CHAPTER 10

COMPARISON WITH OTHER GLACIATIONS

10.1 Introduction

In this chapter the late Precambrian glacial deposits of East Finnmark are compared with sections of the same age in other areas, many of which have been interpreted in part as glacial, and with Pleistocene deposits of glacial and non-glacial origin.

10.2 Comparison with Other Late Precambrian Sequences

Late Precambrian sequences in many widespread localities contain glacial or glacial-like sediments. This distribution has been interpreted as the result of a very severe glaciation (Mawson, 1949; Harland, 1964) and alternatively as due to polar wandering (Crawford and Daily, 1971). A comparison of a few of the better described sections may reveal to some extent the local and regional controls of sedimentation.

10.2.1 North Atlantic Region

This area includes four main localities (aside from East Finnmark): south Norway, Spitsbergen, Greenland and Great Britain. Tillites have recently been described from Newfoundland.

Numerous authors have suggested correlations between north and south Norway (Spjeldnaes, 1964; Bjørlykke, 1967; Føyn, 1967). Complications arise from the presence of only one tillite horizon and of coarse, arkosic sandstones and conglomerates (sparagmites). The 20 m thick Moelv tillite is interpreted as an ice rafted deposit because of the transitional lower contact with the Moelv sparagmite, a deltaic or shallow water deposit (Bjørlykke, 1966, pp. 29, 31). The author was shown these units and the contact between them by Dr. Bjørlykke. Viewing the apparently transitional junction brought to mind the large quantities of Nyborg sediment in the basal parts of the Mortensnes Tillite producing in some cases a contact gradational in appearance. In addition, deformed layering was observed which may be shear banding. Other evidence cited by Bjørlykke favouring a glacial marine origin for the Moelv tillite is the "almost random" long axis orientation of clasts. Describing the fabric as <u>almost</u> random shows that it does not possess very much significance.

In summary, there is little similarity between the Finnmark and south Norway sections. The contrasting lithologies between the two areas suggests that the tectonics and palaeogeography were considerably different between the areas.

Spitsbergen has one late Precambrian tillite horizon about 150-280 m thick which appears to rest conformably upon the underlying shales (Harland and Wilson, 1956), and for which reason it was considered to be an ice rafted deposit. However, marked changes in clast composition between different localities (Fleming and Edmonds, 1941) argue for a ground moraine origin, although the authors attempted to reconcile their observation with a marine origin. More recently, detailed observations by Chumakov (1968) have confirmed a terrestrial origin for the tillite: boulder pavements and sand wedges interpreted as freeze-thaw phenomena have been described. The tillite, 200 m thick, is here directly overlain by 35 m of dolomite.

The terrestrial origin of the tillite and the readvances of the ice sheet suggested by the boulder pavements and sand wedges within the tillite succession suggest an origin somewhat similar to the tillites of Finnmark. The author has not yet located detailed descriptions of the non-glacial sediments adjacent to the tillite.

A late Precambrian glacial sequence occurs in the Mørkebjerg Formation of the Eleanore Bay Group of east Greenland (Katz, 1961). Two tillite complexes are separated by thin bedded sandstones with shale, showing ripple marks and cross-lamination. The lower tillite passes laterally into conglomerate and sandstone interpreted as outwash deposits. The upper tillite may be only a few metres thick at some localities. Six tillite units are recognised in the two tillite complexes: these show a change from locally derived sedimentary clasts in the lower part to exotic basement derived clasts towards the top. The base of the lower tillite appears gradational as lamination dies out and clasts appear. Both tillites pass up into dolomite. According to Koch (1961) varved shales are associated with the tillites, and the glacial sequence is usually 200-1,000 m thick. All of these features are remarkably similar to those of the Finnmark tillites. Interestingly, Katz (1961) took great pains to show that the transitional basal contact of the lower tillite signified a marine origin for the tillite. The other features, particularly the development of distinct tillite units of contrasting composition, and the lateral passage of the lower tillite into outwash deposits suggest a subglacial origin for the tillite. The transitional lower contact may have been due to glacial incorporation of the substrate. The "stratification" may be shear banding of the type observed at Trollfjord in the Smalfjord Tillite.

Late Precambrian (Dalradian) boulder beds 870 m thick extend in a belt across Northern Ireland and Scotland. Forty-seven tillite beds, some with intercalated sandstone, conglomerate and varved shale are interpreted as deposits formed during 17 advances and retreats of a grounded ice sheet (Spencer, 1971). Abundant sandstone wedges at the top of many of the tillite beds indicate subaerial periglacial conditions. In view of the abundance of stratified deposits within and between tillite beds, and other features, either a ground moraine or a supraglacial origin is feasible (see Howarth, 1971). The interbedded sandstones are not described (Spencer, 1971) and thus it is impossible to determine whether or not the 250 m sandstone near the top of the succession represents a major interglacial period, analogous to the Nyborg Formation. The tillite formation is overlain by up to 80 m of shallow water dolomite (Spencer, 1971). The sequence is very different from that in Finnmark.

In southeastern Newfoundland, two tillites are present, each 30-40 m thick, separated by a few metres of sandstone and occurring about 7-8,000 m below the lower Cambrian. The tillites are massive and contain striated clasts (Bruckner and Anderson, 1971). Insufficient data are available for a comparison with the Finnmark succession.

10.2.2 More Distant Localities

Late Precambrian glacial sequences have recently been described from western U.S.A., Australia, the Sahara, and west Congo.

In Idaho and Utah the late Precambrian sequence contains two tillite horizons represented laterally in shelf and basin environments. The lower horizon, up to about 1,000 m thick, consists of tillite intercalated with volcanics, conglomerate, and sandstones. An upper tillite horizon is overlain by a 2 foot bed of dolomite (Crittenden et al., 1971). The tillite is of suspected marine origin because of the intercalated sandstones, and the presence of dolomite (p. 583). However, Crittenden (pers. comm., 1971) has suggested that the tillites in the type area, mostly massive, are continental in origin, having been deposited in valleys eroded into the underlying rocks. Although the number of tillite horizons and the nature of the interglacial sediments is not yet known, the presence of a dolomite immediately above one of the tillites is intriguing.

Austalia has long been a classic location of late Precambrian glacial deposits. The sequences are from about 300 to 7,500 m thick, and are composed of two well defined tillite horizons separated by an interglacial formation of sandstone, shale and limestone. The upper tillite is followed by a dolomite marker bed (Dunn et al., 1971). In West Australia each tillite rests on an angular unconformity (Dow, 1965). In an unusually thick deposit (15,000 m) in the Bibliando Dome, Flinders Range, Mawson (1949) described two tillite formations each with laminated and varved siltstones, and other water-lain and possible aeolian deposits. Except for the great thickness, the Australian successions are reminiscent of the Finnmark Tillites: two tillite formations, ground moraine deposition, complex facies changes, and dolomite immediately overlying the tillite.

The late Precambrian glacial horizon in the western Sahara (Biju-Duval and Gariel, 1969) is about 60 m thick and includes tillites near the base, intercalated with laminated and varved shales with dropstones, and cross-bedded sandstones which may be outwash as well as aeolian deposits. The succession rests unconformably upon older late Precambrian sediments and crystalline basement which were faulted prior to glacial deposition. In their interpretation the authors emphasized that deposition was in part by continental glaciers, of which advances and retreats can be detected. Furthermore, the succession is very varied containing marine and terrestrial deposits.

The succession is quite different from that in East Finnmark.

Perhaps the most interesting late Precambrian sequence occurs in the west Congo (Schermerhorn and Stanton, 1963). The poorly sorted rocks there have been termed tilloids, rocks which appear glacial in origin but are not (p. 203). The two tilloid formations present are both of great lateral extent and rest on an angular unconformity above older late Precambrian sediments. The lower tilloid is 300-500 m thick and includes intercalations of mudstone and greywacke. It is capped by a conglomeratic greywacke. The upper tilloid is generally less than 50 m thick and includes mudstones, sandstones and conglomerates. It is overlain by a persistent dolomite bed. The clast lithology of each tilloid matches the composition of the underlying formation. The intertilloid formation varies from about 100-1,000 m thick and consists of mudstones in the lower part and mudstones, limestones and greywackes above.

Many of the features described above are similar to those in the Finnmark succession. However, the tilloids are bedded. The beds are 5 cm to 10 m thick and appear to be laterally continuous. The composition of adjacent beds may be quite different, though beds may be internally homogeneous. Some beds are stratified within, and often appear graded. The bedding and the interstratification with mudstones and with limestones led Schermerhorn and Stanton to suggest a marine rather than continental origin for the tilloid formations. They suggested that the tilloids were emplaced by submarine mudflows in a rapidly subsiding geosyncline. In their interpretation a ground moraine origin was not considered (as a continental origin had been ruled out). Bedded sequences containing tillite can form in a glacial environment by glacial advance and retreat (e.g. Spencer, 1971), and by slumping, either beneath an ice shelf (Carey and Ahmed, 1961) or in a supraglacial environment (Boulton, 1968) or in a marine proglacial environment (Chapter 4, Smalfjord Tillite at Kvalnes and Bigganjargga). The rapid subsidence invoked by Schermerhorn and Stanton to explain the occurrence of each tilloid formation upon a regional unconformity seems very improbable. Their argument is not aided by the association of shallow water limestones and orthoquartzites (their interpretation of some of the sediments). In conclusion, the origin of the diamictites in the west Congo late Precambrian sequence is still uncertain, and may have been glacial.

10.2.3 Discussion

A comparison of the sequences in the North Atlantic region with those of more distant localities shows that sequences similar to that in East Finnmark are not restricted to presently adjacent areas. Generally speaking (Table 26) one or two tillite horizons are present. Each rests on an unconformity, is intimately associated with dolomite, and has been interpreted in most cases as the deposit of a continental glaciation. As discussed above, evidence cited for a marine origin of tillite should be reconsidered in the light of findings presented in Chapters 5 and 7: for example, a basal erosion surface may appear gradational, or shear banding may be mistaken for lamination, or bedded tillite intercalated with other sediments may form in several glacial subenvironments. The thickness often appears to be related to the tectonic conditions: in general the thickness of the tillite is proportional to the overall thickness of the late Precambrian accumulation. Finnmark seems average in this respect. It appears that the thicker sequences tend to contain two tillite horizons, while the thinner successions have one. The Dalradian boulder bed in Great Britain is an exception.

The presence of two tillite horizons over a wide area is the only strong argument for a world-wide glaciation in the late Precambrian. Otherwise, the distribution could be explained by polar wandering (Crawford and Daily, 1971) as has been done apparently with great success for the late Palaeozoic glaciation (Crowell and Frakes, 1970).

The glacial "dolomite problem" is as yet unsolved. The dolomite at the base of member 1 of the Nyborg Formation can be explained by supratidal and intertidal deposition in a warm, possibly arid environment. This is not apparently so for the dolomite tillite on top of the Mortensnes Tillite in the north of the study area. At any rate, the development of the dolomite seems largely independent of local tectonic conditions, and is therefore analogous to the tillites in having been controlled by world-wide climatic events.

10.3 Comparison with the Pleistocene

10.3.1 Introduction

As mentioned in Chapter 9, the glacial sediments of the Smalfjord and Mortensnes Tillites are sharply set off from the non-glacial Nyborg Formation and the Lillevatn Member. Although the Nyborg Formation is interglacial, coming between glacial horizons, the sharp rise in sea-level marked by member 1 and the change in climate indicated by the dolomite suggest that the ice sheets may have melted away completely. Interglacials during the Pleistocene and earlier time do not appear to have been associated with complete ice wastage; the Antarctic and Greenland ice sheets are a permanent feature of the Pleistocene (Hollin, 1962; Goodell *et al.*, 1968; Mercer, 1968).

10.3.2 The Glacial Formations

It is likely that the advances and retreats which compose each tillite formation are approximately equivalent to the glacials and interglacials of the Pleistocene. The Pleistocene glacials are characterised by the formation of ground moraine, while glacial retreats preceding interglacials formed proglacial and periglacial deposits. For the Finnmark tillites the latter was mainly subaqueous: either sandstone or varved and laminated siltstone. Occasionally outwash and loess formed in terrestrial conditions. As discussed in Chapter 5, both the development of ice dammed lakes and a rise in sea-level could cause the formation of stratified silts during an interglacial period. It was argued that retreat on land would probably have formed more stratified sand and gravel deposits than are actually observed in the tillite formations. Thus, if retreat from a marine area is accepted, the overall environment of deposition was in a shelf environment; around sea-level during glacials, and below sea-level during interglacials and non-glacials. In addition, the area must have been one of very low relief as shown by the slight changes in gradient of the unconformities beneath each tillite formation, and by the relative uniformity of facies in the immediately overlying sediments. The Varangerfjord area was an exceptional case for the Smalfjord Tillite.

Pleistocene glaciated areas which satisfy these two conditions include shields (Canadian, Baltic) and shelf or inland seas (Hudson Bay, Baltic). In the Hudson Bay Lowland, south of Hudson Bay (McDonald, 1968), three till sheets averaging about 20 m thick are intercalated with marine and lake silts and some outwash and peat horizons. Two of the tills are of uniform thickness and can be traced for about 500 miles. The tills are interpreted as ground moraines deposited by successive advances and retreats of an ice sheet. Overlying the upper till in some areas is lake silt, followed by marine silts and clays. This sequence is believed to have formed by the flooding of ice dammed lakes as the remaining ice wasted away and sea-level rose. A somewhat similar succession formed in southern Finland where fresh-water and subsequently marine varved silts and clays overlie ground moraine (Sauramo, 1923). The change to saline conditions was believed to represent the connecting of the Baltic with the ocean as sea-level rose and the ice sheets retreated.

On the 200 km wide glaciated shelf off Nova Scotia, end moraines occur in depths of 100-200 m, 30-100 km from the coast (King, 1969). While end moraines make up about 10% of the surface deposits, ground moraines, forming a blanket deposit 10-20 m thick, locally up to 100 m thick where filling irregularities, and proglacial silts underlie the rest of the area. The silts occur above and adjacent to moraine and are believed to have formed by ice rafting. They are stratified, poorly sorted, and interfinger laterally with moraine. Most of the moraine appears massive, rarely with stratified inclusions.

The glacial sediments rest unconformably upon seaward dipping Ordovician and Cretaceous-Tertiary sediments. The unconformity is believed to have formed at least partially by subaerial erosion (see also Oldale and Uchupi, 1970), and the topography is an important control on the local thickness of the glacial deposits. The glacial deposits are overlain in deeper water (>100 m) by marine clays, and in shallower water (<100 m) by sand and gravel associated with reworking during the Holocene transgression.

There are two important differences between the deposits described from the Scotian shelf and the Finnmark tillites. First, end moraines are not prominent in the Finnmark tillites, and second, large-scale alternations of moraine and silt were not observed on the Scotian shelf. Otherwise, the moraine to silt sequence formed during the glacier retreat is similar to the mechanism envisaged for the Finnmark tillites (fig. 40). Analogous to the sand and gravel deposits resting on moraine and silt in shallow depths is the conglomerate bed resting erosively upon the Mortensnes Tillite in the northern part of the study area. The marine clays which formed in deeper water are analogous to the silts and clays of the thick lower submember of the Lillevatn Member.

In conclusion, Pleistocene glacial deposits formed on present day continental shelves and seas of low relief bear significant similarities in terms of till body shape and type of facies present to the Finnmark tillites. Deposits formed directly over the glacial materials during the Holocene transgression are similar to the transgressive deposits of the Mortensnes Tillite - thick and thin lower submember boundary. Descriptions of carbonate to siltstone sequences formed during the Holocene transgression have not been encountered by the author.

10.3.3 The Non-glacial Formations

Members 2 and 3 of the Nyborg Formation and the lower submember of the Lillevatn Member formed during strongly regressive conditions following glacial episodes, probably related to the stabilisation of sea-level after postglacial transgressions. Although modern conditions are not entirely analogous to the ancient non-glacial conditions, certain periods of the Pleistocene were characterised by intense sedimentation. Coring and geophysical investigations have revealed to some extent the composition and internal structure of the Pleistocene sedimentary cover of non-glaciated shelves.

Deltaic progradation was an important process in the construction of the continental terrace off Mexico (Curray and Moore, 1964). Progradation was associated with lower sea-level, about 70-130 m below present level, and occurred while sea-level was falling. The deltaic bodies consist of topsets of coastal plain facies, and foresets up to 200 m thick (depending on the depth into which the delta was prograding) which grade offshore into bottomsets and continental slope deposits. Curray and Moore concluded that the continental terrace which they studied is a constructional feature formed by deposition both on the shelf and on the slope. In a non-deltaic setting the position of the shelf break was controlled by the balance between deposition and removal by waves in a broad zone around wave base.

Similar foresets and topsets were also described from the continental shelf off the northeastern United States (Knott and Hoskins, 1968). As with the Mexican structures, these are associated with internal erosion surfaces formed by the rise and fall in sea-level. It is possible that these formed in a similar way to the structures found off Mexico.

These foreset structures appear to have formed in association with rapid regression during low stands of sea-level. A broad comparison with the regressive sequence at the top of member 3 of the Nyborg Formation can be made. The nature of this regression was shown to have been controlled both by the influx of turbidites and the change of wave influence with depth. The sequence was divided into shelf, slope and basin environments (fig. 52) which may correspond approximately to the topsets, foresets and bottomsets described by Curray and Moore, although marine rather than fluvial processes were important in the formation of the topsets. Instead of passing offshore into continental margin slope deposits, the Nyborg bottomsets continued as a basin environment of a continental sea.

Coring of the postglacial sediments of the Rhone delta (Oomkens, 1970) has shown the presence of a thick accumulation of marine silts and clays overlying pre-transgression coastal plain silts and sands, and gravelly alluvial deposits. The fine grained marine deposits are believed to have formed by the progradation of the Rhone delta following the post-glacial transgression. The sequence is similar to that of the thick lower submember of the Lillevatn Member.

The deltaic deposits formed during lower stands of sea-level were buried and preserved by sedimentation in deep water following the postglacial transgression. If, for some reason, the remaining ice sheets were to melt, the Rhone delta, amongst others, would likewise be inundated and covered by marine sediments. Such a history of deglaciation is a possible but unlikely explanation for the two phase postglacial transgression made up of the lower submember and the upper submember - Innerelv Member junction.

10.3.4 Conclusions

Continental shelf sediments formed during the rapidly changing sea-level of the Pleistocene bear certain similarities to the postglacial Nyborg Formation and lower submember of the Lillevatn Member. Foreset and topset structures in some shelf deposits may be of similar construction to the upper part of member 3 of the Nyborg Formation, while the marine part of certain deltaic transgressive sequences may be equivalent to the lower submember.

As the regressive parts of both the Nyborg Formation and the Lillevatn Member are believed to have formed following postglacial transgressions associated with complete deglaciation, there can be no exact equivalents found in present day shelves as the Pleistocene glaciation is evidently uncompleted.