cm recorded at Profile 2 and 15 cm at Profile 8. This probably represents localized movements of the tephra deposit during or soon after initial deposition as there is a minimal admixture of silt. Even small amounts of silt are visible against the white pumice, and these deposits lack any staining. The tributary gully is cut into the overlying beds of re-worked Hekla 1104 pumice and lenses of either Hekla 1693 or Hekla 1766 tephra within the scalloped top surface show that stabilization only occurred in the very late seventeenth or eighteenth century.

One profile (9) was recorded on the hill slopes west of Stöng, in the outfields, outside the immediate area of settlement and homefields. An erosional surface cuts into prehistoric tephra layers; accumulation above this hiatus commences with reworked deposits of Hekla 1104, but this accumulation is mixed as the Hekla 1300 tephra does not form a discrete layer and stability only resumed in the late fifteenth century with the deposition of Katla 1500 as a discrete un-mixed layer.

Discussion

These new data provide a mixed picture of landscape change from Landnám through the occupation of the Þjórsárdalur farms to the present day. Aeolian sediment accumulation rates increase by an order of magnitude at Landnám. This could be in response to changes in both the depositional and erosional environment. Changes in surface vegetation cover produced by settlement (e.g., Hallsdóttir 1987) could locally change sediment deposition by reducing the ability of some areas (such as steep or convex slopes) to trap fallout. In addition, new sources of aeolian sediment could have been created by woodland clearance and localized breaches of vegetation cover (e.g., Dugmore and Erskine 1994). Local sediment sources can significantly increase nearby accumulation rates (Arnalds 1999).

One factor contributing to abrupt changes in sediment accumulation rates after settlement could be the thickness of the Landnám tephra layer and its proximity to the surface. It was deposited and stabilized only a few years before the settlement of the valley and the first introduction of grazing mammals. Consequently the tephra would have formed a 6–35 cm deep layer of unconsolidated silt-sand sized sediment with little cohesion and very susceptible to erosion just under the land surface. This layer could have been easily exposed and mobilized as a result of woodland clearance and the introduction of sheep, goats, cattle, horses, and especially pigs. Once triggered, erosion scars probably become an enduring feature of this landscape.

After the deposition of tephra in 1104 A.D. some areas (such as the environs of Profiles 2 and 8) saw a rapid stabilization of the airfall indicating a deep vegetation cover that continued to grow through at least 35cm of pumice. Other areas were affected by erosion cutting into underlying sediments and/or they experienced prolonged phases of instability, with discrete episodes of surface transport and mixing of layers of pumice and silt. These processes continued until 1300 A.D. The fact that the subsequent tephra fall of Hekla in 1300 A.D. resulted in stabilization of land surfaces indicates processes other than geomorphic change were at work. This is especially notable given the general increase of landscape degradation in Iceland associated with the period of changing climate known as the Little Ice Age (Simpson et al. 2002). Stabilization of shifting surface deposits of tephra simply through the addition of more tephra seems at first sight to be rather improbable—a geomorphological equivalent of putting out fires with petrol. One indirect way in which additional tephra deposition could explain the geomorphic change is through its effect on human activity. It could be that human impact continued after 1104 A.D., effectively delaying ecological recovery from the tephra fall, but in the immediate aftermath of the 1300 A.D. eruption this ceased. Most probably occurs because of a major reduction or removal of grazing pressure. It is notable that even in areas where erosion had taken place in the twelfth and thirteenth centuries (e.g., Profiles 4 and 6), once stabilization had been achieved in the aftermath of the 1300 A.D. eruption, uninterrupted sediment accumulation has been taking place to the modern day. As this period includes the most ecological unfavorable decades of the Little Ice Age, it would suggest that climate change did not play a primary role in earlier episodes of localized landscape instability.

Although Þjórsárdalur is currently an iconic example of volcanic impact, environmental destruction, and farm abandonment, it is notable that it is an area where significant woodland survives, despite being an ecologically marginal location for birch trees (*B. pubescens*) (Fig. 2). Recent work on fuel utilization and woodland management in Iceland has highlighted the importance of Þjórsárdalur in early modern times as a woodland reserve and the source of almost all the charcoal for several hundred households on Iceland's southern plain. At the end of the sixteenth century there were still extensive birch forests in Þjórsárdalur, mostly owned by the Bishop of Skálholt who was also the principal landowner in the region. The bishop's tenants in large tracts of the mostly treeless county of Árnessýsla had the right to make charcoal for household needs (critical for the carburizing of scythes) in the Þjórsárdalur woods. At this time the valley floor was probably already denuded but the hillsides were still largely covered in wood, suggesting that the valley was not as completely devastated in the Middle Ages as has traditionally been imagined and we propose that an abandonment of the valley in the thirteenth century would accord well with the rise of the Bishop of Skálholt as the major landowner in the region. If the valley farms were in a decline due to volcanic impacts and environmental degradation it may have made them all the more vulnerable to the encroachments of major landowners, in whose interests it might have been to clear the farms to protect the woodlands for the lowland tenants (cf. Vésteinsson and Simpson 2004).

A similar situation of farm abandonment related to woodland conservation seems to have occurred in Þórsmörk in south Iceland (Dugmore et al. 2006. There, Landnám farms were abandoned by the late thirteenth century; while the farms were occupied extensive soil erosion took place in their outfields, but woodland survived. By the thirteenth century these trees probably formed the bulk of the surviving woodland in the region, as lowland forest clearance to create pasture and mid-valley timber exploitation to produce charcoal, had cleared woodland from areas down-valley of Þórsmörk itself. It is probable that the final clearance of farms from Þórsmörk occurred in order to protect the surviving woodland as a charcoal resource for the lowland farms. In both Þórsmörk and Þjórsárdalur a similar general pattern can be seen, with land use change and the conservation of surviving woodland occurring at a time when trees had becoming a limited (if not completely depleted) resource in nearby lowlands. Any settlements in the areas of surviving woodland had to cope with extreme environmental pressures of rangeland destruction by volcanic fallout and/or soil erosion. Perhaps occupation of these areas could have continued, but the needs of the lowland farms seem to have made fundamental land use change inevitable.

Although the dramatic reduction in the extent of woodland in Iceland from some 27% of total land area to about 1% can be interpreted as an ecological disaster, perhaps it is more appropriate to consider it as a "landscape fit for purpose." Sufficient woodland did survive scattered around the country to provide essential supplies of charcoal. It is probable that woodland is much less vulnerable to tephra fall than grassland. Indeed, in some circumstances tephra may actually enhance tree and shrub development if it acts as a ground level mulch, reducing root competition from grass and herb vegetation, and potentially creating opportunities for seedlings to develop in areas formally covered by a dense, well-knit turf.

Conclusion

The application of tephrochronology in landscape studies enhances debates about medieval Icelandic farm abandonment by introducing ideas of how settlement and landscape processes are connected. The onset of landscape destabilization at Þjórsárdalur effectively begins at Landnám, not simply resulting from the arrival of people and grazing animals, but as a consequence of the combination of grazing pressure and the deposition of the Landnám tephra a few years earlier and the creation of a 6–35 cm deep layer of unconsolidated tephra just below the surface vegetation. Grazing pressure and human impact caused an increase in the sediment accumulation rates from an average of hundredths of a millimeter per year prior to Landnám to an average of 0.38 mm/yr in the period directly after settlement.

The deposition of tephra from the Hekla eruption in 1104 A.D. caused variable effects in the landscape. The geomorphic instability illustrated at some locations, which persisted until 1300 A.D., was most probably a result of continued grazing pressure. Although this is not direct evidence for continued occupation of farm sites within Þjórsárdalur it does suggest a continuity of land use and grazing that effectively limited stabilization of the landscape. After the deposition of Hekla 1300 tephra, slopes were quick to stabilize. This indicates that after the 1300 A.D. eruption, a change in the nature of human impact, perhaps related to a major reduction or removal of grazing pressure, allowed the stabilization of the surface tephra deposits. This was probably related to woodland conservation, because despite its ecologically marginal location and climatic deterioration, the woodland survived through to modern times. Also, woodland cover makes the landscape less vulnerable to destabilization following a tephra fall.

Following the stabilization of the Hekla 1300 tephra, continuous silt accumulation occurred into the twentieth century. An influx of coarser sediment after 1918 A.D. suggests a period of renewed local slope instability. There is no indication of instability caused by climate change in the Little Ice Age, suggesting that climate change did not play a primary role in earlier episodes of landscape instability.

Acknowledgments. We gratefully acknowledge the support of Leverhulme Trust and National Science Foundation of America. Field assistance by the class of 2003 on the Research Experience for Undergraduates program is also gratefully acknowledged. Chemical analyses were undertaken at the Electron Probe Unit, University of Edinburgh with the support of Dr Peter Hill and Dr Anthony Newton.

References Cited

Arnalds, Ólafur
1999 The Icelandic 'Rofabard' Soil Erosion Features. Earth Surface Processes and Landforms 24: 1–12.

Bruun, Daniel
1897 Fortidsminder og Nutidshjem paa Island. Orienterende Undersøgelser Foretagne i 1896 [Ancient Remains and Modern Homes in Iceland. Informative Investigations Undertaken in 1896]. København: Nordiske Forlag.

Dugmore, Andrew J. and Paul C. Buckland
1991 Tephrochronology and Late Holocene Soil Erosion in South Iceland. *In* Environmental Change in Iceland. Judith K. Maizels and Christopher Caseldine, eds. Pp. 147–159. Dordrecht: Kluwer.

Dugmore, Andrew J. and Camilla C. Erskine
1994 Local and Regional Patterns of Soil Erosion in Southern Iceland. Münchener Geographische Abhandlungen 12:63–79.

Dugmore, Andrew J., John S. Shore, Gordon T. Cook, Anthony J. Newton, Kevin J. Edwards, and Guðrún Larsen
1995 The Radiocarbon Dating of Tephra Layers in Britain and Iceland.Radiocarbon 37:286–295.

Dugmore, Andrew J., Anthony J. Newton, Guðrún Larsen, and Gordon T. Cook
2000 Tephrochronology, Environmental Change, and the Norse Colonization of Iceland. Environmental Archaeology 5:21–34.

Dugmore, Andrew J., Mike J. Church, Paul C. Buckland, Kevin J. Edwards, Ian T. Lawson, Thomas H. McGovern, Eva Panagiotakopulu, Ian A. Simpson, Peter Skidmore, and Guðrún Sveinbjarnardóttir
2005 The Norse Landnám on the North Atlantic Islands: An Environmental Impact Assessment. Polar Record 41:21–37

Dugmore, Andrew J., Mike J. Church, Kerry-Ann Mairs, Thomas H. McGovern, Anthony J. Newton, and Guðrún Sveinbjarnardóttir
2006 An Over-Optimistic Pioneer Fringe? Environmental Perspectives on Medieval Settlement Abandonment in Þórsmörk, South Iceland. *In* The Dynamics of Northern Societies. Jette Arneborg and Bjarne Grønnow, eds. Pp335–345. Copenhagen: Aarhus University Press.

Eldjárn, Kristján
1951 Tvennar Bæjarrústir frá Seinni Öldum [Two Farm Ruins from Later Times]. Árbók Hins Íslenzka Fornleifafélags 1949–50:102–119.

1961 Bær í Gjáskógum í Þjórsárdal [A Farm in Gjáskóagar in Þjórsárdalur]. Árbók Hins Íslenzka Fornleifafélags 1961:7–46.

Erlingsson, Þorsteinn
1899 Ruins of the Saga Time: Being an Account of Travels and Explorations in Iceland in the Summer of 1895. London: D. Nutt.

Friðriksson, Adolf
1994 Sagas and Popular Antiquarianism in Icelandic Archaeology. Aldershot (UK): Worldwide Archaeology Series Monograph, 10.

Gísladóttir, Guðrún Alda
2004 Gripir úr Þjórsárdal. [Artefacts from Þjórsárdalur]. Masters thesis, Department of History and Archaeology, University of Iceland.

Grönvold, Karl, Níels Óskarsson, Sigfús J. Johnsen, Henrik B. Clausen, Claus U. Hammer, Gerard Bond, and Edouard Bard
1995 Tephra Layers from Iceland in the Greenland GRIP Ice Core Correlated with Oceanic and Land Based Sediments. Earth and Planetary Science Letters 135:149–155.

Halflidason, Hafliði, Guðrún Larsen, and G Ólafsson
1992 The Recent Sedimentation History of Þingvallavatn, Iceland. Oikos 64:80–95.

Hallsdóttir, Margrét
1987 Pollen Analytical Studies of Human Influence on Vegetation in Relation to the Landnám Tephra Layer in Southwestern Iceland. Lund: Lund University.

Jónsson, Brynjúlfur
1885 Um Þjórsárdal. [On Þjórsárdalur]. Árbók Hins Íslenzka Fornleifafélags 1884–5:38–60.

Karlsson, Gunnar
2000 Iceland's 1100 Years: History of a Marginal Society. Reykjavík: Mál Og Menning.

Kirkbride, Martin P. and Andrew J. Dugmore
2001 The Timing and Significance of Mid-Holocene Glacier Advances in Northern and Central Iceland. Journal of Quaternary Science 16:145–153.

Larsen, Guðrún
1984 Recent Volcanic History of the Veiðivötn Fissure Swarm, Southern Iceland—An Approach to Volcanic Risk Assessment. Journal of Volcanology and Geothermal Research 22:33–58.

1996 Gjóskutímatal and Gjóskulög frá Tíma Norræns Landnáms á Íslandi [Tephrochronology and Tephra Layers from the Period of Norse settlement in Iceland)]. *In* Um Landnám á Íslandi. Guðrún Á. Grimsdóttir, ed. Pp. 81–106. Reykjavik: Societas Scientiarum Islandica.

Larsen, Guðrún and Sigurdur Þórarinsson
1977 Hekla 4 and Other Acidic Hekla Tephra Layers. Jökull 27:28–46.

Larsen, Guðrún, Andrew J. Dugmore, and Anthony J. Newton
1999 Geochemistry of Historical Age Silicic Tephras in Iceland. The Holocene 9:463–471.

Mairs, Kerry-Anne, Mike J. Church, Mike J. Andrew J. Dugmore, and Guðrún Sveinbjarnardóttir
2006 Environmental Change and Long-Term Settlement: The Mörk and Dalur Farm Complexes of Eyjafjallasveit, South Iceland. *In* The Dynamics of Northern Societies. Jette Arneborg and Bjarne Grønnow, eds. Pp365–373. Copenhagen: Aarhus University Press.

McGovern, Thomas H., Orri Vésteinsson, Adolf Friðriksson, Mike J. Church, Ian T. Lawson, Ian A. Simpson, Árni Einarsson, Andrew J. Dugmore, Gordon T. Cook, Sophia Perdikaris, Kevin J. Edwards, Amanda M. Thomson, W. Paul Adderley, Anthony J. Newton, Gavin Lucas, and Oscar Aldred
In Press Landscapes of Settlement in Northern Iceland. American Anthropologist 109.

Rafnsson, Sveinbjörn
1977 Sámsstaðir í Þjórsárdal [Sámsstaðir in Þjórsárdalur]. Árbók Hins Íslenzka Fornleifafélags 1976: 39–120.

Ian A. Simpson, W. Paul Adderley, Garðar Guðmundsson, Margrét Hallsdóttir, Magnús Á. Sigurgeirsson, and Mjöll Snæsdóttir
2002 Soil Limitations to Agrarian Land Production in Pre-Modern Iceland. Human Ecology 30: 423–443.

Steffensen, Jón
1943 Þjórsdælir Hinir Fornu [The Ancient People of Þjórsárdalur]. Samtíð og Saga II:7–42.

1950 Enn um Eyðingu Þjórsárdals [Yet Again on the Destruction of Þjórsárdalur]. Árbók Hins Íslenzka Fornleifafélags 1949–50:63–72.

Stenberger, Mårten, ed.
1943 Forntida Gårdar i Island. Nordiska Arkeologiska Undersökningen i Island 1939 [Early Farms in Iceland. The Nordic Archaeological Expedition in Iceland 1939]. København: Munksgaard.

Sveinbjarnardóttir, Guðrún
1992 Farm Abandonment in Medieval and Post-Medieval Iceland: An Interdisciplinary Study. Oxford: Oxbow Books.

Thoroddsen, Þorvaldur
1889 Rauðukambar, Kerlingarfjöll og Kjalvegur. Ferðasaga (1888) [Rauðukambar, Kerlingarfjöll and Kjalvegur. Travelogue (1888)]. Andvari 15: 56–119.

Þórarinsson, Sigurður
1943 Þjórsárdalur och Dess Förödelse [Þjórsárdalur and its Abandonment]. *In* Forntida gårdar i Island [Early Farms in Iceland.] The Nordic Archaeological Expedition in Iceland 1939. Mårten Stenberger, ed. Pp. 9–52. København: Munksgaard.

1944 Tefrokronologiska Studier på Island [Tephrochronological Studies in Iceland]. Geografiska Annaler 26:1–217.

1949 Örlög Byggðarinnar á Hrunamannaafrétti í Ljósi Öskulagarannsókna [The Fate of the Settlements in Hrunamannaafréttur in the Light of Tephra

Studies]. Árbók Hins Íslenzka Fornleifafélags 1943–48:44–65.

1951 Viðauki. Heklugosið 1693 og Eyðing Bæjarins í Sandártungu [Addendum: The Hekla Eruption in 1693 and the Abandonment of the Farm in Sandártunga]. Árbók Hins Íslenzka Fornleifafélags 1949–50:115–18.

1954 The Tephra Fall from Hekla on March 29th 1947 [The Eruption of Hekla 1947–48 II, 3]. Reykjavík: Societas Scientiarum Islandica.

1961 Uppblástur á Íslandi í ljósi Öskulagarannsókna [Wind Erosion in Iceland: A Tephrochronological Study]. Ársrit Skógræktarfélags Íslands 1961:17–54.

1967 The Eruptions of Hekla in Historical Times. A Tephrochronological Study of The Eruption of Hekla 1947–1948 I. Reykjavík: Societas Scientiarum Islandica.

1981 The Application of Tephrochronology in Iceland. *In* Tephra Studies. S. Self and R. S. J. Sparks, eds. Pp. 109–134. Dordrecht: Reidel

Vésteinsson, Orri
1998 Patterns of Settlement in Iceland: A Study in Prehistory. Saga-Book 25:1–29.

2004 Icelandic Farm House Excavations. Field Methods and Site Choices. Archaeologia Islandica 3:71–100.

Vésteinsson, Orri and Ian A. Simpson
2004 Fuel Utilisation in Pre-Industrial Iceland: A Micro-Morphological and Historical Analysis. *In* Current Issues in Nordic Archaeology. Proceedings of the 21st Conference of Nordic Archaeologists. Garðar Guðmundsson, ed. Pp. 181–187. Reykjavík: Society of Icelandic Archaeologists.

Vilhjálmsson, Vilhjálmur Ö.
1989 Stöng og Þjórsárdalur-Bosættelsens Ophør [Stöng and the End of the Þjórsárdalur Settlement]. Hikuin 15:75–102.

Zielinski, Gregory A., Mark S. Germani, Guðrún Larsen, Michael G. L. Baillie, Sallie Whitlow, Mark S. Twicker, and Kendrick Taylor
1995 Evidence of the Eldjá (Iceland) Eruption in the GISP-2 Greenland Ice Core: Relationship to Eruption Processes and Climate Conditions in the Tenth Century. The Holocene 5:129–140.