GEOLOGY OF THE THULE AREA, GREENLAND

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INTRODUCTION

Thule, located on the northwest coast of Greenland in Wolstenholme Fiord, is a small settlement of Danes and Greenlanders. Nearby Mt. Dundas, a diabase capped knob, has been recognized as a prominent landmark by arctic mariners for hundreds of years. In spite of the latitude of the settlement (76° 30′), the summers are quite equable, temperatures sometimes going up to 60 or 70 degrees with many days of clear, bright weather. The principal geographic features are shown on the geologic map (Fig. 1). Of these, Thule Lobe and Edisto Creek are new names.

During the summer of 1949, the authors investigated the geology of Devon Island, Northwest Territories, Canada. The opportunity to study the Thule area came when it was necessary for our ship to stop at Thule before proceeding on to Devon Island. It was hoped that a possible correlation with the rocks on Devon Island could be made. The amount of work accomplished in the field during our ten days in the area was possible only through the splendid cooperation of the United States Navy. The authors wish to express their sincere appreciation to Captain Rittenhouse, Captain Kirvin, Commander Warner, and the other officers and personnel of the USS Edisto for the many courtesies extended and facilities offered during our stay.

Detailed measuring of sections was made by tape and Brunton compass. As it was impossible to measure the complete section of rocks in this manner, more generalized methods were also used. Overall thicknesses were calculated from aerial photographs and altimeter readings.

GENERAL GEOLOGY

The relative ages of the rock units are, oldest to youngest: Agpat formation, Wolstenholme quartzite, Danish Village formation, and Narssarssuk formation. Diabase intrudes all the above strata.

AGPAT FORMATION. The oldest rocks exposed are considered to be the equivalent of the Agpat formation, the type area of which is at Agpat, Umanak Fiord, West Greenland. Koch (3) asserts that this formation can be traced from the type area northward to Inglefield Gulf. Detailed examination of the Agpat formation was made on Wolstenholme Island. Here it consists of chloritic-amphibolitic, biotitic and quartzose schists and gneisses, and granitic and pegmatitic intrusives. The mineral suite in the schists suggests low to middle grade metamorphism.

The history of the Agpat formation can be traced from the laying down of the first sediments to uplift and peneplanation. First was the deposition of sediments, predominantly shales and calcareous rocks. Sometime after the sedimentation intense deformation with dragfolding and faulting occurred. This deformation was accompanied with or just preceded by the

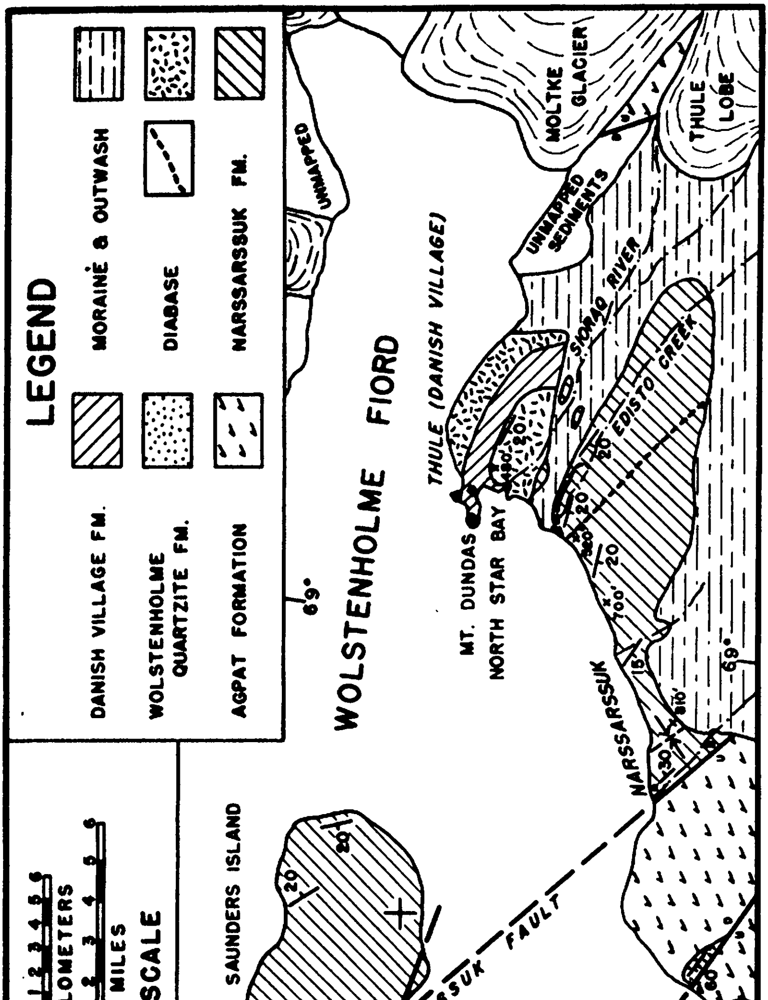

FIGURE 1. Geologic Map of the Thule Area.

intrusion of granitic and dioritic dikes and sills. Considerable lit-par-lit injection into the surrounding sediments accompaned by alteration from solutions gave much of the rock a gneissic character. The dikes and sills were reduced to linear pockets and swells during the deformation. Later, granitic and pegmatitic material intruded through fissures forming dikes. Some of the dikes contain crystals of orthoclase up to six inches in length. The final event was small scale faulting which displaced the latest dikes from a few inches to several feet. This was followed by regional uplift and peneplanation. Near the fault on the mainland just south of Wolstenholme Island a small part of the upper contact is exposed. The structures are truncated, and the surface shows minor irregularities of only a few inches. The thickness of the formation is not known, but is believed to be at least several thousand feet.

WOLSTENHOLME QUARTZITE. The name Wolstenholme quartzite is proposed for the thick unit of medium to coarse, red to white, crossbedded, massive, partially conglomeratic orthoquartzite exposed on Wolstenholme Island and nearby areas. Minimum thickness is about 1600 feet, but since the top contact is not known the maximum thickness cannot be determined. This unit probably corresponds to the lower part of the Thule formation of Koch (1). On Wolstenholme Island the base of the formation is concealed, but to the south on the mainland near the fault, the lower contact is well exposed. The "basal" conglomerate is not at the base, but several feet above it. The lowest beds are red siltstones, probably reworked residual soils, with a few scattered pebbles of Agpat gneisses and schists at their base. The conglomerates are characterized by angular to well rounded pebbles of vein quartz imbedded in a coarse quartz sand matrix.

On the south part of Wolstenholme Island near the bottom of the formation is a conglomeratic bed about five feet thick with rounded boulders of quartz measuring a foot in diameter. Just south of the center of the island, near the top of the strata, several layers of conglomerate are exposed which have been stripped by erosion until they resemble a "pavement". The greater part of the Wolstenholme quartzite consists of coarse grained orthoquartzite. Crossbedding is common in its middle part and is regarded as subaqeous in origin. Diffusion banding brought about by solutions from a diabase dike has produced the appearance of crossbedding in nearby sediments. In general, the upper part of the formation is white and the lower part red. Some of the lower part is also white but this seems to be due to chemical action of solutions from the diabase moving along the many minute fractures in the rock, reducing the iron and eliminating the red coloration.

DANISH VILLAGE FORMATION. The name Danish Village formation is proposed for a series of dolomites, shaly dolomites, and black bituminous shales exposed south and east of Danish Village (Thule). About 800 feet of this formation was measured by altimeter on the cliff south of the settlement. More is probably present to the northeast, but because of the presence of thick diabase sills and talus the rocks are not exposed. The lowest beds examined are a sandy dolomite. Above these is a series of alternating beds of black bituminous shale and shaly dolomite. The upper part consists of alternating layers of finely crystalline, buff, dolomite and shaly dolomite that culminates in a 30 foot layer of more massive material at the top. A careful examination of the sediments revealed no fossils. The lower contact of the formation is not exposed and the upper contact is drawn at the base of a diabase sill.

NARSSARSSUK FORMATION. The name Narssarssuk formation is proposed for a thick series of rocks made up of layers of red siltstones, coarsely crystalline, grey, porous dolomite, and fine-grained, shaly dolomite, arranged in a cyclical fashion. Excellent exposures of these rocks occur along the cliffs between Edisto Creek and the native village of Narssarssuk, and on Saunders Island, the latter being formed entirely of this formation. As one looks at the cliffs the banded appearance of the sediments is striking, hence part of the formation just southwest of Edisto Creek was measured in detail. The measurements confirmed the cyclic arrangement. The following is a typical cycle:

SHARP CONTACT — DISCONFORMITY?

4. Siltstone, red—30 feet.
3. Shale, grey to green, fissile, sometimes dolomitic—2 feet.
2. Dolomite, buff to grey, finely crystalline, shaly toward top—30 feet.
1. Dolomite, grey, coarsely crystaline, porous, massive—30 feet.

SHARP CONTACT — DISCONFORMITY?

Contacts between units making up the cycles are gradational. All cycles are not exactly the same, some being more complete than others. Variations are usually due to changes within the cycle itself such as differences in the amount of shale and dolomite in unit 2 and lack of red color in unit 4. Mud cracks, ripple marks, and a flat pebble conglomerate in unit 2 indicate at least partial shallow water deposition. The massive blocky character of the redbeds containing occasional large grains of feldspar and quartz seems to indicate rapid deposition of unit 4. Fifty-eight cycles, as evinced by the prominent redbeds at the top, were counted. There are a few more uncounted cycles in the poorly exposed part of the formation in Sioraq River valley.

Minor sedimentary features of interest are stylolites in unit 2, and evidence of penecontemporaneous faulting. The stylolites are not sharp, but have a strongly undulating surface, varying as much as six inches. There is an obvious relationship between the amount of shale in the dolomite above and below the stylolite, the amount of shale in the plane of the stylolite, and the irregularity of the plane. The less shale in the dolomite the less there is in the plane of the stylolite, and the more irregular the plane becomes. With an increase of shale in the dolomite the conditions are reversed. The above relationships, coupled with the fact that the stylolites cut across bedding planes, show that these stylolites are a secondary solution phenomenon. In the same unit with the stylolites there are occasional cone-in-cone structures.

A series of normal step faults that cut the contact between two of the cycles southwest of the mouth of Edisto Creek demonstrates that the faulting occurred soon after deposition. Maximum displacement is about three feet at the contact, but the top of unit 1 is perfectly regular and any evidence of faulting extends only a few feet up into the unit. Only the top few feet of unit 4 is exposed so that the depth of faulting could not be determined.

The bottom of the Narssarssuk formation is at the top of a 58 foot diabase sill lying between it and the top of the Danish Village formation. The top contact is not known, as succeeding sedimentary formations are not present in the Thule area. No fossils were found although a careful search was made. Some beds contained scattered, irregular bits of carbonaceous film which may represent some type of seaweed, crustacean remains, or merely organic impurities. Minimum thickness of the formation is about 6000 feet.

DIABASE. Diabase sills and dikes intrude the rocks in the Thule area and are especially well developed on the south side of Wolstenholme Fiord just east of Thule. The diabase is fine to medium grained, brownish black, with minute laths of plagioclase producing a good diabasic texture. The preponderance of sills in the lower part of the Danish Village formation may be due to the black shale layers offering planes of weakness for the intrusion. Only two other sills were observed, one between the Danish Village and Narssarssuk formations, the other about 1500 feet above the base of the latter formation. The Wolstenholme quartzite is cut by several dikes and the Narssarssuk formation by one that is nearly vertical.

Alteration of the surrounding sediments by solutions from the diabase is usually negligible and suggests a low temperature magma. However, a three foot bed of white, coarsely crystalline dolomite containing minute flecks of pyrite lies above the only sill in the Narssarssuk formation. The dolomite may be in contact with the diabase or separated from it by a foot or more of altered shaly dolomite. The color change and diffusion banding in the Wolstenholme quartzite has been discussed.

The authors believe that the diabase was intruded along the Narssarssuk fault. Upon reaching weak sedimentary beds the magma spread, forming sills which extend northwestward past Thule. It also moved along fractures and faults in the crystalline rocks west of the major fault, rising and cutting the sediments on Wolstenholme Island. Approximately 660 feet of diabase was measured and the authors estimate that at least 1000 additional feet are present.

MORAINE AND OUTWASH. Changes in the margin of the Greenland Ice Sheet have left bouldery moraines in the southwest part of the Thule area. Early in the Pleistocene the glaciers extended much farther than at present. The deposits are very irregular in thickness, especially in the broad valley of the Sioraq River. In general, the closer to the ice, the thicker and more irregular the moraine becomes. Close to the margin of the Thule Lobe there are two well defined recessional moraines, and at present, there is a deep valley between the innermost moraine and the ice. Kettleholes are abundant throughout the Sioraq River valley and especially in the vicinity of the junction of the two tributaries where moraine and outwash materials are mixed. Further to the west patches of bedrock show through these surficial deposits and the whole west end of the valley appears underlain by outwash. Only a thin moraine covers the rocks in the south part of the Thule area.

The Thule Lobe once extended to Wolstenholme Fiord. While still active the glacier divided, part of the ice moving down the Sioraq River valley, the other branch moving northward from near the present position of the river fork. At the time of maximum ice advance it is probable that the high land area east of Mt. Dundas, the long ridge further to the east, and Saunders and Wolstenholme Islands were nunataks.

AGE OF THE ROCKS

The highly folded, intruded, and metamorphosed Agpat formation is considered early Algonkian in age by Koch (3). However, definite criteria for determination of age is lacking. The age of the remaining sediments is questionable. Koch (1) placed them in the Thule formation, which he (2) considered late Cambrian or early Ordovician in age. Later (3) he assigned them to the late Algonkian. He believed the Thule formation was present to the north on Ingelfield Land. Diabase dikes intrude the rocks of Inglefield Land but do not cut overlying Lower Cambrian sediments. Also, on Devon Island, diabase dikes do not intrude the Lower Cambrian sediments. If there is only one intrusion of diabase in these areas, then the Wolstenholme quartzite, Danish Village, and Narssarssuk formations, and diabase are Pre-Cambrian in age. If there was more than one intrusion the age of the sediments in the Thule area is open to question. The black fissile shales in the Danish Village formation would normally indicate a later age than Pre-Cambrian. Such a lithology in the Algonkian is unlikely, although not impossible. Diagnostic fossils are absent. The best conclusion is that the sediments are late Algonkian in age. On the east side of Wolstenholme Island a diabase dike cuts a prominent fault but is not displaced by it. Nowhere does the diabase appear faulted. Thus it is concluded that the diabase is younger than the faulting. The moraine and outwash materials are considered Pleistocene in age.

Structural Geology

The geologic structure of the Thule area is not complicated and can be readily ascertained from the geologic map (Fig. 1). The most prominent feature is the assymmetrical syncline extending from Thule to Narssarssuk. The Narssarssuk fault terminating the southwest limb of the syncline must have a displacement of at least 10,000 feet, the total thickness of the Wolstenholme quartzite, Danish Village, and Narssarssuk formations being cut out. The long straight southwest shore of Saunders Island is believed to reflect an extension of the Narssarssuk fault on the mainland. The dips of the sediments to the northeast of the fault are nearly the same in both areas. Intense block faulting is dominant on Wolstenholme Island. The faults in the Thule area are normal, with the downthrown side to the northeast, with the exception of the most eastern and western faults in the area.

Minor structures include small scale fracturing, jointing, and local warping. Most of the rocks, especially the diabase, show jointing. The Wolstenholme quartzite and red beds of the Narssarssuk formation show only widely spaced joints, and in local areas, no jointing at all. Small scale faulting is present in the Agpat formation and Wolstenholme quartzite. A great deal of local warping has made it difficult to get a true picture of the attitude of the beds in the Narssarssuk formation. Those shown on the map (Fig. 1) are an average of local readings.

Geomorphology

Erosion by glaciers moving out from the continental ice sheet and the cold dry climate of northwest Greenland has produced a rugged topography, with vegetation, in the form of mosses and grasses only locally present.

Structural Influences. The area just east of Thule underlain by the Danish Village formation and capped by diabase forms a large hogback. The diabase along the shore was injected as two separate sills, each now forming a cuesta. The area on the mainland underlain by the Narssarssuk formation is marked by a series of hogbacks. A diabase dike cutting the structure stands out as a prominent ridge. Saunders Island has a relatively flat top, the structures having been truncated by erosion. Metamorphism has caused the Agpat formation to be quite uniformly resistant to erosion, and it is characterized by rounded surfaces.

Effects of Glacial Activity. The sheer cliffs extending most of the way from Edisto Creek around Cape Atholl, and around Saunders and Wolstenholme Islands were eroded by ice that filled Wolstenholme Fiord during maximum glacial activity. Advances and retreats of glacial ice on land have left eroded areas covered by moraine and outwash. Erosion by the advancing ice was dominant in the Sioraq River valley and the branch to the north. Retreat left a hummocky topography with many kettles. Next to the Thule Lobe there are prominent ridges of recessional moraine. The moraine covered area east of Narssarssuk is relatively smooth due to filling of preexisting valleys by ground moraine, rather than by planation by erosion.

Periglacial Climatic Effects. The land is underlaid by permanently frozen ground but the depth to which the frost extends is not known. A few feet of surface material thaws each summer, but the frozen ground underneath prevents water from percolating downward, and its movements in the unfrozen layer are slow, a large part remaining suspended in the soil. The lubricating action of the water facilitates relatively rapid soil flowage. On the eleventh of August, two observations of the unfrozen layer were made in a swampy area on the north side of the hill just below the sill immediately north of Edisto Creek. About halfway down the hill ice was encountered at a depth of three feet. The ground was still unfrozen at this depth further on down the hill.

Frost action has caused sorting into coarse and fine grained materials, and as a result, areas with the right amount of drainage develop prominent soil structures. If the area is well drained and dry, or too wet and swampy, structure soils do not form readily. Grain size is more important than topography in determining movement of soil water. Fine grained soils hold water on steep slopes and hills. Along the crest of a high hill, the ground may be soft and soggy although rain has not fallen for many weeks. The south part of Wolstenholme Island best exhibits soil structures, but in most other areas as well, frost action has caused sorting into geometrical figures, or patches of coarse and fine grained material.

The most prominent soil structures developed are polygonal ground, stone polygons, and stone "stripes". Polygonal ground occurs on nearly level areas where considerable water is suspended in the soil. The surface may be barren or covered with a thick mat of grass or moss. Vegetation is more abundant on fine grained soil. The binding action of plant material is responsible for steep sided polygons, in contrast to more gently sloping sides of the polygons devoid of vegetation. Stone polygons form in bouldery, usually barren, well drained areas. Well shaped polygons form only on level ground where they may be much as ten feet in diameter but are usually less. The obvious relationship between stone polygons and stone stripes is well demonstrated. As the level top of a ridge breaks away to a steep slope, the polygons on top become stone rings, broad ovals, long ovals, and finally linear belts of stones extending down the hill.

SUMMARY

The metamorphosed Agpat formation is considered early Algonkian in age. Peneplanation preceded the deposition of the overlying Wolstenholme quartzite. The latter is believed to have been deposited in a slowly advancing sea under stable conditions. The succeeding Danish Village black shales and dolomites indicate near still-stand of the seas with possible anaerobic conditions prevailing during black shale deposition. Rhythmic sedimentation then followed, imparting a cyclical nature to the Narssarssuk formation. The conditions causing cyclic deposition could not be determined. Large scale faulting then occurred, followed by intrusion of diabase dikes and sills. On the basis of rocks not intruded by diabase on Inglefield Land and Devon Island, a late Algonkian age is accepted for the unmetamorphosed sediments and diabase. During most of the Pleistocene, glaciers moving out from the continental ice sheet advanced much farther than at present and left moraine and outwash. The land areas are underlain by permanently frozen ground, and the thawing and freezing of the surface layer has produced prominent soil structures. A glacial climate much like that of the Pleistocene still exists in Greenland.

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