Periglacial processes in the Mestersvig region, central East Greenland

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The earliest thorough investigations of periglacial processes in Greenland were conducted from 1956–1961 in the Mestersvig region (72°N 24´W) of central East Greenland, where a number of experimental sites were established by A.L. Washburn (Fig. 1; Washburn 1965, 1967, 1969). Results from these investigations are still of relevance, and are quoted in recent periglacial literature (e.g. Ballantyne & Harris 1994; French 1996).

During the field seasons of 1998 and 2000 a resurvey of Washburn's original experimental sites was undertaken. The main purpose was to describe the state of preservation of the sites and to derive estimates of long-

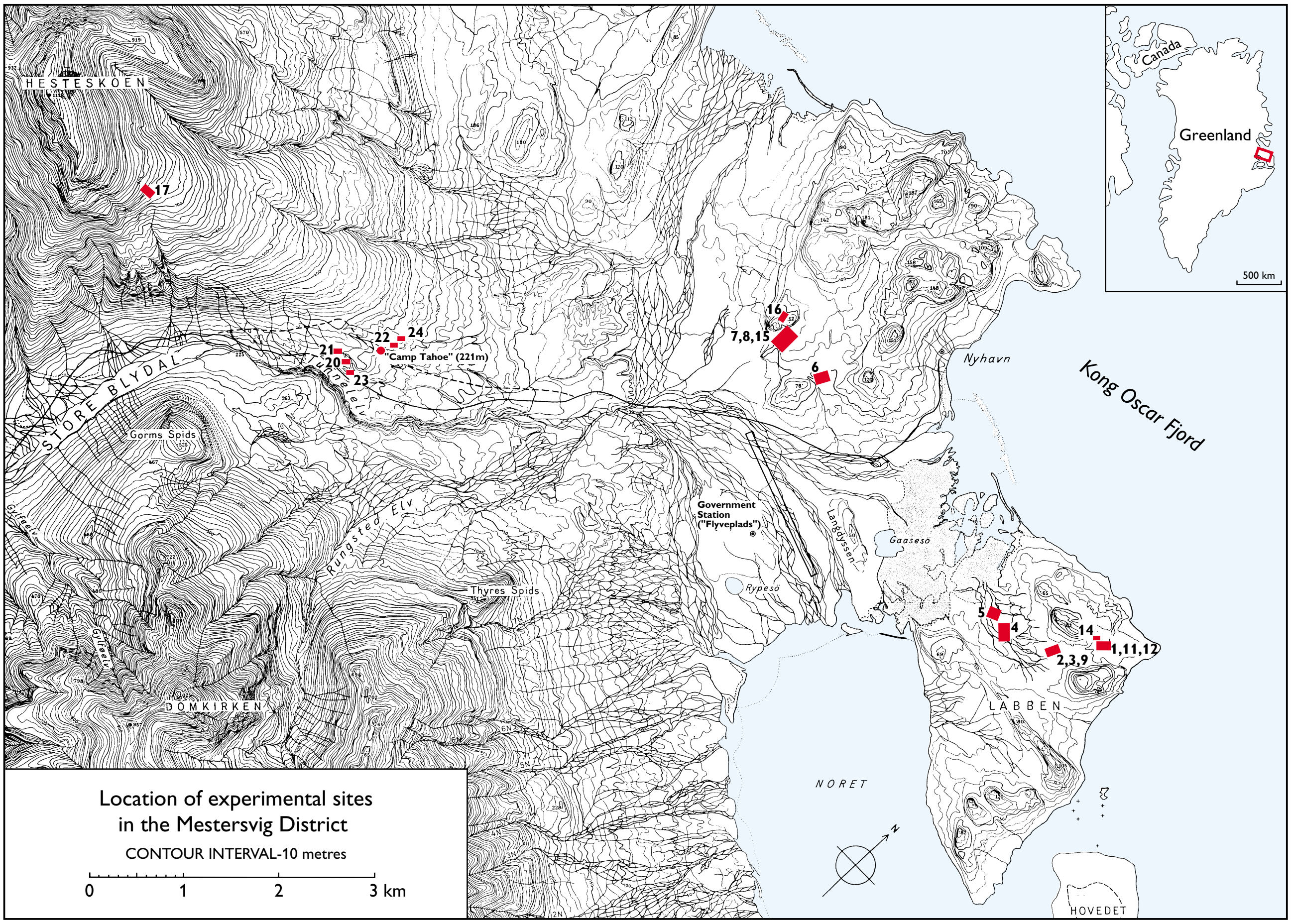

Fig. 1. Map of the Mestersvig region in central East Greenland reproduced from Washburn (1965, plate 5) with slight modifications. Locations shown as **red blocks** indicate the numbered experimental sites established by A.L. Washburn in 1956–1961. Place names on land areas of this map are in their original spelling, some of which are not in their approved modern form (correct spellings include Thyre Spids, Gorm Spids, Gåsesø and Rypesø). Mestersvig airport is here designated 'Government Station ("Flyveplads")'. On inset map the location of the Mestersvig region in central East Greenland is shown by the **red rectangle**.

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Table 1. Site locations

Site 1	As for Site 11
Site 2	72°14.738'N 23°50.229'W
Site 3	25 m NE of Site 2
Site 4	72°14.642'N 23°51.200'W
Site 5	72°14.616'N 23°51.579'W
Site 6	72°14.942'N 23°57.029'W
Site 7	72°14.917'N 23°58.247'W
Site 8	72°14.945'N 23°58.187'W
Site 9	30 m NW of Site 2
Site 11	72°14.980'N 23°49.766'W
Site 12	As for Site 11
Site 14	72°14.956'N 23°49.848'W
Site 15	72°14.976'N 23°58.089'W
Site 16	72°15.035'N 23°58.261'W
Site 17	72°12.991'N 24°08.183'W
Site 20	72°13.103'N 24°03.506'W
Site 21	72°13.107'N 24°03.617'W
Site 22	72°13.361'N 24°03.075'W
Site 23	72°13.071'N 24°03.205'W
Site 24	72°13.468'N 24°03.127'W

The geomorphological sites used for field experiments and observations in 1956–1961 (Washburn 1967). Site positions were measured in 2000 using a WGS-84 conversion for the GPS positioning system. Sites 10, 13, 18 and 19 were abandoned at an early stage of the field experiments (Washburn 1967).

term (40+ years) rates of mass-wasting to compare with Washburn's original short-term rates. The field work also assessed the possibility of re-establishing some of the original sites for inclusion in a new periglacial research programme in the Mestersvig region, aimed at monitoring the impact of long-term global change on the Arctic periglacial environment in a coastal area.

Periglacial investigations in central East Greenland

The geomorphological investigations in the Mestersvig region by A.L. Washburn and coworkers included studies of frost creep and gelifluction, rock weathering and vegetation (Washburn 1965, 1967, 1969, 1973; Ugolini 1966a, b; Raup 1969, 1971). During the study period (1956–1961) Washburn established 24 experimental sites in the vicinity of the Mestersvig airfield (Fig. 1; Table 1). Each site was selected and designed to monitor periglacial processes, and to allow for comparative studies. Six of the sites (Sites 4, 5, 6, 7, 8, 17) were installed as experimental target lines, with the purpose of determining mass-wasting rates (Figs 2, 3). The observed rates of movement were subsequently related to parameters such as slope gradient, soil type, moisture and vegetation. Thermo-couples installed at Sites 6, 7 and 8 enabled ongoing registration of soil temperatures at various depths. Ambient temperature and moisture conditions were measured at all sites, and recording weather instruments were maintained at Sites 7 and 8. Additional experiments at some sites were undertaken utilising mass-wasting strain and movement-metering devices, with varying success. At experimental Site 2 a strain gauge was installed to study possible pressure build-up in connection with the formation of polygons and patterned grounds. In addition one polygon structure (close to Site 20) was excavated in the late 1950s enabling detailed study of the cross-section of the polygon.

A number of other sites were established with thin 10 cm long dowel sticks (Fig. 4) placed in well-defined patterns to study small-scale movements within patterned grounds, polygonal soil features and solifluction lobes (Sites 14, 15, 20, 21). Other dowel-stick sites allowed observations of small-scale periglacial processes on the slopes of a weathering basalt section covered by talus products (Site 16). Three sites were used for observations on the rate of exfoliation and weathering of different types of rocks (Sites 22, 23, 24). At an early stage of the field programme, Sites 10, 13, 18 and 19 were abandoned, as they were considered unsuitable for various reasons (Washburn 1967).

Detailed climatic and meteorological data were collected in conjunction with Washburn's geomorphological observations and experiments during the study period. The climate of the Mestersvig region is truly arctic with mean annual air temperature for the period 1956–1961 ranging from –9.2°C to –10.6°C, and a mean annual precipitation of 372.5 mm mostly falling as snow (Washburn 1965). Despite its location north of the Arctic Circle, Mestersvig has relatively mild, though short, summers with maximum temperatures reaching as high as 20°C in July and August (Harpøth *et al.* 1986). However, minimum temperatures can fall well below 0°C at any time during the summer season, and as such the soils in the area are clearly subject to marked freeze–thaw cycles.

The Mestersvig region is located in a zone of continuous permafrost (Christiansen & Humlum 2000), which extends to a depth of up to 125 m, while the thickness of the active surface layer ranges from 0.5 m to 2 m (Washburn 1965). Ongoing periglacial research in other parts of Greenland includes nivation studies (Christiansen 1998) and monitoring of active layer dynamics (Christiansen 1999).

Fig. 2. Close-up of target cone in mass-wasting target line at Site 5 in the summer of 2000. The 10 cm high wooden cone mounted on a wooden peg was inserted into the ground in 1956.

Field observations

The original experimental target lines resurveyed in 1998 and 2000 were easily identified in the field due to orange paint still being present on the target cones (Fig. 2). Of the six experimental mass-wasting lines, only Sites 4, 5 and 6 in the hills south and south-west of Nyhavn and Site 17 located on the east slope of the mountain Hesteskoen were found suitable for remeasurement (Fig. 1). Unfortunately, two important sites in the 'Nyhavn Hills' south and south-west of Nyhavn (Sites 7, 8) had been stripped of target cones by others and re-employed for later experiments. The dowel-stick sites were difficult to locate due to weathering and dispersal of the tiny sticks (Fig. 4). The pressure gauge of Site 2 was still in place, but not functioning, and the excavated profile of the polygon close to Site 20 was found to be partly slumped.

During the resurvey, measurements of target movements were recorded relative and perpendicular to the original target line. Brief descriptions of the different types of experimental sites are presented below.

Experimental mass-wasting (Sites 4, 5, 6, 17)

Experimental Sites 4 and 5 are located at altitudes of approximately 10 m and 9 m, respectively, on the Labben peninsula (Fig. 1), on a 1° to 2° gently northward-sloping surface. The area is dry and dominated by non-sorted polygons in sandy-silty clay that is almost barren of vegetation. Site 4 was established in 1956 with 30 target cones, of which 17 were considered *in situ* in 1998/2000, while at Site 5 a total of 21 of the original 27 target cones were considered to be *in situ* (Fig. 3). Preliminary estimates (by S.C.) indicate mean long-term movement rates of the order of 0.3 to 0.4 cm/yr. The general low rates are presumably due to the dryness and shallow gradient of the slope. After installation of the experimental lines, Washburn subsequently

Fig. 3. The orange target cones of experimental Site 5 are still in line after 45 years of frost creep and gelifluction on the gently sloping hill at Labben. The pegs were originally inserted into the soil to the base of the 10 cm high cone and placed in a straight line perpendicular to the slope, with a spacing of approximately 2 m. A theodolite placed at a fixed point at the end of each target line was employed to record target movements at regular intervals over four or five seasons.

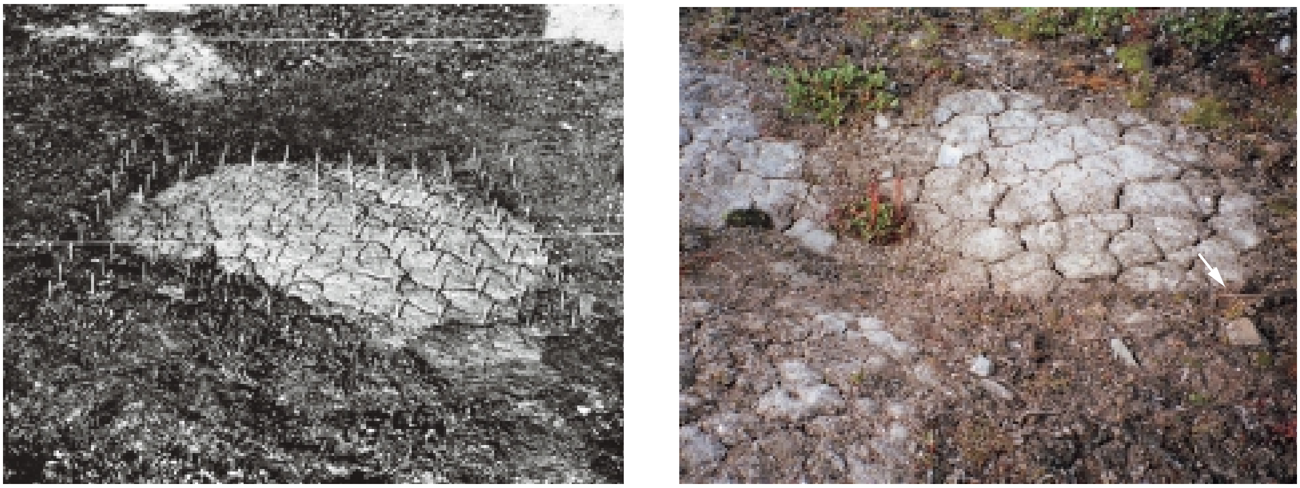

Fig. 4. Experimental Site 9 originally instrumented with short dowel sticks 0.3 cm in diameter. The dowels were spaced at intervals of 10 or 20 cm at the beginning of the experiment and inserted to depths of 5 or 10 cm in lines or grid patterns (**left**). The original dowel patterns established in the late 1950s were found to be obliterated when revisited in 2000 (**right**), due to up-freezing by the intervening freeze–thaw cycles. **Arrow** indicates one of the uprooted dowel sticks.

considered Sites 4 and 5 of limited value for detailed studies of mass-wasting, as the boulders selected for the theodolite stations were found to be subject to frost action. The target cones nevertheless provided important information on frost action such as heaving and tilting.

Experimental Site 6 is located in a N–S-trending dell south-west of Nyhavn with a gradient of approximately 3°. At the time of the 1998 and 2000 field work, a small stream traversed the valley, and the experimental area was well vegetated and characterised by wet conditions and by silty and clayey soils. Of the 43 cones installed in 1956, only 23 were considered to be in situ. Mean movement rates (estimated by S.C.) for the period 1956–1998 were about 6 cm/yr and thus slightly higher than the average short-term rate of 4.9 cm/yr calcu-

Fig. 5. Experimental Site 17 located on a gelifluction lobe on the southern slope of Hesteskoen at an altitude of 720 m. The periglacial processes at this site, which is characterised by high altitude, steep slope and wet conditions, are pronounced compared to drier sites at lower altitudes of the Mestersvig region. The two photographs from 5 August 1957 (**left**) and 22 July 2000 (**right**) show the impact of long-term periglacial processes, especially affecting the shape of the lobe front.

Fig. 6. Weathering of a tholeiitic diabase boulder at Site 22. The photograph of the rock in 1960 (**left**) was taken before a linen sheet was placed under the rock to collect weathering products for quantitative calculations on granular disintegration. **White ruler** is 17 cm long. The sheet had almost disintegrated by summer 2000 (**right**). It is evident from the two photographs taken 40 years apart that granular disintegration has been substantial in this arctic environment.

lated for the period 1956–1961 by Washburn (1967). Soil moisture would appear to have a major influence on movement rates.

Experimental Site 17 is located on a prominent gelifluction lobe at an altitude of 720 m on the east slope of Hesteskoen. The lobe has very sparse vegetation and is composed of stony diamicton and pebbles and cobbles in a clay-silt-sand matrix. The lobe is approximately 30 × 20 m in size; the upper lobe surface slopes at 15° to 23°, while the 3 m high down-slope front exceeds 45°. The lobe was originally equipped with 15 cones, of which 14 were found; however, all but three were toppled. Estimates of the average rates for long-term movement (by S.C.) were approximately 12 cm/yr, somewhat higher than the average short-term rate of 7.7 cm/yr calculated for the period 1957–1959 by Washburn (1967).

Comparisons of the outline and overall morphology of the gelifluction lobe on Hesteskoen in 1957 and 2000 show pronounced changes due to periglacial processes, notably in the shape of the lobe front (Fig. 5).

Rock weathering (Sites 22, 23, 24)

Washburn (1969) established three sites in the vicinity of 'Camp Tahoe' (Fig. 1) at altitudes of *c.* 200 m to study weathering processes of different rock types and obtain quantitative data on granular disintegration. Originally, white linen sheets were placed at the base of the boulders to collect weathering products for quantitative estimates. Sites 22 and 23 are tholeiitic diabase boulders (Fig. 6) and Site 24 a granitic boulder. Washburn (1969) concluded that granular disintegration of rocks was more widespread in polar environments than was commonly realised. The original sheets were still in place in 2000, but unfortunately so fragmented that it was impossible to collect weathering products for determination of long-term rates to compare with the short-term rates of Washburn (1969).

Patterned ground and dowel sticks (Sites 14, 15, 16, 21)

Mass-wasting and frost action on a variety of patterned ground forms were studied in detail at sites instrumented with wooden dowel sticks (Washburn 1969). The dowels are short sticks, 0.3 cm in diameter and commonly spaced at intervals of 10 or 20 cm at the experimental sites. They were inserted to depths of 5 or 10 cm in lines or grid patterns to record frost action and mass-wasting effects as measured with reference to strings or wires (Fig. 4). The original experiments showed that the maximum up-freezing that an object undergoes during a single freeze–thaw cycle is proportional to the effective object height, which is the vertical dimension of the buried portion frozen to, and therefore heaved with, the adjacent material (Washburn 1965). At the resurvey in 2000 the original dowel stick patterns established in 1956 were completely obliterated as a consequence of more than 40 years of freeze–thaw cycles.

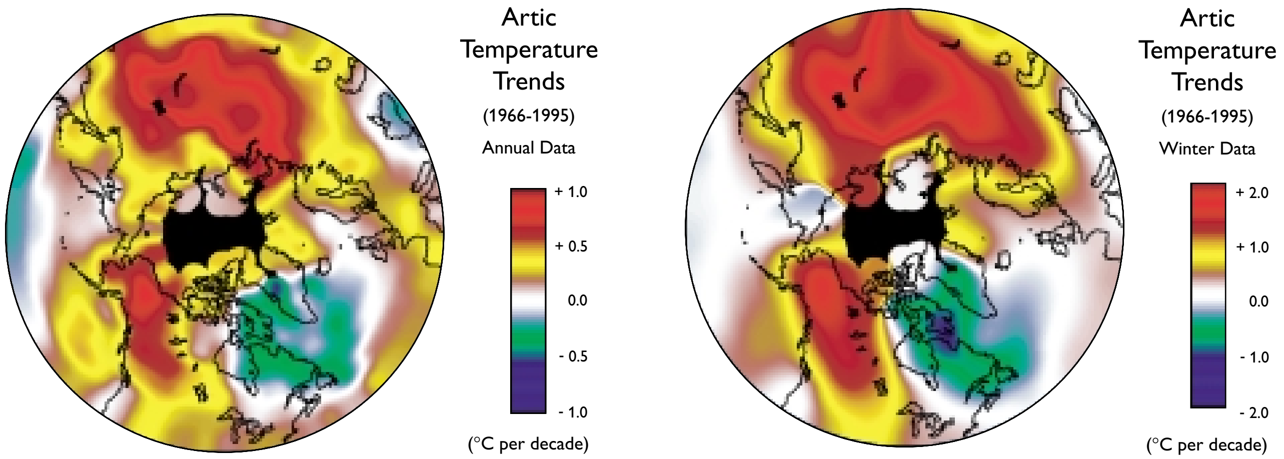

Fig. 7. Observed trends of arctic winter mean temperature from 1966 to 1995. The mean temperatures in northern and north-eastern Greenland have warmed over the last three decades, whereas the temperatures in southern Greenland show a cooling. The general temperature increase in north-eastern Greenland is considered to have had an influence on freeze–thaw cycles and thus periglacial processes in the Mestersvig region. Reproduced from IASC (1999), based on Chapman & Walsh (1993).

Preliminary results and possible effects of climate change

Interpretation of data obtained during the 1998 and 2000 resurvey is indicative of a number of problems related to the long time period elapsed between target line installation in the late 1950s and the remeasurements 40+ years later. The main difficulty lies with determining which target cones have been moved solely by the processes of frost creep and gelifluction, and which have been subject to other forces, natural or otherwise. Surface wash, particularly on the wetter Sites 6 and 17, may account for some of the longer distances travelled by toppled target cones. Some cones may also have been tilted by strong winds or influenced by human or animal activity. For example, vehicle tracks can be seen traversing Site 5. Furthermore, the data collected in 1998 and 2000 do not quantitatively distinguish between frost creep and gelifluction, but rather represent combined data on long-term mass-wasting rates for these sites.

Despite uncertainties the resurvey of all mass-wasting sites in the Mestersvig region points to some general trends. Two resurveyed sites (Sites 4, 5), both characterised by shallow gradients and fairly dry terrain, displayed very low rates of movement. The long-term rates for two other sites (Sites 6, 17), each in steeper and notably wetter terrain, showed more rapid mass-wasting rates than the short-term rates recorded more than 40 years ago.

The average global temperature has increased by *c.* 0.6°C since 1860 (Houghton *et al.* 1996) with the warmest years in the late 1990s. This temperature increase is not uniform worldwide, and regional differences also occur in Greenland (Fig. 7). Thus the average winter temperature in South-West Greenland has decreased over the last 30 years, whereas the average temperature in central East Greenland has apparently increased by approximately 0.5°C per decade during the same period. Despite all uncertainties related to the remeasured data, it is notable that the preliminary long-term mass-wasting rates (40+ years) obtained from the 1998/2000 field work are slightly higher than the short-term rates (2–5 years) obtained in the late 1950s for the wetter experimental sites with steeper slope gradients. This situation may, with some reservations, be interpreted in support of an increase in average mass-wasting rates linked to general global warming.

The detailed records of periglacial processes and mass-wasting rates in the Mestersvig region by A.L. Washburn and coworkers, together with the detailed meteorological data, provide a unique data set. These data are highly relevant to a possible new monitoring research programme and may provide insights into the longer term impact of global change on periglacial processes and on the vulnerable arctic environment.

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References

Ballantyne, C.K. & Harris, C. 1994: The periglaciation of England, 330 pp. Cambridge, UK: Cambridge University Press.

Chapman, W.L. & Walsh, J.E. 1993: Recent varations of sea ice and air temperature in high latitudes. Bulletin American Meteorological Society **74**, 33–47

Christiansen, H.H. 1998: Nivation forms and processes in unconsolidated sediments, NE Greenland. Earth Surface Processes and Landforms **23**, 751–760.

Christiansen, H.H. 1999: Active layer monitoring in two Greenlandic permafrost areas: Zackenberg and Disko Island. Danish Journal of Geography **99**, 117–121.

Christiansen, H.H. & Humlum, O. 2000: Permafrost. In: Jakobsen, B.H. *et al.* (eds): Topografisk atlas Grønland. Atlas over Danmark Serie II **6**, 32–35. København, Danmark: Det Kongelige Danske Geografiske Selskab / Kort & Matrikelstyrelsen.

French, H.M. 1996: The periglacial environment, 2nd edition, 341 pp. Harlow: Longman.

Harpøth, O., Pedersen, J.L., Schønwandt, H.K. & Thomassen, B. 1986: The mineral occurrences of central East Greenland. Meddelelser om Grønland Geoscience **17**, 139 pp.

Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. & Maskell, K. (eds) 1996: Climate change 1995, the science of climate change, 572 pp. Cambridge, UK: Press Syndicate, University of Cambridge.

IASC 1999: Impact of global climate change in the Arctic regions. Report from workshop on the impacts of global change, 25–26 April 1999, 28 pp. Tromsø, Norway: Norwegian Polar Institute.

Raup, H.M. 1969: Observations on the relation of vegetation to mass-wasting processes in the Mesters Vig district, Northeast Greenland. Meddelser om Grønland **176**(6), 216 pp.

Raup, H.M. 1971: The vegetational relations of weathering, frost action and patterned ground processes, in the Mesters Vig district, Northeast Greenland. Meddelelser om Grønland **194**(1), 92 pp.

Ugolini, F.C. 1966a: Soils of the Mesters Vig district, Northeast Greenland. 1. The arctic brown and related soils. Meddelelser om Grønland **176**(1), 22 pp.

Ugolini, F.C. 1966b: Soils of the Mesters Vig district, Northeast Greenland. 2. Exclusive of arctic brown and podzol-like soils. Meddelelser om Grønland **176**(2), 25 p.

Washburn, A.L. 1965: Geomorphic and vegetational studies in the Mesters Vig district, Northeast Greenland. General introduction. Meddelelser om Grønland **166**(1), 60 pp.

Washburn, A.L. 1967: Instrumental observations of mass wasting in the Mesters Vig district, Northeast Greenland. Meddelelser om Grønland **166**(4), 296 pp.

Washburn, A.L. 1969: Weathering, frost action and patterned ground in the Mesters Vig district, Northeast Greenland: Meddelelser om Grønland **176**(4), 303 pp.

Washburn, A.L. 1973: Periglacial processes and environments, 320 pp. London: Edward Arnold.

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