

## GLACIAL DEPOSITS IN SOUTHEASTERN NORWAY

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ABSTRACT. In his recent mapping of the surficial geology of southeastern Norway, the author has distinguished the following types and subtypes of glacial drift:

- (A) Deposits left by active glaciers as ground moraine, terminal moraines, and, below the marine limit, as marine sediments.
- (B) Deposits left by inactive glaciers ("dead-ice bodies") as glacial-fluvial deposits, eskers, dead-ice moraines, and ground moraine covered by ablation moraine.

Geomorphic features and stratification of deposits left by active glaciers distinguish them from those left by inactive ice bodies.

(A) is divided into (1) an area of raised submarine deposits, and (2) an area showing ground moraine, commonly as a thin layer in patches between protruding rock.

(B) is divided into (3) an area of glaciofluvial deposits in the valleys, (4) an area of dead-ice deposits, on plateaus and near the ice divide, and (5) a mountainous area where rock is partly weathered into extensive block fields and where the thin drift is marked by frost phenomena.

The relative heights of the drift zones are indicated by the numbers given above, but because their occurrence is connected with circumstances pertaining to the decaying ice sheet, their borders do not correspond closely to altitude in the terrain.

### DEVELOPMENT OF GLACIAL THEORY IN NORWAY

For more than a hundred years geologists have recognized that an ice sheet, such as the Inland Ice observed by H. J. Rink in Greenland in 1852, once covered the Scandinavian Peninsula. The Norwegian geologist Theodor Kjerulf taught this as early as the year 1858 and began studies concerning the wastage of the ice masses. He believed that melting of the ice cover proceeded from the coast toward the high mountains in central Norway and considered that the present glaciers are relicts of the last glacial age. He found that the distribution of moraines near the coast indicates progressive deglaciation inland. In central Norway, however, morainic lines cannot be traced from one valley to another. Kjerulf therefore supposed the ice sheet was divided into several centers: Kjølén territory in the east, Jotunheimen, Røldal mountains, and Folgefonn territories in the west, and Rondane and Høg-Gia centers in the north.

The validity of Kjerulf's views was questioned by the botanist Axel Blytt (1876) as well as by the geologist Andr. M. Hansen (1886). Blytt maintained that since several mountains in central Norway now support an arctic-alpine flora, they were ice free while glacial conditions prevailed near the coasts. Hansen, calling attention to observations made by J. C. Hørbye 20 years earlier, stated that the distribution of erratics in east-central Norway testify to an ice movement upslope toward the northwest. Hansen therefore inferred that the ice divide of the Norwegian Inland Ice was southeast of the present water divide. He believed that the ice sheet first disappeared in the vicinity of the present water divide, while large ice masses remained to the south, blocking the Glåma river system, and creating large, ice-dammed lakes. Hansen investigated remnants of former lake strand lines at different levels and proposed that lake levels sank as successively lower outlets were formed during the melting of the ice.

Dr. Hans Reusch, an early Director of the Norwegian Geological Survey,

was the first geologist to accept Hansen's hypothesis, and stated (1901, p. 88), "Melting of the Inland Ice did not proceed during deglaciation in such a manner that still active glaciers moved down the valleys. Lack of terminal moraines lends favor to the idea that the ice cover in central Norway during the melting period became a dead mass successively decaying in thickness and extent until its final wastage took place".

Thus Reusch as early as the turn of the century made use of the term "dead" ice mass in the meaning of an inactive glacier. In 1909 he wrote (p. 49), "As the surface of a glacier sinks during its decay, it is most probable that the glacier will be divided, the dead glacier remnants filling hollows of the drift. The ice here being thickest remains longer than in other places where it is thinner. During this stage melt water may deposit its debris at intervals between the ice remnants".

Subsequent studies (Gunnar Holmsen, 1915) showed that remnants of the ice sheet in Østerdalen made an extended barrier damming the Femund Basin south of Lake Femund, Rendalen valley north of Storsjøen lake, and the valley of the Glåma at Koppang with the axis of the barrier oriented southwest-northeast. Per Holmsen (1951), through his studies of erratics and their bedrock sources, showed that the ice divide was situated very near the ice dam.

Gunnar Holmsen (1918) also showed that the lateglacial history of the Laugen River drainage in Gudbrandsdalen to the west was similar to the events in Østerdalen. Sediments and ancient strand lines testify to the existence of an ice-dammed lake, the dam having been situated at Rusten in Sel. Before stagnation of the ice, the glacier had moved up the valley, as erratics and striations show.

Also to the east, in Sweden, remnants of the last ice sheet dammed a series of glacial lakes between the main watershed of the peninsula and the ice divide (Magnusson and Lundqvist, 1949).

West of Gudbrandsdal, however, as in Valdres, Hallingdal, Numedal, Telemark, and Sørlandet, no traces of glacier-dammed lakes are found. Thus it is probable that the ice divide in those districts was situated near the main watershed.

Deglaciation resulted from a change of climate accompanied by elevation of the snowline. When the snowline rose to the crest of the ice divide no snow remained at the end of the summer. As glaciers received no nourishment their movement ceased, and the ice sheet shrank, chiefly by melting from the surface. The first ice-free areas were those where the active glaciers had been thinnest. Mountains emerged from the ice sheet while large ice bodies remained in the valleys.

Transition from active glacial movement to inactive conditions began as the ice sheet receded from the moraine in the Moss-Horten area of the Oslo Fjord. The advance to this moraine, called the Ra moraine, is synchronous with the cold Younger Dryas period in Denmark. This advance was followed by a climatic amelioration causing "a violent melting of ice masses" (Hafsten, 1960) whereby the ice sheet was divided into several lobes, the recession of which was not regular, as at times the ice margin was stationary or readvanced (Isachsen, 1940).

Paleobotanical investigations indicate that during postglacial time amelioration of climate reached an optimum in the warm and dry Sub-Boreal, about 2500 to 500 B.C. At that time the timber line in south Norway, and presumably even the firn line, was 300 meters higher than at present. At the end of the Sub-Boreal deterioration took place, lowering the firn line to its present level.

#### DESCRIPTION OF THE DEPOSITS

The author has recently completed a new series of six 1:250,000-scale maps of surficial geology which extend over southeastern Norway from the Oslo district to Trondheim (fig. 1). Each is accompanied by a Norwegian text and English summary and is issued as a separate publication in the Norwegian Geological Survey series. Figure 2 is a generalized glacial map based on the new sheets.

On these maps, a distinction is drawn between *sparsely covered rock*, a thin layer of drift frequently broken by protruding rock, and *morainic drift*, a thick, almost continuous cover of drift concealing bedrock. Those symbols on the map indicate what are here called, respectively, areas of former active glaciers and areas of former stagnant glaciers.

In areas of former active glaciers terminal moraines occur. Ice of an active glacier is moving throughout, down to its terminus. Most of the drift is accumulated at the border of the glacier during its advances or halts. Between the moraines only a thin cover of drift, patchy in places, was deposited. In the areas that were postglacially submerged, marine deposits cover the rock and drift.

In the areas of former stagnant glaciers, the "dead-ice territory", bedrock is covered by a thicker and almost unbroken layer of drift. In valleys and basins meltwater streams deposited massive deposits of sand and gravel. Their forms as well as their characteristic stratification testify to the decay of a stagnant ice sheet.

According to the special conditions inferred from the wasting of ice, the geological map of Quaternary deposits shows the following zones of drift:

- (A) Deposits of active glaciers
  - (1) Uplifted marine sediments and terminal moraines.
  - (2) Thin, discontinuous till, chiefly in the form of ground moraine.
- (B) Deposits of stagnant glaciers
  - (3) Glaciofluvial sediments and ablation drift in valleys.
  - (4) Dead-ice deposits on plateaus and along the ice divide.
  - (5) Thin drift, marked by frost phenomena, in mountain areas.

#### *A. Deposits of Active Glaciers*

(1) *Uplifted marine sediments and terminal moraines.*—During ice recession from the present coast to the glaciomarine terraces of Romerike, sand and clay were deposited between the moraine belts. These deposits were isostatically elevated above sea level; uplift was greatest at the heads of deep, indented fjords, and least on the open coast. The highest strand line, marking the marine limit, in the Oslofjord and Trondheimsfjord areas, is 220 m above sea level; at places near the open coast, however, marine deposits are apparent only up to 10 m.



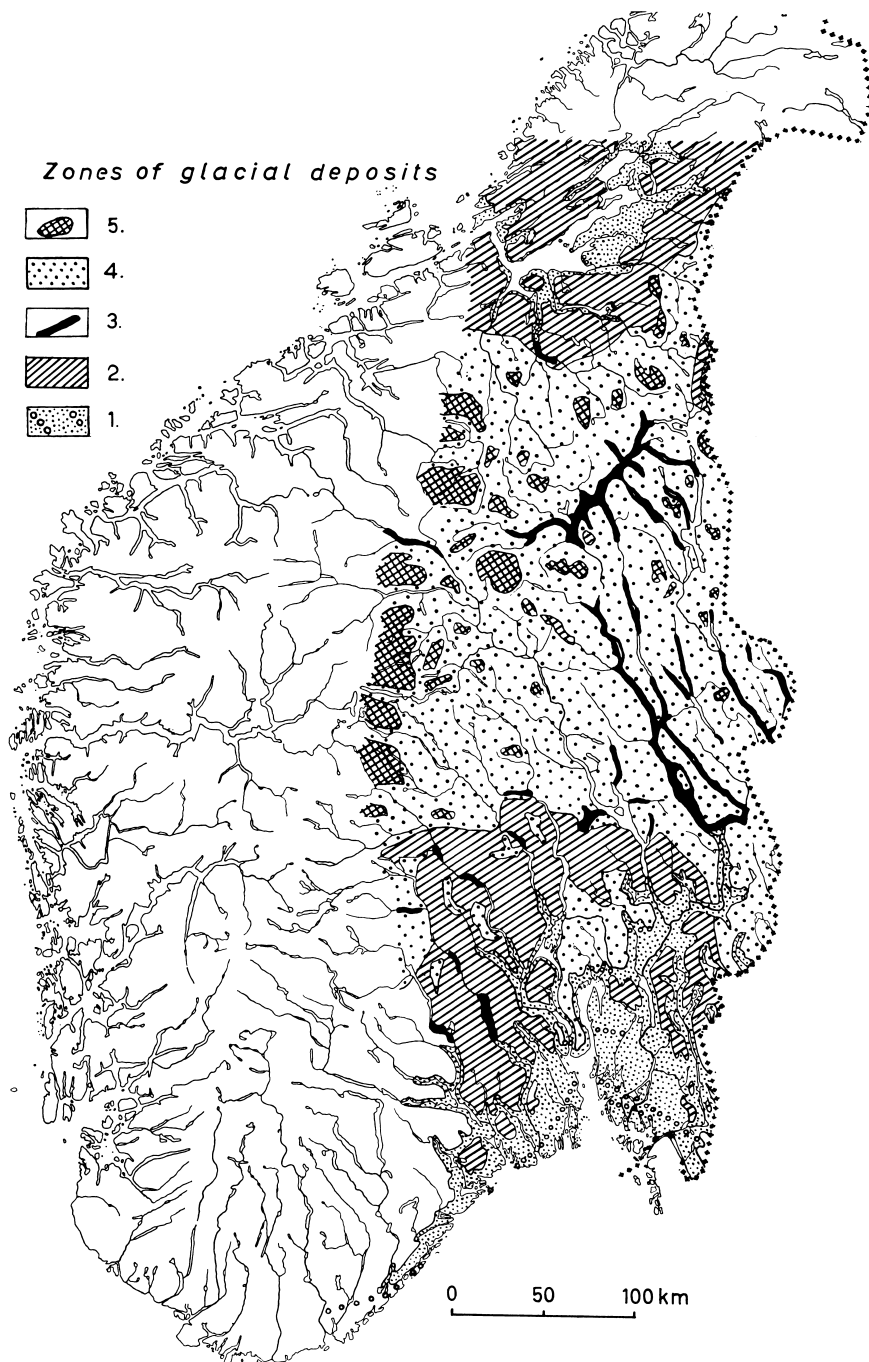


Fig. 2. Map showing zonal distribution of glacial sediments in southeastern Norway. (1) Uplifted marine sediments, including terminal moraines (shown by lines of circles). (2) Thin discontinuous till, chiefly ground moraine. (3) Glaciofluvial sediments and ablation drift in valleys. (4) Dead-ice deposits on plateaus and along the ice divide. (5) Thin drift, marked by frost phenomena in mountain areas.

On the map (fig. 2), terminal moraines are shown in the districts around the Oslofjord and the Trondheimsfjord. During uplift, the surf reworked the surficial parts of the moraines into stratified sand and gravel. At some places gravel fans were deposited by glacial streams at the retreating glacier front. Extended ice-retreat terraces in the Oslo district occur south of Randsfjord, at Hauer seter, near Dal, and at the outlet of lake Mjøsa. Some subglacially formed stream deposits occur at several places.

The belts of terminal moraines and marginal deltas formed by the receding ice sheet were deposited nearly at the sea level of the time. The thickness of the marine sediments seldom exceeds 100 m, as is known from well drillings. Both clay and sand contain marine shells. The fossils, reflecting temperature and salinity, indicate progressive increase in water temperature during deposition.

Radiocarbon dates of fossil shells collected from Yoldia clay on both sides of Oslofjord south of the Ra moraine are  $9950 \pm 300$  yr BP at Sarpsborg, and  $9920 \pm 220$  yr BP at Tønsberg. Two similar radiocarbon dates of shells from the Aker moraine in the northern part of Oslo are  $9450 \pm 250$  yr and  $9250 \pm$  yr BP (Holtedah, 1960). Thus the recession of the ice border from the Ra moraine to the moraines at Aker, a distance of 80 km, required about 500 to 700 years.

The zone of uplifted marine sediments has its greatest distribution on both sides of Oslofjord and north as far as lake Mjøsa. Much of the Trondheimsfjord area also belongs to this zone. Elsewhere the zone encircles the coast of Norway as a border, comparatively wide in southern Norway, and more or less narrow on the west coast. The zone includes the strandflat, with its many isles partly covered by peat and with a very sporadic distribution of drift. In northern Norway the width of the zone is variable.

The border of marine sediments was recognized by K. O. Bjørlykke as early as 1902. He showed its areal extent on a general map on a small scale (Bjørlykke, 1902). Later, in his last treatise (Bjørlykke, 1940), he developed the subject.

(2) *Thin, discontinuous till.*—Till extends inland from the marine limit and occurs also as inliers within the area of marine sediments. The zone inland from the marine limit is dissected, with high mountains and deep valleys. The cover is very uneven, and ground moraine of considerable thickness occurs only in basins and on slopes that were not exposed to glacial scour. Generally, gravel carried by streams from active glaciers bypassed this zone.

If distinct end moraines exist above the marine limit, they are rare. As shown on the geologic maps, the bedrock, where covered, carries a thin, patchy layer of till. An almost naked rock surface characterizes this zone of drift in some places. The scarcity of drift may depend partly on postglacial weathering and partly on rate of movement of the ice sheet. The faster the movement, the less drift was deposited.

A thin layer of heather humus commonly overlies till or bedrock. It accumulates owing to the slow rate of decay of lichens, mosses, and heather.

In certain places ground moraine was deposited on the upglacier sides of hills, as demonstrated by Bjørn Andersen (1960, p. 107) in southern Norway.

He reported "On the plateaus between deep valleys in Sørlandet there is mainly bare bedrock apart from the moraine belts, but in the hill slopes facing north (upglacier) there are very often thick moraines. These hill slopes are stoss slopes, and the moraines have been called stoss moraines. The stoss moraines are thickest immediately to the north of, and parallel with, the moraine belts. It is therefore evident that the glaciers have not been able to carry all of their load up the steepest hills near their ends".

Because of the great depths of lakes in southeastern Norway, thick bodies of dead ice occupied their basins, even after lesser active glaciers had withdrawn from surrounding hills and mountains. Intersected by glaciofluvial deposits in valleys, the zone of scantily distributed till cover extends from the highest strand line into the zone of dead-ice traces on plateaus and along the ice divide.

The zone of thin, discontinuous till attains higher altitudes in the mountains of central Norway than near the ice divide in Østerdalen. Whereas in Østerdalen, south of the ice divide, the zone rises only to 450 m, in the districts of Valdres-Hallingdal it reaches 700 m, and in Numedal still higher, indicating an ice divide in the last mentioned districts situated at the main watershed of the Scandinavian Peninsula. The deposits of the zone cover large areas on undulating mountainous plateaus in South Norway and probably also much of the area west of the main watershed.

### B. Deposits of Stagnant Glaciers

(3) *Glaciofluvial and ablation drift in valleys.*—Above the marine limit in the major valleys marine sediments are replaced by glaciofluvial deposits. In southeastern Norway the sea followed in the wake of the retreating ice border to the basins of deep lakes, such as Mjøsa, Randsfjord, Sperillen, and Krøderen, where dead ice bodies barred the sea from entering.

In most valleys in central Norway extensive dead-ice deposits with kettles, eskers, and hummocky drift suggest that the valleys were filled with stagnant ice during deglaciation. Valley floors are generally marked by sandy terraces, in places appearing as large deltas built by glaciofluvial streams. Elsewhere sandy ablation moraine untouched by glacial or postglacial streams directly overlies till.

The glaciofluvial deposits consist of rock types transported from a distance, whereas the underlying till, presumably the ground moraine, was derived mainly from the underlying rock. The terraces commonly stand 20 to 30 m and in a few places 80 m above the streams. Steep slopes rise from the flood plains to the terrace surfaces where kettles and drainage channels indicate that the deposits are glaciofluvial. Apparently the till underlying the stratified drift was deposited as side moraines of active glaciers from material derived from steep valley sides, as well as from ablation drift.

In the Glåma and Rena drainages, strand lines of glacial lakes occur at several positions. One, the lowest, at an altitude of 666 m, extends from the watershed between the rivers Glåma and Gaula to the outlet of the Atna, tributary to the Glåma, a distance of 120 km. Above this strand line unstrati-

fied material is common on the slopes. Mounds and ridges of stratified or unstratified drift occur between strand line and valley floor.

Although the valleys in central Norway, east of the main watershed, are covered widely with glaciofluvial sediments, the valleys of the southern and western parts of South Norway are mainly covered with ground moraine.

At the mouths of tributaries to such rivers as Glåma, Rena, and others, delta terraces with steep distal slopes probably were built against remnant dead ice. Valleys between the ice divide and the main watershed have more extensive glaciofluvial deposits than any other valleys in Norway. Eskers are especially common in this district, as shown on the Røros and Østerdalen sheets of the Geological Survey 1:250,000 series.

Some excavations in valleys reveal laminated fine sand overlain by ablation drift, indicating lake-filled cavities in dead ice. The roofs of the cavities, loaded with ablation drift, were probably supported by ice pillars.

During deglaciation ice bodies filled the basins of such lakes as Mjøsa and Randsfjord to depths of several hundred meters. Upstream from the lakes the valleys contain much evidence of melting of inactive ice lobes, such as eskers and other perforation deposits.

(4) *Dead-ice deposits on plateaus and along the ice divide.*—The zone of ablation drift and ground moraine on plateaus is the most extensive in the area mapped. It extends from the Kongsvinger district across the mountainous hills surrounding lakes Mjøsa and Randsfjord to the main watershed at Hemsedal, and it covers large areas on Hardangervidda, as well as between that locality and Hallingdal. The ice sheet here underwent general downwasting during which most of its load was deposited in place. This zone lacks end moraines. Its smooth cover of drift is broken by dead-ice moraines, explained formerly as terminal moraines. Among the highest dead-ice moraines, strandlines of glacier-dammed lakes occur. Some of them are associated with abandoned rocky outlets.

Glaciofluvial deposits in adjacent valleys suggest that “dead” plateau glaciers existed while ice bodies occupied valleys. Meltwater from ice on the plateaus carried sand and gravel to the valleys, deposited the material along or upon remnant ice bodies.

(5) *Thin drift, marked by frost phenomena, in mountain areas.*—Thin, discontinuous drift occurs even on high mountains, though rarely concealing the rock. On the other hand, frequent alternations of frost and thaw produce broken rocks, which at higher latitudes almost completely mantle the bedrock.

The first geologist to draw attention to the difference between drift on high mountains and drift at lower altitudes was Reusch (1901, p. 231) who wrote: “The uppermost rather flat parts of the highest mountains present a peculiar aspect. There is almost no vegetation, and the loose material which covers the ground consists of angular or subangular stones; where the rock is exposed ‘in situ’ it is partially weathered into blocks which show no sign of ice polishing or glacial striae. The composition of the stones on the surface is the same as that of the rock in the ground, and one first thinks that no traces of ice action are to be found. But by closer examination a few erratic stones are found, which prove that the ice (or perpetual snow) has been in movement

over these heights even if it had only force to carry away a little of the material formed by weathering”.

The lower limit of the zone is determined not only by climate but also by susceptibility of the bedrock to splitting. Foliated rock such as slate is more susceptible to the effect of frost and splits more easily than does igneous rock. Under the same climate the zone descends to lower altitudes in districts of fissured rocks than in districts of massive rocks. Thus the zone in slaty Trysil sandstone descends to 900 m, in nearby Archean granite to 1050 m, and in granite at Atnesjø only to 1200 m.

Mean summer is an important factor in determining the altitude of block fields. From central Norway to the coast of northern Norway mean summer temperature decreases from 14°C to 9°C, corresponding to a depression of the lower limit of this zone from 1200 to 300 m, averaging 200 m per degree of mean summer temperature.

In central Norway barren block fields are chiefly limited to territories built of Trysil sandstone or of sparagmite. Within the domain of the sparagmite group, block fields cover the bedrock above 1100 m while on Trysil sandstone the lower limit of block fields is only 900 m.

On sparagmite mountains south of Atnedalen extensive block fields occur above the 1200-m contour. Mountains lower than 1100 m have sporadic patches of broken rock.

The large block field called Hindfly, between the Sjoa and Veo Rivers in Jotunheimen, is in Caledonian intrusive rocks and has its lower limit at 1500 m.

Warm summers during the last 50 years have thawed perennial snow fields. This is recognized by the light color of recently exposed block fields, which have not yet acquired the dark lichen cover that prevails upon surrounding rocks and block fields.

In lower parts of this zone, freezing and thawing produce patterned ground, such as fissure polygons, stone rings, and hummock fields, and solifluction is active in silty and clayey soil, downslope from perennial snow fields.

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