Leucite from East Greenland: A new petrographic sub-province of the Tertiary North Atlantic province

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A new occurrence of ultramafic alkaline rocks in the Kangerdlugssuaq district of East Greenland is briefly described and more detailed petrological and mineralogical data are presented for a leucite ankaratrite, which consists of diopside, leucite, nepheline, alkali feldspar, magnetite and phlogopite. The presence of potassic rocks in this area provides important additional evidence for the rifted origin of the area. This is the first well-substantiated report of leucite from Greenland.

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Leucite is a characteristic mineral of potassium-rich volcanic and sub-volcanic rocks and, although it is well known and abundant in certain areas, it is otherwise a rare mineral. In this note, we report an occurrence of leucite from East Greenland and this is the first reported occurrence not only from Greenland but from the entire Tertiary North Atlantic province. For this reason and also because its occurrence here lends weight to an earlier interpretation of the tectonics of the area (Brooks, 1973; Brooks & Rucklidge, 1974) we feel it is advisable to publish a preliminary note at this stage even though the available specimens are few and the field relations poorly known. Furthermore, the intrusion from which these samples originate is extremely inaccessible and it is doubtful when a new visit can be made to the locality.

Geological setting

The fjord of Kangerdlugssuaq is best known for the Skaergaard intrusion, which lies close to its mouth in an area of extensive Lower Tertiary tholeiitic plateau lavas which are regarded as being formed around the time of continental break-up in this part of the North Atlantic (Brooks, 1973). Rocks of alkaline affinities occur along the fjord (see fig. 1) and this led Brooks (1973) to postulate that the fjord is the non-spreading arm of a triple rift system.

Recent discoveries show that the rocks are considerably more undersaturated beyond the head of the fjord, where a completely different petrographic province of unknown extent crops out from under the inland ice. Thus, Brooks & Rucklidge (1974) have described undersaturated, alkaline rocks as erratic blocks which are believed to originate in this area and Frisch & Keusen (in press) report a circular intrusion, named Gardiner intrusion (see fig. 1), which consists of dunites, pyroxenites, uncompahgrites (melilite rocks) and possibly carbonatites.

The samples described here were taken from an intrusion, for which the name 'Batbjerg intrusion' is proposed, which is located on the innermost nunatak on the north-east side of the Kangerdlugssuaq Glacier (68°40'N, 28° 50'W, see fig. 1). It is probably also circular in plan, but a substantial part is hidden under glacier ice.

About twenty rock samples from the Batbjerg intrusion have been examined by us and although the number of samples is too small to give a reliable picture of the intrusion it would appear that it is made up predominantly of olivine and pyroxene rocks. The pyroxenites are medium-grained, vary from

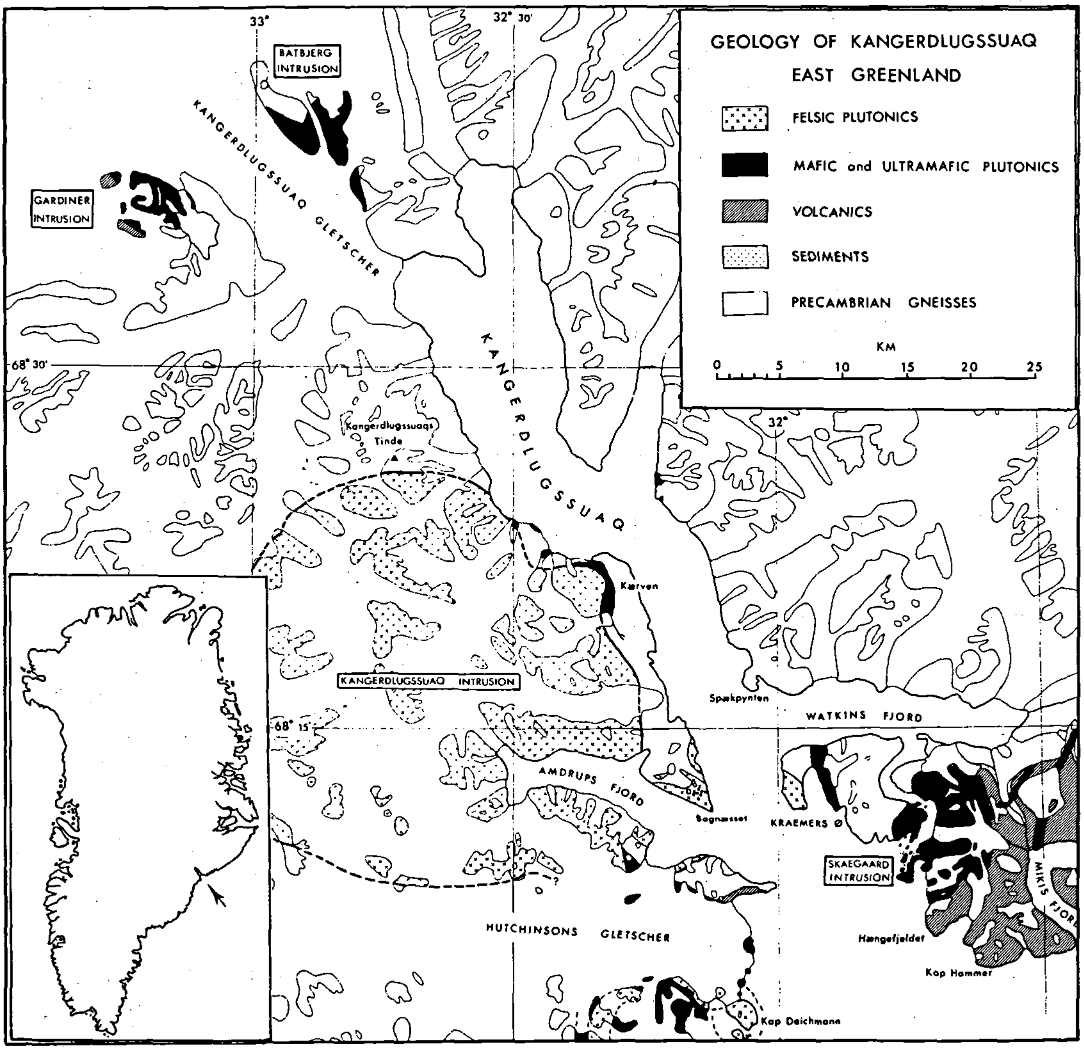

Fig. 1. Geological sketch map of the Kangerdlugssuaq district, East Greenland, showing the location of the Batbjerg, Gardiner and other intrusions.

olive green to almost black in hand specimen and tend to be fresh and rather friable. The dunitic rocks are dark-coloured and many specimens are sheared and serpentinized, probably due to faulting in a north-easterly direction, as reported by Polegeg & Köck (pers. comm., 1971). Phlogopite is abundant in many of these rocks and variants enriched in apatite and magnetite also occur. Felsic minerals are often completely absent, but in others nepheline is present and with increasing nepheline content the pyroxenites pass into melteigitic and ijolitic types. One dike rock in the collection is a porphyritic ultramafic type with phenocrysts of clinopyroxene (ca. 4 mm in size) in a fine-grained groundmass of clinopyroxene, phlogopite and ore with a total absence of light minerals. Also present are syenite dikes and a fenitized zone in the surrounding Precambrian gneisses.

These rocks from the Batbjerg intrusion are strongly reminiscent of those reported from the Gardiner intrusion (Frisch & Keusen, in press), in that they belong to an alkaline ultramafic association similar to that reviewed by Upton (1967) and, as such, are the only known representatives of this association in the Tertiary North Atlantic province. The main difference between the two intrusions appears to be the absence of melilite and perovskite at Batbjerg, both of which are important constituents of the Gardiner rocks. On the other hand, leucite, the subject of this note, does not appear to occur in the Gardiner intrusion. Whether the differences are real or apparent can only be determined when more work can be carried out, especially on the Batbjerg intrusion.

It is probable that these rocks are the intrusive equivalents of lavas similar to the nephelinite described by Brooks & Rucklidge (1974), just as the ijolitic and carbonatitic intrusive core of the Napak Volcano, Uganda (King, 1965) is regarded as the intrusive equivalent of the surrounding nephelinitic lavas and pyroclastics (Middlemost, 1974).

The field relationships of the Batbjerg intrusion does not allow a more precise dating than post-Precambrian, but the Gardiner intrusion cuts the plateau basalts which have been dated to the interval 55–60 m.y. by the K–Ar method (Beckinsale et al., 1970) and, in view of the petrographic similarity between the intrusions, a similar age is assumed for the Batbjerg intrusion.

Table 1. Leucite-bearing rock from the Batbjerg intrusion, Kangerdlugssuaq: chemistry and mineralogy.

		Trace elements	
SiO_2	45.75		
Al_2O_3	8.92		
Fe_2O_3	8.04	Rb	128
FeO	4.98	Ba	76
MgO	9.30	Sr	1970
CaO	13.45	Y	7
Na_2O	3.50	Zr	32
K_2O	3.25	Nb	0
MnO	0.19	Cu	122
TiO_2	1.01	Co	54
P_2O_5	0.97	Ni	73
H_2O^+	0.68	V	290
		Cr	194
sum	100.04		

C.I.P.W. weight norm (calculated) with analytical values and with Fe_2O_3/FeO adjusted to 0.44

or	15.66	4.70
lc	2.78	11.37
ne	15.05	15.05
ac	1.61	1.61
di	47.37	48.95
ol	1.88	8.31
mt	10.85	4.77
il	1.92	1.92
ap	2.25	2.25

Mode (volume percent)

leucite	10
nepheline	12
feldspar	4
clinopyroxene	52
phlogopite	3
opaque ore	10
apatite	1
alteration (nepheline + feldspar)	8
no. of points:	ca. 4000

Major element analysis: Geological Survey of Greenland, Geochemical Laboratories.

Trace element analyses: Rb, Sr, Y, Zr & Nb by J. Bailey, Institute of Petrology, Copenhagen University (X-ray fluorescence). Ba, Cu, Co, Ni, V, Cr by Haldis Bollingberg, Institute of Petrology, Copenhagen University (optical spectrography).

The leucite-bearing sample

Leucite is confined to a single sample, but, in view of the rather dull appearance of this rock, there is no reason to believe it has been specially sampled. Unfortunately, the precise field relationships of this rock are not known. It is a dark green, melanocratic rock, in which white spots of leucite, up to 1 cm in size, may be seen on the weathered surface. In thin section, the leucite phenocrysts are seen to be accompanied by nepheline, up to 0.5 cm in size, set in a matrix of clinopyroxene prisms oriented to give a weak fluxion structure. Pools of clear, untwinned alkali feldspar and a turbid alteration product, the latter also occurring as rims on the leucite, are also present. Where nepheline is enclosed by the alkali feldspar it is perfectly euhedral. The alteration product was identified as a finely-divided mixture of alkali feldspar and nepheline. Also present are titaniferous magnetite, phlogopite and apatite as minor constituents. These phases have been investigated using the Hitachi XMA-5B microprobe at the Institute of Mineralogy, University of Copenhagen and the experimental techniques described by Pedersen et al. (in press). The approximate modal composition is shown in table 1.

Leucite, which shows the characteristic complex twinning, has a composition very close to the ideal leucite composition with only 1.1 mole percent of the soda-leucite ($NaAlSi_2O_6$) component. It is stoichiometric, unlike the leucites analysed by Carmichael (1967) from the Leucite Hills of Wyoming. The twinning, which was absent in Carmichael's samples, would seem to indicate fairly slow cooling from above the cubic-tetragonal inversion temperature of ca. 600°C (Faust, 1963).

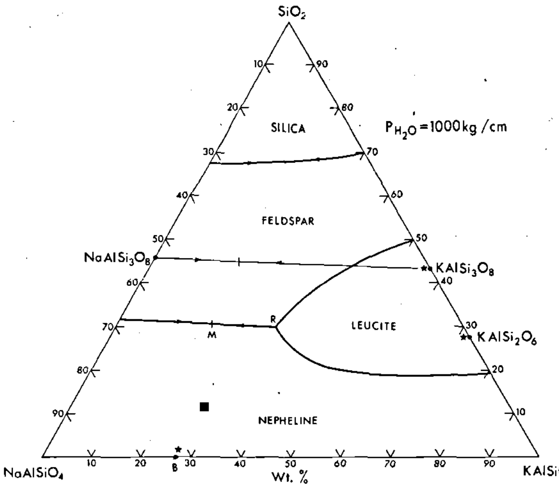

Fig. 2. Felsic mineral compositions in the leucite-bearing sample, indicated by stars, plotted in terms of SiO_2-$NaAlSiO_4$-$KAlSiO_4$. Field boundaries are after Hamilton & MacKenzie (1965) at the indicated water vapour pressure, while M is the phonolite minimum and B the Buerger nepheline composition (Tilley, 1954). The salic composition of the leucite-bearing sample is indicated by the filled square in the nepheline field.

Table 2. Composition of clinopyroxene in the leucite-bearing rock from the Batbjerg intrusion, Kangerdlugssuaq.

Average of 11 complete point analyses		Cations on basis of 4 cations and 6 oxygens		
SiO_2	52.6	Si	1.946	2.000
TiO_2	0.55	Al	0.039	
Al_2O_3	0.91	Fe^{3+}	0.015	
Fe_2O_3*	4.60			
FeO*	2.64	Fe^{3+}	0.113	1.998
MnO	0.14	Ti	0.015	
MgO	14.4	Fe^{2+}	0.082	
CaO	22.84	Mn	0.004	
Na_2O	1.24	Mg	0.789	
K_2O	0.03	Ca	0.905	
		Na	0.089	
sum	99.95	K.	0.001	
Atomic		End members (mol. %) after Kushiro, 1962		
Mg	44.30	$NaFe^{3+}Si_2O_6$		4.8
Fe^{2+} + Mn	4.86	$CaTiAl_2O_6$		0.8
Ca	50.85	$CaFe^{3+}(Fe^{3+},Al)SiO_6$		1.3
		CaAl $AlSiO_6$		0.0
		$Ca_2Si_2O_6$		46.6
		$Mg_2Si_2O_6$		42.2
		$Fe_2Si_2O_6$		4.6

* Estimated from stoichiometry.
Maximum observed variation:

41.73 Mg	7.43 Fe^{2+}	50.84 Ca
to 45.45 Mg	2.52 Fe^{2+}	52.03 Ca

Nepheline ($Ne_{72.5}Ks_{23.6}Qz_{3.9}$) approaches closely the Buerger ideal composition (Tilley, 1954) of $Ne_{73}Ks_{27}$ and falls below the *500° curve* of Hamilton (1961). It is clearly of very low temperature origin, which is rather surprising, as the salic composition of the rock (see below) suggests that it should be the first felsic mineral to crystallize.

Alkali feldspar has a composition of $Or_{98.5}Ab_{1.3}An_{0.2}$ (mole percent). Lattice constants were refined from Guinier powder data and after Smith's (1974, figs 9–11) proposed nomenclature it is a potassian intermediate sanidine. We are not aware of occurrences of such a pure potash feldspar in rocks of this type, although some of the feldspars from ijolite-carbonatite complexes in Ontario analysed by Watkinson (1973) approach it, as do those from potassic lavas of Africa described by Sahama (1952).

The compositions of the light minerals are shown diagrammatically in fig. 2 along with the salic composition of the rock. It is clear that these minerals represent an equilibrium at very low temperatures. The leucite nepheline dolerite from Meiches, Hessen, described by Tilley (1958), which has a closely similar salic composition, shows a much greater degree of solid solution in the felsic phases.

Pale green *clinopyroxene* is subhedral and about 1.5 × 0.5 cm in size. Often the crystal centres and margins are clear, but an intermediate zone has a gridwork of exsolved iron ore lamellae. The average composition is shown in table 2, there being very little variation, although the cores and crystal margins tend to be slightly more magnesian than the intermediate zone.

In the allocation of cations to the tetrahedral sites, Fe^{3+} has been taken before Ti as suggested by Hartman (1969) and required to form the Ca ferri-Tchermak's component ($CaFe^{3+}SiO_6$). In this way an almost perfect distribution into the molecules suggested by Kushiro (1962) may be achieved. These are diopsides with small amounts of acmite, titanpyroxene and Ca ferri-Tschermak's component as seems to be fairly typical of pyroxenes from alkaline, undersaturated and possibly oxidising environments (Sahama, 1952; Bell et al.; 1972; Upton & Thomas, 1973; Thompson, 1974), although the calculation of the Fe_2O_3/FeO ratio from stoichiometry is subject to considerable errors (Finger, 1972).

Similar diopsides are reported from African potash ankaratrites (Sahama, 1952), the ijolites of Magnet Cove, Arkansas (Erickson & Blade, 1963) and the nearby Gardiner intrusion (Frisch & Keusen, in press), while similar, but more Fe-rich pyroxenes, occur in the nephelinite-ijolite suite of Uganda (Tyler & King, 1967). The diopsides described by Upton & Thomas (1973) from potassic ultramafic rocks in the Gardar province of South Greenland differ in that they have a much higher TiO_2 and Al_2O_3 content.

Titaniferous magnetite occurs in two generations: as small (ca. 0.04 mm) euhedral inclusions in the pyroxenes, and as larger grains, comparable in size with the pyroxenes, which they partially enclose. The second type have lamellae of exsolved ilmenite.

Phlogopite forms poikillitic plates enclosing other constituents. Partial analysis shows it to contain MgO: 16.3 %, FeO: 12.7 % and TiO_2: 10.6 %. This is an exceptionally TiO_2-rich phlogopite even for such rock-types. For example, Prider (1939) reported ca. 9 % TiO_2 in phlogopite from a leucite lamproite.

Apatite in euhedral prisms is the main accessory mineral, while a turbid *alteration product* occurs as rims on the leucite and as patches throughout the rock.

Chemistry. The composition of this sample is shown in table 1. It has an Na_2O/K_2O ratio close to unity, a rather unusual feature of basic rocks, which generally have more than twice as much Na_2O as K_2O (Wilkinson, 1974). The low Al_2O_3 and high CaO reflect the abundance of pyroxene and together with the high total FeO relative to MgO are characteristics of the kamafugitic association (Sahama, 1974).

Similarly, a high Fe_2O_3/FeO ratio appears, from the compilation of Upton (1967), to be a characteristic of alkali pyroxenites. However, in view of signs of subsolidus oxidation we have also calculated a norm with a lower degree of oxidation, using that observed in a fresh nephelinite from the area (Brooks & Rucklidge, 1974). The effect of this is to substantially increase the amount of normative leucite and olivine simultaneously reducing that of orthoclase and magnetite and bringing the norm into much better agreement with the mode (table 1).

This rock is similar petrographically to many described from the Toro-Ankole district of Uganda by Holmes & Harwood (1932) and is best matched chemically by the leucite ankaratrites of this area. Mineralogical and chemical data have recently been presented by Cundari (1973) for leucitites from Australia and although no samples are directly comparable there are clear similarities. Finally, as noted above, the salic composition ($Ne_{61.6}Ks_{26.8}Qz_{11.6}$) is very close to that of the leucite nepheline dolerite from Hessen described by Tilley (1958).

The *trace elements* are unusual in that there is no significant enrichment in either residual elements (Ba, Sr, Zr, etc.) or compatible elements such as Ni and Cr, as is usual in leucite-bearing rocks (Higazy, 1954; Erickson & Blade, 1963; Cundari, 1973).

Conclusions

Leucite is a mineral which is limited to potassium-rich rocks in two distinct tectonic settings. It occurs in rifted continental environments such as the Western Rift of Uganda (Holmes & Harwood, 1932) or above deeplying parts of subduction zones as, for example, in Indonesia (De Roever, 1975). This report of its occurrence in Greenland, in which we have argued its similarity to the occurrences of rifted areas, is strong evidence for the rifted nature of Kangerdlugssuaq as suggested previously by Brooks (1973) and Brooks & Rucklidge (1974). Furthermore, its occurrence here reinforces the observations of Brooks & Rucklidge (1974) and Frisch & Keusen (in press) that there is in the interior parts of Kangerdlugssuaq a petrographic sub-province of highly undersaturated alkaline rocks which is unique in the entire Tertiary North Atlantic province.

This is the first well investigated occurrence of leucite in Greenland. Bøggild (1953) referred to an earlier report of leucite from South Greenland, but this now seems to be doubtful (Sørensen, pers. comm., 1974). Noe-

Nygaard (pers. comm., 1974) reports the possible presence of altered leucite (pseudoleucite?) in dikes from the Holsteinsborg district, but this is as yet unconfirmed.

Acknowledgements. The samples examined by us were collected by Siegfried Polegeg and Hermann Köck (Leoben, Austria) while prospecting for the Northern Mining Company (Nordisk Mineselskab A/S) of Copenhagen and we are extremely grateful both to them and to the company for kindly allowing us access to their samples and field descriptions.

We thank Ib Sørensen, Geological Survey of Greenland, for the major element analysis and Haldis Bollingberg and John Bailey, Institute of Petrology, University of Copenhagen, for trace element analyses.

Dansk sammendrag

En nyopdaget forekomst af ultramafiske alkaline bjergarter i Kangerdlugssuaq området (Østgrønland) beskrives kort og resultaterne af en mere detaljeret mineralogisk og petrologisk undersøgelse af en leucit ankaratrit præsenteres. Denne bjergart består af diopsid, leucit (den først veldokumenterede forekomst i Grønland), nephelin, alkali feldspat, magnetit og phlogopit. Forekomsten af disse K-rige bjergarter underbygger den pladetektoniske model for områdets udvikling i nedre tertiær.

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Knud Jessen

Nov. 29th 1884 – April 14th 1971

Knud Jessen died on April 14th 1971.

Few have engaged themselves more deeply in the study of the forest-trees and the story of their immigration into Denmark than Knud Jessen. It is therefore tempting and seems appropriate to vizualize him as equal to the oak – *Quercus robur*.

The oak is tall and rugged. In early spring the crisp young leaves tinged with red and gold unfold against a sky of clearest blue. In autumn the surface of the leaves turns silvery grey. Even on the young tree the bark is rough and cracked in a characteristic manner. The oak takes time to get established. The acorn is rich in nutrients and has latent strength which enables it to germinate under difficult conditions. Having established itself over a period – by way of a tap-root – the young oak grows rapidly putting forth long shoots not only in spring, but also later in midsummer and sometimes even towards the end of summer. These shoots, jutting out in all directions, often develop into large quite trunk-like branches. But if the tree grows old – and the oak is the most long-lived tree in Denmark – given plenty of air and light, a multitude of interlacing branches will in time create an open dome generously admitting the light and allowing for a vigorous undergrowth. The fully grown tree gives much fruit in the shape of acorns and the wood is hard and well nigh indestructible.

In the forest history the oak comes after the short-lived pioneers: aspen, birch, pine, juniper and hazel, which prepare the soil. It is, however, the oak which develops and establishes the dominion of the forest. It holds its place in the forest even after the lime, the climax tree, with its large shadowy crown has spread and taken over the role as the predominant tree in the forest.

Knud Jessen was born at Frederiksberg on November 29th, 1884. His father P. Jessen belonged to a highly esteemed North Schleswig family of farmers, but a visit to Askov Folk High-School awoke in him the wish to study. He became a vet and later a consultant to 'Det kongelige Landhusholdningsselskab' (The Royal Agricultural Society). He died at the age of 39, the year of the birth of his son, and was buried at Ryslinge. The mother, Henriette Amalie Povlsen was the daughter of a school-teacher and precentor at Randers, Hans Christian Henrik Povlsen. She had four brothers and sisters and there is reason to mention: Karl Povlsen, who became clergyman at a 'valgmenighed' (a segregate community) of the parish church at Ryslinge, and Harald Alfred Povlsen who started as a teacher at Lyngby Agricultural College, later became the principal at Ryslinge Folk High-School. Four years after the death of her husband his mother married a farmer, Niels Petersen from Trustrup, south of Randers. It was on this farm, at the base of fertile Djursland, close to the Gudenå, that her son grew up.

Thanks to his family background Knud Jessen was firmly placed in a lively and fertile Folk-High School milieu closely connected with farming. He stood with both legs firmly planted in the soil and occasionally he – with a twinkle – would remind us that for 5.000 years the Danes had thrived on barley porridge. As professor of botany he was generally gentle and indulgent, yet woe betide the student who could not tell the difference between the various cereals.

Having been prepared for matriculation at the Lang and Hjort courses at the age of 21, he went to study botany at the University of Copenhagen. Here he found E. Warming a most inspiring teacher, who opened his eyes to the excitements of vegetation historical studies. He took his degree six years later, in 1911, at the age of 27. A short period he worked with Warming helping to write and edit the work: 'The structure and biology of arctic flowering plants'; in 1914, however, Hartz left his post as a 'plant-palaeontologist' at the Geological Survey of Denmark and Knud Jessen took over, first as an assistant and later, 1917, as the head of the department. – In 1931, on the sudden death of Ostenfeld, he was called as professor of botany to the University of Copenhagen and at the same time appointed director of the Botanical Gardens and of the Botanical Museum: 'Summus botanicus'. In 1955, at the age of 71 he retired. His retirement was to be long and active.

In 1912, the year after his degree he married a school-teacher, Ingrid Holm, the daughter of Harald Holm, B.D., a member of parliament, and his wife Gudrun, née Høgsbro. The marriage was blessed with four children.

In 1929 Knud Jessen was made a member of the Academy of Science and in 1937 came on the board of the Carlsberg Foundation, where he remained until the end of 1959. Moreover his honours and honorary offices were legion – and rightly so!

The life work of Knud Jessen is so extensive and many-sided that an account necessarily must be limited to some few essential aspects. I have chosen the following topics: The study of fossil cereals and weeds, post-glacial vegetation historical research including his fixation of pollen analytical zone boundaries, the many datings of archaeological and zoological finds, the studies of interglacial plants in Denmark, vegetation historical studies in Ireland and last, but not least, the botanical studies, the solid foundations of the work, with which he commenced and finished his entire career.

In 1917 the Academy of Science worded a prize subject, offered by the Classen Foundation, as follows: "Vore Ukrudtsplanter, særlig Agerukrudtets Indvandringshistorie, ønskes oplyst, navnlig ved Hjælp af palæontologiske og historiske Data, samt ved Studiet af disse Planters Vandringsmaader, Vandringsveje, nuværende Udbredelse og deres Forekomstmaade". ("Information is required as to Danish weeds with special emphasis on the immigration history of weeds on cultivated soil, mainly to be based on palaeontological and historical data as well as on the study of means of travel and travel routes, present distribution and ways of appearance of the above mentioned plants".). Two responses were received in 1919 and both were awarded prizes. One prizewinner was Jens Lind who had put major emphasis on the literary-historical and biological aspects of the theme, the other was Knud Jessen who had made special use of archaeological-palaeo-botanical material. The two treatises, that were supplementary, were amalgamated and appeared in 1922–23 under the title of 'Det danske Markukrudts Historie' ('History of the weeds of Denmark') in the series of publications issued by the Academy of Science; a book of some 500 large pages. It appears as a harmonious whole yet it is easy to identify the contribution of Knud Jessen, that is most of the introductory chapters and all the extensive archaeological and palaeo-botanical material.

The book is a capital work, a nearly inexhaustible goldmine of knowledge and scholarship. The basis of the work – as pointed out by the authors in the preface – is commonsense and intuition due to years of intercourse with nature and devotion to the study of the life of plants. It is regrettable that this, within its sphere quite exceptional work, has not been translated into one of the main languages.

Weeds – as is well known – are plants whose demands are so similar to those of the cultivated plants that they, to the trouble and detriment of the farmer, may easily ruin his vital crops. The farmers' fights against weeds have raged since the beginning of grain-growing. Having started with the reverse of the medal it was only natural that Knud Jessen should also wish to study the front.

A Swiss, Osvald Heer, was presumably the first to study and identify fossil grains. In 1865 he published his classical examinations of plant remains in the Swiss lake pile dwellings. 30 years were to pass before the study of fossil cereals was to be taken up again, this time in Denmark, and thanks to a school-teacher, Frode Kristensen, at Tørring, who in 1894 found the imprints of grain in earthenware fragments from the Bronze Age. Sarauw, then attached to the National Museum as a botanist, started a search for imprints of cereals in Danish pre-historic pottery. When he left the National Museum Knud Jessen took over the unpublished material which he had left behind. This proved to be a most inspiring inheritance and throughout the rest of his life Knud Jessen continously returned to this theme. He has published his studies in numerous papers and drawn on the material in order to assist others.

He examined the cereal finds from nearly all periods such as the Neolithic Age (Bundsø), Iron Age (Ginderup), Viking Age (Aggersborg) and, together with Hans Helbæk, he published a monograph: 'Cereals in Great Britain and Ireland in Prehistoric and Early Historic Times' in the papers of the Academy 1944. In 1951 he gave a synopsis of his studies in the archaeological periodical 'Viking' entitled 'Oldtidens Korndyrkning i Danmark' ('The Cultivation of Cereals in Denmark in Prehistoric Times').

To his great regret Knud Jessen never got round to writing a monograph about the cultivation of cereals in Denmark on the basis of Sarauw's and his own observations. His work with prehistoric cereals has been continued by the conservator Hans Helbæk to whom Knud Jessen was a paternal friend and generator of inspiration. Personal in his approach yet based on the tradition of cereal identification initiated by Sarauw and, more especially, by Knud Jessen, Helbæk is responsible for most of the fundamental examinations of the cereal-finds from among the most ancient agricultural discoveries that have been appearing at excavations in the near East during the last 20 years. A complete publication of the many Danish cereal identifications does, however, still await an author.

When in 1914 Knud Jessen became employed at the Geological Survey of Denmark, there was nobody capable of teaching him peat-geology. The then director, Victor Madsen, however, saw to it that he went abroad where he was instructed by the best possible teachers. In Sweden by Gunnar Andersson, the critical plant identifier, and by Lagerheim, who taught him to identify pollen, and last but not least by his contemporary Lennart von Post, an acquaintance that was to prove of great and lasting value. It was von Post who established the pollen statistical method which has become the most important tool of the vegetation historian – and one of which the possibilities of further refinement are far from exhausted. He was taught geology, especially Quaternary geology, under the learned guidance of Milthers, the State geologist. As a result Knud Jessen was well equipped when it came to tackling Quaternary geological and vegetation historical problems.

In 1920, six years after his appointment to the Geological Survey of Denmark, he published his thesis 'Moseundersøgelser i det nordøstlige Sjælland' ('Mire-investigations in North Eastern Sealand'), of more than 200 pages. In this he sums up the results of a great many separate investigations embracing all available material, published or unpublished, in order to arrive at a summarized survey of the following themes: (1) the immigration history of trees, bushes and flowering plants, (2) the stratification of the bogs and the evidence they give of climatic changes, (3) the dating of the Littorina Sea deposits in relation to the vegetation history, and (4) the dating of the archaeological periods. The result of the entire investigation was concentrated in a single diagram which since then has only been subject to minor changes.

Pollen analysis formed only a minor part of his thesis, but in the years to come Knud Jessen developed this method into an important means of dating. In 1935 he carried out a great number of pollen analytical investigations and the material gave rise to a summing up of the Danish history of vegetation in 9 pollen zones. The first three cover the late glacial of which the middle one (zone II) is identical with the warmer Allerød period which in the deposits generally is characterized by a layer of gyttja between layers of clay or clay-gyttja. (Older and Younger Dryas period). The principle of division for this and the following period (IV Pre-Boreal) is the changes in sediments. Then follow the zones IV-VII, where the order of immigration of bushes and trees is the basis on which the periods are fixed. The boundary between the Atlantic and the Sub-Boreal periods (zones VII–VIII) is fixed at the point where the mixed oak forest and especially the lime are in steep decline. Finally the boundary between the Sub-Boreal and the Sub-Atlantic periods (VIII–IX) is placed where the beech starts to spread and Sphagnum peat extends widely, that is to say on the basis of immigration and change in climate. The basis of the divisions is exceedingly heterogeneous, but the division itself is extremely practical and advantageous. With slight alterations Knud Jessen's zone division is still being used in the greater part of Central and Northern Europe and that in spite of the staggering progress of pollen analysis within these last 40 years.

Provided that the pollen zone boundaries were, broadly speaking, contemporaneous within the boundaries of Denmark, it ought to be possible, with the aid of archaeological bog finds belonging to different cultures, to date the vegetation historical periods in relation to prehistoric cultures. And vice versa it should be possible to date the archaeological bog finds in relation to the history of vegetation (the pollen zones: the Mullerup culture (1935), the types in their culture-historical connection. During the following 10 to 15 years Knud Jessen succeeded in placing the major part of the archaeological periods in relation to the pollen zones the Mullerup culture (1935), the Ertebølle culture (1937), the Late Stone age (1938 and 1939) the Bronze age (1935), the Iron age (1935 and 1937) the Viking age, Trelleborg (1948). One of the results was that he was able to prove that parts of a plough found in a bog at Vebbestrup were contemporaneous with Roman Iron age.

Bog finds of bones, the evidence of an ancient fauna, could likewise be dated in relation to the pollen-zones. In this connection mention should be made only of one article written by Knud Jessen in 1929 about the former appearance of the brown bear in Denmark. Not only does he offer a large number of pollen analytical datings of bones of bears, but he also sheds light on the theme through references and interpretations of place names and through mentions in the old provincial laws.

The work of dating has since been continued and the development of the pollen analytical method has brought about that the precision of such datings has now been considerably improved. It was, however, Knud Jessen who laid the foundation.

Having successful dealt with the late glacial and postglacial vegetation history in Denmark in his thesis Knud Jessen went on to tackle the problems of the interglacial deposits. The pioneer work had been done by his predecessor N. Hartz who in Jutland had found bogs from various interglacial periods. Hartz, like Knud Jessen, was a first rate connoisseur of plant fragments and had identified some 120 different kormophytes. The method of pollen analysis, however, had not yet come in use at this stage (1909), in fact, this did not happen till after 1916, when von Post had published the results of his pollen analytical studies.

Together with the State geologist V. Milthers who in his capacity of quaternary geologist was concerned with the Ice Age deposits, Knud Jessen started to reexamine the well-known sites. More detailed surveying was carried out and material for both plant identification and pollen analysis was collected. The numbers of interglacial sites was increased from 9 to 30 and the work was extended to cover the North Western part of Germany as well.

The investigations resulted in the work 'Interglacial Freshwater Deposits in Jutland and Northwest Germany' (1928, some 400 pages and 40 plates). The number of plants determined as to species could be further increased with about 70 and on the basis of the pollen analysis a detailed account could be given of the forest development right through the last interglacial period.

A division in zones of the forest historical stages proved valid for all the bogs in question.

The publication of the interglacial studies proved beyond doubt that Knud Jessen was one of the leading vegetation historians in Europe. He became internationally known and in March 1934 he was asked to lead a research program with the purpose of clarifying the vegetation history of Ireland. The invitation was issued by a committee including the most prominent Irish geologists, botanists, zoologists and archaeologists.

The task set him was an extensive and difficult piece of pioneering yet it had great appeal to Knud Jessen. Ireland has since ancient times been known to be a phytogeographical area with a character of its own, containing American as well as Mediterranean European plants to which must be added the exciting combination of bog-geology, vegetation history and archaeology.

In the summer of 1934 he spent two months in Ireland and already that same autumn he published an account of the investigations of the past summer and mapped out a five point program for the investigations to come: (1) Investigation of the late glacial sediments in various parts of Ireland with regard to a possible brief spell of warmer climate corresponding to the period known in Denmark as Allerød and the gathering of information about where the Mediterranean European plants might have survived the last glacial. (2) An attempt should be made through archaeological peat finds, to link the vegetation history with the archaeological periods, especially the connection of Bronze and Iron age with the alternating layers in the ombrogenous bogs indicating respectively dry and moist periods. (3) Monographic studies of typical bogs in Ireland should throw light on the there occurring types of bogs and their dependence on topography, nutrition and climate. (4) Investigation of the various tree limits in the Irish mountains during and after the Ice Age. (5) Investigation of the occurrence of plants belonging to the Mediterranean European and American flora.

Who would to-day have the courage to tackle a research-program of this magnitude, still less who would be able to carry it through? Knud Jessen was 50 when he started and 75 when the last treatise was published. – He both ventured and won.

Already a mature scholar when starting the field work he knew where to concentrate his efforts. He mastered the bog-geological knowledge of the day and was able to identify most plant remnants on the spot, and he also possessed the physical strength and doggedness necessary in order to accomplish the very demanding work of plant collecting in trackless bogs, far from everywhere, within a time limit of only four months, with only two assistants. – This was the credit side but there was also a debit one.

In 1931 Knud Jessen was appointed professor of botany and with it followed many educational obligations and much administrative work as director of the Botanical Gardens and the Botanical Museum. In 1937 he joined the board of the Carlsberg Foundation and heavy demands were made on him because of his great capacity for work. It was only natural that the working up of the material made slow progress, in fact, 25 years before the task was ended.

In 1938 appeared the first publication, in collaboration with an Irishman, Farrington. It was a special study of the late-glacial sediments in the Ballybetagh bog, famous for its many examples of the now extinct Irish giant deer. The bog had been chosen with the specific purpose of arriving at an exact date of the occurrence of this strange animal. In the deposits Knud Jessen succeeded in tracing a passing spell of milder weather in the late-glacial period, corresponding to the Allerød period, and to demonstrate that the remains of the Irish giant deer belonged to precisely this period. Apart from this he found a number of plant species: *Arenaria ciliata, Oxyria digyna, Thalictrum alpinum*, which do not longer occur in this lowlying part of the country, but only in the highest mountains of West and Northern Ireland.

The principal publication: 'Studies in Quarternary Deposits and Flora-History of Ireland' (about 200 pages) appeared in 1949, after 15 years. 49 bogs from all parts of Ireland had been examined. In the case of every single bog account is made of the layers and the history of their filling up and, on the basis of pollen analysis and the identification of plant remains, of their vegetation history.

It became possible on the basis of this extensive material to give a survey of the limnic and telmatic classifications as well as a classification of the bogs and their geographic distribution. The many pollen diagrams made it possible to split up the late and post glacial periods in Ireland into a number of vegetation periods or pollen zones, that reflect the vegetation history. These periods are, furthermore, correlated with climate, sea-level and archaeological periods or seen in connection with the contemporary forest development in other parts of Northwestern Europe.

Meticulous account is made of the many, often difficult, identifications of remains of plants and pollen (a total of some 200 types) with regard to ecologic demands and geographic distribution. This is the solid foundation on which the account of the vegetation history in Ireland is based. Towards the end of the treatise the question is raised whether the flora, or parts of it, has survived the last glacial. The conclusion arrived at is, that it is likely that certain groups did survive, namely the arctic alpine groups as well as certain light demanding plants that are thermo-indifferent including the Mediterranean-European and American plants. Forest trees and the rest of the flora must, on the other hand, have immigrated after the last glacial. One did, however, regret the lack of a thorough knowledge of the flora in the Irish interglacial deposits.

The same year as the above-mentioned treatise appeared Knud Jessen had the opportunity of examining a plant containing deposit near Gort from which G. H. Kinahan in 1865 had published a number of plant finds which he considered as being of interglacial age. The locality and the publications has been forgotten, but in 1935 Farrington, the old collaborator of Knud Jessen, rediscovered the locality.

On the basis of material gathered in 1949 and in collaboration with the much younger, able pollen analyst Svend Th. Andersen, he in 1959, published a paper with the title 'The Interglacial Deposit Near Gort Co. Galway, Ireland'. The deposit turned out to date from the last but one interglacial period (Holstein interglacial period) and it was possible to identify more than 100 taxa of which 19 species no longer occur in Ireland. The deposit can be divided in 6 vegetation periods and there are thorough descriptions of the plant communities that have succeeded one another next to the bog. The result was a number of new conclusions e. g. the facts that silver fir, spruce and beech were then more common in Ireland than now, that southern and eastern European plants like *Buxus, Rhododendron ponticum* and *Lysimachia punctata* occurred and that there was a wide distribution of Eu-oceanic plants including e. g. *Erica ciliaris, E. scoparia* and *Hyoconium flagelare* as well as of American plants such as *Eriocaulon.*

The main result of the investigation was that it supported and advanced the idea that Europe by the end of the Tertiary period had a flora rich in species common with America, but that the repeated glaciations wiped out more and more species in Europe. What is left in Ireland of American or Mediterranean European plants can be found in scattered localities – they are relict occurrences.

It was his profound knowledge of the plants, their taxonomy, their geographic distribution, requirements, application to medicine and place in folk-lore that was the basis of Knud Jessen's comprehensive investigations.

Before taking up his post at The Geological Survey of Denmark in 1914 he had – as previously mentioned – made essential contributions to the book 'The Structure and Biology of Arctic Flowering Plants'. He was concerned with the two large families of plants 'Ranunculaceae' and 'Rosaceae', and in the case of every single species he gives an account of its morphology, biology, ecology and geographic distribution. His brief yet exhaustive descriptions served as a model for later contributions.

At the initiative of a committee (set up in 1904) with C. H. Ostenfeld as the prime mover, information about the geographic distribution of Danish plants had been collected through a number of years. Knud Jessen became the secretary in 1912, a member of the committee in 1927 and in 1926 he published a summarized survey of the distribution of Kormophytes in Denmark. The plan was to describe the spreading of the different species of the plant families in a series of monographs. Knud Jessen initiated this important as yet unfinished work with two volumes, 'Papilionaceae' (1931) and 'Liliflorae' (1935).

But Knud Jessen contributed to the development and sharpening of the botanist's tools in many other ways. Together with K. Wiinstedt he published a revised edition of Raunkiær, 'Dansk Ekskursions-Flora' (1934) and in collaboration with K. Gram he published 'Nøgle til at bestemme de i Danmark vildtvoksende og hyppigst forvildede, løvfældende løvtræer og Buske i Vintertilstand' ('Key to an Identification of Wild and Common Non Endemic Deciduous Trees and Bushes in Denmark in Winter') in 1936. Later (1955) he published a useful key to an identification of the fruits of the pond weed family *(Potamogeton).*

The small island of Vorsø situated in Horsens fjord was purchased in 1928 for the purpose of creating a sanctuary for plants and animals. The area of which the main part was under cultivation was to be left entirely to itself and the interaction of animals and plants was to be left unchanged by human interference. It was the admirable osteologist and zoologist Herluf Winge who by a considerable bequest had made the purchase possible and it was at his request that nature was allowed to have its way. This offered an exceptional opportunity to study the process of agricultural land turning into forest, and to observe the changes from year to year. Knud Jessen took part in the planning, and after the publication by K. Wiinstedt of the results of the years 1929–38 Knud Jessen took over. He spent his holidays at Vorsø undoubtedly very much attracted by this mixture of leisure and botanical activities in nature. Through some 30 years he had the good fortune to be able to follow the changes in vegetation in this small island, and at the meeting of the Academy on February 23rd 1968 – at the age of 84 – he was able to give an overall account of his work through the years.

This was the last time Knud Jessen was to present the results of a piece of research. All the important tasks he had taken up had been brought to completion. His work was done; the rich and fertile work of a great scholar.

Not only as a teacher at the University of Copenhagen but also as a director of the Carlsberg Foundation was Knud Jessen in a position to influence the study of natural history during the lifetime of a generation. His versatility and sense of proportions enabled him to choose and support a number of sound research programs. Many will recall, with vivid gratitude, this aspect of his activities.

A lifework of such magnitude and multiformity as that of Knud Jessen demands as a preliminary condition not only physical health, energy and tenacity, but also presumably a special sort of mind. Of prime importance in this context were to my mind the following two abilities.

He was a sharp observer and had an exceptional memory. He was well read and had an extensive knowledge of the literature within his fields of study. He knew his plants to the smallest detail and was, as a consequence, able to identify even quite small fragments on the spot. That was the first quality. Secondly, he was no dialectician. He did not contemplate things endlessly. He went straight to work well knowing how to attack the problems, and the material when collected was evaluated on the background of earlier investigations causing a constant widening of the boundaries of knowledge.

In the company of Knud Jessen one was made to partake of his extensive knowledge; he was a good and willing raconteur of anecdotes that were stamped by his considerable powers of observation and by his lively sense of humour – they were never malicious. But he did not discuss problems all night long. In private he was kind and helpful, vigorous and infectuously gay, yet at heart he was modest, shyness was part of his being, and all through life he retained that specific dignity which is the mark of true nobility.

Knud Jessen was tall and heavily built with strong features. His amiable and cheerful presence and his curly reddish-golden hair lit up the room whenever he appeared. His hands were large and chapped yet nobody could handle with more infinite delicacy any fragment of a plant so frail that most would have crushed it between their fingers.

It did, however, take some time before he got started. Only at 21 did he finish school, preparing for matriculation at a special course. Yet he was from birth blessed with great talents. He grew up in a healthy and fertile spiritual milieu and already as a child at the farm he learnt the importance of work. When going to university in order to study botany he quickly matured and at all ages he produced books of lasting value. The seemingly so different spheres of interest of the young man: botany, plant geography, vegetation history, bog geology, quarternary geology, archaeology and history grew with age into a comprehensive understanding of the changing periods of the quarternary period in North-western Europe. Thanks to the many-sidedness of his research he opened up large new fields for future more intensified investigations – virgin land where collaborators and successors were equally welcome.

As a teacher he was generous and to many scholars Knud Jessens professional help and guidance – and not to forget his human support and encouragement – were of decisive importance. He acted as a pathfinder within the fields of study that were his and many were the beacons he lit in the form of well-organized, conscientiously gathered material and impregnable plant identifications.

It was pioneers such as the Danes Dau, Japetus Steenstrup and Hartz, the Norwegian Blytt and the Swedes Sernander, Gunnar Andersson and von Post who in their various ways promoted the study of mire-geology and vegetation history. Rather more than anyone else has Knud Jessen extended and consolidated this study and established a sound foundation of future work. He lived to see a younger generation take up the problems and he gave it his whole-hearted support.

At the recommandation of Bøggild, Lindhard, Kolderup Rosenvinge, Ostenfeld and Raunkiær Knud Jessen was to join the Academy in 1928. The proposal was worded in the following terms,

'Jessen can, on the whole, be characterized as an extremely reliable, thorough and able scholar imbued with ardent zeal as regards his studies which he carries out with a never failing capacity for work. It seems likely that Denmark thanks to his efforts possibly may regain the leading role within mire-geology, which was ours thanks to the epochmaking labours of Steenstrup after whose death we have been greatly outdistanced by our neighbouring countries.' – The wise men were indeed right. Later events were to prove the justification of their prophecy.

Let us pay tribute to the memory of Knud Jessen. *J. Troels-Smith.*

The above is a translation of a speech read before the Royal Danish Academy of Sciences and Letters, 2nd. Feb. 1973. My sincere thanks are due to Mrs. Gertrud Købke Sutton for the work of translation.

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