History of exploration and geology in the Nares Strait region

PETER R. DAWES and ROBERT L. CHRISTIE

Dawes, P. R. & Christie, R. L. 1982. History of exploration and geology in the Nares Strait region. – In: Dawes, P. R. & Kerr, J. W. (eds), Nares Strait and the drift of Greenland: a conflict in plate tectonics. – Meddr Grønland, Geosci. 8: 19–36.

Exploration in the Nares Strait region in the late 19th and early 20th centuries was connected with the seaway's position as a principal route of geographic discovery. Few of the early expeditions were directed towards obtaining data for the young science of geology. At the turn of the century, with the passing of the main era of geographical discovery, including the race for the North Pole and the establishment of Greenland's insularity, geological understanding of the region advanced rapidly and geologists more or less became 'standard' members of expeditions to this part of the Arctic.

Systematic geological studies in the Nares Strait region began when Lauge Koch mapped the Greenland side of the Strait in the period 1916–23; such investigations on the Canadian side by the Geological Survey of Canada took place in the 1950s and later. Early private expeditions and later work by university and petroleum and mineral enterprises have also contributed many geological data, as have several 'military operations' centred on Thule Air Base in Greenland. Regional geological mapping in Greenland was renewed by the Geological Survey of Greenland in the 1970s and continues today.

Cooperative Danish–Canadian projects, initiated by "Operation Grant Land" in 1965–66 in northern Nares Strait, have aimed at coordinating field studies in order to better assess correlation of stratigraphy and structure across the Strait.

Greenland and Nares Strait held important positions in the early ideas about the horizontal mass movements of the continents, and both Frank B. Taylor and Alfred Wegener featured the narrow linear channel between Ellesmere Island and Greenland in their respective theories of continental drift. These two creative theorists built on the immense global knowledge assembled by Eduard Suess, who published one of the earliest appraisals of the region. Early geological maps of the Nares Strait region by Bailey Willis and Lauge Koch were used by Wegener in support of his theory of continental drift.

P. R. Dawes, Grønlands Geologiske Undersøgelse, Øster Voldgade 10, DK–1350 Copenhagen K, Denmark and R. L. Christie, Department of Energy, Mines and Resources, Geological Survey of Canada, Institute of Sedimentary and Petroleum Geology, 3303–33rd St. N.W., Calgary, Alberta, Canada, T2L 2A7.

The southern extremity of Nares Strait was discovered in 1616 by William Baffin and Robert Bylot, sailing in the *Discovery*. Guided by Baffin, the navigator, they negotiated the ice-filled seas of Melville Bugt and named a cape — "Sir Dudley Digges' Cape" (Fig. 1). They reached a wide sound with an island at its entrance which were duly named "Sir John Wolstenholme's Sound and Ile". Further north they entered an even wider inlet and named it "Whale Sound" after the great number of whales they found there. The ship's northerly progress was halted by ice at a small island — "Hakluit's Ile". Turning west, the explorers saw to the north another great entrance, "Sir Thomas Smith's Sound". This sound, they remarked "runneth to the North of seventy eight degrees ..." (S. Purchas in Taylor 1955: 16). Baffin and Bylot had sailed past the entrance of a linear series of basins and channels that is now named Nares Strait and which "runs to the north" beyond latitude 82°N, or some 500 km.

After discovering the "Careyes Islands" in the middle of the seaway, Baffin sailed southward and found the entrance of what he called "Alderman Jones Sound". A brief landing in this sound is the first recorded European landing in the vicinity of Nares Strait; which of the islands Ellesmere, Coburg or Devon was touched on, however, cannot be told from Baffin's description.

Nares Strait is named after Admiral Sir George S. Nares of the Royal Navy, who commanded the first successful navigation of the Strait to and from the shores of the Polar Sea in 1875–6 (Fig. 2, Nares 1878). Up to about the turn of the 19th century, expeditions in the Nares Strait region were primarily aimed at geographical discovery and were often fired by national ambition, one result of which was the "race to the North

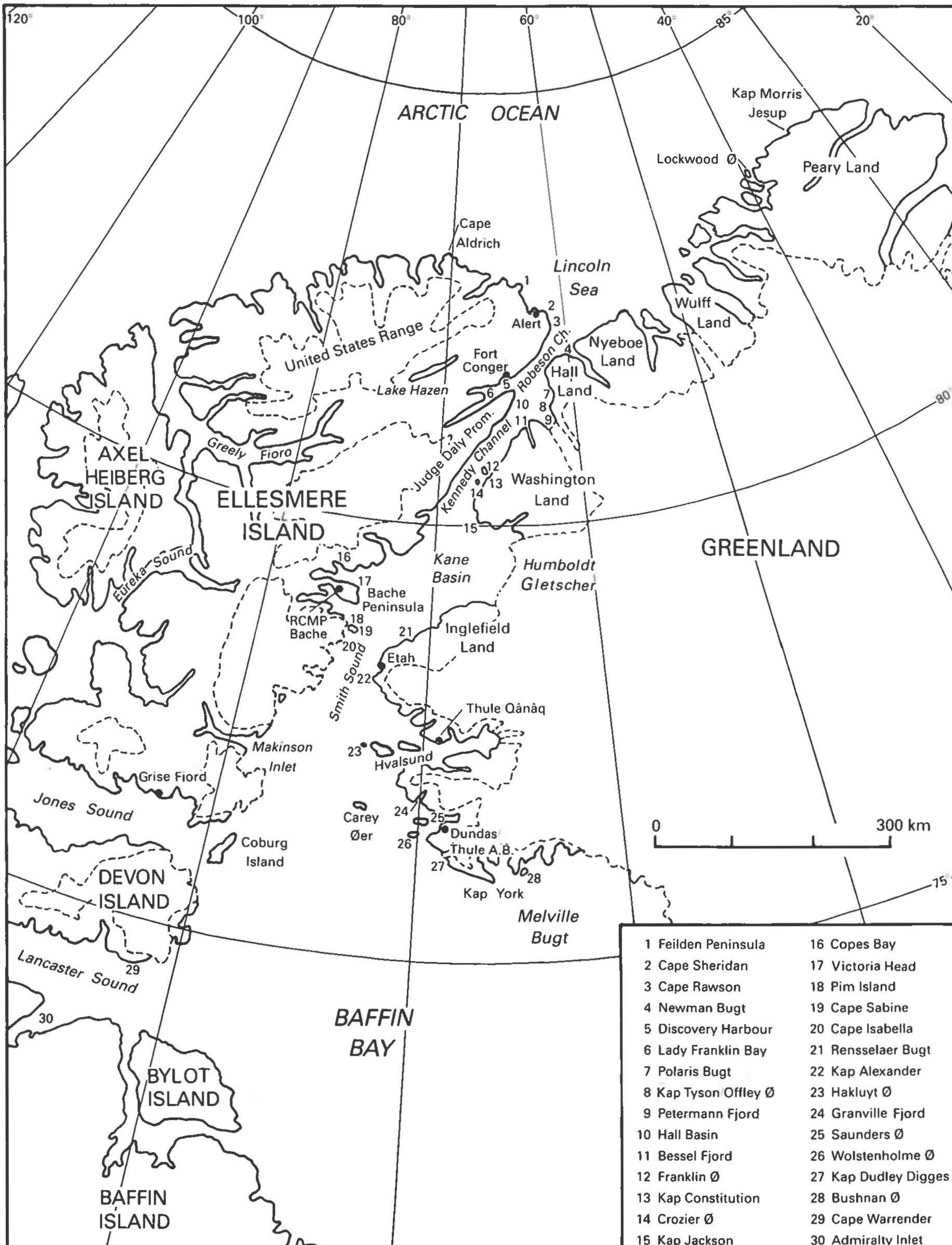
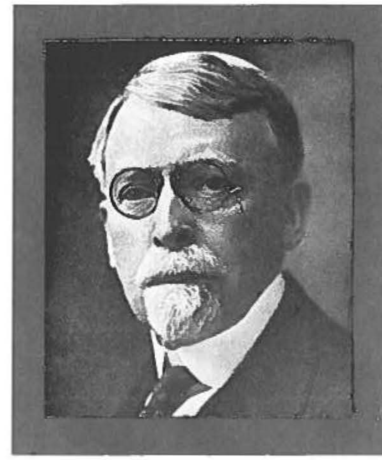


Fig. 1. Index map of the Nares Strait region.

Sir George S. Nares
1831–1915

Henry W. Feilden
1838–1921



Frank B. Taylor
1860–1937

Per Schei
1875–1905

Alfred L. Wegener
1880–1930

W. Elmer Ebklaw
1882–1949

Lauge Koch
1892–1964

Robert Bentham
1913–1968

Johannes C. Troelsen
1913–

Fig. 2. Personalities in the history of exploration and geology of the Nares Strait region. For sources see acknowledgements.

Pole". By 1900, when R. E. Peary reached Kap Morris Jesup and proved the insularity of Greenland, the position of Nares Strait as a linear channel linking "Baffin's Bay" to the "Open Polar Sea" was established.

Geological knowledge of the Nares Strait region has been accumulating since early in the 19th century. Although geologist-naturalists had visited the Nares Strait region as members of the early exploration expeditions, the type of geological data obtained was often cursory and few expeditions included teams specifically directed to geology. Systematic geological mapping in the Nares Strait region began in 1916 with the Danish 2nd Thule Expedition on which Lauge Koch acted as geologist and cartographer, but these investigations were restricted to the Greenland side of the Strait. Regional studies on the Canadian side began somewhat later, in the 1950s, through the efforts of the Geological Survey of Canada. The systematic collection of data has continued on both sides of the Strait, albeit at various paces, until the present day.

The work style and type of data obtained have, of course, changed considerably over the years. Thus, the early practise of wintering in the Arctic and relying mainly on spring and autumn sledging has been superseded by aircraft-supported operations allowing a wide diversity of geological studies to be carried out where and when demanded. The introduction of airborne operations in the late 1940s is an important landmark and is here taken as a convenient point of dividing the chronological description (see Christie & Kerr 1981).

Early exploration (1818–1946)

Two centuries passed after Baffin's and Bylot's exploration in 1616 before others sailed in northern Baffin Bay: John Ross in 1818, following Baffin's course; William E. Parry, in 1819, entering Lancaster Sound; and Parry, again entering the sound in 1825. Few landings were made and beyond John Ross' meeting with the "Arctic Highlanders" — the "Eskimaux" of the Thule region — geographical knowledge of Nares Strait was little advanced. Thus, while Ross had named the opposite capes of Smith Sound after the two ships of his expedition, HMS *Isabella* and *Alexander,* he regarded "Smiths Sound" as closed and indicated this on his map (Ross 1819).

The first step in reporting on the geology of the region had been made: the country forming northern Baffin Bay was described as being composed of "primary formation" (Precambrian) granite and gneiss with some greenstone. Samples were collected along the Greenland coast at "Bushnan's Isle" and "the coast between Cape York and Cape Dudley Digges" and these were described by Dr. J. M'Culloch (Ross 1819). On Parry's later voyage (1825), R. Jamieson reported and collected Precambrian rock at Cape Warrender on Devon Island.

Sir John Franklin of the Royal Navy began a search for the Northwest Passage in 1845. Franklin's entire expedition was lost, but this disaster led to the launching, over the next decades, of numerous search expeditions to the Arctic Islands. Two of these, one led by Commander Edward A. Inglefield in 1852 and a second by Dr. Elisha K. Kane, 1853–55, contributed to the geological knowledge of Nares Strait.

The earliest description of the geology of Nares Strait is that by Peter C. Sutherland, surgeon and naturalist in 1852 on the *Isabel,* commanded by Cdr. Inglefield. Inglefield achieved a new northing (78°28'21''), just entering Kane Basin before being driven southward by storm winds and wind-driven ice. The *Isabel* then

Fig. 3. The Crystal Palace Cliffs, Greenland, seen from the north. "At Cape Alexander, the eastern boundary of the entrance of Sir Thomas Smith's Sound, in latitude 78°15'N, we again find the strata a little curved; but only a few miles farther north they are so regular in parallelism and succession, as to vie with a distant view of the Crystal Palace ..." (Sutherland 1853b: 156). Precambrian crystalline basement overlain by sediments and basic sills of the Proterozoic Thule Group. The height of the cliffs is about 400 m above sea level.

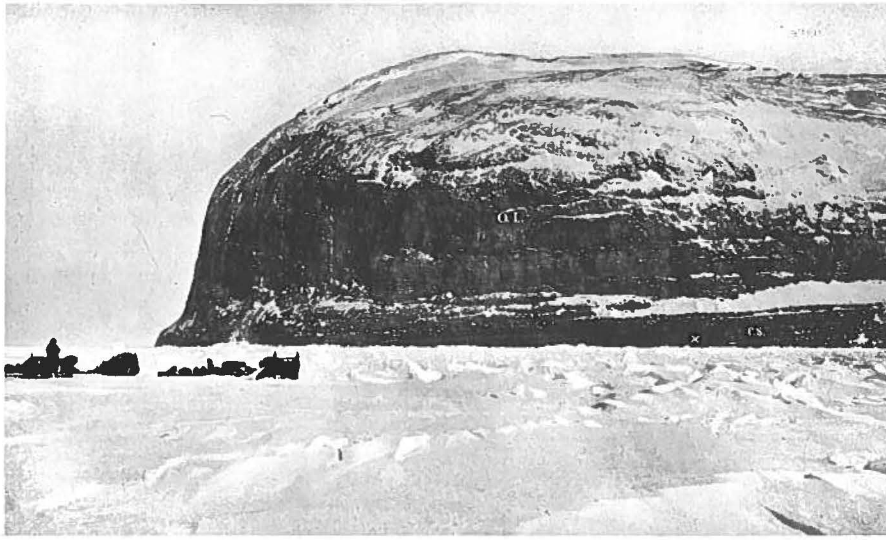


Fig. 4. Kap Constitution, Greenland, viewed from the south — the northernmost point reached by the Kane expedition 1853–55. "The cliffs ... were perpendicular, and nearly two thousand feet high" (W. Morton in Kane 1856, vol. 2: 378). A Silurian carbonate mound about 500 m high. Photograph Lauge Koch (from Dawes & Haller 1979: fig. 9).

coasted south-eastern Ellesmere Island and entered Jones Sound, without landing. Sutherland's description of the "physical geography", presented to the Geological Society of London, is extremely illuminating, made so by his many sketches of the coastline and by his attention to structural detail, so that inclinations of strata for several localities were reported. Sutherland (1853a, b) recognised the gneiss and granite basement and the overlying homoclinal cover of unmetamorphosed strata with associated trap rocks (Thule Group, Fig. 3). He compared these formations with the Tertiary igneous and sedimentary rocks of the Disko region of West Greenland, with which he was familiar.

The American explorers, Kane (in 1853–55 as noted) and Isaac I. Hayes (in 1860–61) pushed into Smith Sound and wintered there, at the southern entrance of Nares Strait. Exploring parties sledged with great difficulty northward along the shores of the now named Kane Basin and viewed the immense reaches of Kennedy Channel. The Kane and Hayes expeditions, however, contributed mainly geographical rather than geological knowledge, although several references to the granitic and gneissic rocks, trap, basalt and greenstone, and the overlying sediments can be found in the expedition reports (Kane 1856, Hayes 1867).

Kane's expedition wintered in Rensselaer Bugt, Greenland and travelled widely in the Inglefield Land – Humboldt Gletscher region about which Kane remarks: "Its geological structure is of the older red sandstones and silurian limestones, overlying a primary basis of massive syenites. The sandstones to the south ... are in series, with intercalated greenstones ..." (Kane 1856, vol. 2: 308); a pertinent description of the general geology. Kane's expedition must be credited with the discovery of the homoclinal platform strata north of the Humboldt Gletscher (Fig. 8); these were reached by William Morton en route to a new farthest north just south of Kap Constitution (80°34′N), where the perpendicular cliffs were scaled with much difficulty (W. Morton in Kane 1856, vol. 2: 378) (Fig. 4).

Isaac Hayes, who had been surgeon on the Kane expedition, chose the Ellesmere Island shore of Kennedy Channel for his push northward. He briefly described the "geological features of coast" that included "cliffs of silurian rocks – sandstone and limestone" (Hayes 1867: 340). Fossils collected from the shore of Kane Basin were identified by Prof. F. B. Meek as Silurian in age and this represents the first palaeontological description from the Nares Strait region (Meek 1865).

Geological understanding of the southern part of Nares Strait had advanced but slowly during the mid-1800s. Thus, a map compiled by Samuel Haughton in 1858 showed only "granitic and granitoid rocks" between "Cape York" and "Granville Bay" in Greenland, on the "Carey Isles" and on eastern "North Devon" Island (Fig. 5). In the text, however, Haughton (1858, 1859) does mention the sandstone and conglomerate of the region "Wolstenholme and Whale Sounds" that overlie the crystalline rocks.

In 1871, Charles Francis Hall, an American, took the ship USS *Polaris* to 82°11′N, actually entering the long-sought-for Polar Sea at the northern entrance of Robeson Channel. The unfortunate Hall died during the winter (probably poisoned by one of his divided crew (Loomis 1971)) and the party retreated southward next spring. Some geological observations were made, particularly by Emil Bessels, surgeon and chief of the scientific staff, and these are included in his and the official account of the expedition (Davis 1876, Bessels 1879). Of particular interest is the recognition in the Hall Basin region of an extensive southern area of flat-lying, mainly limestone rocks that included fossiliferous Silurian strata and, to the north, a series of folded sandstone rocks. This is the first record of the southern

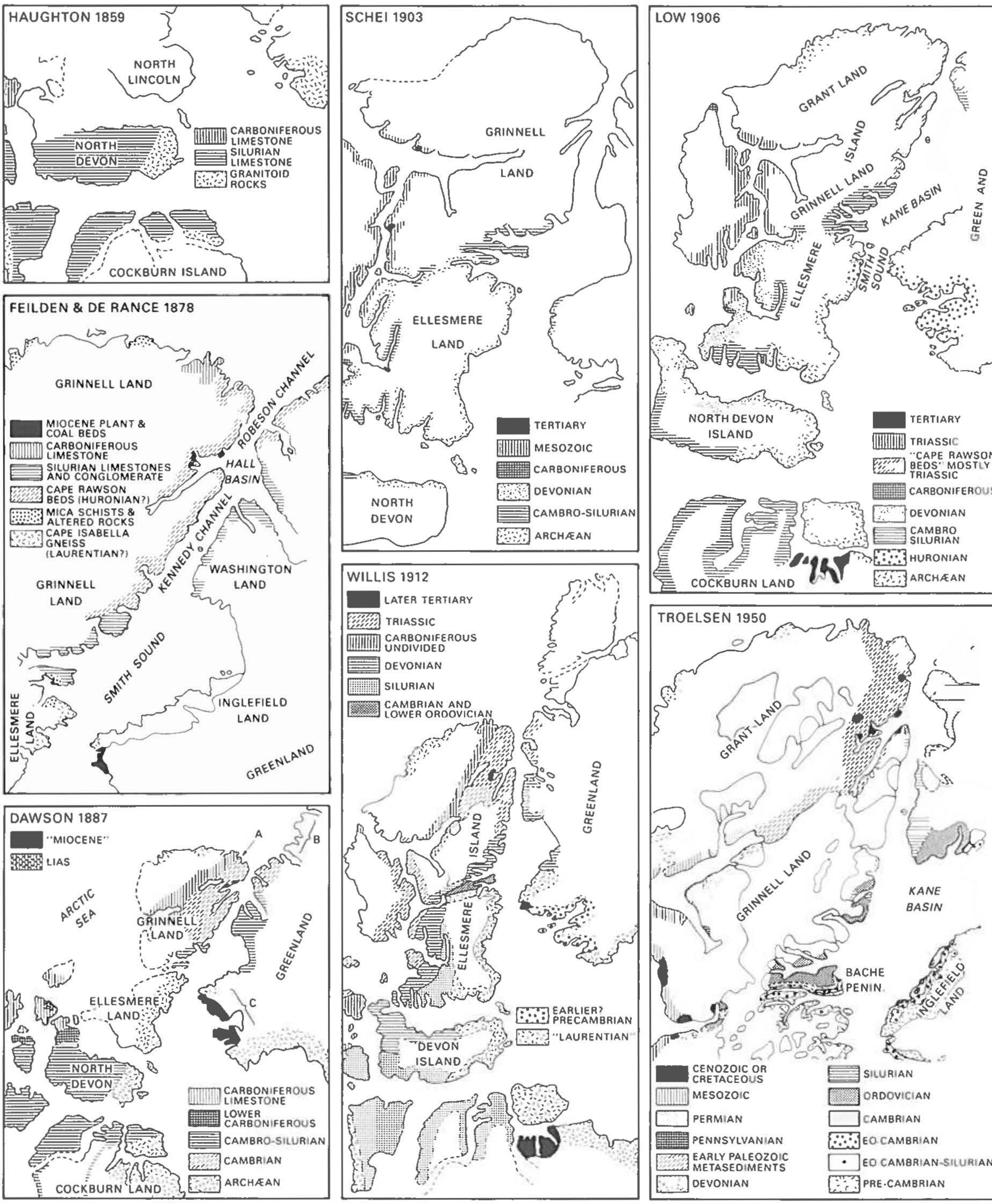


Fig. 5. Seven bedrock geological maps of the Nares Strait region from the early exploration period (1818–1946). Maps redrawn from the originals with some modifications. *Feilden & De Rance 1878,* Silurian symbol along the coast of southern Washington Land is included from the description in text (1878: 558); *Dawson 1887,* "Cambro-Silurian" of legend "probably including Devonian in Arctic Islands", A = "Devonian fossils", B = "coast probably Cambrian or Archæan", C = "coast described generally as consisting of trap rocks, sandstone etc. probably Tertiary. Archæan rocks are, however, also present"; *Schei 1903,* geology compiled from Schei (1903, 1904) and Holtedahl (1917), "Cambro-Silurian" of legend includes Schei's "Series B"; *Low 1906,* "Cambro-Silurian" of legend refers to "Silurian and Cambro-Silurian"; *Willis 1912,* "Laurentian" of legend includes "gneisses and associated plutonic rocks", "Earlier? Precambrian" refers to "unclassified" strata of "Huronian" or "Algonkian" age, "Later Tertiary" refers to "Miocene and Pliocene"; *Troelsen 1950,* legend has been abbreviated from the original map at scale 1:1 660 000 and the two-tone colouring scheme into "formations of known age" and "formations whose age is not known with certainty" has been omitted. "Pre-Cambrian" of legend refers to "metamorphic and igneous rocks", "Eo-Cambrian–Silurian" refers to "Eo-Cambrian, Cambrian, Ordovician and Silurian, undifferentiated", "Early Paleozoic metasediments" refers to "metamorphosed sediments, probably of Early Paleozoic age", "Mesozoic" refers to "Triassic and Lower Jurassic?".

margin of the Franklinian geosyncline — carbonate platform flanked on the north by the Ellesmere –Greenland fold belt.

In 1875, the British government sent a naval expedition northward under the command of Capt. George S. Nares. The two ships, HMS *Alert* and *Discovery*, followed the route pioneered by Hall and prepared for wintering at two localities on Ellesmere Island: the *Discovery* in Discovery Harbour of Lady Franklin Bay and the *Alert* at Cape Sheridan, latitude 80°28′N. Spring journeys with man-hauled sledges were made northward toward the Pole and westward and eastward along the north coasts of Ellesmere Island and Greenland. Considerable geographical and geological exploration and mapping was accomplished by these parties in spite of their short period in the field: Nares withdrew and returned to England in 1876 because of an outbreak of scurvy. The northern coasts, as well as the channels, basins and tributary fjords of Nares Strait had been charted by these skilled navigators and their maps formed the bases for atlases until well into the 20th century.

The senior naturalist of the expedition, Henry W. Feilden (Fig. 2), prepared a geological map and report (with C. E. De Rance) founded on geological data obtained through his own and others' field studies and rock collections. Feilden's map (Fig. 5) of the region between Discovery Harbour and Feilden Peninsula, Ellesmere Island, was the first on Arctic geology prepared by a geologist from his own field work and his report included important observations that had been made farther south along Nares Strait during the initial sail northwards, for example on Bache Peninsula and the shore of Kane Basin (Fig. 6). The fossils were described by Etheridge (1878). Feilden and his co-author commented on the similarity of the Carboniferous limestone of Feilden Peninsula to that of Svalbard and suggested that "a continuation of the direction of the known strike of the limestones of Feilden Peninsula, carried over the Polar area, passes through the neighbourhood of Spitzbergen ..." (Feilden & De Rance 1878: 560).

The first formal stratigraphic name given to rocks in the Nares Strait region was introduced by Feilden, viz. the Cape Rawson Beds, to describe a series of folded slates and sandstones; strata that were suggested to be "the equivalents in time" of the "Huronians of Nova Scotia". Of particular importance was the recognition of the Cape Rawson Beds on both sides of the Robeson Channel and of the unfolded Silurian limestone terrain to the south. In Greenland this limestone terrain was traced from the southern Kennedy Channel at 80°N to the Hall Basin at 81°30′N. Concerning the junction between the two terrains we find "the boundary, of whatever character it may be, traverses Kennedy Channel, and reappears in Hall Land, traversing the country from Polaris Bay to the southern end of Newman Bay, its situation being determined within narrow limits by the occurrence of Cape-Rawson beds at Thank-God Harbour to the north, and of Silurian limestones at Cape Tyson and Offley Island to the south, whence the limestones extend to both sides of Petermann Fiord and Bessel's Bay, and southward by way of Franklin and Crozier Islands, Capes Constitution and Andrew Jackson to the great Humboldt glacier, and they doubtless underlie the whole of the ice-cap covering Washington Land" (Feilden & De Rance 1878: 558 — see Fig. 8 for "Cape Andrew Jackson"). This is an amazingly accurate description of the geology of northern Nares Strait. It also outlines the geological boundary that has been most discussed in the question of lateral displacement along the Strait since Wegener (1915) first referred to it in that context.

Geology matured rapidly as a science during the late 1800s and the northern expeditions returned with many new collections and observations. Lieut. Adolphus W. Greely of the U.S. Army led a scientific expedition to Discovery Harbour in 1881–83; Greely's station, Fort

Fig. 6. The flat-lying Lower Palaeozoic carbonates at Victoria Head, eastern Bache Peninsula, seen from the south. The "syenitic and granitoid rocks" of the southern coast of Bache Peninsula are overlain by coarse basement rocks that "are overlain by mural cliffs of limestone, rising to a height of more than 1000 feet, dipping gently to N.N.W. as far as Victoria Head, where a landing was effected and a small collection of fossils obtained" (Feilden & De Rance 1878: 557. From Christie (1967: pl. XV).

Fig. 7. The Robeson Channel, the northernmost part of Nares Strait, with Hall Land, Greenland in the foreground. "Whether this channel was carved in the solid land by the force of pre-Adamite glaciers, or whether it is a Titanic cleft formed by the breaking off of Greenland from Grant Land, is a question still undetermined by geologists" (Peary 1910: 92).

Conger, was one of several occupied simultaneously during the "International Polar Year" of that time. The "Polar Year" was aimed mainly at meteorological, auroral and magnetic observations, but despite the lack of a geologist, the Greely party made important geological discoveries during their travels across Ellesmere Island, on Judge Daly Promontory and along the north coast of Greenland. Incidentally, the Greenland sledge party led by Lieut. J. B. Lockwood achieved a new farthest north (83°24'N) at Lockwood Ø, where volcanic rocks were recognised and collected by Sgt. D. L. Brainard, the first report of the Kap Washington volcanics (Greely 1886, vol. 1: 338). The Greely expedition began its disastrous retreat southward from Fort Conger in 1883 and was obliged to abandon the rock collections. During the same summer, Alfred G. Nathorst on the *Sophia* examined the geology in southern Nares Strait, although little information from this was published (Nathorst 1884, Nordenskiöld 1885).

George Mercer Dawson (1887), one of the pioneers of the Geological Survey of Canada, was able to include data from the Greely expedition in his geological map of the northern part of the Dominion of Canada and Greenland that was compiled in 1886 (Fig. 5). His report contains a full geological description of Nares Strait in a section "Ellesmere Land, Grinnell Land and neighbouring coast of North Greenland" (Dawson 1887: 51–58).

Lieut., later Commander, Robert E. Peary of the U.S. Navy travelled the length of Nares Strait by sledge and by ship several times between 1898 and 1909. His objectives were mainly in the exploration of northern Greenland and the attainment of the North Pole. Thus, while earth scientists were part of, or auxilliary to, the Peary expeditions (e.g., Thomas C. Chamberlin, C. C. Craft, L. L. Dyche, Angelo Heilprin, Rollin D. Salisbury and John M. Verhoeff), geological work was concentrated in the southern Nares Strait area and few geological results were released. Perhaps the most important is Chamberlin's (1895) description of the Thule region in which he makes a subdivision of the flat-lying strata seen by Sutherland 40 years before. Little attention was paid by Peary to the geology of the northerly channels and we are left with but sporadic references in Peary's accounts — see, for example, Peary's (1898) account of his early expeditions between 1891 and 1897.

In view of this it is perhaps surprising to find in Peary's (1910) book "The North Pole" one of the earliest references to the origin of Nares Strait and to the possibility of the tectonic displacement of Greenland (Fig. 7).

Following Fridtjof Nansen's epic crossing of the Arctic Ocean, the polar ship *Fram,* again commanded by Capt. Otto Sverdrup, was sailed into the Canadian Arctic Islands in 1898; when the party at last returned to Norway in 1902 they had advanced geographical and geological understanding of the islands more than any expedition to that time. The first winter in the ice was spent at Fram Haven, inside Pim Island, not far from a ship on which Peary was also wintering, on the the west shore of Kane Basin. The geologist, Per Schei, explored the surrounding region. The geology of both the Precambrian metamorphic complex and the overlying Palaeozoic and Mesozoic sedimentary rocks was firmly established through Schei's preliminary reports and sketch maps (Schei 1903, 1904, Fig. 5) and, following his death soon after his return, by amplified reports on his work written by others (Bugge 1910, Holtedahl 1913, 1917).

A Canadian government expedition in the DGS *Neptune,* with the geologist Albert P. Low in charge, navigated as far north as Cape Sabine in 1904; the ship had sailed northward along the Greenland coast before crossing to Ellesmere Island. The expedition was in part scientific, but its main objectives were the establishment of Canadian sovereignty in the islands and the collection of whaling dues. Low (1906) included in his report a summary of the geology then known of the region traversed by his ship; his geological map included the eastern and northern islands and the northern part of the west coast of Greenland to the Robeson Channel (Fig. 5).

Schei and Low had occasion for only a brief examination of rocks in Greenland but remarked on the similarity of the geology on the two sides of Smith Sound. Schei noted in both lands that the crystalline basement was composed of a peculiar complex of igneous and metamorphic rocks overlain unconformably by a comparable sequence of homoclinal strata containing basic sills. Low recognised on both coasts steeply-dipping metasedimentary rock series containing crystalline limestone which were intruded by granites (Low 1906: 208). The state of geological knowledge of Nares Strait at that time is illustrated by Low's map, and also by Bailey Willis' (1912) map compilation included in his "Stratigraphy of North America" (Fig. 5). Naturally, both Low and Willis were influenced by Schei's work; in fact Schei's discoveries of deformed Devonian and Mesozoic deposits in central west Ellesmere Island radically affected geological interpretation of the Nares Strait region. Thus, the Cape Rawson Beds, considered of possible Huronian age by Feilden & De Rance (1878) and of Cambrian age by Dawson (1887), were interpreted as Triassic by Low and Willis. In addition, the flat-lying fossiliferous Silurian limestones of the Hall Basin – Kennedy Channel area, the age of which had been established decades before by Meek (1865) and Etheridge (1878), were indicated as Devonian. This age designation is interesting in the context of this symposium, since it was Willis' map that formed the basis of Wegener's (1915) initial comments about the geological evidence for the displacement of Greenland along Nares Strait (Fig. 13).

Geological exploration of the Nares Strait region was carried out by numerous 'explorer-geologists' using dog sledge and ship during the decades between 1910 and the late 1940s when aircraft began to be used in geological reconnaissance. The main studies were concentrated in the southern part of Nares Strait and it was during this phase that the similarity in the geology across Smith Sound, recognised by Schei and Low, was confirmed and placed in a regional context. The geologists involved in this phase were: W. Elmer Ebklaw of the Donald B. MacMillan Crocker Land Expedition 1913–17 (MacMillan 1918), who visited both sides of the Strait; Lauge Koch with Knud Rasmussen's 2nd Thule Expedition 1916–18 (Rasmussen 1921) and later on his own Bicentenary Jubilee Expedition 1920–23 (Koch 1926a); L. J. Weeks of the Geological Survey of Canada, who visited the Royal Canadian Mounted Police posts on Devon and Ellesmere Islands in 1925 (Weeks 1927); Robert Bentham of the Oxford University Ellesmere Land Expedition 1934–35 and indepen-

Fig. 8. Flat-lying strata of the Arctic platform — part of Lauge Koch's "great sediment plain" (see Fig. 14). These spectacular coastal cliffs of Ordovician limestones about 500 m high are of Kap Jackson, Washington Land, seen from the south-east. The homoclinal Lower Palaeozoic platform rocks of the Inglefield Land – Washington Land region of Greenland were first recorded by the Kane Expedition 1853–55. Photograph is from Koch (1920: fig. 7).

dently in 1936–38 and who wintered in both Greenland and Ellesmere Island (Bentham 1936, 1941); Sole Munck on the Danish Natural History Expedition to Northwest Greenland in 1936 (Munck 1941); James M. Wordie in 1937, who visited Bache Peninsula, southern Ellesmere Island and North-West Greenland (Wordie 1938) and finally Johannes C. Troelsen of the Danish Thule and Ellesmere Land Expedition 1939–1941, who travelled widely in Greenland and the Canadian Arctic Islands (Troelsen 1950).

Knowledge of the stratigraphy, structure and geological history steadily accumulated during this period and geological syntheses of the region were made by Koch (1920, 1925, 1929a, 1935) and Troelsen (1950, 1956). Koch travelled the entire Greenland coast from Melville Bugt to Peary Land carrying out cartographical and glaciological work, in addition to his geological tasks. He recognised the main stratigraphical and structural elements of the Nares Strait region (Fig. 14A), helped in his dog sledge reconnaissance methods by the beautifully exposed sea-cliff sections (Fig. 8). Koch's geological map contribution, particularly noteworthy, takes the form of five map sheets that cover the entire south-eastern coast of Nares Strait from Melville Bugt to eastern Peary Land (Fig. 9). Troelsen's work represents the first comprehensive study of parts of both sides of the Strait and his travels took him along much of the Greenland side between 77° and 81°N and across central Ellesmere Island and into Axel Heiberg Island. The geological map accompanying his 1950 report covers the region 78° to 82°N, with only a few blanks on the western side of Kennedy Channel marked as "unexplored" (Fig. 5).

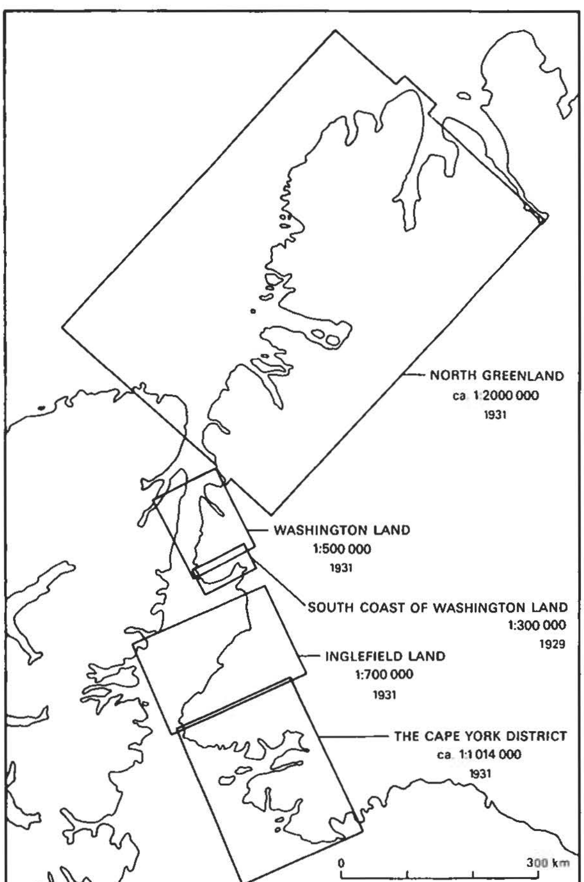


Fig. 9. Sketch showing the coverage of Lauge Koch's five coloured geological maps. The "south coast of Washington Land" and the "Inglefield Land" sheets were published by Koch (1929b, 1933); the remaining three maps, although originally printed in 1931, were published nearly half a century later (Dawes & Haller 1979).

Bentham (1936) had been impressed by the peneplained surface of the Precambrian basement in southwestern Inglefield Land and Bache Peninsula and also by the similarity of the overlying strata. He remarks that parts of the cover series in Bache Peninsula "are indistinguishable from the Thule Formation of Inglefield Land. This similarity is emphasised by the occurrence in these beds, at Cape Camperdown, of two sills of dolerite" (Bentham 1936: 336). Troelsen, building on the observations of Bentham and Koch, established a common stratigraphic framework for the unmetamorphosed cover rocks of the Smith Sound region. The period of "early exploration" thus closes with identical formational names in use for both the Greenland and the Ellesmere Island successions.

Modern exploration (1946–1980)

The modern period of geological reconnaissance, in which aircraft support of field work became increasingly prominent, comprises the late 1940s and later decades. During this period, two strategic airports were established at the two ends of Nares Strait: the jointly operated Canadian–United States weather station at Alert in north-eastern Ellesmere Island, and the U.S. Thule Air Force Base at Dundas in Greenland (Fig. 1). Geological and other scientific studies were stimulated by the logistic services available during both the establishment of the airfields in the late 1940s and early 1950s and their later operation.

Many of the early helicopter operations in Greenland were restricted to the immediate area of Thule Air Base (Kurtz & Wales 1951, Fernald & Horowitz 1954, Davies et al. 1963) although some geological work (for example that of Vincent E. Kurtz and others (1952) in 1949 from the icebreaker USS *Edisto*) extended to the Canadian side of the Strait. The military projects "Operation Ice Cap" (1953–54), "Operation Defrost" (1956) and "Operation Groundhog" (1957–60) covered large areas of northern Greenland and during this period William E. Davies of the U.S. Geological Survey and others carried out a variety of bedrock and superficial studies on the Greenland side of Nares Strait

Fig. 10. View from Judge Daly Promontory across Hall Basin to Hall Land, Greenland. The Judge Daly fault — commonly regarded as the onland segment of the Wegener Fault joining Baffin Bay to the Arctic Ocean — is the conspicuous linear valley parallel to the outer coast. National Air Photo Library, Canada, T397C–148.

(Clebsch 1954, Davies et al. 1959, Nichols 1961, Davies 1972). John Cowie (1961) studied the Proterozoic and Lower Palaeozoic strata of Inglefield Land in 1957 and, having also visited equivalent units on Ellesmere and Devon Islands, later suggested correlation of certain formations across the Strait (Cowie 1971).

The Geological Survey of Canada began airborne geological reconnaissance in the Arctic Islands in 1947 (Fortier 1948). In the 1950s and following years with the development of 'bush flying' in the Far North, a number of operations used the logistic network of the "Joint Arctic Weather Stations" (or JAWS) and carried out work in the Nares Strait region. V. K. Prest, accompanying an icebreaker resupply mission in 1950 to the northernmost of the JAWS stations at Alert, made some geological observations in northern Baffin Bay and Nares Strait. Prest (1952) recorded coast-parallel faults in eastern Ellesmere Island along the Kennedy Channel and one of these — the Judge Daly fault (Fig. 10, see also Mayr & de Vries, this volume: fig. 3) — is a particularly conspicuous linear feature which has a significant place in the context of this symposium (Wilson 1963). Other investigations followed: G. Hattersley-Smith and R. G. Blackadar at Alert in 1953; Blackadar and R. R. H. Lemon in the Admiralty Inlet area of Baffin Island in 1954; R. Thorsteinsson at Copes Bay, Kane Basin, during the GSC's "Operation Franklin" in 1955 (Fortier et al. 1963); R. L. Christie, travelling the Hazen Plateau and Judge Daly Promontory during the Defence Research Board of Canada's "Operation Hazen" in 1957–58; Christie, in 1960 and 1961, carrying out a reconnaissance of south-eastern Ellesmere Island; J. W. Kerr and H. P. Trettin in central and eastern Ellesmere Island in 1961–62; and Blackadar, W. L. Davison and Trettin during the Survey's "Operation Admiralty" on northern Baffin Island in 1963.

The year 1965 marked a new venture in Nares Strait geological exploration: a two-year cooperative project of the Geological Surveys of Canada and Greenland — Operation Grant Land — was launched to examine the geology on both sides of the Kennedy Channel – Lincoln Sea region (Christie 1966). Christie, Trettin, J. H. Allaart, P. R. Dawes, T. Frisch, W. W. Nassichuk, B. S. Norford and A. A. Petryk took part in this operation. In 1968–69, Christie continued the reconnaissance of south-eastern Ellesmere Island and eastern Devon Island, in 1968 in the company of J. W. Cowie.

Special mention in this period must be made of B. R.

Pelletier, who carried out reconnaissance of the submarine geology of parts of Nares Strait and northern Baffin Bay in 1963, and of H. P. Trettin, who studied the central part of the Franklinian geosyncline of northern Ellesmere Island during much of the 1960s and 1970s. In addition, the 1960s saw the beginning of systematic aeromagnetic flights over the High Arctic and some of these programmes reached northern Baffin Bay and Nares Strait (e.g. Hood & Bower 1975).

The past decade, from 1970, has seen considerable work by the Geological Surveys of Canada and Greenland, some of it cooperative, on both sides of Nares Strait and carried out by geologists too numerous to list in this paper. The field programmes have been generally undertaken with helicopter and fixed-wing support and a wealth of more detailed information has been placed in its regional context, helped by the scientific cooperation between the two Surveys. The results of these recent field projects, of course, are but recently published and many appear in this volume.

In addition, field parties of mineral exploration groups have collected valuable structural and stratigraphic data. In this field no history would be complete without mention of the pioneer work of the Canadian J. C. Sproule whose confidence in the economic potential of the Far North led to geological studies that stretched from the Beaufort Sea across the Canadian Arctic Islands to north-eastern Greenland. A notable contribution was the regional assessment of northern Greenland from Melville Bugt to Peary Land carried out from 1969 to 1973. This work made available important new information, including, incidentally, the initial discovery of Upper Cambrian strata in the High Arctic (1969, in Washington Land). Geologists of the J. C. Sproule company covered much of the Canadian side of Nares Strait and of note in the context of this symposium is the discovery in 1972–73 of deformed Tertiary conglomerates on the shore of the Kane Basin — information released by the company for this symposium (Mayr & de Vries, this volume).

Geological syntheses

The papers that follow in this volume will consider today's understanding as well as the problems of the Nares Strait region. First, however, it should be interesting to take note of the ideas expressed in some published syntheses arising from the early geological reports: Eduard Suess, Frank B. Taylor, Alfred L. Wegener and Charles Schuchert each considered various geological aspects of Greenland, the Canadian Arctic Islands or the intervening seaways, while Lauge Koch as a geologist involved in the actual collection of the early data, also expressed ideas pertaining to the regional geology of Nares Strait.

Eduard Suess, Viennese professor of geology, is justly famous for his monumental treatise, *Das Antlitz der Erde* (The face of the Earth), published in several volumes and translations between 1885 and 1924. In volume 2, Suess, writing about the regional geology of the North American continent north of the great Archaean Shield, states that "... the several sedimentary formations of this border are so arranged that they strike to the east or north-east, and become progressively more recent as they are traced towards the pole" (Suess 1906: 40) — an early description of the passage from the Precambrian craton and platform into the Franklinian geosyncline. Chapter VII of volume 4 (translation published in 1909) of the monograph concerns "Laurentia and the Northern Islands". Suess described the fold mountains of Kennedy Channel as due to south-directed orogenic forces with the Canadian Shield acting as a foreland; he further compared the folded range with the "Asiatic arcs" and regarded the Ellesmerian folds as a "terminal part of the Asiatic structure extending across the North Pole" (Suess 1909: 251). Greenland was considered to be a fragment of Laurentia (the ancient continental nucleus of North America) that stands as a horst "between subsidences of different age" (Suess 1909: 258). In this early and remarkably complete synthesis of Nares Strait geology it is clear that Suess recognised the faulted character of the Strait and considered the "fragments" of Laurentia, Greenland and the Canadian Shield to be more or less undisturbed in a horizontal sense along Nares Strait.

Two creative theorists soon used Suess' compendious information on the geology of the Earth to advance new global theories: F. B. Taylor in the United States and Alfred Wegener in Germany both proposed that the continents had been horizontally displaced or had "drifted". Greenland was an important element in each of the new theories and both authors regarded the narrow channel between Ellesmere Island and Greenland as a rift along which there has been appreciable sinistral transcurrent motion (Fig. 11A and B), although they interpreted the movement roles of the two crustal blocks — North America and Greenland — differently. Their respective theories, earlier often referred to as "The Taylor–Wegener hypothesis", differed also in other important respects.

Frank Bursley Taylor, a Quaternary geologist by training, had deliberated for many years on "the structure and disposition of continents"; according to Totten (1981) at least 20 years. Finally, he read a paper in 1908 to the Geological Society of America on "continental movement" and its relationship to the Earth's Tertiary mountain belts. Taylor (1910) described a "mighty creeping" movement of the continental crust away from the Earth's poles. He regarded the Tertiary mountain belts to have formed by horizontal collision of crustal "sheets", i.e. the "plates" of Suess, and he described the mid-Atlantic ridge as "a residual ridge along a line of parting or rifting" so that "the two continents on opposite sides of it have crept away in nearly parallel and opposite directions" (Taylor 1910: 217–218). He

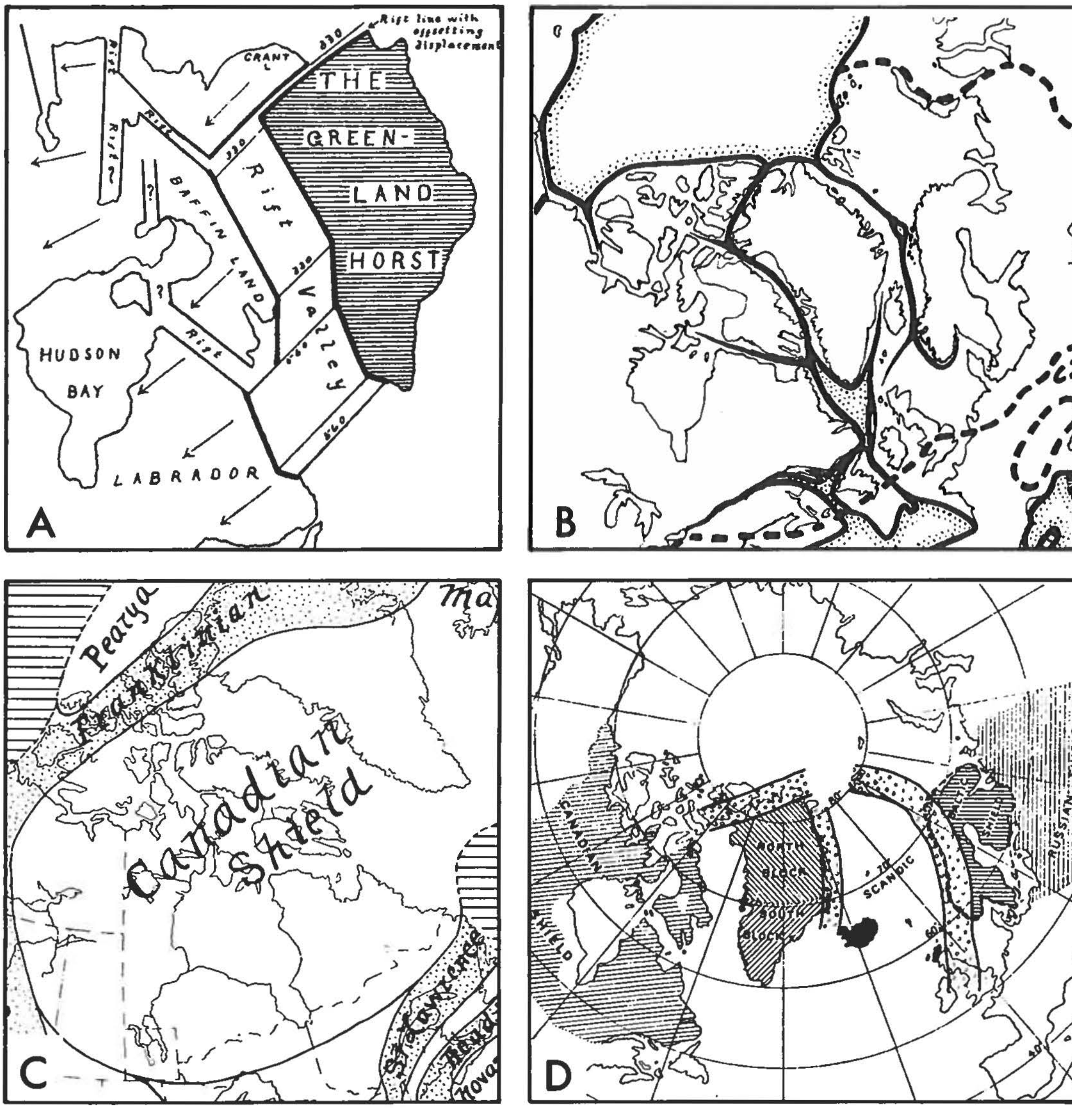


Fig. 11. Maps illustrating some early regional geological syntheses of the Nares Strait region. A = Taylor (1910), B = Wegener (1915), C = Schuchert (1923), D = Koch (1929a). Maps reproduced at approximately the same scale as the originals; B, C & D are taken from larger maps.

matched the coastlines of the Atlantic Ocean and concluded that Greenland was once united with NW Europe, noting the reconstructed shape of the mountain belts. The west coast of Greenland he matched with the eastern edge of the Canadian Arctic Islands: Greenland, according to Taylor, was alone an immovable region of the northern hemisphere. He called Greenland "the great northern horst" and concluded that North America had moved some 330 miles away from this horst (Fig. 11A).

Alfred Lothar Wegener held a doctorate in astronomy and had a keen interest in meteorology and geophysics as well as polar exploration. At about the time that Taylor's first paper appeared, he became inspired by an English collier, W. H. Pickering, who suggested that the Earth's moon was former continental material that had been flung out into orbit (Wood 1980). That part of the crust remaining on Earth "was torn in two to form the eastern and western continents. These then floated on the liquid surface like two large ice-floes" (Pickering 1907: 30). Pickering, like Taylor, also matched the coastlines of the Atlantic Ocean. Wegener also quoted Taylor's paper and accepted Greenland's stationary "keystone" position in the North Atlantic Ocean. Wegener's first papers appeared in 1912 and his book, in which "Pangaea" is described, was published in 1915. Revised 2nd, 3rd and 4th editions were published in 1920, 1922 and 1929, and his work was translated into

Fig. 12. Alfred Wegener at his desk in the expedition station "Borg", at Storstrømmen, East Greenland during the winter 1912–13. Wegener gave his first public lectures on continental drift early in 1912 and his initial short papers on the subject were written on his way by ship to Greenland later the same year (Wegener 1912a, b). His first book on the subject, including the appraisal of the geology of the Nares Strait region, was published on his return from the 1912–13 expedition after the crossing of the Inland Ice. Photograph copyright, Arktisk Institut, Denmark.

several languages between 1924 and 1926. Wegener believed that geodetic measurements between Greenland and Europe could confirm the (supposedly rapid) active separation of the continents. By 1913 Wegener had participated in two Greenland expeditions (Fig. 12) and in 1929 he organised an expedition to the subcontinent, one goal of which was the accurate measurement of longitude using radio. Wegener died in 1930 during an early winter trek, and he was buried in the firn of the Inland Ice. The subcontinent Greenland and the theory of continental drift have since become immortally associated with the memory of Alfred Wegener. The geology of the Nares Strait region featured prominently in Wegener's arguments for the horizontal displacement of the continents (Fig. 13) and Nares Strait has become synonymous with "The Wegener Fault".

Charles Schuchert, Yale professor of palaeontology and historical geology, is the last of the early writers considered here, who synthesised Arctic geology into 'continental' models. Schuchert (1923) assigned the name Franklinian geosyncline to the sedimentary belt of northern Ellesmere Island and Greenland, and he also named Pearya, a hypothetical landmass that was to have lain 'outboard' of the geosyncline (Fig. 11C). Metamorphic rocks of north-coastal Ellesmere Island and Peary Land were taken to be remnants of the ancient borderland, much of which had "fractured into ocean depths". The fractures that transect the continent, however, were not considered, so that the Canadian Shield or "Laurentia" appears, in Schuchert's figures, as an undisturbed landmass. The Franklinian geosyncline was depicted as a sedimentary belt unaffected by major displacement along Nares Strait; incidentally, later, Schuchert (1928) did consider the implications of the reconstruction of Wegener's Pangaea on the disposition of the northern geosynclinal belts and he argued against Wegener's treatment of the geological data.

Lauge Koch was a cartographer, geologist and explorer. His field work in the Nares Strait region was specifically directed to Greenland territory, although in 1921 he visited Ellesmere Island. Koch recognised Schuchert's Franklinian geosyncline, but in his doctorate thesis "Stratigraphy of Greenland" (1929a) referred to it as the Smith Sound geosyncline. The 1929 paper outlines Koch's early ideas about the "Shields and geosynclines of the North Atlantic Ocean" and he divided the Smith Sound geosyncline into a number of structural units (Fig. 14A). Koch regarded this geosyncline, deformed by "Caledonian Folding", to strike uninterruptedly across Nares Strait, to join up with the northern parts of the East Greenland and Scandinavian–Svalbard geosynclines in the Barents Shelf region (Fig. 11D).

Koch was impressed by the fault tectonics in the southern Nares Strait region and he described "a new fault zone in Northwest Greenland" (Koch 1926b) as a major Tertiary feature and suggested its counterpart in the Arctic Islands (Fig. 14). He concluded that "future investigations will reveal strong faulting north of Baffin Bay, which faulting has possibly some connection with the development of Davis Strait – Baffin Bay" (Koch 1929a: 319). However, the "new fault zone" traverses southern Nares Strait and the Strait itself was not considered an associated lineament.

Koch's (1920) early geological map of the Nares Strait region was used by Wegener in later editions of his thesis on continental drift, replacing the map by the U.S. Geological Survey, i.e. compiled by Bailey Willis

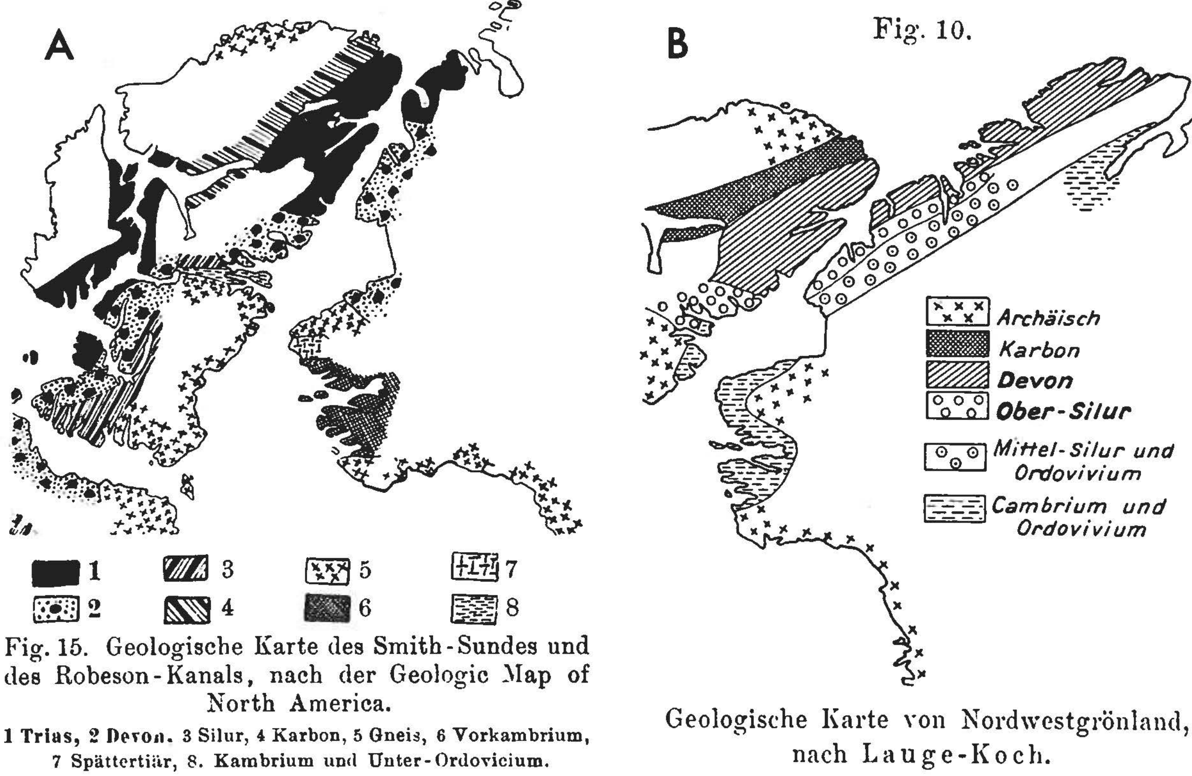


Fig. 13. The geological maps used by Wegener in his account of the horizontal displacement of Greenland relative to North America. A: U.S. Geological Survey map compiled by Willis (1912) (from Wegener 1915: fig. 15). B: Lauge Koch's (1920) map (from Wegener 1922: fig. 10).

(Figs 5 and 13). Wegener drew attention to the position of two geological boundaries which he regarded as indicative of major strike-slip displacement of Greenland past Ellesmere Island. "If one looks for the boundary line between the Devonian and the Silurian periods, this lies at 80°10′ in Grinnell Land and 81°30′ in Greenland. Also, in the Caledonian fold system discovered by this author [Koch], which stretches across from Greenland to Grinnell Land, one can detect the same displacement" (Wegener 1966: 79). However, Koch did not agree with this interpretation and remarked "that detailed investigations, especially on Grinnell Land, are required before a decided standpoint can be taken for or against Wegener's view" (Koch 1929a: 312). Incidentally, Koch (1924) had noted the absence of faults on the Greenland shore of the "Smith Sound–Robeson Channel" and concluded that the seaway was mainly a product of river erosion, although later (1929a: 313) he raises the possibility that the channel could be a "Grabensenkung".

Wegman (1948) included Koch's viewpoint in his account of the scientific planning of geological tests of continental drift, while Willis (1928), although not directly referring to Wegener's use of his map compilation of the Nares Strait, argued strongly from geological evidence against the theory of continental drift.

Interestingly enough, the early dispute about the interpretation of the geology of the Nares Strait region illustrated above has continued, albeit in various nuances, until the present day — hence this symposium. Thus Taylor's and Wegener's ideas about the mass movements of continental blocks and more specifically the relationship between Greenland and North America have gained recognition through the modern concept of plate tectonics and sea-floor spreading which predicts Nares Strait to be a site of appreciable transcurrent motion. Likewise, Schuchert's and Koch's ideas about continental models, cratons and geosynclinal belts have been expounded upon by the systematic study of the continental blocks and sedimentary basins which has strengthened the view that the geology of the Nares Strait region does not indicate that such major strike-slip displacement has occurred.

Present status

From the preceding paragraphs it is evident that the geological understanding in the Nares Strait region proceeded at a slow pace during early exploration, but quickened with time and the development of the science. In addition, progress has 'see-sawed' on the two

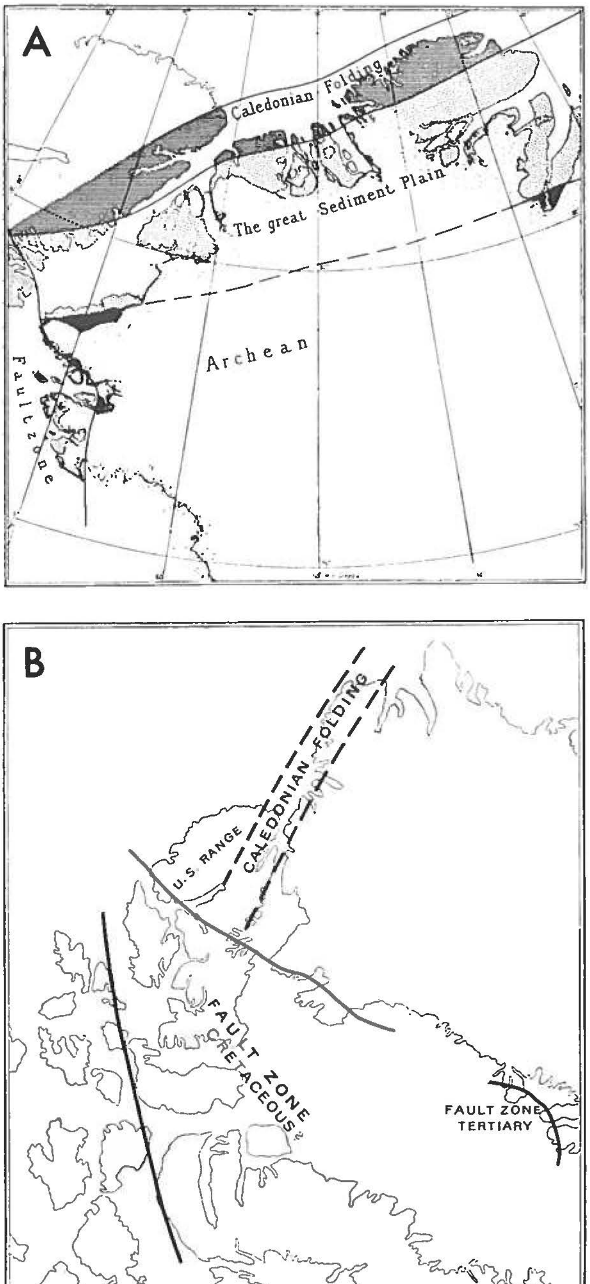


Fig. 14. Koch's interpretation of the structural framework of the Nares Strait region. A = main structural elements of eastern Ellesmere Island and northern Greenland (from Koch 1925: fig. 2). B = relationship of the late Phanerozoic faults of Baffin Bay and the Caledonian folding (from Koch 1929a: fig. 61).

sides of the Strait: thus, following Lauge Koch's reconnaissance mapping of the Greenland side between 1916 and 1923, systematic work on the Canadian side did not begin until the 1950s when aircraft were used in the field work. The Geological Survey of Canada's work has continued through a series of airborne 'operations' until today. The Geological Survey of Greenland began its systematic mapping of the Greenland side of the Strait in the Thule region in 1971 and studies have continued along the Strait up to the present day.

In terms of modern onshore geological map coverage, the whole of the Nares Strait region (Baffin Bay to Lincoln Sea) has been mapped at 1:250 000 and in many areas at 1:100 000 or larger scales. Many of the maps of the Canadian side have been published; maps of the Greenland side are in compilation or in drafting stage. The cumulative knowledge of the region is now at a level which allows reasonably confident assessment and correlation of the stratigraphy and structure of these parts of Greenland and adjacent Canada.

Acknowledgements

We are grateful to the following persons and institutions for providing or allowing publication of the photographs reproduced in Fig. 2: The Royal Geographical Society, London (G. S. Nares), The Museum of the King's Own Royal (Lancaster) Regiment, Lancaster (H. W. Feilden), The Allen County Public Library, Fort Wayne, Indiana (F. B. Taylor), Det Norske Videnskaps-Akademi, Oslo (P. Schei), H. Hirschsprungs Forlag, Copenhagen (A. L. Wegener), Gyldendalske Boghandel, Nordiske Forlag, Copenhagen (W. E. Ebklaw), Ove Koch and family, Copenhagen (L. Koch), Mrs Patricia O. Bentham, Sussex, England (R. Bentham) and Eigil Knuth, The Danish Peary Land Expeditions, Copenhagen (J. C. Troelsen).

We also thank the following persons for information and help in tracking down the photographs and biographical data used in Fig. 2: Lord Shackleton and Geoffrey Hattersley-Smith (London), George White (Univ. of Illinois), Knut Heggelund (Norsk Polarinstitutt, Oslo), Terence Armstrong and H. G. R. King (Scott Polar Research Institute, Cambridge), Mrs. Edith Tyson (Lancaster City Council, U.K.), Brig. R. J. Lewendon (Royal Artillery Institution, London), Mrs. Susan Pallone (Fort Wayne, Indiana), Ole G. Evensen (Norges Geologiske Undersøkelse, Trondheim) and D. S. Stonham (National Maritime Museum, London). Figures 10 and 12 are reproduced with permission of the National Air Photo Library, Ottawa and the Arktisk Institut, Denmark, respectively.

The paper was critically read by Anthony K. Higgins and for his comments and those of Esben Glendal and W. Stuart Watt, we are most grateful. The paper is published with the permission of the Director of the Geological Survey of Greenland.

References

Bentham, R. 1936. Appendix IV, Geology. – In: Shackleton, E., Arctic journeys. The story of the Oxford University Ellesmere Land Expedition 1934–5: 333–337. – Hodder & Stoughton Ltd., London.

Bentham, R. 1941. Structure and glaciers of southern Ellesmere Island. – Geogr. J. 97: 36–45.

Bessels, E. 1879. Die amerikanische Nordpol-Expedition. – Von Wilhelm Engelmann, Leipzig: 647 pp.

Bugge, C. 1910. Petrographische Resultate der 2ten Fram-Expedition. – Rep. 2nd Norwegian Arctic Exped. "Fram" 1898–1902, 22: 38 pp. – Videnskabs-Selskabet, Kristiania.

Chamberlin, T. C. 1895. Appendix A. Geology. – In: Bryant, H. G., The Peary Auxiliary Expedition of 1894. – Bull. geogr. Club Philadelphia 1(5): 166–174.

Christie, R. L. 1966. Operation Grant Land. – Pap. geol. Surv. Can. 66–1: 3–4.

Christie, R. L. 1967. Bache Peninsula, Ellesmere Island, Arctic Archipelago. – Mem. geol. Surv. Can. 347: 63 pp.
Christie, R. L. & Kerr, J. W. 1981. Geological exploration of the Canadian Arctic Islands. – In: Zaslow, M. (ed.), A century of Canada's Arctic Islands, 1880–1980: 187–202. – Royal Soc. Can., Ottawa.
Clebsch, A. 1954. The bedrock geology of Inglefield Land. – Prelim. rep., Program Operation Ice Cap 1953, SRI Project 828. – Stanford Res. Inst., California.
Cowie, J. W. 1961. Contributions to the geology of North Greenland. – Meddr Grønland 164(3): 47 pp.
Cowie, J. W. 1971. The Cambrian of the North American Arctic regions. – In: Holland, C. H. (ed.), Cambrian of the New World: 325–383. – Wiley-Interscience, New York.
Davies, W. E. 1972. Landscape of northern Greenland. – Spec. Pap. Cold Reg. Res. Engng Lab. 164: 54 pp.
Davies, W. E., Needleman, S. M. & Klick, D. W. 1959. Report on Operation Groundhog (1958) North Greenland. Investigation of ice-free sites for aircraft landings, Polaris Promontory, North Greenland. – U.S. Air Force Cambridge Res. Center, Bedford: 45 pp.
Davies, W. E., Krinsley, D. B. & Nicol, A. H. 1963. Geology of the North Star Bugt area, Northwest Greenland. – Meddr Grønland 162(12): 68 pp.
Davis, C. H. 1876. Narrative of the North Polar Expedition U.S. Ship Polaris, Captain Charles Francis Hall commanding. – Gov. Print. Off., Washington: 696 pp.
Dawes, P. R. & Haller, J. 1979. Historical aspects in the geological investigation of northern Greenland. Part 1: New maps and photographs from the 2nd Thule Expedition 1916–1918 and the Bicentenary Jubilee Expedition 1920–1923. – Meddr Grønland 200(4): 38 pp.
Dawson, G. M. 1887. Notes to accompany a geological map of the northern portion of the Dominion of Canada, east of the Rocky Mountains. – Geol. Nat. Hist. Surv. Can. Ann. Rep. II (R): 56 pp.
Etheridge, R. 1878. Palæontology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R. N., K. C. B., F. R. S. – Q. Jl geol. Soc. Lond. 34: 568–636.
Feilden, H. W. & De Rance, C. E. 1878. Geology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R. N., K. C. B., F. R. S. – Q. Jl geol. Soc. Lond. 34: 556–567.
Fernald, A. T. & Horowitz, A. S. 1964. Bedrock geology of the Nunatarssuaq area, Northwest Greenland. – Meddr Grønland 172(6): 44 pp.
Fortier, Y. O. 1948. Flights in 1947 over the region of the North Magnetic Pole and the mainland between the Arctic coast, Great Slave Lake, and Hudson Bay, Northwest Territories. – Pap. geol. Surv. Can. 48–23: 11 pp.
Fortier, Y. O., Blackadar, R. G., Glenister, B. F., Greiner, H. R., McLaren, D. J., McMillan, N. J., Norris, A. W., Roots, E. F., Souther, J. G., Thorsteinsson, R. & Tozer, E. T. 1963. Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). – Mem. geol. Surv. Can. 320: 671 pp.
Greely, A. W. 1886. Three years of Arctic service. An account of the Lady Franklin Bay Expedition of 1881–84 and the attainment of the farthest north. – Richard Bentley & Son, London, vol. I: 428 pp., vol. II: 444 pp.
Haughton, S. 1858. Geological notes and illustrations. – In: M'Clintock, F. L., Reminiscences of Arctic ice-travel in search of Sir John Franklin and his companions. – J. Roy. Dublin Soc. 1: 183–250.
Haughton, S. 1859. Appendix No. IV. Geological account of the Arctic Archipelago, drawn up principally from the specimens collected by Captain F. L. M'Clintock, R. N., from 1849 to 1859. – In: M'Clintock, Capt. [F.L.], A narrative of discovery of the fate of Sir John Franklin and his companions: 372–399. – John Murray, London.
Hayes, I. I. 1867. The Open Polar Sea. A narrative of a voyage of discovery towards the North Pole in the schooner "United States". – Hurd and Houghton, New York: 454 pp.
Holtedahl, O. 1913. The Cambro-Ordovician beds of Bache Peninsula and the neighbouring regions of Ellesmere Land. – Rep. 2nd Norwegian Arctic Exped. "Fram" 1898–1902, 28: 14 pp. – Videnskabs-Selskabet, Kristiania.
Holtedahl, O. 1917. Summary of geological results. – Rep. 2nd Norwegian Arctic Exped. "Fram" 1898–1902, 36: 27 pp. – Videnskabs-Selskabet, Kristiania.
Hood, P.[J.] & Bower, M.[E.] 1975. Aeromagnetic reconnaissance of Davis Strait and adjacent areas. – In: Yorath, C. J., Parker, E. R. & Glass, D. J. (eds), Canada's continental margins and offshore petroleum exploration. – Mem. Can. Soc. Petrol. Geol. 4: 433–451.
Kane, E. K. 1856. Arctic explorations: The Second Grinnell Expedition in search of Sir John Franklin, 1853, '54, '55. – Childs & Petersen, Philadelphia, vol. 1: 464 pp., vol. 2: 467 pp.
Koch, L. 1920. Stratigraphy of Northwest Greenland. – Meddr dansk geol. Foren. 5(17): 78 pp.
Koch, L. 1924. De videnskabelige resultater af Jubilæumsekspeditionen Nord om Grønland. Rapport 1: Kartografi og geologi. – Geogr. Tidsskr. 27: 208–218.
Koch, L. 1925. The geology of North Greenland. – Am. J. Sci. 9: 271–285.
Koch, L. 1926a. Report on the Danish Bicentenary Jubilee Expedition north of Greenland 1920–23. – Meddr Grønland 70,1(1): 1–232.
Koch, L. 1926b. A new fault zone in Northwest Greenland. – Am. J. Sci. 12: 301–310.
Koch, L. 1929a. Stratigraphy of Greenland. – Meddr Grønland 73,2(2): 205–320.
Koch, L. 1929b. The geology of the south coast of Washington Land. – Meddr Grønland 73,1(1): 39 pp.
Koch, L. 1933. The geology of Inglefield Land. – Meddr Grønland 73,1(2): 38 pp.
Koch, L. 1935. Geologie von Grönland. – In: Krenkel, E. (ed.), Geologie der Erde: 159 pp. – Gebrüder Borntraeger, Berlin.
Kurtz, V. E. & Wales, D. B. 1951. Geology of the Thule area, Greenland. – Proc. Oklahoma Acad. Sci. 31: 83–89.
Kurtz, V. E., McNair, A. H. & Wales, D. B. 1952. Stratigraphy of the Dundas Harbour area, Devon Island, Arctic Archipelago. – Am. J. Sci. 250: 636–655.
Loomis, C: C. 1971. Weird and tragic shores. The story of Charles Francis Hall, explorer. – Alfred A. Knopf, New York: 367 pp.
Low, A. P. 1906. Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on board the D. G. S. Neptune 1903–1904. – Gov. Print. Bureau, Ottawa: 355 pp.
MacMillan, D. B. 1918. Four years in the white north. – Harper & Brothers Publishers, New York: 426 pp.
Mayr, U. & de Vries, C. D. S. 1982. Reconnaissance of Tertiary structures along Nares Strait, Ellesmere Island, Canadian Arctic Archipelago. – This volume.
Meek, F. B. 1865. Preliminary notice of a small collection of fossils found by Dr. Hays, on the west shore of Kennedy Channel, at the highest northern localities ever explored. – Am. J. Sci. 40: 31–34.
Munck, S. 1941. Geological observations from the Thule District in the summer of 1936. – Meddr Grønland 124(4): 38 pp.
Nares, G. S. 1878. Narrative of a voyage to the Polar Sea during 1875–6 in H. M. Ships 'Alert' and 'Discovery', with notes on the natural history edited by H. W. Feilden, F. G. S., C. M. Z. S. naturalist to the expedition. – Sampson Low, Marston, Searle and Rivington, London, vol. 1: 395 pp, vol. 2: 378 pp.
Nathorst, A. G. 1884. Den Svenska expeditionen till Grønland år 1883. – Ymer 4(1): 15–38.

Nichols, R. L. 1961. Geomorphology of Inglefield Land, North Greenland. – Meddr Grønland 188(1): 109 pp.
Nordenskiöld, A. E. 1885. Den andra Dicksonska expeditionen till Grønland dess inre Isöken och dess Ostkust utförd år 1883. – F. & G. Beijer, Stockholm: 328–334.
Peary, R. E. 1898. Northward over the "Great Ice". A narrative of life and work along the shores and upon the interior ice-cap of northern Greenland in the years 1886 and 1891–1897. – Frederick A. Stokes, New York, vol. 1: 521 pp., vol. 2: 618 pp.
Peary, R. E. 1910. The North Pole. – Hodder and Stoughton, New York: 326 pp.
Pickering, W. H. 1907. The place of origin of the moon – the volcanic problem. – J. Geol. 15: 23–28.
Prest, V. K. 1952. Notes on the geology of parts of Ellesmere and Devon Islands, Northwest Territories. – Pap. geol. Surv. Can. 52–32: 15 pp.
Rasmussen, K. 1921. Greenland by the Polar Sea. The story of the Thule Expedition from Melville Bay to Cape Morris Jesup. – William Heinemann, London: 326 pp.
Ross, J. 1819. A voyage of discovery, made under the orders of the Admiralty in His Majesty's Ships Isabella and Alexander, for the purpose of exploring Baffin's Bay, and inquiring into the probability of a North-West Passage. – John Murray, London: 252 pp. + appendices: cxliv pp.
Schei, P. 1903. Summary of geological results. – In: Sverdrup, O., The Second Norwegian Polar Expedition in the "Fram", 1898–1902. – Geogr. J. 22: 56–65.
Schei, P. 1904. Appendix 1. Preliminary account of the geological investigations made during the Second Norwegian Polar Expedition in the Fram. – In: Sverdrup, O., New Land. Four years in the Arctic regions, vol. 2: 455–466. – Longmans, Green, and Co., London.
Schuchert, C. 1923. Sites and nature of the North American geosynclines. – Bull. geol. Soc. Am. 34: 151–230.
Schuchert, C. 1928. The hypothesis of continental displacement. – In: van Waterschoot van der Gracht, W. A. J. M. et al., Theory of continental drift. A symposium on the origin and movement of land masses both inter-continental and intra-continental, as proposed by Alfred Wegener: 104–144. – Am. Ass. Petrol. Geol., Tulsa, Oklahoma.
Suess, E. 1906. The face of the Earth (Das Antlitz der Erde). Vol. II. – Clarendon Press, Oxford: 556 pp. (Transl. by H. B. C. Sollas).
Suess, E. 1909. The face of the Earth (Das Antlitz der Erde). Vol. IV. – Clarendon Press, Oxford: 673 pp. (Transl. by H. B. C. Sollas).
Sutherland, P. C. 1853a. On the geological and glacial phænomena of the coasts of Davis' Strait and Baffin's Bay. – Q. Jl geol. Soc. Lond. 9: 296–312.
Sutherland, P. C. 1853b. Appendix II. A few remarks on the physical geography, & c., of Davis Strait, and its east and west shores. – In: Inglefield, E. A., A summer search for Sir John Franklin; with a peep into the Polar Basin: 145–192. – Thomas Harrison, London.
Taylor, A. 1955. Geographical discovery and exploration in the Queen Elizabeth Islands. – Mem. Geogr. Branch, Dept. Mines Tech. Surv. Can. 3: 172 pp.
Taylor, F. B. 1910. Bearing of the Tertiary mountain belt on the origin of the earth's plan. – Bull. geol. Soc. Am. 21: 179–226.
Totten, S. M. 1981. Frank B. Taylor, plate tectonics, and continental drift. – J. geol. Education 29: 212–219.
Troelsen, J. C. 1950. Contributions to the geology of Northwest Greenland, Ellesmere Island and Axel Heiberg Island. – Meddr Grønland 149(7): 85 pp.
Troelsen, J. C. 1956. The Cambrian of North Greenland and Ellesmere Island. – In: El sistema Cámbrico, su paleogeografía y el problema de su base. – 20 Intern. geol. Congr. México, Symp. 3(1): 71–90.
Weeks, L. J. 1927. The geology of parts of eastern Arctic Canada. – Sum. Rep. geol. Surv. Can. 1925, pt. C: 136–141.
Wegener, A 1912a. Die Entstehung der Kontinente. – Peterm. Mitt. 58(1): 185–195, 253–256, 305–309.
Wegener, A. 1912b. Die Entstehung der Kontinente. – Geol. Rund. 3: 276–292.
Wegener, A. 1915. Die Entstehung der Kontinente und Ozeane. – Friedr. Vieweg & Sohn, Braunschweig: 94 pp.
Wegener, A. 1922. Die Entstehung der Kontinente und Ozeane. – Friedr. Vieweg & Sohn, Braunschweig: 144 pp. (3rd revised edit.).
Wegener, A. 1924. The origin of continents and oceans. – Methuen & Co., London: 212 pp. (Transl. 3rd edit. by J. G. A. Skerl).
Wegener, A. 1966. The origin of continents and oceans. – Dover Publications, Inc., New York: 246 pp. (Transl. 4th edit. by J. Biram).
Wegmann, C. E. 1948. Geological tests of the hypothesis of continental drift in the Arctic regions. Scientific planning. – Meddr Grønland 144(7): 48 pp.
Willis, B. 1912. Index to the stratigraphy of North America. – Prof. Pap. U.S. geol. Surv. 71: 894 pp.
Willis, B. 1928. Continental drift. – In: van Waterschoot van der Gracht, W. A. J. M. et al., Theory of continental drift. A symposium on the origin and movement of land masses both inter-continental and intra-continental, as proposed by Alfred Wegener: 76–82. – Am. Ass. Petrol. Geol., Tulsa, Oklahoma.
Wilson, J. T. 1963. Hypothesis of Earth's behaviour. – Nature, Lond. 198: 925–929.
Wordie, J. M. 1938. An expedition to Northwest Greenland and the Arctic Islands in 1937. – Geogr. J. 92: 385–421.
Wood, R. M. 1980. Coming apart at the seams [on the centennial of Alfred Wegener's birth]. – New Scientist 85: 252–254.