Winderosion within the Arctic Deserts.

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Winderosion within the Arctic Deserts.

By Børge Fristrup.

A very extensive literature exists concerning deserts, their morphology and climate, and during the last few years especially numerous treatises have been published on this question. Geographically it is nearly exclusively the tropical and subtropical deserts, which have been studied. Important investigations upon subarctic deserts on Iceland have been carried out by *professor Niels Nielsen* (1933). The high-arctic deserts are seldom mentioned in literature and are not included in most of the larger handbooks.

The extent of the high-arctic deserts is small. They are to be found in Greenland and arctic Northamerica and reaches the most characteristic development in the continental parts of Greenland, especially around Søndre Strømfjord and in Peary Land. The high-artic deserts are characterized by a violent winderosion and strong evaporation, that cause saltcrustations and salt-lakes. In Greenland the salt-lakes and the occurrence of saltcrustations have been known from old times and are mentioned by Henric Christopher Glahn in his diaries from 1768 (1921). A more detailed description of the West-Greenland deserts is to be found in J. A. D. Jensen's description af the westcoast of Greenland between 64° and 67° northern lat. (1889). These early descriptions are published in Danish only and therefore have no place in international literature. Some informations concerning the character of the Greenland deserts are to be found especially in the botanical works by Warming (1888) and C. Kruuse (1912) a. o. The desert at Søndre Strømfjord was studied by the University of Michigan's Greenland Expeditions 1926—33 and was described by Hobbs (1927), while R. L. Belknap (1941) has given a more detailed descriptions of

the climate and erosion. In 1946 extensive botanical investigations were carried out in the area at Søndre Strømfjord under the leadership of Tyge W. Bøcher (1949, 1949 a). The wast deserts areas in Peary Land was discovered during the Danish Pearyland Expedition 1947—50, and informations have been given in the provisional reports made by the expedition (Fristrup 1949, 1951, 1952 and Eigil Knuth 1952).

Fot. B. Fristrup.
High arctic desert in the interior Heilprin Land, Peary Land.

The Climate of the Arctic Deserts.

The climate in the higharctic deserts is extremely continental with high temperature during the summer, insignificant precipitation and a violent winderosion, as a rule due to definite activity of the foehn. In the first place the arctic deserts owe their existance to the evaporation and to the eroding force of the wind, and Werth (1906) has preposed the name "Windwüste" for these deserts, a name which especially is used within the botanical literature.

The climate of Peary Land was studied during the wintering of Danish Pearyland Expedition 1948—50, and a regular meteorogical observation with 8 observations a day were carried out at Jørgen Brønlunds Fjord, a side-branch of the Independence Fjord, which cuts in between Heilprin Land and Melville Land and so is continued

in Wandels Dal. The observations started on August 2nd 1949 and were continued until August 12th 1950 and they have been published by Fristrup (1952 a). To the north Jørgen Brønlunds Fjord is limited by the steep escarpment of the tableland, reaching a height of above 1000 meters and south of the fjord the land raises in terrasses to a height of about 1000 meters.

"Brønlund Hus", the winterstation of the expedition, was placed on the southern side of the Jørgen Brønlunds Fjord at 82° 10,4' lat. N. and 30° 29,8' long. W. The station, thus, was placed in a long valley going from east to west, and eastern and western winds are the only possible directions of the wind. The observations from "Brønlund Hus" therefore, will be strongly marked by lokal conditions where the foehnwinds especially take a violent part. Apart from the station a series of observations were made during the sledgetrips of the expedition, from which it will be seen that the observations from "Brønlund Hus" mainly concern the conditions within the whole of the inner southern Peary Land, while at the outer coast facing the Arctic ocean and in the western fjords a very extreme maritime climate is to be found with lower temperature and bigger precipitation.

Table I. Climate at Brønlund Hus (Average 1948-50).

	Temperature			Wind
	Average of the month	Absolute maximum	Absolute minimum	Average velocity m/sec.
January	— 31,0	— 15,2	— 39,3	4,2
February	— 29,3	— 14,4	— 54,1	6,0
March	— 26,6	— 11,5	— 43,4	6,6
April	— 22,2	— 9,0	— 37,6	5,6
May	— 7,1	4,2	— 19,7	5,5
June	2,6	16,5	— 5,5	6,0
July	6,2	16,1	0,2	6,8
August	3,7	17,0	— 4,9	4,6
September	— 5,4	5,0	— 16,3	4,2
Oktober	— 19,2	— 8,0	— 29,3	2,9
November	— 24,4	— 8,7	— 35,7	3,4
December	— 77,4	— 12,4	— 41,3	5,7
The year	— 15,0	18,0	— 44,1	5,1

From the table I will be seen, that the month with the highest temperature is July with an average temperature nearly matching

the stations of the Southgreenland coast. The winters are a little colder than at the other Greenland stations. The summerperiod is very long and the continious period without frost is more than 70 days, thus being a considerably longer time than at the other high-arctic stations. In the autums it starts freezing very suddenly, on the other side the warm weather comes very quickly during sprintime, and there are only few days during the year with changing thawing and freezing. On account of the very low declination of the sun the diurnal varietions of temperatures are very small. The total precipitation is insignificant. From measurements taken along

Table II. Average yearly numbers of observations of the different wind-velocity at Jørgen Brønlunds Fjord 1948-50 (8 daily observations).

Meter pr. second	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Annual
Calm.....	96	67	80	74	24	8	8	31	72	113	93	70	736
1	10	8	11	6	7	3	3	12	16	21	26	13	136
2	12	12	11	15	8	5	5	19	12	11	14	13	137
3	20	10	14	14	23	7	10	34	26	17	17	16	208
4	17	15	12	19	32	22	21	33	19	18	17	22	247
5	11	15	14	13	37	50	41	32	38	17	13	11	282
6	14	16	8	14	49	51	57	25	16	14	10	12	386
7	12	13	6	5	22	37	25	17	10	9	8	9	173
8	8	11	4	8	9	25	27	16	10	11	7	11	147
9	7	7	4	5	8	12	10	9	5	4	9	8	88
10	9	9	9	6	13	11	15	12	6	6	12	13	121
11	5	4	5	10	4	3	4	3	4	1	2	6	31
12	4	6	8	9	5	5	6	3	3	2	9	15	75
13	2	4	9	3	1	1	4	1	3	1	3	11	34
14	6	2	12	6	4	1	3	2	5	1	3	5	50
15	4	5	11	13	2	1	3	0	3	2	1	8	52
16	4	3	5	8	3	0	2	0	3	1	0	1	29
17	1	2	5	4	1	0	2	0	4	2	0	1	22
18	1	4	3	3	1	0	0	0	2	1	0	0	15
19	1	1	5	3	0	0	1	0	1	1	0	0	13
20	1	5	2	1	0	0	1	0	0	0	0	2	12
21	0	1	1	0	0	0	1	0	1	1	0	0	5
22	0	2	1	0	0	0	0	0	0	0	0	1	4
23	1	2	1	0	0	0	0	0	0	0	0	0	4
24	1	0	1	0	0	0	0	0	0	0	0	1	3
25	0	0	1	0	0	0	0	0	0	0	0	1	2
26	1	3	2	0	0	0	0	0	0	0	0	1	7
27	1	1	0	0	0	0	0	0	0	0	0	3	5
28	0	1	0	0	0	0	0	0	0	0	0	1	2
29	0	0	0	0	0	0	0	0	0	0	0	1	1

stakes on Chr. Erichsen Bræ in the inner Heilprin Land, it will be seen that the precipitation hardly gets above 100—125 mm and perhaps is considerably lower. During the winter the snow is very dry finely graines, and even by calm weather the air can be full of thin iceneedles, pouring down from the clouds. The total quantity of snow is so small, that the land is not covered by a continious cover of snow, but large areas that are exposed to the wind are free from snow. It is thus only possibly to use sledge travelling on the ice of the fjords and on the larger rivers and lakes. This fact however, only applies to central and southern Peary Land, especially to the country around Jørgen Brønlunds Fjord, while the country along the outer coasts and in the western fjords has a larger precipitation and a lot of deep and soft snow. In the aride parts of Peary Land the evaporation is very pronounced and even in the winter the relative humidity of the air is rather low. By measuring the loss of weight of Pyrex-glass pans filled with snow or ice and placed at snow level it was found, that about ⅓ or perhaps even more of the winter precipitation will have been evaporated before the heat of the summer starts. The climate is windy, and from table II will be seen that violent storms and blizzards are frequent, as the forces of the wind in the table II only show the average speed and not the maximum speed in the gusts.

A quite similar climate as in Peary Land is found in Søndre Strøm-

Table III. Climate at Mount Evans according to J. E. Church (1941).

	Average temp.	Average wind velocity
May 1928	5,3	5,6 m/sec.
June	1,11	3,8 »
July	10,1	3,3 »
August	—	—
September	5,3	3,5 »
October	— 2,8	2,9 »
November	— 9,0	3,7 »
December	— 11,8	3,4 »
January 1929	— 6,5	5,0 »
February	— 11,3	4,0 »
March	— 7,4	2,6 »
April	— 3,3	3,2 »
May	3,8	4,4 »
June	6,7	4,9 »
July	13,2	4,6 »

fjord, the climate at Søndre Strømfjord has been studied by the University of Michigan and Pan American Airways Greenland Expeditions and is described by R. L. Belknap (1941) and J. E. Church (1941). The climate at Søndre Strømfjord (and especially at the head of the fjord) is considerably warmer and the average wind velocity is lower than in Peary Land. The climate of Mount Evans (66° 51' lat. N. and 50° 55' long W.) will be seen by table III.

The annual precipitation is very small, at Mount Evans thus only 69,9 mm in the course of 11 months. The foehn activity is violent and with a speed of 12 meters per sec. reaching above 50 meters per sec. during shorter periods. Strong gales therefore are of frequent occurance. Some of the most extreme aride areas in the Arctic is the outer islands of the Canadian Arctic. Especially Eureka Sound has an extremely low annual precipation, according to R. W. Rae (1951) only 4,2 mm in average of three years.

The Winderosion in Arctic Deserts.

In the arctic deserts the windpolishing is very pronounced. From Søndre Strømfjord J. A. D. Jensen (1889) has already given a very vivid description of stones that are smoothly polished to a plate supported only by a thin stem, that the whole stone resembling a table. Jensen describes rifled or grooved stones, where the hard layers protude as sharp edges or the softer layers have completely vanished, so that the stone is riddled, while again other stones, where the disintegration is not yet so advanced, look like a sponge. In Peary Land the hard dolerite is completely polished, while the softer sandstone is pitted and eroded into the most bizarre forms. There are numerous observations of windpolishing from the arctic regions made under such conditions that the polishing is due only to drifting snow and not to drifting sand. Some examples have been given by Carl Samuelsson (1926) and since then numerous others have been added. The hardness of the ice stated in the geological handbooks is 1,5 to 2,0 and it has therefore been denied that drifting snow should be able to polish the hard dolerites. By experiments K. J. V. Steenstrup (1893) tried to prove that the hardness of the ice grew by declining temperature and he found that the ice at — 70° reached a hardness of about 3, and thought this fact a proof of the inability of the ice-needles to polish harder materials. Koch und Wegener (1930) found, that the hardness of drifting ice was exactly 4 at — 44° and 3—4 at — 15°. In a paper from 1939 Curt Teichert however, from observations in the Alps and in Green-

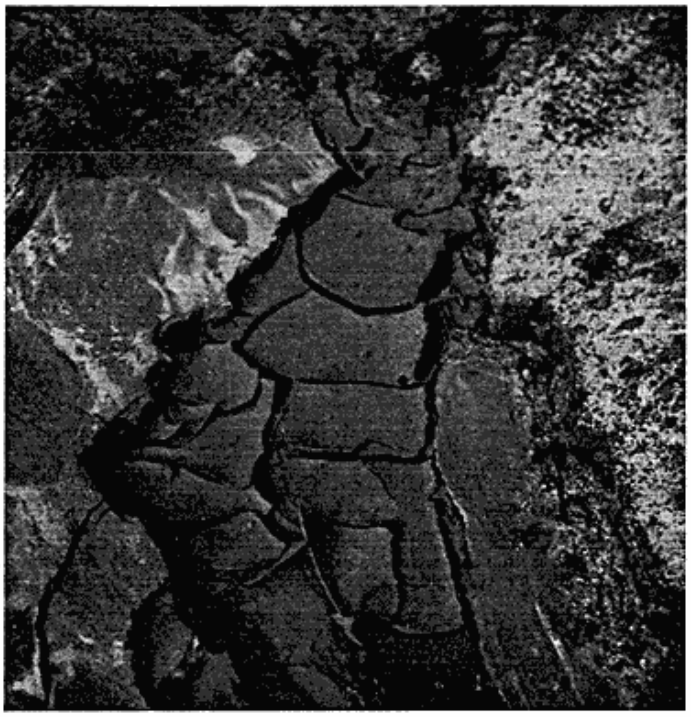
land showed that the hardness of the ice had to be considerably greater and found it to be about 4 at — 44° and about 6 at — 50°. From later, especially Russian observations it appears that the physical qualities of the ice are conditioned by the temperature and the pressure, thus the coefficient of viscosity of ice according to Tsytovich and Sumgin (1937) (Muller, 1945) will raise violently by falling temperature. At the request of Eliot Blackwalder (1940) a

Fot. B. Fristrup.
Ventefacts at the coast of Melville Land, Peary Land.

number of laboratory experiments on the hardness of ice were carried out by examining blocks of ice, frozen to — 78,5° by aid of solid carbon dioxide, and by this temperature the ice was found to have a hardness of 6 (on the Mohr's scale) matching orthoclase feldspar. Within the arctic areas the temperature of the iceneedles will be considerably lower than — 40° — 50° found by the macromatic observations and according to the experiments referred to it is thus to be regarded as having been proved that the iceneedles in drifting snow often will be of a hardness of about 6 or perhaps even more.

In Peary Land the strongest winderosion occurs during the winter. The country itself at that time is more or less free from snow, and the fallen snow will drift over the surface until it settles in

a drift sheltered by a slope or behind a big stone. The snow surface is pressed hard with a strong sastrugi. The winderosion is strongest in the lawlands because the foehn winds are much more stronger here than on the plateaus. During the winter the interior tablelands will be covered by a layer of snow and only the larger stones submerged. The upper parts of these stones as a rule are windpolished, while the lower parts, protected by the snow, will not get polished.



Fot. B. Fristrup.
Dried clay with salterustations, Heilprin Land, Peary Land.

The windpolishing seems to take place very quickly. Investigations upon measuring the winderosion in Peary Land have been done by J. Troelsen (1952). A standard for the windpolishing may be obtained by observing the polishing of the stones in Esquimaux tentrings. Eigil Knuth (1951, 1952 a) has described a number of these tentrings and judging by the archæological findings he has been able to define them as belonging to the Dorset-culture. These stones are polished by the wind and often greatly diminished since they have been raised in their present position by the Esquimaux. A precise dating has not yet taken place with carbon 14. At present time Peary Land is not inhabited, and it is probable, that the age of the Esquimaux tentplaces is within a thousand

years, and during that time some of the stones have been diminued to nearly the half seize.

In many valleys the windpolishing at the stones are rather insignificant. This is owing to the formation of an icelayer that protects the stones. The ice is formed during the autumn and the beginning of the winter. The frost sets in quite suddenly, and the upper surface of the earth therefore freezes, and on many places the water

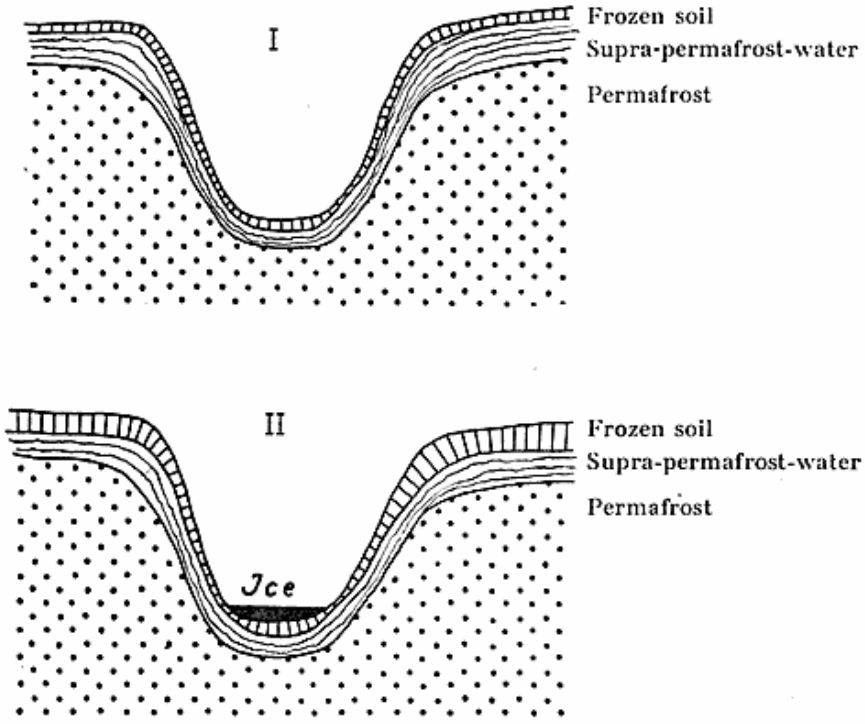


Diagram of the formation of ice at the ground, for further explanation see the text pag. 59.

in the active layer between the permafrost-layer and the frozen surface will be exposed to pressure, and at the weak places, especially in the floor of the valleys and in dried-up rivers the water will be forced ahead, overflow the frozen earth and there freeze. The icelayers thus formed will vary from one year to another, but they can obtain quite significant dimensions.

At all times of the year drifting sand may occur in Peary Land. On account of the dry earth even in the middle of the winter the earth is at many places not firmlyl frozen and can be kicked loose. After long periods where the snow had been swept from the country, drifting sand was not rare to a smaller extent, and during the winter small heaps of sand were deposited in the snow. In spring

the sand and dust will be gathered in pits and melt down in the ice on account of their dark colour and consequently great ability of absorbing the heat. When the sea ice melted, a number of holes in the ice have been formed similar to the cryoconite holes in the glacier-ice. In most arctic regions loess-deposits are playing an important part, but sand deposits and especially sand dunes are rare. In Peary Land dunes existed in very few places along the riverbeds in Etukussuks Dal and in Børglum Elvens Dal. The dunes are very small, but protected by slopes along the rivers and at the seacoast smaller drifts can be formed reaching a height of about two meters or more. The sand of the dunes is quite dry in summer, and the permafrostlayer is deep under the sand. On the area around Søndre Strømfjord the dunes are better develloped than in Peary Land and may reach much bigger dimensions here. Landscapes may be formed, which are similar to the Danish "Indsande" in physiographical respect with smaller dunes, partley covered by vegetation and great open sandplanes with drifting sand. Outside of Greenland dunes in arctic regions have been studied in Alaska by Robert F. Black (1951). The dunes are especially found along the north-coast and in Central Alaska, and the dunes here have much larger dimensions than those in Greenland.

Winderosion in Tropic and Subtropic Deserts.

When comparing the collected material concerning the study of winderosion in the Arctic and in subtropical and tropical deserts, it will be quite apparant how much stronger the winderosion in the Arctic is when compared to the deserts in warm climates. The Sahara is a very old desert and in many places a surface exists that has been left quite unaltered for a very long period, while the arctic deserts are relatively younger on account of the pleistocene glaciation. Typical ventefacts and other forms of winderosion will be found in Sahara, but only in exceptionel cases they are able to reach the same dimensions and the same formation as in the Arctic. From the works of J. Dubief (1952) it will be seen that the climate of Sahara in first place is a climate of weak winds, with long periods of calm and short gales. The nights in the deserts are nearly always calm, and even in daytime most meteorological stations will show a calm of about 30—40 % of the observations. Some places as Ouallen and Tabelbala will even show 70 % calm of the total number of observations at 7^{00} hrs. Weak winds are frequent, and stations like Biskra, El Oued, Tamanrasset and

Touggourt in reality will show very few observations with absolute calm, on the other hand there will only be few observations with gales. Tamanrasset belongs to the most windy stations in Sahara, but compared with conditions in Peary Land it will be apparent from fig. cc that the average force of the wind only reach about half the values of those at Brønlund Hus. The average of the wind velocity can not be taken as a direct measurement of the winderosion, as the sandpolishing only starts with a force of about

Fot. B. Fristrup.
Subtropical desert with wind-erosion, North of Beni Abbès, Sahara.

3 Beaufort or above this. From the investigations made by Dubief it will be seen that forces above 3 Beaufort are not frequent. At few stations theses forces may reach 20 % of the total amount of observations. As an example of the dispersion of the various wind velocities may be taken table IV, showing the wind conditions at El Golea, representing the average conditions in Sahara, and at Brønlund Hus in Peary Land.

From the table will be seen that the great forces of the wind are much more rare in Sahara than in the Arctic.

From Arabia exists only few informations concerning the wind-conditions. R. A. Bagnold (1951) has shown by studying the literature that regular sandstorms are unknown from Rub al Khali. From Central Arabia meteorogical observations exists from two stations only: Hail and Riyadh, which were founded in March 1941 support-

Table IV. Wind forces at El Golea and Brønlund Hus, number of observations pr. 1000.

	El Golea									Brønlund Hus								
Beaufort	4	5	6	7	8	9	10	11	total	4	5	6	7	8	9	10	11	total
January	146	76	32	23	10	5	0	0	292	149	60	73	40	28	8	8	1	367
February ...	173	90	53	32	16	4	0	0	368	196	80	85	49	2	49	2	2	465
March	196	110	47	27	12	4	0	0	396	113	32	89	129	40	44	12	12	471
April	217	116	66	40	14	1	0	0	454	133	54	104	92	50	29	0	0	462
May	298	154	80	65	19	2	0	0	623	435	69	88	28	16	4	0	0	640
June	253	122	62	32	10	3	0	0	482	575	154	79	13	0	0	0	0	821
July	146	40	16	5	1	0	0	0	208	495	149	101	40	16	12	0	0	813
August	162	69	19	10	6	3	0	0	269	298	101	73	12	0	0	0	0	484
September ..	206	82	30	8	0	0	0	0	433	225	63	54	46	29	16	0	0	433
Oktober	149	68	33	67	7	0	0	0	297	161	60	36	16	12	12	0	0	297
November ..	164	72	25	6	3	0	0	0	321	129	67	96	29	0	0	0	0	321
December ..	121	50	21	18	11	4	0	0	463	129	77	137	93	8	8	8	3	463
Mean	186	88	41	24	9	2	0	0	349	253	81	85	49	17	15	3	2	503

ing the R.A.F. during the second World War. From the table V will be seen that the Arabian desert in the first place is characterized by very weak windactivity, and even winds of insignificiant force are rare and gales and storms does not exist at all.

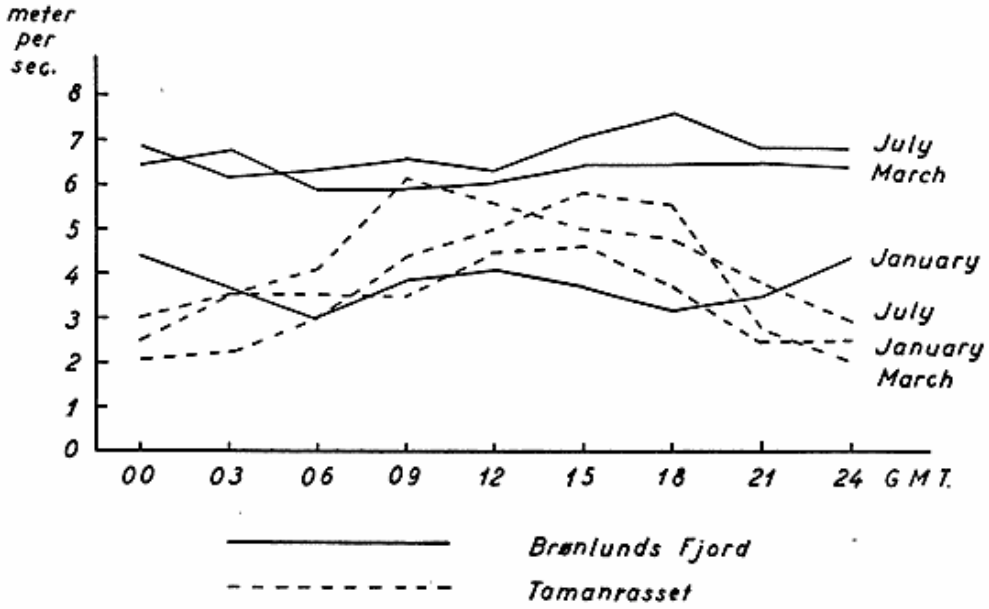
From the above meteorological summary will be apparent that most of the subtropical and tropical deserts can be characterized by little activity of the wind and that violent sandstorms are rare. In most places in Sahara the sandpolishing will therefore will take place on very few days the year, and in Central Arabia there is next to none possibility of winderosion under the present elimatic conditions.

In the warm climates the polishing is only due to drifting sand and as mentioned above, the sandpolishing only takes place on few

Table V. Vindobservations in Central Arabia.

	Hail	Riyadh
Number of observations at year	2 995	2 095
» » » ≧ 3 Beaufort....	72	67
» » » ≧ 6 »	6,6	0

days. When a strong windpolishing yet exist in various places, it therefore probably must be caused by the geological long period, where these areas have existed as deserts. It is also possible that part of the observed windpolishing has taken place, when the climate was more windy than at the present moment. In the high-arctic deserts the wind polishing is due partly to drifting sand and partly to drifting snow. Judging by the observations in Peary Land the iceneedlepolishing probably is the most important. Compared



The diurnal variation of the average wind velocity at Jørgen Brønlunds Fjord and Tamanrasset.

with the Tropics the storms are more frequent and longlasting in the Arctic and snowdrift and snowpolishing may happen even by 2 contrary to that sanddrift first start at 3 or 4 Beaufort. But according to observations from different parts of Greenland it is most probably that the snowdrift is only polishing during the heavy gales; if storms are rare, as f. inst. Washington Land, only an insignificant polishing exists on account of drifting snow.

The winderosion in the arctic area is especially strong in the continental areas in front of the indlandice, and similar conditions have been prevailing along the pleistocen Indlandice. In Denmark thus the "Indsande" are a part of the dunes from the lateglacial period, and in many of this places beautifull develloped ventefacts can be observed. Thus the study of higharctic deserts will help to explain the conditions around the pleistocene icecaps.

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