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Otto Nordenskjöld's Contribution to Glaciation History

A Bipolar Effort with a Southern Focus

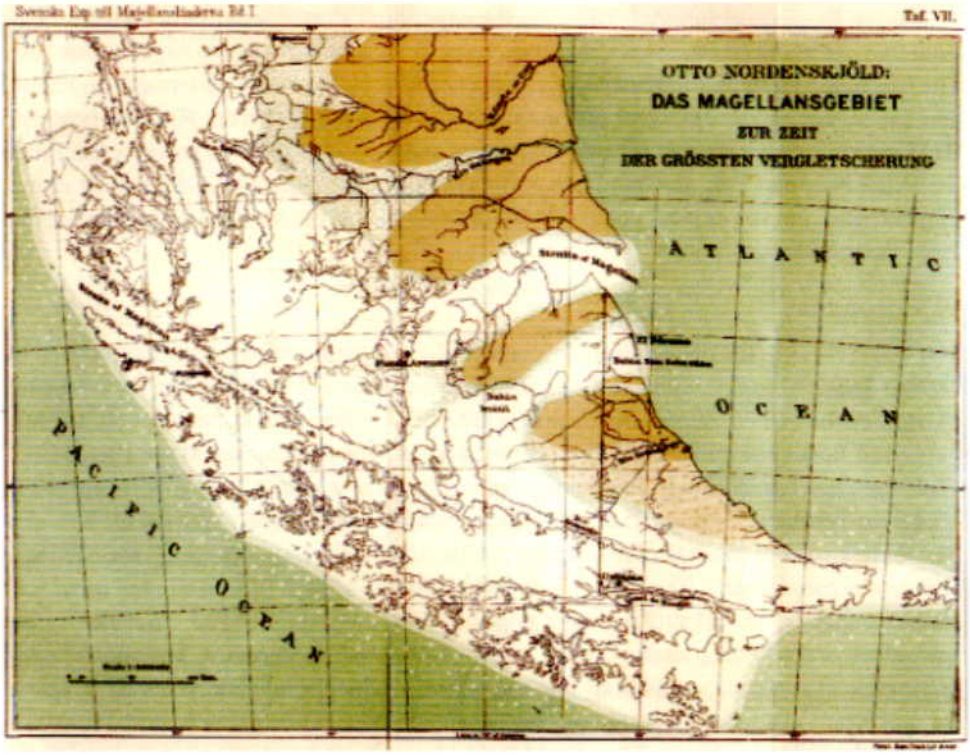
On 5 December 1895 Otto Nordenskjöld and his team were put ashore at Bahia San Sebastian on northern Tierra del Fuego, from the Argentine naval vessel *Uruguay*.[1] A few days later they started inland with a mule-train, from the gold-prospecting camp Páramo, initiating a sequence of investigations which would lay important parts of the foundations of our knowledge about the glaciation history of the southern hemisphere. As for Nordenskjöld himself, the field part of this work ended 8 years later, when the very same ship *Uruguay* brought his stranded Antarctic expedition out of the Weddell Sea.[2] However, the legacy of these initial expeditions, to Tierra del Fuego and Patagonia in 1895–97 and to Antarctica in 1901–03, led much further than that!

Tierra del Fuego and Patagonia, 1895–97

The background

In 1895 the basic concept of ice ages was still a rather hot scientific subject and exciting news to the general public.[3] Although it was already more than 50 years since the three Swiss pioneers Venetz, Charpentier and Agassiz had concluded that the glaciers in the Alps had earlier been much larger, it was only 20 years since the Swede Otto Torell (also the initiator of large-scale Swedish Arctic research) had given his famous lecture at the meeting of the Geologisches Gesellschaft in Berlin on 3 Nov. 1875, where he described a continental glaciation which had reached all the way south to Berlin. And that was only some years after the final acceptance of that idea by the Geological Survey of Sweden, confirmed by the publication in 1868 of Axel Erdman's *Bidrag till kännedomen av Sveriges kvartära bildningar*. However, although the scientific community generally accepted that large areas in the northern hemisphere had previously been covered by continental ice masses, most geologists found it hard to believe that this had happened repeatedly in the past. Thus, by 1895 "monoglacialism" still prevailed.

As to former glaciations in southern South America, including Tierra del Fuego, virtually nothing substantial was known when Nordenskjöld arrived. One piece of information available was observations made by Charles Darwin during the 1833 cruise of the *Beagle*[4] when, e.g. in the Beagle Channel, he observed "drift" deposits, indicating formerly more extensive glacial conditions ("drift" was a term for glacial deposits introduced by the famous geologist Charles Lyell who, however, believed it mainly to derive from icebergs)[5]. Some observations on the glaciers in the western part of the Strait of Magellan also seem to have been made by Louis Agassiz (1872)[6], but in general this was still a virgin region when entered by the Nordenskjöld expedition in 1895. One purpose of the expedition was



Map 1. Otto Nordenskjöld's map from 1898, showing the maximum extent of glaciation in southernmost South America. The area with ice-floe structures to the north suggests glaciolacustrine basins.

to compare glacial conditions in the southern hemisphere with those in the northern hemisphere, as according to the Croll hypothesis (a forerunner to the present Milanchovich theory, which explains the rhythms of ice-ages through the Earth's geometric relationship to the Sun) large-scale climatic shifts like ice-ages should be out-of-phase between the hemispheres.

The field work

The glacial-history related field work during the southern summer of 1895/96 was carried out in Tierra del Fuego, in both Argentina and Chile. The expedition worked along the Atlantic coast, with its spectacular erosional cliffs exposing glacial deposits, and along the Strait of Magellan. The almost completely unknown interior of Tierra del Fuego was also visited, such as the large, glacially overdeepened lake Lago Fagnano, and the southern parts of the island along the Beagle Channel were briefly studied. Evidence of former large-scale glaciation and of higher than present marine levels were found in many places.

During the second summer, 1896/97, the expedition started from Punta Arenas. This time they focussed on southern Patagonia, on both the Chilean and the Argentinean side. The plains, the foothills, the glacially overdeepened lake basins with their terminal moraines, and the higher mountains were all investigated, following the rivers Rio Gallegos and Rio Coig o Coyle westwards to their headwaters and into what is now known as the Torres del Paine National Park in Chile. Much information was gathered on the former extent of glaciation, but the present glaciers were also studied in the western areas fringing the large Patagonian ice-fields.

The results

The main results in the fields of geology, geography and anthropology were summarized by Nordenskjöld in the first issues of the series *Wissenschaftliche Ergebnisse der schwedischen Expedition nach den Magellansländern 1895–1897.*[7] The glacial history results were published under the title "Über die posttertiären Ablagerungen der Magellansländer". With the reports came two geological maps. The first was a "Geological Map of the Magellan Territories" (scale 1: 1,500,000), on which, besides the older rocks, was also shown the extent of "Postglacial deposits", "Glacial deposits (boulder clay)" and "Shingle (*Tehuelche formation*)". The "Glacial deposits" comprise both glacial till and other ice-contact deposits, and glaciolacustrine deposits with drop-stones. The "Shingle" is the equivalent of the "Patagonian gravels", to which we shall soon return. The second map, in the present paper shown as Map 1, is a synthesis of the glacial history results. It shows the maximum glaciation of southernmost South America, when glaciers from the Andes reached the Atlantic Ocean along three main channels; through the eastern part of the Strait of Magellan, through the Bahia Inútil-Bahia San Sebastian lowlands and along the Beagle Channel in the south.

Nordenskjöld discussed these glacial deposits and their geomorphology and stratigraphy in detail, and he concluded that there must have been two stages of glaciation, with a rather long interglacial period in between. The widespread Patagonian Gravels, which to a large extent occur on plateaux between the valleys but which had often been interpreted as marine, he suggested were old glacifluvial deposits – which still holds! It was surmised that they had been laid down during a time of glaciation predating the main period of valley formation – which then must have taken place during the suggested interglacial. Thereafter, when many of the valleys had been formed, followed a new glaciation, the maximum one (Map 1), which Nordenskjöld believed to be rather young and more or less contemporaneous with that glaciation in the northern hemisphere about which Otto Torell had lectured in Berlin 1875. He also discussed the reasons behind the ice-ages and their relative timing in the two hemispheres, according to Croll's pre-Milankovichean hypothesis.

Nordenskjöld's results seen from our present perspective

It is an impressive achievement to have gathered all this data in only two summers, especially considering that he worked in areas that were partly geographically unknown and usually quite difficult to traverse! The conclusions on the glacial history and the

discussion of the genesis of the various sediments, their stratigraphic relationships and the overall geomorphological evolution of the region were impressively modern and to a large extent are still valid. Nordenskjöld's conclusion that more than one major glacial episode had occurred in southernmost South America also contributed to the end of monoglacialism. He simply proved himself an excellent geologist and geomorphologist!

But of course we know much more today.[8] This includes the knowledge that there have been more than two glaciations in Patagonia (at least six major ones) and elsewhere, and that relative changes in sea level have been much more complicated than Nordenskjöld could envisage (some of his "marine levels" are in fact glaciolacustrine shore-lines). In Nordenskjöld's day earth scientists had no means with which to get absolute ages for the events they documented, but had to rely on palaeontologically based relative datings. By using such methods Nordenskjöld suggested a late Pliocene age for the glaciation during which the Patagonian Gravels were laid down. This was rather close to the truth, as these deposits are today regarded as dating from a sequence of Pliocene – early Pleistocene glaciations.[9] He also wrote a paper[10] about the Pampas Formation, a partly eolian deposit (loess) with a widespread occurrence north of Rio Negro in Argentina and in Paraguay and south-western Brazil. On palaeontological grounds he correlated its lower parts with his late Pliocene glaciation and the Patagonian Gravels. But he seriously underestimated the age of the maximum glaciation (Map 1). We now know that its deposits are about 1 million years old – rather than the c. 20,000 years of the "Otto Torell Stage" in Berlin, with which Nordenskjöld wanted to correlate it.

Northern interlude – East Greenland, 1900

Besides the scientific results from Tierra del Fuego and Patagonia, the most important thing to come out of the South American expedition of 1895–97 was that it led directly on to the Antarctic expedition of 1901–03. However, first Nordenskjöld spent a summer at Klondike and in the Yukon (1898) and, more important in our glacial history context, went to the Scoresby Sund area in East Greenland in 1900, with a Danish expedition led by G. Amdrup.

At that time the only geological work done in East Greenland north of 70°N. (from Scoresby Sund northwards) was such as had been carried out by the "Second German North Polar Expedition" in 1869–70, by the Danish Ryder Expedition in 1891–92, and by a Swedish expedition under A.G. Nathorst in 1899. Nordenskjöld did extensive geological mapping in the Scoresby Sund area, and building on the existing knowledge he compiled a geological map of East Greenland up to 75°N. on a scale of 1: 2,000,000. With this he laid the foundation for the detailed geological mapping of Northeast Greenland which was carried out by Lauge Koch and co-workers from the mid-1920s to the late 1950s, later revised and completed by the Geological Survey of Greenland (GGU) under Niels Henriksen between 1968 and the late 1990s.

Besides mapping the bedrock of the Scoresby Sund area, Nordenskjöld studied the glacial sediments covering it. On the interior plateaux of Jameson Land, on the northern side of the Scoresby Sund fjord, he found widespread deposits of till, sand and gravel, which were collectively given the name "Jameson Land Drift".[11] He compared them

Fig. 1. Studying a profile through a coarse glaciofluvial part of the Jameson Land Drift in East Greenland, 90 years after Otto Nordenskjöld first described these sediments. Photo: Christian Hjort.

with the Patagonian Gravels, which he had tentatively dated as late Pliocene, and thus the Jameson Land Drift was for long regarded as much older than other glacial deposits in East Greenland. Not until 1990 and 1992 were these sediments thoroughly studied again[12] and absolutely dated with the help of the thermoluminescence method. It was then confirmed that the Jameson Land Drift deposits were indeed of glacial origin (Fig. 1), of both sub-glacial (the tills) and proglacial genesis (the glaciolacustrine and glaciofluvial sediments). The proglacial categories are in principle similar in origin to the Patagonian Gravels, but Nordenskjöld's timing turned out to be wrong. The stratigraphical studies and the datings showed that the Jameson Land Drift is a rather complex sedimentary sequence, laid down during the two or three last glaciations (Weichsel, Saale, and possibly Elster), i.e. within the last c. 300,000 years. The end of the Pliocene was c. 2 million years ago.

The Greenland expedition was Nordenskjöld's first venture into the real polar regions, and it also served as a logistic preparation for the upcoming Antarctic expedition. He became acquainted with both his future expedition vessel, the *Antarctic* (which had also been used by Nathorst, in 1898 on Svalbard and in 1899 in East Greenland) and with the Danish way of travelling and their experience of "prefabricated" expedition housing. Such housing was later to be used by the Swedish expedition to Antarctica.

Antarctica, 1901–03

The background

If little was known about the glacial history of southernmost South America when Nordenskjöld arrived there in 1895, even less was known about it in Antarctica at the time when the *Antarctic* sailed southwards in 1901.[13] Arçtowski, who wintered with the *Belgica* in 1898–99 on the west side of the Antarctic Peninsula, had noted that the region had been even more glaciated sometime before than it was at his time.[14] This, together with some brief comments on iceberg rafting made by Darwin and others[15], was about all that was known about the former glaciation in Antarctica on the arrival of the Swedish expedition.

During this expedition the work on glaciation history was carried out both by Otto Nordenskjöld himself and by J. Gunnar Andersson. The results, together with the other geological achievements, were summarized by Andersson in his benchmark paper "On the Geology of Graham Land".[16] Andersson also had an Arctic background and had written his doctoral thesis on the geology of Bear Island, the southernmost island in the Svalbard archipelago.[17] After returning home from Antarctica he became Director of the Geological Survey of Sweden, and in 1914 he went to China to prospect for coal, iron ore and other mineral resources.[18] There he also became involved in archaeology and vertebrate palaeontology, and it was he who found the first traces of the Peking Man – and for the rest of his life he was known as "China Gunnar". Andersson did not go south with Nordenskjöld in 1901, and did not join the *Antarctic* until March 1902 at Port Stanley in the Falkland Islands, after the ship had returned from Nordenskjöld´s winter quarters on Snow Hill Island. During the southern winter (February–October) of 1902 Andersson carried out field work in the Falkland Islands, on South Georgia and on Tierra del Fuego, before the *Antarctic* returned south to Antarctica in early November.[19]

The field work

Some glaciation history field work was carried out when the *Antarctic* visited the west side of the Antarctic Peninsula, in January and again in November 1902. Especially the area around the Gerlache Channel was studied, and here the Swedish observations supported those made by Arçtowski. Andersson concluded that the whole Gerlache Channel had earlier been filled by a large ice-stream.[20]

But most of the glaciation history work was done in the north-western Weddell Sea: on the islands of Snow Hill, Seymour, Vega, James Ross and Cockburn, southwards along the Larsen Ice Shelf, which fringes the east coast of the Antarctic Peninsula, and around Hope Bay at the northern end of the peninsula. Some of Nordenskjöld's main contributions to this work were made during his long sledge journey in October 1902, together with the Argentinean José Maria Sobral, across the Larsen Ice Shelf via Robertson Island and the Seal Nunataks south to Borchgrevink's Nunatak at c. 66°S.[21] Andersson's main glaciation-history work in the Weddell Sea area was done during the forced wintering at Hope Bay, and during later visits to Seymour and Cockburn Islands.

Andersson's field work in the Falkland Islands, on South Georgia and Tierra del Fuego has already been mentioned.

Fig. 2. Glacially transported boulder from the Antarctic Peninsula on the top plateau of Seymour Island, near the present Argentinean Marambio Base. Photo: Christian Hjort.

The results

The main glacial history conclusions made by the Nordenskjöld expedition in Antarctica[22] were the following: 1) They found evidence suggesting that during some earlier time the glaciation had been much more extensive than at present, e.g. filling the Gerlache Channel with a north-flowing ice-stream, depositing crystalline boulders from the Antarctic Peninsula on top of Seymour Island (Fig. 2), and reaching more than 300 m higher than today on the Borchgrevink Nunatak. 2) They also noted, especially on Cockburn Island and on the "Naze" peninsula on northern James Ross Island, raised marine and beach deposits which indicated that since the period with more extended glaciation, land had emerged perhaps as much as 20 m.

Besides making important notes on the former extension of glaciation also on South Georgia[23], Andersson[24] contributed to the periglacial history of the Falkland Islands, e.g. by correctly interpreting the famous "stone runs" there as products of solifluction – a term he had actually introduced himself when writing up his experiences of the water-saturated ground on Bear Island.[25] During the short visit to Tierra del Fuego in September-October 1902 he both studied the former glaciation and postglacial emergence of the Beagle Channel and made a trip to Lago Fagnano, an almost 100 km long, glacially overdeepened lake visited by Otto Nordenskjöld as early as February 1896.[26]