SVERIGES GEOLOGISKA UNDERSÖKNING

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CHRISTER PERSSON

TEPHROCHRONOLOGICAL INVESTIGATION OF PEAT DEPOSITS IN SCANDINAVIA AND ON THE FAROE ISLANDS

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C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ

CONTENTS

Abstract

This paper reviews data previously published on tephrochronological investigations in Scandinavia and on the Faroes. Volcanic ash levels in peat deposits have been examined for grain-size distribution and refractive indices of the glass. Organic material associated with the ashes has been dated by the carbon-14 method. A regional correlation between the ash units and volcanic activity on Iceland is proposed.

Introduction

In his dissertation "Tefrokronologiska studier på Island" (Tephrochronological studies on Iceland) Thorarinsson mentioned the possibility of finding volcanic ash, derived from Icelandic eruptions, in peat deposits in Scandinavia and on the Faroe Islands (Thorarinsson 1944, p. 118).

During an excursion on Iceland in 1962 the possibility of regional tephrochronological correlation was discussed and on returning to Sweden an initial investigation was made of two mires. The results stimulated a continuation of the investigation which was enlarged to include six raised bogs and four other mires in Sweden, three mires on the Norwegian west coast and four mires on the Faroes.

Some Quaternary volcanic products have been recorded previously in Scandinavia. In Norway an ash layer has been found in gyttja from the Allerød period (Faegri, 1940, pp. 103–105) and pumice has been found on raised beaches in Spitsbergen, Norway, Denmark, and Sweden (Donner and West 1957; Marthinussen, 1960; Noe-Nygaard, 1951).

After the eruption of the Icelandic volcano Askja on 29th of March 1875 volcanic ash fell over mid-Scandinavia (Fig. 1) (Mohn, 1878; Nordenskiöld, 1876; Thorarinsson, 1944, pp. 96–112) and after the eruption of Hekla on 29th of March 1947 volcanic ash fell in the southern part of Finland (Salmi,

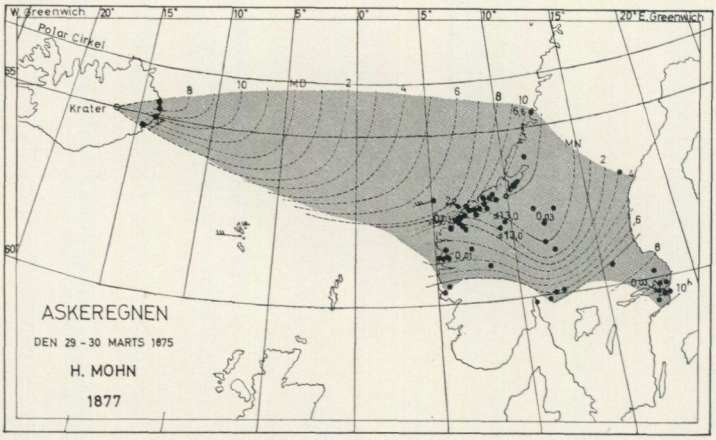

Fig. 1. The range of the ash fall after the eruption of Askja 1875 A. D. Broken lines show the isochrons for the beginning of the ash rain (Greenwich time), dots show the places where ash fall was reported and numbers give the thickness in millimetres (after Mohn 1878).

1948). Besides these, there are reports of ash falls from west Norway and the Faroes during the 17th and 18th centuries. These ash falls can be correlated with eruptions of the Icelandic volcanoes Hekla, Katla and Laki. The ashes produced in these eruptions were basic (Thorarinsson, 1944, pp. 118–120).

During the eruption of Öraefa in 1362 A. D. considerable amounts of acid tephra were produced. The tephra sector on Iceland was directed towards the east-south-east (Thorarinsson, 1958).

Among the pre-historic eruptions, those of Hekla are of special interest. These produced acid tephra, the tephra layers occurring extensively on Iceland (Thorarinsson, 1944 and 1951).

Prior to recent investigations (Persson 1966, 1967 b and 1968) no attempts had been made to locate volcanic ash units in mires of Scandinavia and on the Faroes or to correlate these ash units with Icelandic volcanicity. This paper summarizes attempts to establish the tephrochronological method for correlation of the Quaternary in Scandinavia. The characteristics of volcanic ash units of different localities are compared and associated organic material has been dated by the carbon-14 method.

The first time tephra layers were used for dating strata was in 1928 by Auer (1965). His attention was drawn to an ash layer in a profile from Tierra del Fuego, South America, and ". . . it was quite clear then that this kind of tephra would be of greatest importance for the quaternary geology". In all the bogs investigated in Tierra del Fuego, three ash layers were found which could be used as reference levels when discussing e. g. the history of vegetation and the variations of climate (Auer 1965, pp. 9–10).

The terms tephra, for all types of unconsolidated volcanic ejecta, and tephrochronology, for chronology based on tephra deposits, were introduced by Thorarinsson (1944), who has undertaken detailed tephrochronological studies on Iceland (Thorarinsson 1944, 1951, 1954, 1958, 1967).

In Germany tephra deposits from Laacher See have been investigated and dated (Frechen 1953; Straka 1956).

In cores taken by the Albatross expedition in deep-sea sediments of the eastern Mediterranean, layers of volcanic ash have been identified and investigated. The upper ash horizon was correlated with the Santorin-erouption, dated at 1800–1500 B. C. (Mellis, 1954).

An investigation of volcanic tephra from the eruption of Quizapú 1932, Chile, South America, has been made by Larsson (1936). The tephra was spread over large parts of Argentina.

A summary of the literature on volcanic ejecta deposits and their chronology in North America has been made by Wilcox (1965). He also discussed the recognition and identification of tephra beds.

In Japan, tephrochronology has been used for the dating of Quaternary deposits and pre-historical remains and for the correlation of terrace surfaces. By means of these investigations "evidence of climatic change, fluctuations of sea-level, glacial and peri-glacial phenomena in Japan have been fixed to their proper position in the Quaternary history" (Kobayashi, 1965, p. 783). In the same paper there is a list of Japanese literature on tephrochronology. A summary of tephrochronological studies in Japan up to 1958 has been made by Kaizuka (1958).

All these tephrochronological investigations deal with tephra layers visible by eye in a section or in a core. Attempts to locate and follow ash layers regionally by detailed examination of peat sections under the microscope do not seem to have been made previously.

Collection and chemical treatment of the peat

The material treated was collected by cutting pillar-samples from peat-pits where the stratification was visible. The edges of the square area of these pillar-samples were 10–12 cm and the pillars were divided into lengths of 50 to 60 cm which were packed in folio and kept in boxes. Drillcores have not been treated.

Due to the low concentration of volcanic ash in the Swedish and Norwegian mires, the peat had to be removed before the inorganic content could be investigated. The method used is that generally employed when separating diatoms from gyttja (Freund, 1958, pp. 427–428). Some small changes have been made in the method which is summarized here.

From the pillar-samples, specimens of c. 2 cm^3 were cut out, each one representing 2 vertical cm of the strata. The specimen was put into a round flask of pyrex together with 50 ml conc. H_2SO_4 and a crystal of $CuSO_4$. A Liebig-cooler was attached. The content was heated to the boiling-point over a Meker burner. Small amounts of KNO_3 were then added until the colour of the content turned light yellow. Boiling was continued for about 75 minutes. After cooling, the content should be colourless. This being the case the sample was put into an E-flask together with 400 ml of water. The liquid with the samples was left 3 hours and was then precipitated in a centrifuge and washed. The inorganic residue was kept in a centrifuge tube covered with folio.

In the samples from the Faroes the ash particles occurred in sufficient number for identification under the microscope without chemical treatment of the peat. From each centimeter of the strata collected, a small sample was taken out and investigated for volcanic ash under the microscope. If ash particles were found to be numerous a new sample was taken out and treated by the acetolys method (Erdtmann, 1934) in order to concentrate the particles for determination of the grain-size distribution of the ash and the refractive index of the glass.

Investigation of the inorganic material

When investigating mires from Sweden and Norway, slides were made with Cedax of the inorganic residue from each sample. Cover glasses 26×21 mm have always been used. From each sample at least two slides have been examined. If more than two particles were found per half slide, a new preparation was made and new slides were examined. Examination under the microscope was made with an enlargement of ×100 except for the samples from Kristiansundsmyren where a ×80 enlargement was used.

When analysing samples from the Faroes ×80 and ×200 magnifications were used.

In most ash units, the grain-size distribution of the ash has been investigated under the microscope. The largest diameter of each particle has been measured. The number of grains counted for analysis varies beetween 100 and 270. The results are shown in diagrams.

The determination of the refractive indice of the volcanic glass has been made with the Becke-line method.

Carbon-14 age-determinations

Organic material associated with the ash units has been dated by the carbon-14 method. The thickness of the peat layers taken out for dating has been about 2 cm. The work has been carried out at the Radioactive Dating Laboratory of

Stockholm. The carbon-14 age-determinations given are calculated with the oxalic acid as standard and the half-life 5568 ± 30 years. The ages are given with an accuracy of ± 1 δ.

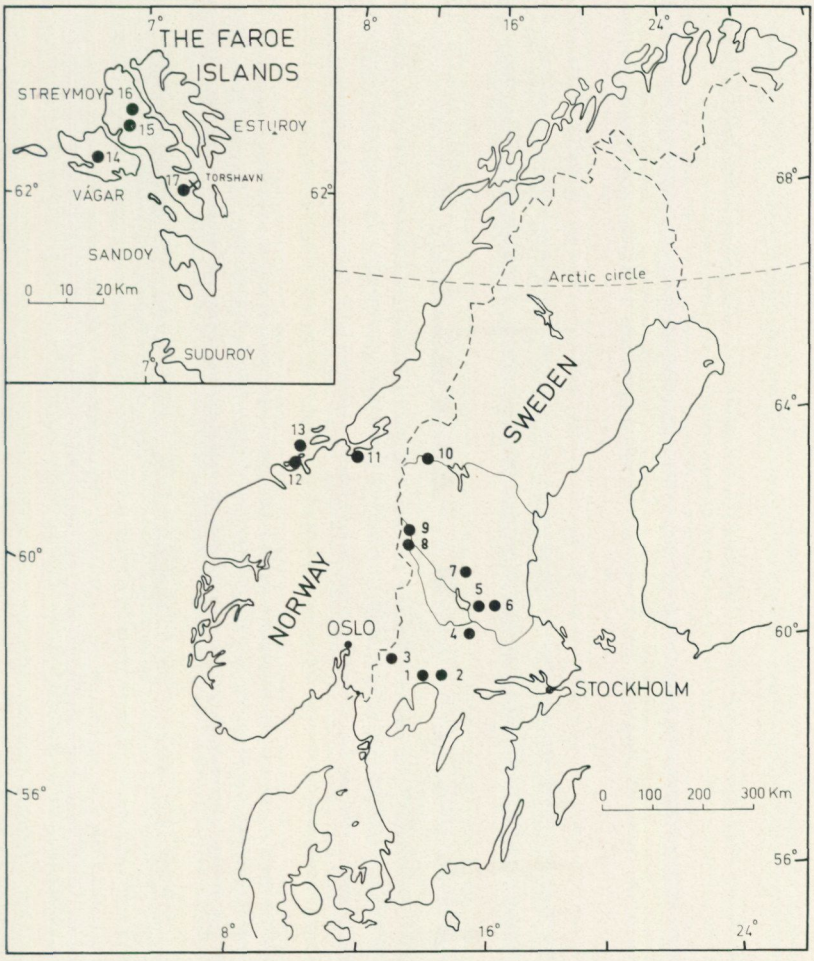

Fig. 2. Mires investigated.

1. Klaxsjömossen
2. Laskerudsmossen
3. Kortlandamossen
4. Mellstabromossen
5. Sundbornsmossen
6. Svensjömossen
7. Koppången
8. Lövåsmyren
9. Grövelsjömyren
10. Klockamyren
11. Sjetnemyren
12. Kristiansundsmyren
13. Setranmyren
14. Klovinmyren
15. Myrarnar
16. Saksunmyren
17. Havnardalsmyren

Description of the localities investigated

KLAXSJÖMOSSEN

A small raised bog 9.3 km west of Kil, the county of Värmland, Sweden.

The bog has been described and pollen-analytically investigated by Sandegren (1937, p. 98) and Persson (1966, pp. 381–384).

Fig. 3 shows the ash units found and the results of the carbon-14 age-determinations.

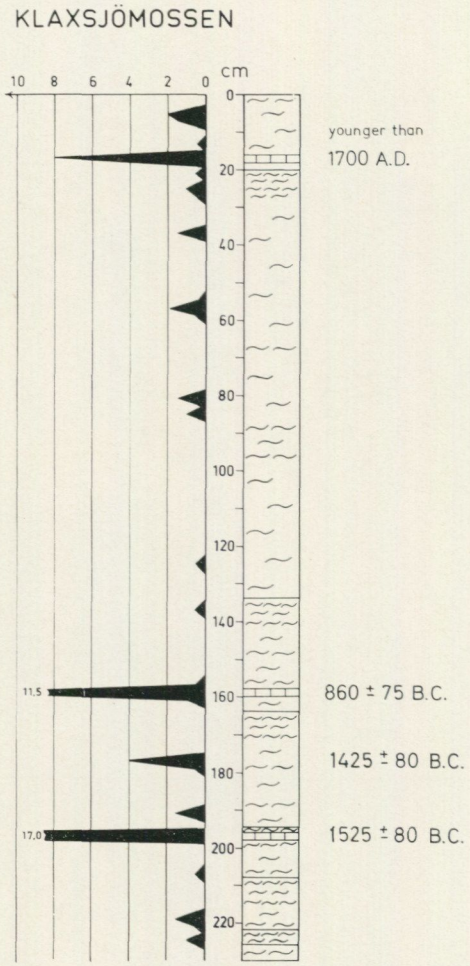

Fig. 3. The strata investigated at Klaxsjömossen. Left: The frequency of ash particles per half slide. Right: Results of the carbon-14 age-determinations. For explanations of the symbols see Fig. 18.

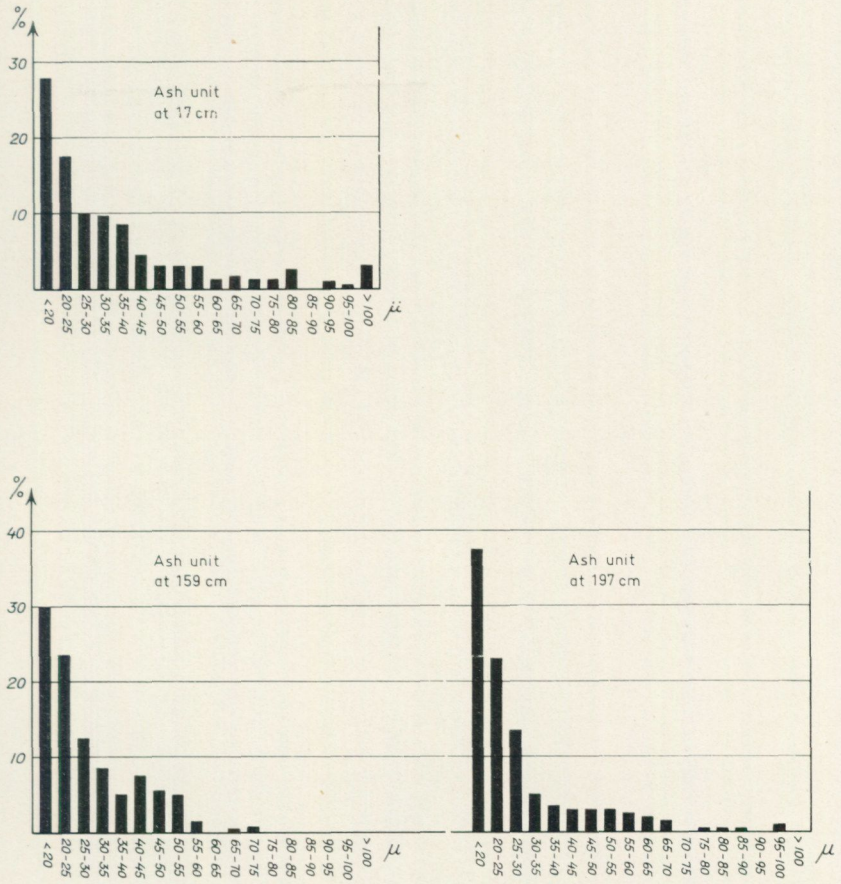

Fig. 4. Diagram from Klaxsjömossen showing the grain-size distribution of the volcanic ash.

LASKERUDSMOSSEN

A raised bog c. 26 km north-east of Karlstad, the county of Värmland, Sweden.

The bog has been described and pollen-analytically investigated by Granlund (1932, p. 116). Some years ago new samples were taken from this locality and several levels were carbon-14 dated (S. Odén, unpublished work). These age-determinations have been used in this investigation.

A pillar-sample 116 cm long has been examined for volcanic ash. The strata are composed of *Sphagnum* peat. One unit with volcanic ash has been found between 2 and 4 cm below the surface. Peat from 2 cm below the ash unit has given an age of 1875 ± 60 A. D. (Persson, 1966, pp. 379–382).

KORTLANDAMOSSEN

A raised bog 2 km north-west of Eda church, the county of Värmland, Sweden.

The bog has been described and pollen-analytically investigated by J. Lundqvist (1958, p. 163).

Only the uppermost 50 cm of the strata has been investigated for volcanic ash. The strata are composed of *Sphagnum* peat. One unit with ash has been found at 9 cm below the surface (Persson, 1966, pp. 384–386).

MELLSTABROMOSSEN

A raised bog c. 3 km north-east of Borlänge, the county of Dalecarlia, Sweden.

The bog has been described and a pollen diagram is presented in the description to the geological map-sheet Falun (Kulling, 1948, p. 148).

A pillar-sample 180 cm long has been investigated for volcanic ash. The strata are composed of *Sphagnum* peat (Persson, 1966, pp. 376–380).

Three units with volcanic ash have been fund, at 0–4 cm, 47 cm (age 860 ± 65 A. D.) and 123 cm (age 905 ± 80 B. C.).

SUNDBORNSMOSSEN

A small raised bog c. 5 km north-east of Falun, the county of Dalecarlia, Sweden.

The bog has been described by Kulling (1948, p. 158) and Persson (1966, pp. 375–378). In the description of the Quaternary deposits of Kopparberg County (G. Lundqvist, 1951, p. 92) there is a pollen diagram from Sundbornsmossen.

Samples covering 2 cm each of the strata have been investigated from the surface down to 170 cm. For the deeper part of the strata each sample investigated covered 5 cm.

Fig. 5 shows the ash units found and the results of the carbon-14 age-determinations. At the 23 cm level a carbon-14 determination has given an age younger than 1700 A. D. If this age is correct there are two possibilities:

1) The ash particles at the 23 cm level have been washed down by percolating water from the overlaying ash unit at the 10 cm level. This appears unlikely, however, as there is a significant difference in the grain-size distribution in the two ash units (Persson, 1966, pp. 385–386) and as the frequency of ash particles between the two units is very low.

2) The ash units belong to two separate ash falls. This is favoured by the above mentioned difference in grain-size distribution. However, a unit of similar age has been found in Sweden at Klaxsjömossen where it should most

probably be correlated with the Askja 1875 ash fall. Ash units from Setranmyren and Sjetnemyren in Norway have been dated at 1620 ± 80 A. D. and 1460 ± 65 A.D. respectively. These units might correspond to the unit in Sundbornsmossen, but if they do the carbon-14 age of the ash unit in Sunbornsmossen is too low.

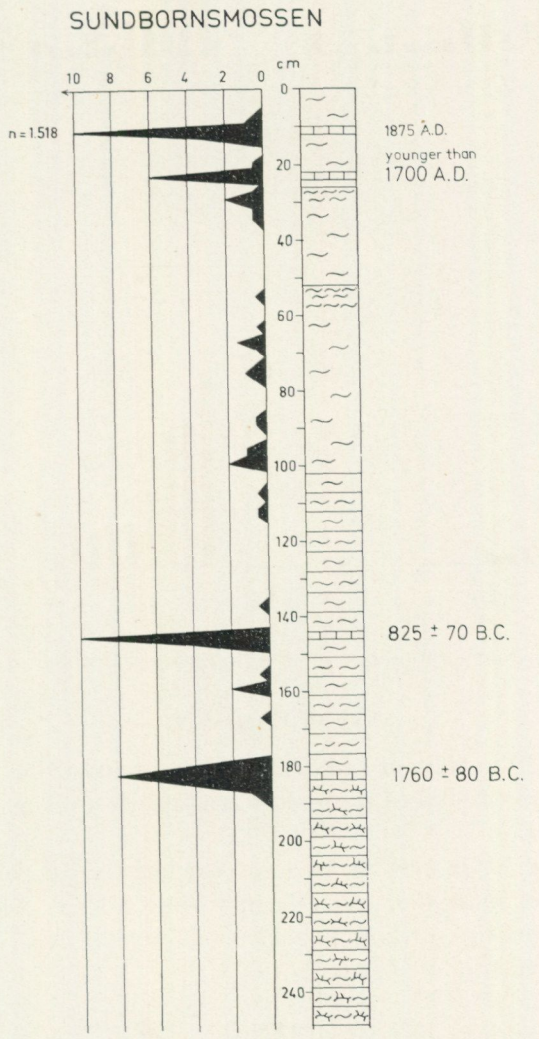

Fig. 5. The strata investigated at Sundbornsmossen. Left: the frequency of ash particles per half slide and refractive index of the glass. Right: Results of carbon-14 age-determinations. För explanations of the symbols, see Fig. 18.

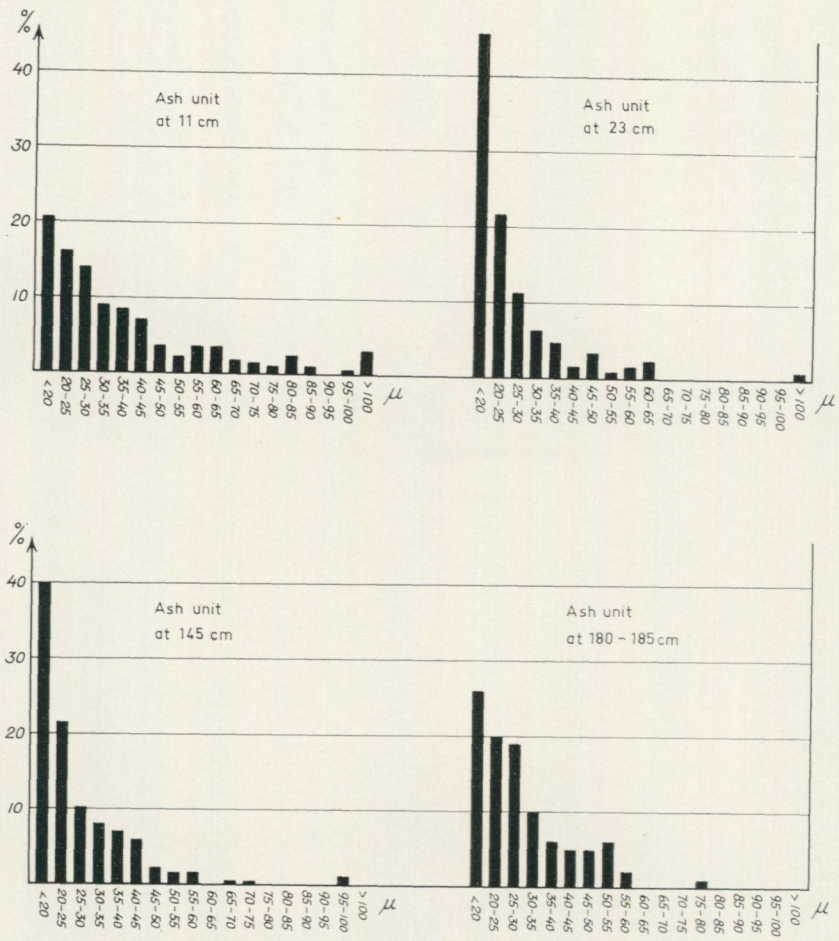

Fig. 6. Diagram from Sundbornsmossen showing the grain-size distribution of the volcanic ash.

SVENSJÖMOSSEN

A raised bog c. 3 km west of Lumsheden, the county of Dalecarlia, Sweden. The bog has been described and pollen-analytically investigated by G. Lundqvist (1951, p. 131).

A pillar-sample 50 cm long has been investigated for volcanic ash. The strata are composed of *Sphagnum* peat. One unit whith volcanic ash has been found at 10–14 cm below the surface. The refractive index of the volcanic glass is 1.518 $\pm$0.002 (Persson, 1966, pp. 373–375).

KOPPÅNGEN

A soligenous mire 6.5 km north-east of Emådalen, the county of Dalecarlia, Sweden.

The mire has been described and pollen-analytically investigated by G. Lundqvist (1951, pp. 178–180).

A pillar-sample 40 cm long has been investigated for volcanic ash. The strata are composed of *Carex-Sphagnum* peat and *Carex* peat. No unit with volcanic ash has been found. The soligenous mire type is very unsuitable for this kind of investigation. Ash particles falling on the mire are likely to have been washed away by streaming surface water (Persson, 1966, pp. 373–374).

LÖVÅSMYREN

A mire south-east of Grövelsjön near Lövåsen, the county of Dalecarlia, Sweden.

The mire has been described by G. Lundqvist (1951, pp. 185–186).

A pillar-sample 40 cm long has been investigated for volcanic ash. The strata are composed of sedge-moss peat. One unit with volcanic ash was found 13 cm below the surface. The number of ash particles is, however, low (only five per half slide). In addition, there was an increase of ash particles at 27 cm (Persson, 1966, pp. 372–374).

GRÖVELSJÖMYREN

A mire 2 km south of the tourist station of Grövelsjön, the county of Dalecarlia, Sweden. It is located on a slope.

The mire has been described and pollen-analytically investigated by G. Lundqvist (1951, p. 184) and Persson (1966, pp. 371–372).

Fig. 7 shows the ash units found and the result of the carbon-14 age-determination.

There is a significant difference in the grain-size distribution of the ash particles in the two uppermost units. Particles of volcanic ash also appear between 40 and 48 cm below the surface. This level lies just above the rise of the *Picea* curve which is here assumed to be about 900 B. C.

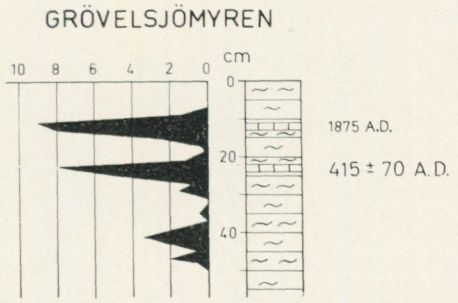

Fig. 7. The strata investigated at Grövelsjömyren. Left: The frequency of ash particles per half slide. Right: Result of carbon-14 age-determination. For explanations of the symbols, see Fig. 18.

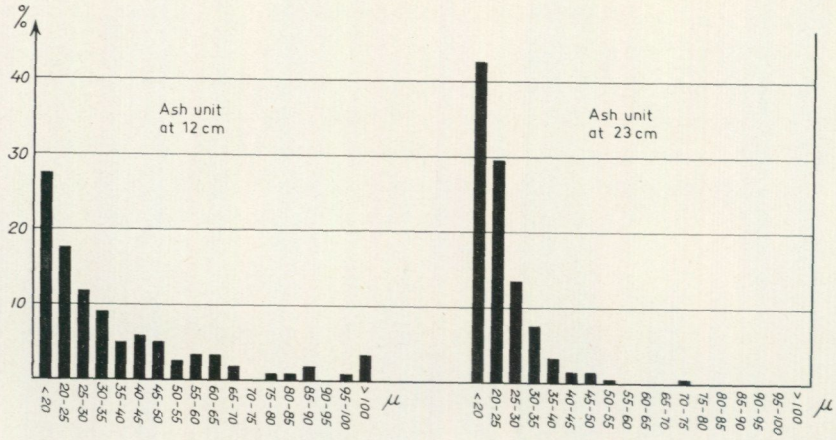

Fig. 8. Diagram from Grövelsjömyren showing the grain-size distribution of the volcanic ash.

KLOCKAMYREN

A mire, west of lake Ånn, the county of Jämtland, Sweden.

The mire has been described and pollen-analytically investigated by J. Lundqvist (1969, pp. 270–272).

A pillar-sample 190 cm long has been investigated for volcanic ash. The strata are composed of *Sphagnum* peat and sedge-moss peat (Persson, 1966, pp. 369–371).

Two units with volcanic ash have been found, at 23 cm and 71 cm below the surface. The frequency of ash particles is rather low in both units. The uppermost unit has been dated at 1375 ±65 A. D. and the lowermost at 1750 ±75 B. C. In the uppermost 15 cm of the strata there is an increase of ash particles but no clear unit can be identified, because in that part of the strata the content of inorganic material is large making identification of ash particles difficult.

SJETNEMYREN

A mire 8.5 km south of Trondheim, the county of Sör-Tröndelag, Norway.

A pillar-sample 60 cm long has been investigated for volcanic ash. The strata are composed of *Sphagnum* peat (Persson, 1967 b, pp. 190–192).

Three clear units with volcanic ash have been identified, at 7 cm, 25 cm and 59 cm below the surface. In the uppermost unit the refractive index of the glass has been determined at 1.518 ±0.003 and partly 1.500 ±0.003. The unit at 25 cm has been dated at 1460 ±65 A. D. and the refractive index of the glass has been determined at 1.500 ±0.003. The two ash units show a significant difference in the grain-size distribution (Persson, 1967 b, p. 192). The lowermost unit at 59 cm has been dated at 850 ±70 A. D.

KRISTIANSUNDSMYREN

A mire c. 6 km south-south-east of Kristiansund, the county of Möre and Romsdal, Norway.

A pillar-sample through the complete sequence of peat, 160 cm, has been investigated for volcanic ash (Persson, 1967 b, pp. 188–190).

Fig. 9 shows the ash units found and the results of the carbon-14 age-determinations. The refractive indices are given with an accuracy of ± 0.003.

Due to a rather low concentration of ash particles in the lowermost unit it has not been possible to examine the grain-size distribution or the refractive index of this ash.

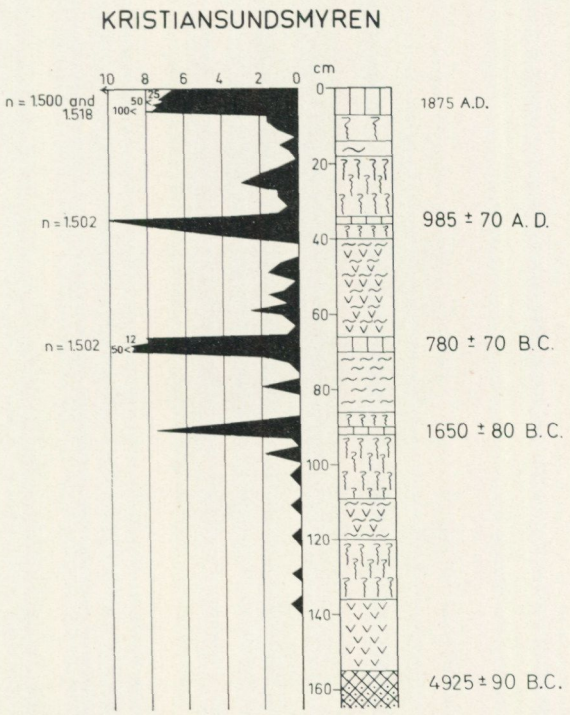

Fig. 9. The strata investigated at Kristiansundsmyren. Left: The frequency of ash particles per half slide and refractive indices of the glass. Right: Results of the carbon-14 age-determinations. For explanations of the symbols, see Fig. 18.

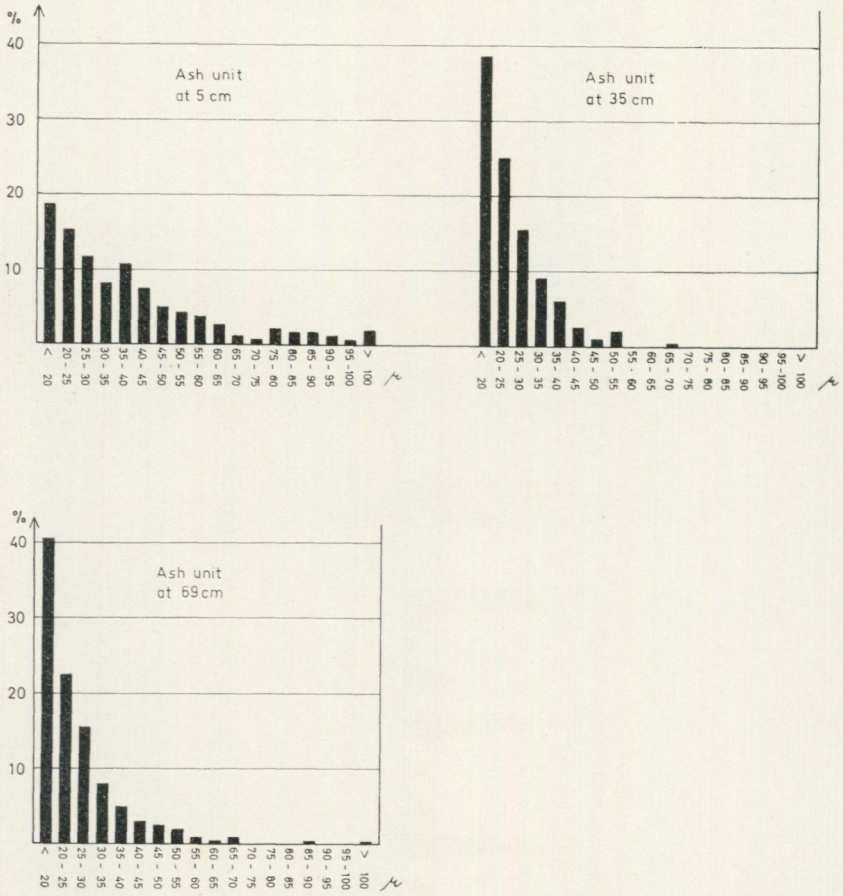

Fig. 10. Diagram from Kristiansundsmyren showing the grain-size distribution of the volcanic ash.

SETRANMYREN

A mire 2.5 km south-east of Hopen on the island of Smøla, the county of Möre and Romsdal, Norway.

A pillar-sample through the complete sequence of peat, 220 cm, has been investigated for volcanic ash (Persson, 1967 b, pp. 184–187).

Fig. 11 shows the ash units found and the results of the carbon-14 age-determinations. The refractive indices are given with an accuracy of ± 0.003.

At the level 15 cm there is an increase of ash particles but the number is rather low. The particles might have been washed down from the overlying unit but might also indicate a separate ash fall. Due to the low concentration it has not been possible to investigate these ash particles.

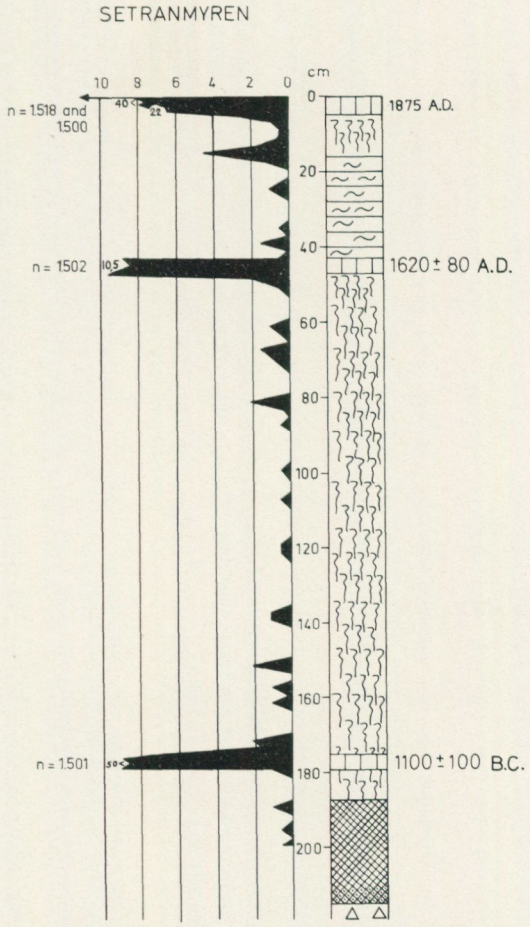

Fig. 11. The strata investigated at Setranmyren. Left: The frequency of ash particles per half slide and refractive indices of the glass. Right: Results of carbon-14 age-determinations. For explanations of the symbols, see Fig. 18.

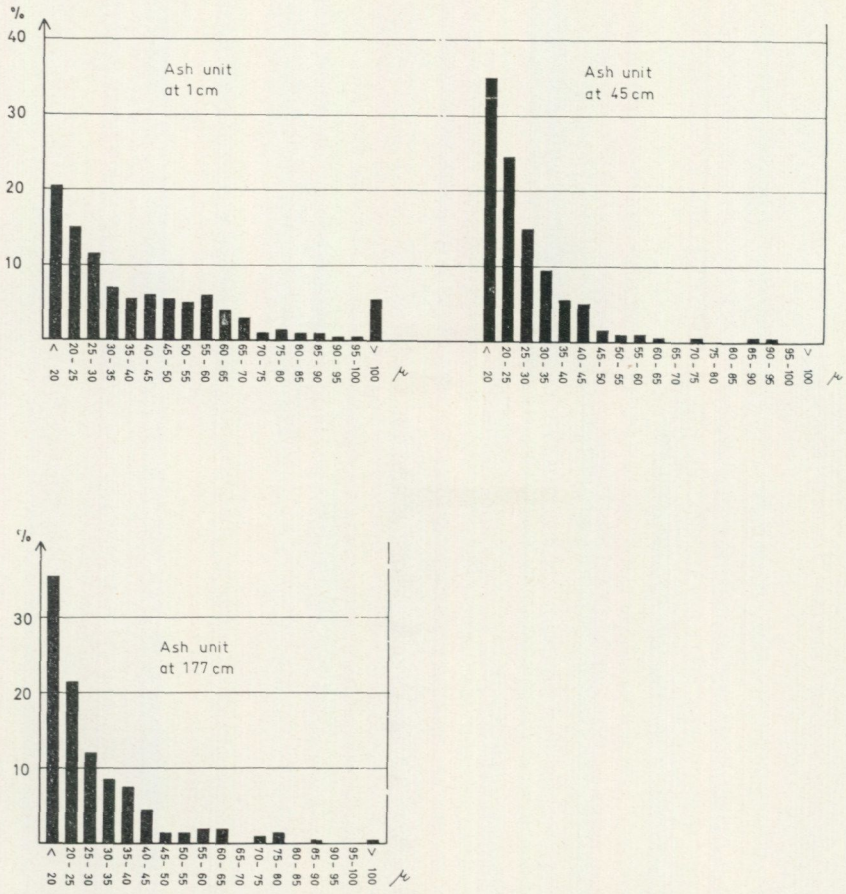

Fig. 12. Diagram from Setranmyren showing the grain-size distribution of the volcanic ash.

KLOVINMYREN

A mire 2.3 km east of Sörvágur, the island of Vágar, the Faroes.

A pillar-sample through the complete sequence of peat, 280 cm, has been investigated for volcanic ash (Persson, 1968, pp. 250–258).

Two layers with volcanic ash have been found, at 35–52 cm and 72–101 cm. The lowermost of these is divided into two sub-layers. Fig. 13 shows the results of the carbon-14 age-determinations. The refractive indices are given with an accuracy of ± 0.003.

The uppermost carbon-14 age-determination indicates that the mire plain has been lowered by peat-cutting.

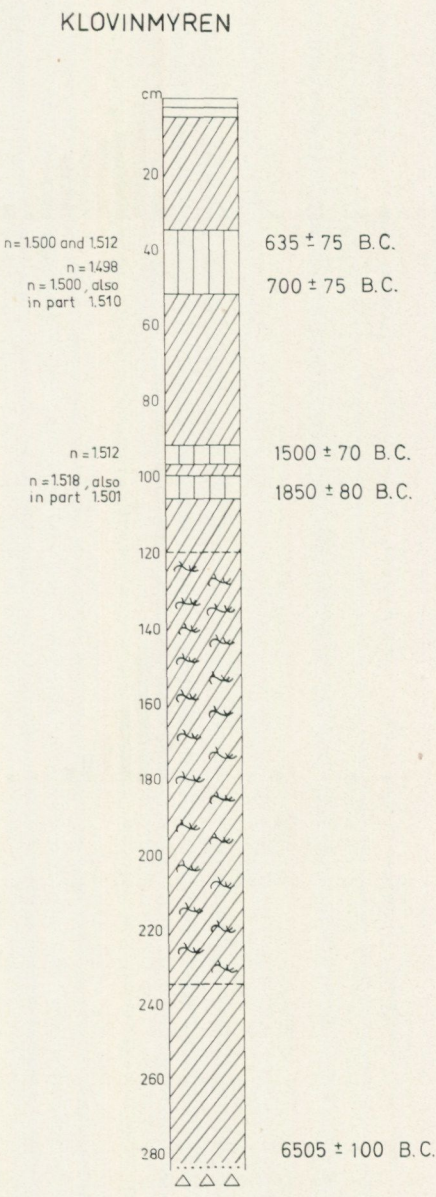

Fig. 13. The strata investigated at Klovinmyren. Left: Refractive indices of the glass. Right: Results of the carbon-14 age-determinations. For explanations of the symbols, see Fig. 18.

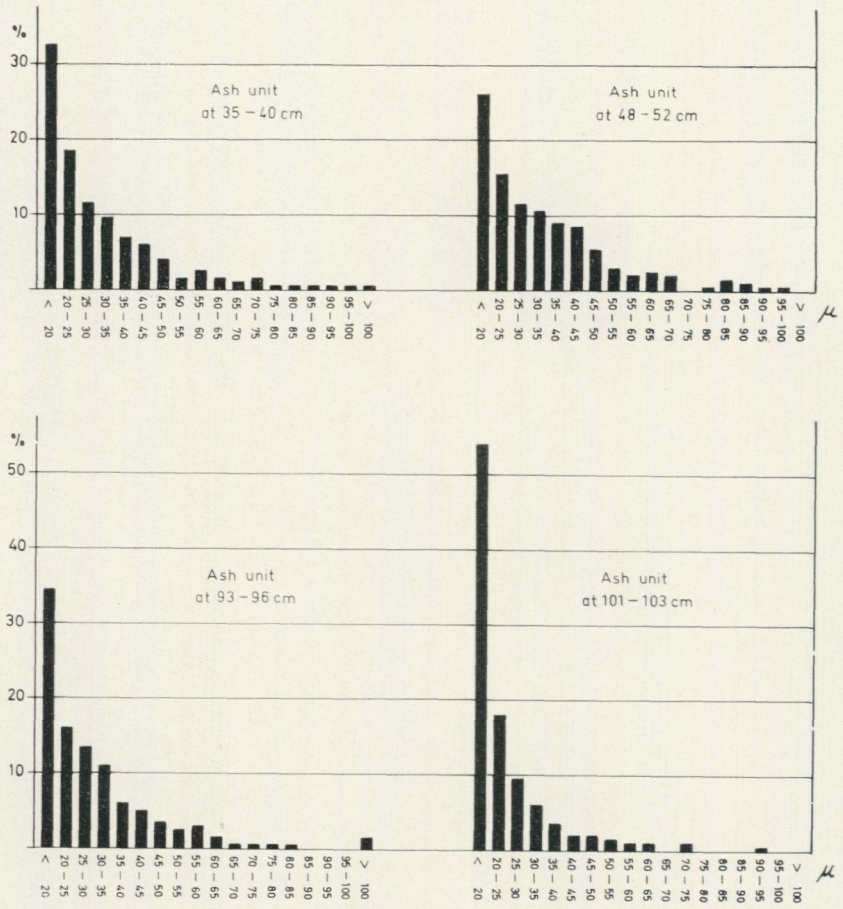

Fig. 14. Diagram from Klovinmyren showing the grain-size distribution of the volcanic ash.

MYRARNAR

A mire c. 4 km east-north-east of Vestmannahavn, the island of Streymoy, the Faroes.

A pillar-sample through the complete sequence of peat, 125 cm, has been investigated for volcanic ash (Persson, 1968, pp. 247–251).

Two layers with volcanic ash have been found, at 20–23 cm and 73–87 cm below the surface. The lowermost of these is divided into two sub-layers. Fig. 15 shows the results of the carbon-14 age-determinations. The refractive indices are given with an accuracy of ± 0.003.

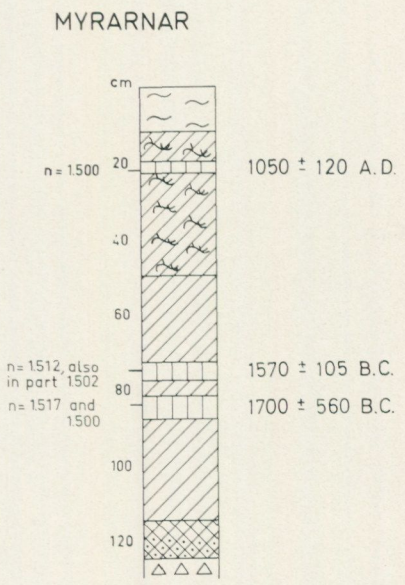

Fig. 15. The strata investigated at Myrarnar. Left: Refractive indices of the glass. Right: Results of the carbon-14 age-determinations. For explanations of the symbols, see Fig. 18.

SAKSUNMYREN

A mire 3 km north-west of Hvalvík, the island of Streymoy, the Faroes.

A pillar-sample through the complete sequence of peat, 170 cm, has been investigated for volcanic ash. The strata are composed of fen peat and gyttja. Between 40 and 115 cm the fen peat contains remains of *Calluna* and *Juniperus*. The carbon-14 dating at the 11 cm level shows that the youngest part of the sequence is missing from the pillar-sample. The surface of the mire has probably been lowered by peat-cutting (Persson, 1968, pp. 245–248).

Two layers with acid volcanic ash have been found, at 10–16 cm and 52–67 cm below the surface. The uppermost of these has been dated at 365 ±70 A. D. and the refractive index of the glass is 1.503 ±0.003. In the ash layer at 52–67 cm the level 55 cm has been dated at 1125 ±100 B. C. and the level 65 cm at 1400 ±130 B. C. The refractive indices of the glass show different values at different levels. At 64 cm the refractive index is 1.498 ±0.003 and in part 1.518 ±0.003 while two centimetres above the dominating value is 1.518 ±0.003 and in part 1.500 ±0.003. Higher up in the layer the refractive index is 1.510 ±0.003 and in part 1.502 ±0.003.

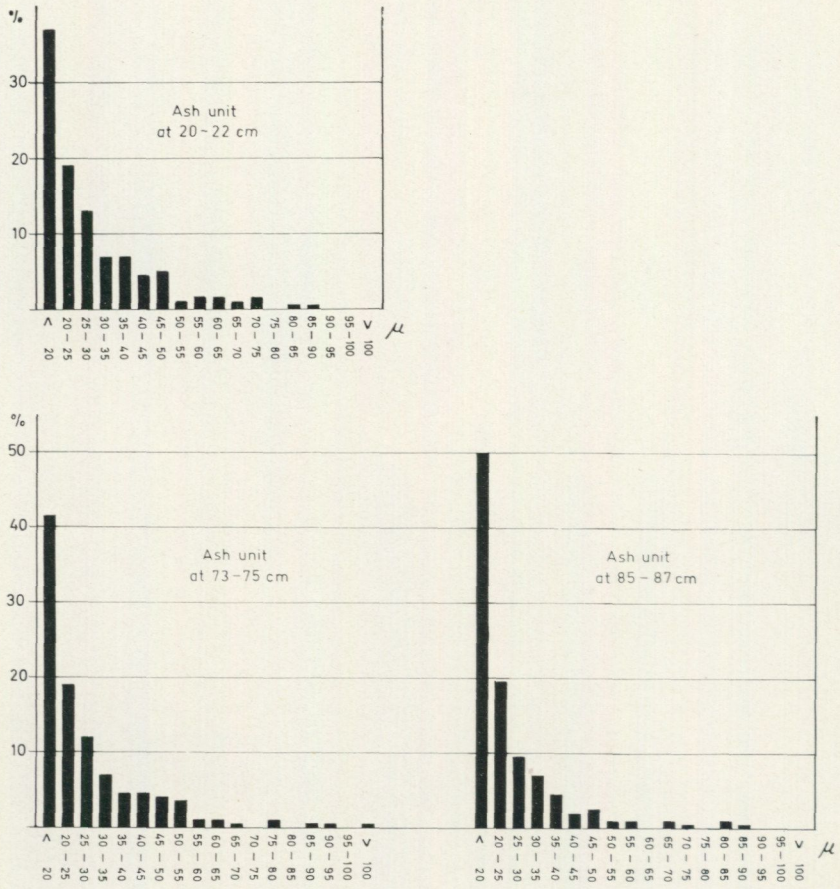

Fig. 16. Diagram from Myrarnar showing the grain-size distribution of the volcanic ash.

HAVNARDALSMYREN

A mire 3.8 km west-north-west of Tórshavn, the island of Streymoy, the Faroes.

A pillar-sample through the complete sequence of peat, 160 cm, has been investigated for volcanic ash. The strata are composed of fen peat. Between 35 and 85 cm the fen peat contains remains of *Calluna* and *Juniperus* (Persson, 1968, pp. 258–260).

One layer of volcanic ash has been found at 5–30 cm below the surface. The refractive indices of the glass are in the lower parts of the layer 1.500 $\pm$0.003 and in part 1.518 $\pm$0.003. Higher up the values 1.518 $\pm$0.003 and, for a small part, 1.500 $\pm$0.003 were obtained. At the 16 cm level the refractive

indices were determined at 1.501 ±0.003 and in part 1.511 ±0.003. Higher up the latter value dominates. At the 5 cm level two values were obtained, 1.502 ±0.003 and 1.513 ±0.003.

No age-determination has been made but the data on the ash make it probable that the layer can be correlated with the oldest layer in the other localities investigated from the Faroes. If so the mire plain has probably been lowered by peat-cutting, the part of the strata younger than c. 1500 B. C. having been dug away. Besides this ash layer there occur ash particles at the level 62 cm, but the concentration is much too low to allow investigation of the ash.

Results

This investigation has demonstrated that:

1. in the mires investigated in Sweden, Norway and on the Faroes particles of acid volcanic ash commonly occur
2. these acid ash particles are not randomly distributed throughout the sections but are concentrated in well defined units
3. the concentration of ash particles in the units increases towards west and north-west. This favours derivation of the ashes from some place west or north-west of the Faroes, probably Iceland
4. the carbon-14 age-determinations indicate that the ash units found fall into six major groups; at 1875 A. D., 1375–1620 A. D., 850–1050 A. D., 365–415 A. D., 635–1100 B. C., and 1525–1850 B. C.
5. no ash unit has been registered between c. 5000–2000 B. C.

None of the investigated levels on the Faroes seem to be older than c. 6500 B. C. In Norway the oldest strata investigated were formed c. 5000 B. C. and in Sweden c. 4500 B. C. All the ash units described here are compared in Fig 17. Comments on the sources of possible errors are given in the chapter "Comments".

GROUP 1 (1875 A. D.)

The volcanic ash deriving from the eruption of Askja in 1875 A. D. although falling over large parts of mid-Scandinavia, was not recorded to touch the Faroes (Mohn, 1878; Nordenskiöld, 1876). In samples collected immediately after the ash rain in Norway and Sweden, the refractive index of the volcanic glass was determined at 1.503 (Drivfjellet, Trysil, Norway), 1.503 and in part 1.518 (Storbo, Norway) and at 1.518 and in part 1.503 (Haga, Sweden) (Tho-

rarinsson, 1944, Tab. IV). In samples collected on Iceland the refractive index of the glass was determined at 1.501 ±0.002 (Persson, 1967 a, p. 505).

Ash from the eruption of Askja 1875 A. D. has been found in all the mires investigated in Sweden and Norway with the exception of Koppången and Klockamyren. In Sundbornsmossen and Svensjömossen the refractive index of the glass has been determined at 1.518 and in the three localities from Norway the refractive index of the glass has been determined at 1.518 ±0.003 and also 1.500 ±0.003. When comparing the grain-size distribution of the ash in the samples collected immediately after the ash rain with the grain-size distribution of the ash belonging to this group found in the mires no significant difference has been detected (Persson, 1966, pp. 385–386; 1967 b, p. 192). A carbon-14 age-determination of the uppermost unit in Klaxsjömossen has indicated that the ash unit was formed later than 1700 A. D. and a determination from 2 cm below the unit in Laskerudsmossen has given the age 1875 ±60 A. D.

GROUP 2 (1375–1620 A. D.)

Ash units belonging to the second main group, 1375–1620 A. D. have been found in Sjetnemyren (1460 ±65 A. D.), Setranmyren (1620 ±80 A. D.) and Klockamyren (1375 ±65 A. D.). It is possible that the unit in Sunbornsmossen (younger than 1700 A. D.) also belongs to this group. In the units in Sjetnemyren and Setranmyren the refractive index of the glass has been determined at 1.501 ±0.003 (mean value). The grain-size distribution of the ash particles shows a significant difference from the grain-size distribution of the particles emanating from the eruption of Askja 1875 A. D. It appears probable that particles from this level in the four localities derive from the same ash fall.

On Iceland there is no acid tephra layer between 1170 A. D. and 1875 A. D. except for that produced by Öraefa 1362 A. D. The SiO_2-content of this tephra is 68.56–70.14 % (two analyses) (Thorarinsson, 1958, p. 40) and the corresponding value of the refractive index should be c. 1.501 (Thorarinsson, 1944, p. 89). The tephra sector on Iceland lies to the east-south-east and the thickness of the tephra layer within the central parts of the sector is larger than 20 cm. It may be ash from the eruption of Öraefa 1362 A. D. that has been found in the four localities in Scandinavia. If this is the case the carbon-14 age-determinations of these units in Scandinavia show excessively young ages. This is explicable if the removal from the dated samples of roots and radicles from the surface vegetation was incomplete.

GROUP 3 (850–1050 A. D.)

Ash units belonging to the third group, 850–1050 A. D. have been found in Mellstabromossen (860 ±65 A. D.), Sjetnemyern (850 ±70 A. D.), Kristian-

sundsmyren (985 ±70 A. D.), and in Myrarnar (1050 ±120 A. D.). The similarity in age of the units makes it probable that the ash was derived from the same ash fall. The refractive index of the volcanic glass has been determined at 1.502 ±0.003 in Kristiansundsmyren and at 1.500 ±0.003 in Myrarnar.

On Iceland there are two layers with acid tephra which might correspond to the units mentioned above. One of these is a layer referred to as Hekla I, dated at 1104 A. D. (Thorarinsson, 1967, pp. 30–38). The SiO_2-content of the ash is 66.84–65.70 % (two analyses) (Thorarinsson, 1967, p. 165) and the corresponding value of the refractive index of the glass should be c. 1.502 (Thorarinsson, 1944, p. 89). The tephra layer is rather widespread in northern Iceland. If the ash units in Scandinavia and on the Faroes correspond to the layer Hekla I on Iceland, the carbon-14 determinations have yielded too high ages. This could possibly be related to transport downwards of the ash particles by percolating water, but it is not clear why this should lead to a concentration at one level. The other Icelandic tephra layer with which the units might be correlated is named "layer G" (Thorarinsson, 1958, p. 50), or "layer VII a+b" (Thorarinsson, 1967, pp. 19–21). This layer has been dated at 850–900 A. D. on the basis of archaeological and pollen-analytical data. The tephra emanents from a locality east of Hekla and the acid part of the layer is thickest to the north and north-east of Hekla. The refractive index of the acid glass is 1.50.

GROUP 4 (365–415 A. D.)

Ash units belonging to the fourth group, 365–415 A. D., have been found in Grövelsjömyren (415 ±70 A. D.) and in Saksunmyren (365 ±70 A. D.). The refractive index of the glass in Saksunmyren has been determined at 1.503 ±0.003. It is very uncertain whether the ash units found in these two localities represent a single ash fall. On Iceland there is no acid tephra layer of similar age that can be correlated with the units in Grövelsjömyren and Saksunmyren.

GROUP 5 (635–1100 B. C.)

Ash units belonging to this group have been found in Klaxsjömossen (860 ±75 B. C.), Mellstabromossen (905 ±80 B. C.), Sundbornsmossen (825 ±70 B. C.), Kristiansundsmyren (780 ±70 B. C.), Setranmyren (1100 ±100 B. C.) and in Klovinmyren (635 ±75 B. C. for the upper part of the layer and 700 ±75 B. C. for the lower part). It is also possible that the concentration of ash particles in Grövelsjömyren at the 40–48 cm level, pollen-analytically dated at c. 900 B. C., belongs to this group. The refractive index of the volcanic glass has been determined at 1.502 ±0.003 in Kristiansunds-

myren and at 1.500 ±0.003 and in part 1.511 ±0.003 (mean value) in Klovinmyren.

On Iceland there is an acid tephra layer of similar age with a widespread distribution north and north-east of Hekla. This layer is named Hekla III and has been dated at 870 ±70 B. C. (Kjartansson et al., 1964, p. 142; Thorarinsson, 1967, p. 21). The refractive indices of volcanic glass on Iceland from this eruption have been determined at 1.512 ±0.002 (mean value) and 1.502 ±0.002 (mean value). In two samples values of 1.518 ±0.002 were also obtained. Two chemical analyses show a SiO_2-content of 63.9 % and 68.99 % (Persson, 1967 a, pp. 512–513). It seems very probable that the units belonging to the group 635–1100 B. C., found in Scandinavia and on the Faroes, can be correlated with the Icelandic tephra layer Hekla III.

GROUP 6 (1525–1850 B. C.)

Ash units belonging to this group have been found in Klaxsjömossen (1525 ±80 B. C.), Sundbornsmossen (1760 ±80 B. C.), Klockamyren (1750 ±75 B. C.), Kristiansundsmyren (1650 ± 80 B. C.), (the only localities in Scandinavia where so old levels have been investigated) and in all the mires investigated on the Faroes. The corresponding ash layers on the Faroes are divided into two sub-layers. The upper of these has been dated at 1500 ±70 B. C. in Klovinmyren and at 1570 ±105 B. C. in Myrarnar; the lower at 1850 ±80 B. C., and 1700 ±560 B. C., respectively. In addition a layer has been found in Saksunmyren divided into two sub-layers but in which the carbon-14 age-determinations do not fall within the specified limits. The upper sub-layer in Saksunmyren has been dated at 1125 ±100 B. C. and the lower at 1400 ±130 B. C. In spite of these differences in age in Saksunmyren there is little doubt that the sub-layers can be correlated with the sub-layers found in Klovinmyren and Myrarnar. The grain-size distribution of the ashes and the refractive indices of the glass in the ashes favour correlation. It would appear that the ash layer in Havnardalsmyren between 5 and 30 cm also belongs to this group. Both the grain-size distribution of the ash and the refractive indices of the glass correspond to the values of the two sub-layers in the other localities on the Faroes.

The refractive indices of the glasses in the younger sub-layers have been determined at 1.510 ±0.003 and in part 1.502 ±0.003, while in the older sub-layers they are 1.518 ±0.003 and 1.500 ±0.003. The difference in the grain-size distribution between the two sub-layers is significant in Klovinmyren, Saksunmyren and Havnardalsmyren (Persson, 1968, p. 261).

On Iceland there are two acid tephra layers which might be correlated with the ash layers belonging to the group 1525–1850 B. C. found in Scandinavia and on the Faroes. One of these is named Hekla IV. This layer has a widespread distribution north of Hekla and has been dated at 1880 ±120 B. C. (Thora-

rinsson, 1958, p. 49). The age has later been changed to 2080 B. C. (Thorarinsson, 1967, p. 21). The layer on Iceland is differentiated and the tephra in the upper part is basic. The refractive index of the acid tephra on Iceland has been determined at 1.501 ±0.002 (mean value) and in two samples also the values 1.512 ±0.002 and 1.508 ±0.002 were obtained (Persson, 1967 a, p. 516).

The other tephra layer is named Hekla II (the Selsund pumice) the age of which lies between Hekla III and Hekla IV (Thorarinsson, 1967, p. 21). The refractive index of the glass is about 1.510 (Thorarinsson, 1967, p. 181). This layer has been correlated with an ash unit dated at 1560 ±120 B. C. found on the Faroes (Waagstein, 1968, p. 258).

It seems rather probable that the ash units belonging to the group 1525–1850 B. C. found in Scandinavia and on the Faroes are derived from either the eruption of Hekla IV or Hekla II. The results from the Faroes, where the layer is divided into two sub-layers, can be interpreted in different ways. The ash in the sub-layers can either emanate from outbursts of two different vulcanoes, one being Hekla, or from two different eruptions of Hekla. According to the carbon-14 age-determinations of the sub-layers, the interval between the eruptions is 150 to 350 years. However, there are no published data to suggest that either the layer Hekla IV or Hekla II on Iceland is derived from two acid tephra falls.

Assuming general correlation of the two sub-layers on the Faroes with the units of similar age in Scandinavia, it is of interest to consider the precise correspondence of the different units. In Klaxsjömossen, 20 cm above the 197 cm level (1525 ±80 B. C.) there is a minor concentration of volcanic ash. About 100 years separates these two levels. It is therefore possible that the two sub-layers on the Faroes should be correlated with the major (197 cm) and minor (177 cm) levels in Klaxsjömossen, and that the lower of these is equivalent to the ash layers of similar age in the other Scandinavian localities.

The refractive indices of the glasses in the Hekla II and Hekla IV tephras and that in the sub-layers on the Faroes show notable differences. However, these differences are not greater than those obtained in Iceland and Scandinavia for the ashes derived from the eruption of Askja 1875. The samples examined from Hekla IV were all taken from the lower parts of the layer (Persson, 1967 a, p. 515) and in view of the differentiation of the unit further work will be necessary to establish the limits of the variation.

Comments

1. During an ash fall the particles tend to be concentrated in surface depressions. This is particularly the case when the ash particles fall together with rain or snow (Salmi, 1948, p. 88). Thus, ash rains with low concentrations of particles will be identified only under favourable circumstances. For this

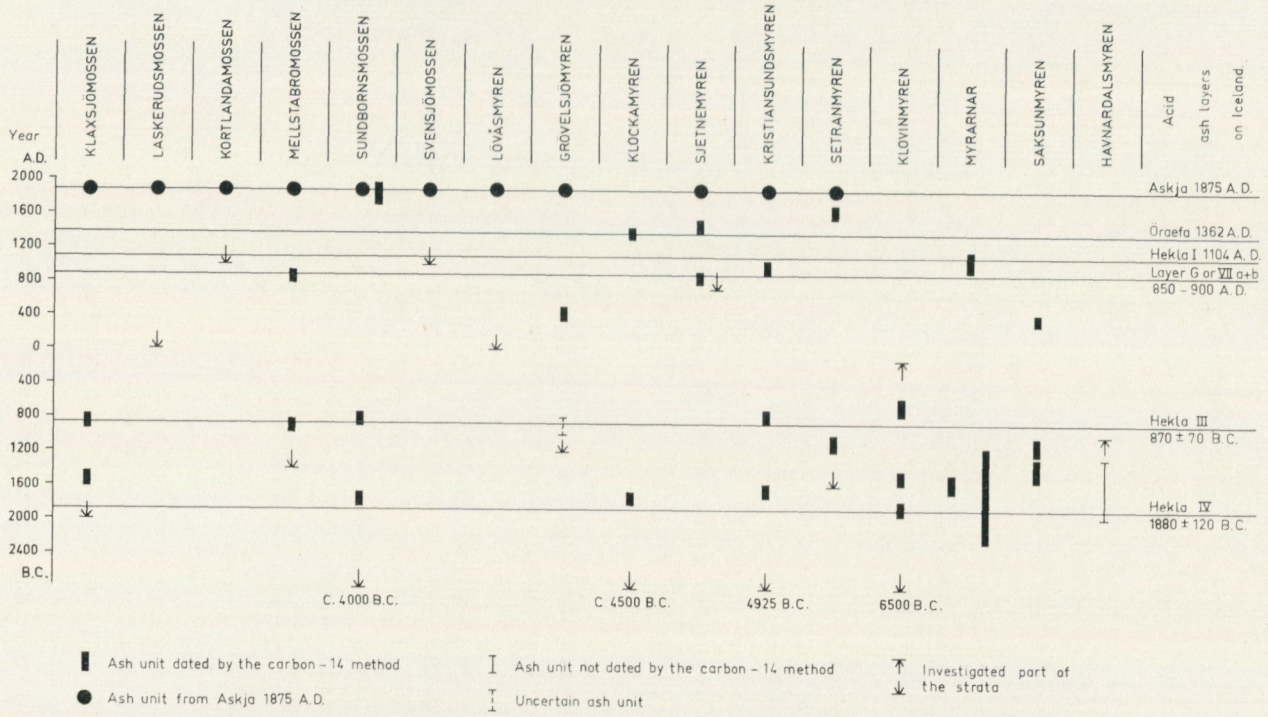

Fig. 17. An arrangement of the carbon-14 age-determinations of the units containing volcanic ash found in mires in Scandinavia and on the Faroes compared with acid tephra layers on Iceland. The carbon-14 age-determinations are drawn with an accuracy of $\pm 1\ \delta$.

reason a quantitative investigation of the number of ash particles per volume peat has not been carried out.

2. Ash particles smaller than 20 μ are not identifiable with the methods used.

3. The amount of peat investigated from each level has been small, being controlled largely by the necessity for rapid processing. Larger amounts would have given a better control of the individual layers but would have considerably restricted the scope of the investigation.

4. In Sweden raised bogs rather than other types of mires have been selected for this investigation. In the latter there is a considerable risk of redeposition of ash particles by streaming water. Also high waters of water basins on mires might create a redeposition of an ash unit. The mires on the Faroes are often situated on slopes and the risk is very great that ash particles have been transported by water and re-deposited lower down on the mire surface or even transported away from the mire. This might be one reason why an ash layer is found in one sequence and is missing in another. On the Faroes the ash layers are often rather thick, as in the case of Klovinmyren between 35 and 52 cm. This might depend on transport and redeposition of particles.

5. On steep slopes peat situated relatively high on the slope has been known to "float" out on to the lower ground, resulting in inversion of the strata. There was no evidence of secondary stratification of this kind in the mires investigated on the Faroes.

6. Peat occurring near the surface may be contaminated with roots and radicles from recent plants on the surface. This will result in a reduction of the age as is possibly the case in the 23 cm unit in Sundbornsmossen.

7. An hiatus or a decayed peat layer might increase the number of inorganic particles and create a "secondary" ash unit. The detailed classification of different units has not revealed the existence of this source of error.

8. In the case of the ash units in Sweden and Norway, it would be of interest to study the refractive index of the glass and the grain-size distribution in the ashes more closely and to analyse the glass in the ash. This would require an improvement of the method of separating the ash from the peat and also a method for separating the ash particles from other inorganic material.

Concluding remarks

The results of this investigation have been sufficiently encouraging for continuation of the work. It is apparent that tephrochronology can usefully be employed in organic strata in parallel with pollen analysis to elucidate Quaternary stratigraphy in Scandinavia and the Faroes. The considerable lateral extent of some ash layers is one of the major advantages of the method.

There is no reason to suppose that the method cannot be applied to deposits

older than those investigated here. It is also probable that the ash units identified in this study occur over wider areas, even outside Scandinavia. It would be of interest, for example, to investigate mires on the Shetland Islands and in Scotland in this connection. Eventual application to the stratigraphy of the North Atlantic sediments may be anticipated.

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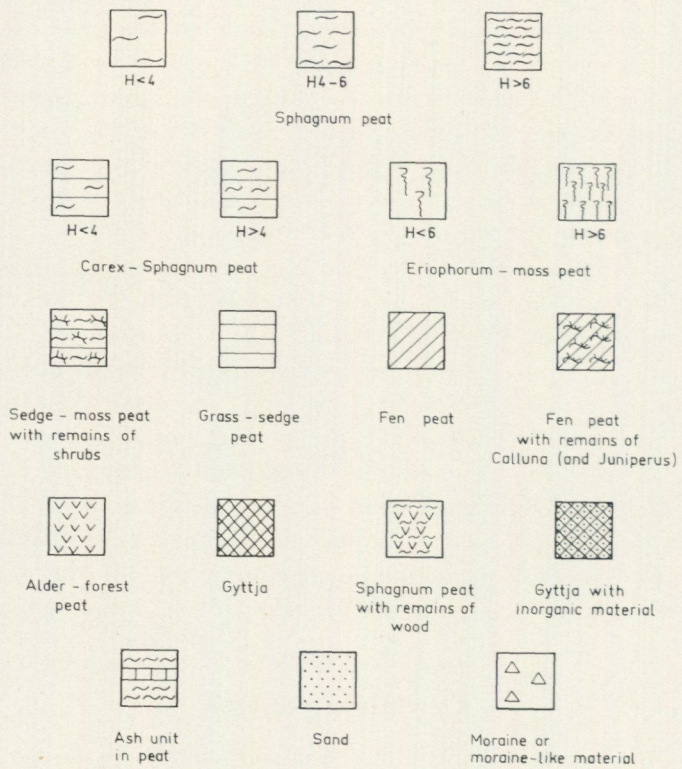

Fig. 18. Legend to the peat diagrams. H = degree of huminosity.

Table of the carbon-14 age-determinations

Locality	Depth below surface	Lab. number	Age	Notes
Klaxsjömossen (59° 30′ N 13° 06′ E)	16–18 cm	St-1455	<250 BP	
„	158–160 cm	St-1456	2810 ±75 BP (860 B. C.)	
„	176–178 cm	St-1519	3375 ±80 BP (1425 B. C.)	
„	196–198 cm	St-1513	3475 ±80 BP (1525 B. C.)	
Mellstabromossen (60° 30′ N 15° 22′ E)	46–48 cm	St-2108	1090 ±65 BP (860 A. D.)	NaOH[1])
„	122–124 cm	St-1493	2855 ±80 BP (905 B. C.)	
Sundbornsmossen (60° 33′ N 15° 42′ E)	22–24 cm	St-1604	<250 BP	
„	144–146 cm	St-1461	2775 ±70 BP (825 B. C.)	
„	180–185 cm	St-1605	3710 ±80 BP (1760 B. C.)	
Grövelsjömyren (67° 05′ N 12° 18.5′ E)	25 cm	St-2119	1535 ±70 BP (415 A. D.)	NaOH
Klockamyren (63° 17,5′ N 12° 28′ E)	22–24 cm	St-2107	575 ±65 BP (1375 A. D.)	NaOH
„	70–72 cm	St-2106	3700 ±75 BP (1750 B. C.)	NaOH
Sjetnemyren (63° 21′ N 10° 23′ E)	25 cm	St-2064	490 ±65 BP (1460 A. D.)	NaOH
„	59 cm	St-2063	1100 ±70 BP (850 A. D.)	NaOH
Kristiansundsmyren (63° 02.3′ N 07° 47.5′ E)	34–36 cm	St-2057	965 ±70 BP (985 A. D.)	NaOH
„	68–70 cm	St-2059	2730 ±70 BP (780 B. C.)	NaOH
„	91 cm	St-2084	3600 ±80 BP (1650 B. C.)	NaOH
„	158 cm	St-2087	6875 ±90 BP (4925 B. C.)	NaOH
Setranmyren (63° 27′ N 08° 04′ E)	45 cm	St-2065	330 ±80 BP (1620 A. D.)	NaOH
„	177 cm	St-2066	3050 ±100 BP (1100 B. C.)	NaOH

Locality	Depth below surface	Lab. number	Age	Notes
Klovinmyren (62° 04.3′ N 07° 15′ W)	37 cm	St-2140	2585 ±75 BP (635 B. C.)	NaOH
„	50 cm	St-2151	2650 ±75 BP (700 B. C.)	NaOH
„	94 cm	St-2155	3450 ±70 BP (1500 B. C.)	NaOH
„	105 cm	St-2156	3800 ±80 BP (1850 B. C.)	NaOH
„	280 cm	St-2078	8455 ±100 BP (6505 B. C.)	NaOH
Myrarnar (62° 09.7′ N 07° 05′ W)	21 cm	St-2135	900 ±120 BP (1050 A. D.)	NaOH
„	75 cm	St-2136	3520 ±105 BP (1570 B. C.)	NaOH
„	84 cm	St-2139	3650 ±560 BP (1700 B. C.)	NaOH
Saksunmyren (62° 12′ N 07° 04′ W)	11 cm	St-2132	1585 ±70 BP (365 A. D.)	NaOH
„	55 cm	St-2133	3075 ±100 BP (1125 B. C.)	NaOH
„	65 cm	St-2134	3350 ±130 BP (1400 B. C.)	NaOH

[1]) The material has been pre-treated with 2 % NaOH.

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