

VOLCANIC ASH FROM VATNAJØKULL

(A MODERN FORMATION OF SIDEROMELAN)

BY

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I.

The vast glacier Vatnajökull in southeastern Iceland is known as an area of intense volcanism. Throughout historical time it has been in vigorous, incessant activity. For the last hundred years or so periodic outbursts seem to have occurred at fairly regular intervals, 5 to 12 years according to Thorkelsson (7). Most of them have been violent, explosive eruptions accompanied by tremendous glacier-bursts, the so-called jökulhlaup.

The last two greater outbursts took place in 1922 and 1934. Both were explosive and accompanied by jökulhlaup and ejection of ash and pumice. No extrusion of lava was observed, but very likely any possible lava flow would have been concealed by the glacier.

Descriptions of the materials erupted are now available; but petrographically the records are very incomplete, some even misleading. The petrographic character of the volcanic ash from the last two eruptions seems therefore worthy of discussion.

II.

Some uncertainty has prevailed as to the exact location of the craters in the frozen wastes of Vatnajökull. Sapper (6) places special emphasis on two loci of activity: Grimsvøtn and Oræfajökull at $64^{\circ} 12' N$, $17^{\circ} 25' W$ and $64^{\circ} 02' N$, $16^{\circ} 39' W$ respectively. However, the location of Grimsvøtn as given by Sapper corresponds to that of the glacier-lake Grænalón on the modern maps of Iceland. The region around this lake was explored by Muir and Wigner (10) in 1904 who contended that no Recent volcanic activity had ever taken place there. Later observations by Áskelsson (1) corroborates this. But about 25 km North of Grænalón in the very central parts of the glacier Wadell (8) in 1919 encountered Recent craters, at that

time, of course, partly buried by the ice. He called the place "Svíagígur". It is probable that most of the eruptions listed in Sapper's book as having occurred at "Grímsvötn" actually took place at Svíagígur. In 1935 Áskelsson was able to identify the scene of eruption of 1934 with Svíagígur. But at the same time he re-named the place and called it "Grímsvötn" (later officially confirmed). But as distinct from the old Grímsvötn the location of this new Grímsvötn (Svíagígur) is $64^{\circ} 23.6' N$, $17^{\circ} 21.5' W$. Undoubtedly this is the centre of the eruptions of 1922 and 1934, and probably the centre of many of the older eruptions.

III.

Dr. Th. Thorkelsson, director of the Meteorological Institute ("Veðurstofan") in Reykjavik, kindly gave me for petrographical examination a number of ash samples collected at various places in Iceland during the ash-falls of 1922 and of 1934.

First we shall consider the ash of 1922: The eruption and the ash-fall have been carefully described by Thorkelsson (7). The days of heaviest ash-fall were the 5th, 6th, and 7th of October. South and southwesterly winds prevailed, the ash thus being carried over large areas of Northern and Eastern Iceland. Thorkelsson examined the ash from various localities, measured the areas covered and the thickness of the ash layers, and concluded that during these three days a minimum amount of 15 million tons ash had fallen down on Iceland, not to speak of what had fallen into the sea. From this fall I received three samples:

(1) Oct. 5, 1922; a violent outburst producing minimum $1\frac{1}{2}$ million tons ash. Sample collected at Eskifjord, 180 km ENE of the crater.

(2) Oct. 6, 1922; another violent outburst producing minimum 11 million tons ash. Sample collected at Papey, 150 km E of the crater.

(3) Oct. 7, 1922; violent outburst producing minimum $2\frac{1}{4}$ million tons ash. Sample collected at Grimstad, 150 km NNE of the crater.

The eruption of 1934 commenced on March 30. It was very violent in the beginning. Nielsen (3) estimated that about 10 km^3 of ice was melted. During the following month the activity gradually died off. The column of ash thrown out of the vent was measured

to be between 10 and 12 km high. The ash-fall has been described in some detail by Áskelsson (1), but no estimate of the total amount of ash erupted has been made.

The site of eruption was later visited by several expeditions. Scoriae, pumice, and ash were observed and examined by Áskelsson (1), Nielsen (3) and Noe-Nygaard (4). From this eruption I have examined ash samples collected at Papey, Grimstad, Reykjahlid, Fagerhólsmyr, Vapnafjord, and Hólar.

IV.

Ash from the eruption of 1922, collected at Papey, Eskifjord, and Grimstad is essentially a homogeneous, brownish, transparent glass whose index of refraction is

$$n = 1.610 \quad .$$

About 1% of crystalline material is present: Mostly feldspar (plagioclase of composition 85% anorthite, mean index of refraction being $\beta = 1.575$), but in the sample from Grimstad also odd grains of olivine were observed (+ 2V 85° , consequently a Mg-rich olivine).

Ash from the eruption of 1934 seems to be the same in all localities. It is also identical with the ash that fell in 1922. To give an indication of the constancy of the composition of the ash the following individual data are given:

Grimstad: Glass: $n = 1.610$, mostly brownish, but some grains are opaque. 2-3% plagioclase, $\beta = 1.575$ (85 An). Odd grains of olivine.

Papey: Glass: $n = 1.610$, brownish, homogeneous. 1% plagioclase, $\beta = 1.575$ (85 An). Very little olivine.

Reykjahlid: Glass: $n = 1.610$, mostly brownish, but many opaque grains are met with. 2% plagioclase, $\beta = 1.575$ (85 An). Some small hair-shaped crystals only $\frac{1}{100}$ mm long occur in some glass grains. Trace of olivine.

Fagerhólsmyr: $n = 1.610$. 1% plagioclase, $\beta = 1.575$ 1.570 (85-80 An). Olivine not observed.

Vapnafjord: Glass: $n = 1.610$, some grains are opaque. 1% plagioclase, $\beta = 1.575$ (85 An). Odd grains of olivine.

Hólar: Glass: $n = 1.610$. 1% plagioclase, $\beta = 1.575$ (85 An). Olivine not observed with certainty.

Table 1.
Chemical Analyses of Volcanic Ash from Vatnajökull.

	I	II	III	IV
SiO ₂	49.80	49.73	48.40	47.40
TiO ₂	2.83	2.51	3.20	3.10
Al ₂ O ₃	13.87	14.80	14.00	14.50
Fe ₂ O ₃	1.84	3.10	2.30	3.00
FeO.....	12.38	11.53	12.80	11.35
MnO.....	0.16	0.15	-	-
MgO.....	4.92	4.92	4.70	5.00
CaO.....	9.75	9.55	10.00	10.50
Na ₂ O.....	3.17	2.86	2.50	3.10
K ₂ O.....	0.55	0.52	0.23	0.36
P ₂ O ₅	0.22	0.23	0.20	0.18
H ₂ O+.....	0.44	0.40	-	-
H ₂ O-.....	0.07	0.08	-	-
Cr ₂ O ₃	nil	n.d.	-	-
SO ₃	nil	n.d.	1.00	0.95
Total.....	100.01	100.28	99.43	99.54
Cl.....	0.02			

- I. Ash collected at Papey, Oct. 6, 1922; Barth analyst.
- II. Ash collected at Papey, April 2, 1934; Barth analyst.
- III. Ash collected at Meðalland, 1934; quoted from Áskelsson, op. cit. p. 39, analyst anonymous.
- IV. Ash collected on glacier, 10 km West of outburst, 1934; quoted from Áskelsson, op. cit. p. 39, analyst anonymous.

Table 2.
Norms of Volcanic Ash.

	I	II	III	IV
Q.....	-	1.4	2.2	-
or.....	3.3	3.3	1.3	2.2
ab.....	26.7	24.1	21.1	26.2
an.....	22.0	25.9	26.1	24.5
wo.....	10.4	8.4	9.2	10.9
en.....	11.2	12.2	11.7	8.9
fs.....	15.5	14.9	16.4	9.4
ol.....	1.7	-	-	5.4
mt.....	2.8	4.4	3.2	4.4
il.....	5.3	4.7	6.1	5.9
ap.....	0.5	0.5	0.5	0.4

Number of analyses as in Tab. 1.

Table 3.
Niggli Parameters of Volcanic Ash.

	I	II	III	IV
si	122	120	117	111
al	20	21	20	20
fm	47	47	47	45
c.	25	25	25	27
alk	8	8	6	8

Number of analyses as in Tab. 1.

Chemical analyses were made of ash collected at Papey, Oct.6, 1922, and at Papey, April 2, 1934. With these two new analyses are compared two analyses of the ash of 1934 published by Áskelsson.

In ash from Eskifjord (1922) ferrous oxide was determined as follows:

$$\text{FeO} = 11.95\%$$

Tab. 2 and 3 give account of the theoretical, normative mineral composition, and the Niggli parameters, of the various ash samples.

The norm shows that the ash is just saturated with respect to silica. The normative feldspar is andesine-labradorite; the modal plagioclase, basic bytownite, reflects the invariably more calcic character of the early-formed plagioclase. Again, magnesia-rich olivine, observed in samples with very little or no normative olivine, reflects the well-known reaction relation between olivine and pyroxene.

The microscope studies and the analyses thus prove the identity of the materials erupted in 1922 and in 1934. It is furthermore clear that the ash is not phreatic but, in spite of the explosiveness of the eruptions, truly magmatic, viz: glass produced by rapid chilling of a lava of basaltic composition.

About one year ago I (2) was able to establish the position of the boundary surface that separates basaltic liquids precipitating feldspar from those liquids that precipitate pyroxene (\pm olivine). The position of this boundary surface was given by the following equation:

$$ab' + 2 di' + 2.3 hy' = 123.$$

If the left side of the equation, which for short may be called $f(\text{norm})$, equals 123 (approximately) the basalt lies on the boundary surface. If it is smaller or greater than 123 the basalt lies in the plagioclase field or in the pyroxene field respectively.

For the two new analyses we obtain:

Papey 1922, $f(\text{norm}) = 123$

Papey 1934, $f(\text{norm}) = 118$.

A simultaneous precipitation of plagioclase and pyroxene would have taken place, therefore, in this glass, if allowed to have cooled slowly. That this deduction is correct is also indicated by the products of the incipient crystallization: plagioclase and olivine. Characteristic features of this glass are thus: basaltic composition on the boundary surface plagioclase \rightleftharpoons pyroxene, and complete saturation with respect to silica. It has therefore all the earmarks of a plateau basalt lava.

It is a well-known fact that volcanoes extruding basaltic lavas differ from those producing acid lavas in the character of their eruptions. The basic volcanoes do not exhibit the more violent phases of volcanism, and are not likely to explode or throw great quantities of magmatic ash up in the air. Vatnajökull is a conspicuous exception to this rule; it is also the only known sub-glacial basic volcano. It is reasonable, therefore, that its explosiveness is caused by the superincumbent load of ice which it has to break through to find egress for its incarcerated lavas and gases.

V.

The production of volcanic glass in Vatnajökull is an example of modern sideromelan in its making; the glass agrees very closely with the substance for which Peacock (5) has revived the old term "sideromelan". Excerpt: "Sideromelan is a black, lustrous, mostly anhydrous basaltic glass which is pale coloured and translucent in thin section; it is known only in fragmental volcanic ejecta. In Iceland sideromelan is the product of drastically chilled, sub-glacially extruded basalt magma. This mode of formation results in the invariable fragmentation of the material and the inhibition of ore-separation producing the characteristic translucency" (op. cit. p. 74).

Peacock points out that sideromelan does not, of course, conform with the criteria of a mineral species, as von Waltershausen (9) thought. The composition of basalt magma varies somewhat and, accordingly, the composition of sideromelan must vary; but all the inter-Glacial sideromelans in Iceland examined by Peacock seem to have a fairly constant composition: olivine and plagioclase persistently appearing as the only crystallized products and the refractive index varying only between the narrow limits of 1.604 to 1.615. Thus the composition must also be similar to that of the Recent sideromelan produced by the eruptions of Vatnajökull.

In the Pleistocene "Palagonitformation" sideromelan-tuff and breccia are abundant; and, furthermore, Peacock has proved that palagonit itself is the hydrogel of sideromelan. The palagonite-tuffs thus being the older sideromelan-tuffs which have suffered hydration usually by submersion or by hot-spring action. It seems very probable, therefore, that the great preponderance of palagonite in the Pleistocene formations of Iceland is due to the fact that favourable conditions for the formation of sideromelan were present: ultra-rapid chilling effect of the Pleistocene ice-sheet on the products of sub-glacial volcanoes.

This contention of Peacock is now verified by the observation that modern sideromelan is produced by the chilling effect of the Vatnajökull ice-sheet on basalt lava of sub-glacial outbursts.

The chief object of the two latest Danish-Icelandic expeditions to Vatnajökull was to observe at close quarters modern analogues of processes and events instrumental in the shaping of the inter-Glacial "Palagonitformation". Hope was entertained that some of the new-formed products at Vatnajökull might correspond to the tuffs or breccias in the "Palagonitformation" and thus give a clue to the genesis of various rock types of alleged sub-glacial origin.

In their recent report Nielsen and Noe-Nygaard (3) express their disappointment of not having encountered any such products. But I think it is safe to say that in the production of the volcanic ash we do have a modern analogue to the formation of the inter-Glacial sideromelan-tuff, the mother substance of an essential unit of the "Palagonitformation".

Summary.

Volcanic ash erupted from a sub-glacial volcano in Vatnajökull, 1922 and 1934, proved to be a brownish, transparent glass of plateau basaltic composition. It is a sideromelan (as defined by Peacock), representing thus a modern analogue to the Pleistocene sideromelans which in Iceland are the products of sub-glacially extruded basalt magma drastically chilled by contact with the superjacent Pleistocene ice-sheet.

References.

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Volcanic ash contains thallium (Tl), which is highly toxic to the biosphere. The aim of this study was to determine the Tl concentration in fractions of volcanic ash samples originating from the Eyjafjallajökull volcano. A sequential extraction scheme allowed for a study of element migration in the environment. Differential pulse anodic stripping voltammetry using a flow measuring system was selected as the analytical method to determine Tl content. The eruption of Grámsvötn, a subglacial volcano under the [Show full abstract] Vatnajökull glacier in Iceland during 21–28 May 2011 produced one of the most spectacular examples of ash and SO₂ separation, which led to errors in the forecasting of ash in the atmosphere over northern Europe.