FAR REACH OF THE TENTH CENTURY ELDGJÁ ERUPTION, ICELAND

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Abstract. At the end of Iceland's settlement period in the 10th century, a great basalt fissure eruption known as Eldgjá (Fire Chasm) occurred near the southern settlements and destroyed a portion of them. This lava outpouring was one of the two largest terrestrial fissure eruptions of the last 11 centuries. Historical documents from Iceland, western Europe, and the Middle East are used to trace the eruption's possible climatic and demographic consequences. The cloud of aerosols from the eruption, traversing northern Europe, dimmed and reddened the Sun. There followed a very cold winter, famine, and a widespread disease epidemic during the next year and, again, 5 to 7 years after the eruption, probably as a result of the long-lived stratospheric aerosol veil. Convergent lines of evidence point to 934 as the year of the eruption. Accordingly, it becomes possible to date within a year a prominent acid horizon in ice laid down in central Greenland and, tentatively, to interpret some critical events and dates in early Icelandic history.

1. Introduction

The great Eldgjá (Fire Chasm) eruption in southern Iceland occurred during the first half of the 10th century, and rivaled in magnitude Iceland's Laki (Skaftár Fires) eruption in 1783. Because the earlier event happened during the European Dark Ages, it has been commonly assumed that little or no evidence of its possible physical and demographic impact on Europe and elsewhere can be gathered from the few available historical records pertaining to this obscure period. Understandably, almost all effort has been focused on the conducting of volcanological studies of the exposed lava and tephra deposits in Iceland (Thoroddsen, 1925; Larsen, 1979, 1993; Miller, 1989; Palais and Sigurdsson, 1989) and glaciological studies of the aerial tephra fallout and acid deposition in Greenland ice (Hammer et al., 1980; Herron, 1982; Hammer, 1984; Johnsen et al., 1992; Zielinski et al., 1994, 1995).

Scuderi (1990) and Zielinski et al. (1995), however, have examined the annual growth rings in a number of North Temperate trees to look for a potential summer climatic signal from the eruption, but in the end they obtained only ambiguous results. This makes it even more important to reconsider the possible usefulness of medieval documentary records. Here the uncovered historical evidence for Eldgjá's aftermath in Europe and the Middle East will be presented and interpreted. Although various quality-control problems in using medieval sources occasionally

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crop up (Bell and Ogilvie, 1978), we will rely chiefly on authors (mostly Christian monks and other clerics) who lived reasonably close in time to the eruption and who described events occurring in their own localities. When it is necessary to utilize later sources, only those authors regarded as generally reliable will be admitted for the additional useful evidence they provide. In all cases, the historical evidence remains only qualitative and anecdotal, as there were no instrumental measurements or systematic observations made at the time. On the other hand, the medieval chroniclers tended to report only the extreme, not the routine, weather events (great storms, cold years, etc.), and this has the benefit of serendipitously filtering out the noise and enabling us to estimate more easily the true frequencies of such extreme events. Thus we know, for example, that very severe winters in western Europe occurred at an average rate of once or twice a century during the period 800–1100 (Easton, 1928; Lamb, 1977). This makes it less likely that the unusually harsh winter immediately following the Eldgjá eruption was a random event.

2. Eldgjá Eruption

The Norse Vikings settled Iceland during a brief 60 year period between the late 9th century and the early 10th century. Around the end of this period, a large volcanic eruption occurred in the south of Iceland, according to the Icelanders' Book of Settlements (*Landnámabók*, 12th century):

> Hrafn hafnarlykill claimed land between Hólmsá and Eyjará and lived at Dynskógar. He foresaw a volcanic eruption and moved his farm to Lágey .... Molda-Gnúpr claimed land between Kúdafljót and Eyjará, the entire Alftaver district; at that time, there was a great lake in the area, where swans were hunted. Molda-Gnúpr sold many people parts of his claim, and it became densely populated before lava flowed down there, at which time people fled westward to Höfdabrekka and set up camp at Tjaldavöllr.

The Book of the Icelanders (*Íslendingabók*, 12th century) tells us that the Norse settlement began in the year 870 and lasted 'sixty winters', which may or may not be an accurate number. On the other hand, *Landnámabók* dates the settlement from 874. Since the first Icelandic historian, Ari Thorgilsson (who died in 1148), wrote most of the former book and was probably the main source for the latter, neither date can be clearly preferred over the other. But there is some internal evidence on the question. The names and tenures of the successive 'lawspeakers' of the Icelandic Parliament listed in *Íslendingabók* start from the creation of this body in apparently the last year of the settlement. If these lists are correct, the settlement must have ended in 930, as reckoned back from the known year that 'King Harald fell in England', 1066. Some skeptical scholars, however, doubt the accuracy of the earlier tenures reported, which were transmitted orally for two centuries before being written down. Moreover, even the highly conservative scholars on this point concede that Ari himself may have had to rationalize the earliest of them (Hermannsson, 1930; Byock, 1988). Good proof of an attempted adjustment is the apparent discrepancy between the two dates given for the beginning of the settlement. Thus, there is no compelling reason why the final year of the settlement could not be 934, as implied by *Landnámabók*. Further evidence concerning this point comes from testimony by the Saxon chronicler Widukind (c. 973) of Corvey, who, as we shall show, probably refers to the same volcanic eruption that is alluded to in *Landnámabók*. He assigns the date to some year before 937, though almost certainly not as early as 930. The extant annals of Iceland (*Royal Annals*, 14th century; *Icelandic Annals*, 14th century) are of no use here, because for this event they ultimately depended on Widukind, as filtered through the chronicle of Sigebert (c. 1111) of Gembloux.

Interestingly, a date of about 934 is not incompatible with what is known volcanologically about the Eldgjá eruption. This eruption broke out along a 75 km long fissure that belongs to the Katla volcanic system in southern Iceland. Parts of the fissure run through mountainous terrain and one large part underlies the Mýrdalsjökull ice cap. Modern studies of the exposed deposits reveal that lava flowed southward across the Alftaver district as well as other districts to the east, producing a total accumulation of 14–16 km^3, including airborne tephra (Miller, 1989; Zielinski et al., 1995). Stratigraphic analysis and radiocarbon dating of wood charred by the lava place the date of the event in the first half of the 10th century (Larsen, 1979, 1993). All this physical evidence ties the explicit documentary evidence for a volcanic eruption in the late settlement period tightly to the Eldgjá eruption, confirming the original conjecture of Thoroddsen (1925).

Additional evidence has been uncovered in the annual layers of ice laid down in neighboring Greenland. In an ice core from Crête, a very large acidity excess appears within a layer dated at 934 $\pm$ 2 (Hammer et al., 1980; Hammer, 1984). This agrees with the Summit ice-core date of 934 $\pm$ 3 based on the same signal in the Dye 3 core (Johnsen et al., 1992). A rougher date from the Greenland Ice Sheet Project Two (GISP2) ice core falls at 938 $\pm$ 4 (Zielinski et al., 1994, 1995). The Dye 3 ice core (Herron, 1982; Hammer, 1984) and the Camp Century ice core (Hammer, 1984) show further details of the signal, but were originally not dated very accurately in this section. All five ice cores reveal that the signal gradually tapers off during the following 2 to 4 years. Such a slow decline, with a time needed to decay by a factor of e of about 1 year, points to stratospheric transport for most of the aerosols that produced the excess acidity. Finally, a chemical analysis of glass shards in the GISP2 ice core demonstrates a very close affinity between this glassy material and the local glass from the Eldgjá eruption (Zielinski et al., 1995).

In what year did the great Eldgjá fissure erupt? If we accept Herron's (1982) finding that the F^- concentration at Dye 3 began to rise a whole year before the SO_4^{2-} concentration, and if we argue by analogy with the 1783 Laki eruption (Fiacco et al., 1994) that massive sulfate deposition on central Greenland ice started about a year after the eruption, the tentative glaciochemically based date would be

933, with a possible error of ± 2 yr. On the other hand, if the dating of the lower layers of the ice cores has depended on assuming 1783 as the year of the main Laki acidity signal, the best glaciochemically based date for Eldgjá would be 934.

3. Dry Fog over Northern Europe

Widukind (c. 973) of Corvey, in northwestern Germany, wrote a history of the Saxon nation to which he belonged. An extraordinary passage, translated from the Latin, runs:

> Indeed before the death of King Henry many prodigies occurred, such as: The brightness of the Sun outdoors in a cloudless sky appeared almost nil, but it streamed indoors, red as blood, through the windows of houses. Likewise for the mountain where the overlord of the states was buried, according to report, because the mountain erupted flames in many places.

The accepted date for the death of King Henry I the Fowler is 2 July 936. Unfortunately, no strictly contemporary European report covering this poorly documented period is now available, as the great medieval renaissance of historical writing did not begin until the next generation, under Henry's son, Otto I the Great, the founder of the Holy Roman Empire. Since the linkage of astronomical portents to the death of kings is not uncommon in medieval chronicles, this particular association should cause no problem with interpretation of the cited passage.

The two prodigies just quoted are repeated out of Widukind by Sigebert (c. 1111) of Gembloux, in Belgium, although he places them wrongly in the year 937. Sigebert and authors who follow him (Saxon Annalist, c. 1139; Kehr, 1904) equate the 'overlord of the states' (*ipse rerum dominus*), a quite general appellation in Widukind, with King Henry. Were this so, the erupting mountain would have to lie within or near the town of Quedlinburg, Saxony, where Henry was buried. Yet this area has not been volcanically active in any geologically recent time, and, not surprisingly, the *Annals of Quedlinburg* (c. 1025) makes no mention of an eruption there. In his later Migne edition of Widukind, Waitz (1853) capitalized the word *Dominus* and thereby implicitly placed the mountain in Jerusalem. But, again, the volcanic facts do not fit. Newton (1972) simply suggested a volcanic eruption somewhere else, outside Germany. An eruption in the Mediterranean area is least likely, as the famous volcanoes there are very well documented and no large eruption of one is recorded for this period (Simkin and Siebert, 1994).

Eldgjá, however, would fit. Report of its devastating effect on the settlements in south Iceland must have quickly reached Germany, where commercial and cultural contacts between Norsemen and Saxons were frequent (La Fay, 1972). The unnamed 'overlord of the states' that the flaming tephra or lava buried was possibly Úlfljótr, the founder, lawgiver, and first lawspeaker of the united Icelandic Parliament. This body, called *Althingi* in Old Icelandic, was an annual summer convening at Thingvellir near Reykjavík of the island's independent parliaments or *thing*'s. At that early time, Iceland consisted of a number of parliamentary states (Latin *res*) (Jonas, 1609) headed by minor lords. Úlfljótr held the lawspeakership during just the year of its establishment, which was also the final year of the settlement. Unless for some honorary reason he was an unelected lawspeaker (Hermannsson, 1930), which seems unlikely, given his legal orientation, he must have died suddenly in that year (Gjerset, 1925), because a lawspeakership term was set by law to be three years long. Having his home in the Lón area on the southeast coast, he could have been traveling to or from the *Althingi* in the southwest when he was unexpectedly caught by the Eldgjá eruption. If so, the eruption can be formally dated at either 930 or 934, according to whether one accepts the final year of settlement from *Íslendingabók* or *Landnámabók*.

Widukind of Corvey's first prodigy, relating to the Sun's brightness and color, has often been interpreted as an observation of the annular solar eclipse of 16 April 934, which would have been visible in northern Germany (Schove, 1984). Since Widukind himself must have witnessed the prodigy (as a child of perhaps nine years of age) and provides significant details, it is remarkable that he did not specify that it was an eclipse, as medieval chroniclers routinely did. This fact, plus the peculiar details, suggests that the prodigy was not an eclipse at all. Newton (1972) thinks not, and, by linking Widukind's first and second prodigies, has attributed the dimming of the Sun to the presence in the atmosphere of volcanic ash of unknown provenance.

An independent account very similar to Widukind's crops up in the Irish *Annals of Clonmacnoise* (1408): 'The sun for one day appeared like blood until noon the next day'. Although the year for this prodigy is given as 933, chronology in the *Annals of Clonmacnoise* is not always completely accurate. Note that the parish of Clonmacnoise lies near the geographic heart of Ireland.

Lastly, Alexander von Humboldt (1852) has quoted a passage from the late 17th-century Portuguese historian Manuel de Faria e Sousa, who claims that, during 934, 'the Earth was without light for two months in Portugal, for the Sun had lost its brightness'. The source of this information was almost certainly Faria e Sousa's immediate predecessor, the Spanish historian Juan de Mariana (1606), who gives further details that indicate, more correctly, a very short-lived darkening of the Sun on two days of different months: 19 July and 15 October, with the year stated as being either 934 or 938. We can readily identify the first episode of darkening as having been due to the total solar eclipse of 19 July 939, on which date the path of totality ran near Lisbon and Madrid (Schove, 1984). For the second darkening of the same year, Mariana simply writes that 'the light of the Sun changed to a pale color'. But as the year was 939, neither darkening seems to have any relevance for the Eldgjá eruption. In a remarkably similar manner, the Renaissance Florentine historian Matteo Palmieri (1448) has garbled an account of the same solar eclipse, which was seen and reported by Liudprand (c. 962) of Cremona.

We are left, then, with the combined testimony of Widukind and the Clonmacnoise annalist. The recorded facts of both a dimming and a blood-red color of the Sun are consistent with the passage over northern Europe of a dense aerosol cloud from the Eldgjá eruption. Widukind's remark that the windows of houses were open and, less importantly, our argument that Úlfljótr might have been traveling far from home at that time would ostensibly point to a summertime eruption. It is not known, however, how long the eruption lasted.

4. Cold Winters, Famine, and Pestilence

A pattern of exceptionally cold weather in Europe and the Middle East characterized at least part of the years 934 and 935. Whether the unusually long cold snap occurred only during the winter of 934–935 or persisted also in the summer of 935 cannot be decided from the fragmentary historical evidence available. Highly unsettled political conditions both in Western Europe and in the Arab lands were not conducive to historical writing at that period. Nevertheless, later writers, using now lost sources, help to fill in some of the gaps.

Baghdad received unaccustomed heavy snowfalls during the winter of 934–935 according to the reliable, though late, historian Bar-Hebraeus (1286). Even in the following June the weather was chilly and very rainy at Nisibis on the northern Tigris River (Elias, c. 1018). In Iran the area around Susa is reported to have been 'unproductive' that year (Ibn Maskawayh, c. 1030).

In Constantinople a similar picture emerges. The unknown continuator (c. 963) of Theophanes Confessor's chronicle relates the following account, which was expressed in much the same manner by Symeon Logothetes (c. 969):

> On 25 December, intolerably cold weather set in, such that the earth was frozen over for 120 days. A great famine followed, exceeding those that had ever happened before. Because of this, there was high mortality, as the living were unable to carry out the dead for burial.

The Byzantine emperor, Romanus I Lecapenus, had temporary shelters built to shield the city's homeless paupers from the snow and cold. He also freely dispensed food and even money to the many who were suffering. The exact year is not stated by the two chroniclers, who sandwiched their accounts between an event of July of the sixth year of the then current indiction (933) and an event of August of the fourth year of the same indiction (931). Since the chroniclers obviously did not follow any strict chronological order, it is reasonable to identify the severe winter as that of 934–935, based on the similar Middle Eastern reports.

A long and bitterly cold winter is also reported for Ireland in the year 934 (*Annals of Clonmacnoise*, 1408). As we shall see below, however, the year given is somewhat uncertain. Jean d'Outremeuse (1400) in Belgium, though possibly merely transferring the Irish report, records that the Meuse River near Liège was frozen solid from 30 November 934 until some time in March 935. An unusually large amount of snow need not have fallen, however, as the other extant western European chronicles do not refer to this winter as a 'very severe' one (Easton, 1928; Lamb, 1977).

At some unspecified time between 14 October 934 and 2 July 936, a 'pestilence' raged at Reims in northern France according to Flodoard (c. 966) and Richer (c. 997), who were natives of that city. It also occurred at Verdun (Hugo, c. 1102). The disease in question was some fatal contagion producing red spots, as it 'afflicted the human body with different diseases' and 'killed off innumerable people when red papules appeared on the skin'. To the southeast, in Iran, a famine began during 935 at Khorasan, and was followed by a 'pestilence' of some indeterminate kind at Isfahan the next year (Ibn al-Athīr, 1234).

Another round of frigid winter months, famine, and pestilence occurred several years later. We read of a 'very harsh winter' of 939–940 in northern Germany (Widukind, c. 973; *Annals of Cologne*, c. 1028) and a 'hard year' in Switzerland (*Major Annals of Saint Gall*, c. 1080). Furthermore, a 'great frost' in Ireland that made lakes and rivers passable struck in probably the same winter all across the island. The year is variously given as 940 (or 941) and 944 (or 945) in the *Annals of Ulster* (1540), as 939 in the *Annals of the Four Masters* (1616), and as 934 in the *Annals of Clonmacnoise* (1408). But O'Donovan (1856) and Britton (1937) have suggested that the same event is possibly being referred to in all three sources. On the other hand, our earliest source, the *Annals of Clonmacnoise*, gives 934, and the *Annals of Ulster* mentions two cold winters separated by four, or possibly five, years. It is therefore easiest to reconcile the apparent discrepancies by inferring the occurrence of two cold winters, 934–935 and 939–940. This also agrees with the independent European and Middle Eastern sources at our disposal.

Weather so crushingly severe in the winter of 939–940 was blamed by the chroniclers for a famine in 940–941 that ravaged Germany and Switzerland. What caused the contemporaneous famine in Italy (Liudprand, c. 962) and in the cities of Baghdad and Cairo (Elias, c. 1018; Ibn Maskawayh, c. 1030; Yahya, c. 1050; Bar-Hebraeus, 1286) is unclear, but was possibly also weather-related. The Tigris River is reported by Bar-Hebraeus to have widely flooded the country in 940. This implies abnormally heavy winter rainfalls or snowfalls in the river's upper reaches.

Worse, in 941 a 'pestilence' broke out among the human populations of Baghdad and Cairo, heavily decimating them (Yahya, c. 1050; Bar-Hebraeus, 1286). This may have been a resurgence of the disease outbreak reported at Isfahan in 936. Possibly it was plague, which is endemic in those regions. Other environmental reasons for suspecting this identification are the wet climate conditions at the time, the possible direction of disease spread from east to west, and the great mortality. No diagnostic description is available, but even if it was not true plague, it must have constituted one of the largest Middle Eastern pandemics of medieval times. Modern authorities on the history of plague (Sticker, 1908; Dols, 1977), however, have failed to mention it, because they depended on a very incomplete study by von Kremer (1880), who consulted only a few Arabic, and no Syriac, sources for this period. The Syriac writer Bar-Hebraeus is an especially valuable source, as he was a physician as well as a historian interested in medical matters. The many deaths that the pandemic of 941 caused were doubtless increased in number by simple starvation and various famine diseases, as people were reduced to eating grass and even dead bodies. In 942 the famine intensified, and more loss of life occurred.

In the north, across western Europe, a heavy die-off of cattle occurred during 942. Accompanied by a famine, the alarming phenomenon struck France and Burgundy (Flodoard, c. 966) and also Germany (Continuator of Regino, c. 967). Widukind (c. 973) called it a ‘pestilence of cattle’, and said that it followed a period of excessive flooding. It might have been an epidemic of cowpox. If the earlier human ‘pestilence’ in c. 935 in northern France was actually smallpox, the survivors of it would have been largely immune to cowpox. In fact, cowpox in cattle can be induced by human smallpox (Razzell, 1977). On the other hand, the ‘pestilence of cattle’ could have been any one of a number of other fatal livestock diseases that are water-borne and cause little harm to humans.

5. Discussion

A great volcanic fissure eruption like Eldgjá has the potential to cool off the northern troposphere by injecting large quantities of sulfur dioxide gas into the stratosphere (Devine et al., 1984; Stothers et al., 1986). Sulfur dioxide reacts with water vapor to form sulfuric acid aerosols, which screen out some of the incident sunlight and so cool the lower atmospheric layers. If the altitude of sulfur injection lies below the tropopause, the aerosol particles have only a brief residence in the atmosphere – typically a few days. In that case, the supply of aerosols holds out only as long as the eruption continues, which can be several months for a large fissure eruption. On the other hand, a stratospheric injection of sulfur virtually guarantees one or more years of residence of some of the aerosols high up in the atmosphere. For a high-latitude eruption, the stratospheric aerosols spread uniformly throughout all latitudes northward of about 30° (Stothers, 1996a).

Two recent studies of Eldgjá’s near-source ejecta have determined that intense fire-fountaining took place during the most active phases of this eruption while violent explosions due to the mixing of magma with meltwater lofted tephra and gas out of the portion of fissure lying under the Mýrdalsjökull ice cap (Miller, 1989; Larsen, 1993). These geological revelations and the Greenland ice-core data imply that a significant quantity of sulfur must have entered the stratosphere. The total amount of tropospheric and stratospheric sulfuric acid formed was of the order of 100 megatons, according to a petrologic and two glaciochemical estimates (Hammer et al., 1980; Palais and Sigurdsson, 1989; Zielinski et al., 1995).

Eldgjá’s sulfuric-acid aerosols drifted across northern Europe, and almost certainly spread much farther. In their sheer abundance and in their direction of dispersal, they resembled Laki’s aerosols (Fiacco et al., 1994; Stothers, 1996b). In other respects, too, Eldgjá mimicked Laki, because Laki was followed by a series of cold years in Europe and the Middle East, the very severe first winter being the prelude to widespread famine and a plague epidemic (Biraben, 1975; Wood, 1992). Some of the damage to crops in northern Europe during Laki's eruption was inflicted by direct deposition of acids (Grattan and Charman, 1994). This could also have been the case in 934, but we do not know for sure. One might wonder whether the cold weather, famine, and pestilence of the years 939–942 was actually related to a large volcanic eruption in 934. After all, comparable phenomena following the Laki eruption lasted only 2 to 3 years. Laki's aerosols, however, remained in the stratosphere for only 1 year owing to a low altitude of injection (Fiacco et al., 1994), whereas Eldgjá's stayed up for 2 to 4 years. Thus climate forcing was much more prolonged, and hence stronger, in the case of Eldgjá. This kind of extraordinary persistence is, in fact, more the rule than the exception after very large volcanic eruptions.

It is surprising how large a punctuation mark in Iceland's early history Eldgjá seems to have been. Our new weather-based date for the eruption, summer 934, if correct, may put to rest some longstanding controversies about the settlement period, viz. the dates of the beginning and end of the *landnám*, the date of founding of the *Althingi*, and the fate of the first lawspeaker, Úlfljótr. But absolute certainty about these historically remote events will probably always remain elusive. Only answers to the scientific questions are definitely within grasp.

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