Radiocarbon dates from the mountain area northeast of Årdal, southern Norway; evidence for a Preboreal deglaciation

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Radiocarbon dates obtained on macrofossil plant remains (mainly *Betula nana*-sticks and mosses) and basal gyttja from a kettle hole at the outlet of Berdalsvatn 1017 m a.s.l. northeast of Årdal, inner Sogn, yielded ages of 9330 ± 60 (T-6777) and 9180 ± 130 (T-6778) yr B.P., respectively. Allowing for some time between the regional deglaciation, melting of the dead ice occupying the kettle hole, and production of sufficient organic material for dating, the area was probably deglaciated at least some decades prior to the older of the two dates.

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Introduction

The deglaciation chronology along the fjords of western Norway is fairly well established (Anundsen & Simonsen 1967, Anundsen 1972, 1985, Vorren 1973, Aarseth & Mangerud 1974, Bergstrøm 1975, Holtedahl 1975, Mangerud et al. 1979, Mangerud 1980, Aa & Mangerud 1981, Aa 1982, Blystad & Anundsen 1983, Hamborg 1983, Fareth 1987, Rye et al. 1987). From the western and central mountain regions of western Norway, however, dateable organic material directly related to the deglaciation of the Late Weichselian ice sheet has been reported from only a few localities. As a consequence, only a few radiocarbon dates closely related to the deglaciation have so far been obtained. An isochrone map, by Andersen & Karlsen (1986), on the Late Weichselian and Early Holocene ice-marginal recession in southern Norway shows the 9000-yr isochrone close to the heads of the fjords in western Norway. The deglaciation of southern Norway, however, was completed at about 8500 yr B.P. (Andersen 1980). Excavations related to dam building at the outlet of Berdalsvatn northeast of Årdal, inner Sogn (Fig. 1), revealed macrofossil plant remains interbedded with deglaciation sediments. The organic material was, therefore, regarded as suitable for obtaining relatively reliable minimum dates on the deglaciation of this mountain area. The chronostratigraphic subdivision of the Holocene adopted here accords with that proposed by Mangerud et al. (1974).

Geological setting

Berdalsvatn (1017 m a.s.l.) is situated in a hanging valley east of Årdalsvatnet (Fig. 1). Generally, the area is dominated by a sparse cover of Quaternary deposits (Nesje & Rye 1985, 1987). The bedrock along the valley sides of Berdalsvatn consists of syenitic gneiss, while the areas to the east are dominated by metagabbro (Koestler 1983).

The deglaciation history of the Berdalsvatn area is not known in detail. However, along both sides of the valleys Tyedalen and Moadalen, and the adjacent valley north of Berdalen (Fig. 1), lateral moraines were deposited by a valley glacier draining from the Tyin area down to Årdalsfjorden during the Early Preboreal Chronozone (Holmsen 1984). At that time, proglacial meltwater deposits were built up to a sea-level ca. 100 m above the present at Moen, øvre Årdal.

West of the outlet of Berdalsvatn, Berdalselva drains through a canyon (Fig. 1), the eastern part of which shows evidence of having been formed by subglacial meltwater flowing north of the present outlet river from Berdalsvatn. Along both sides of the outlet river from Berdalsvatn, glaciofluvial terraces

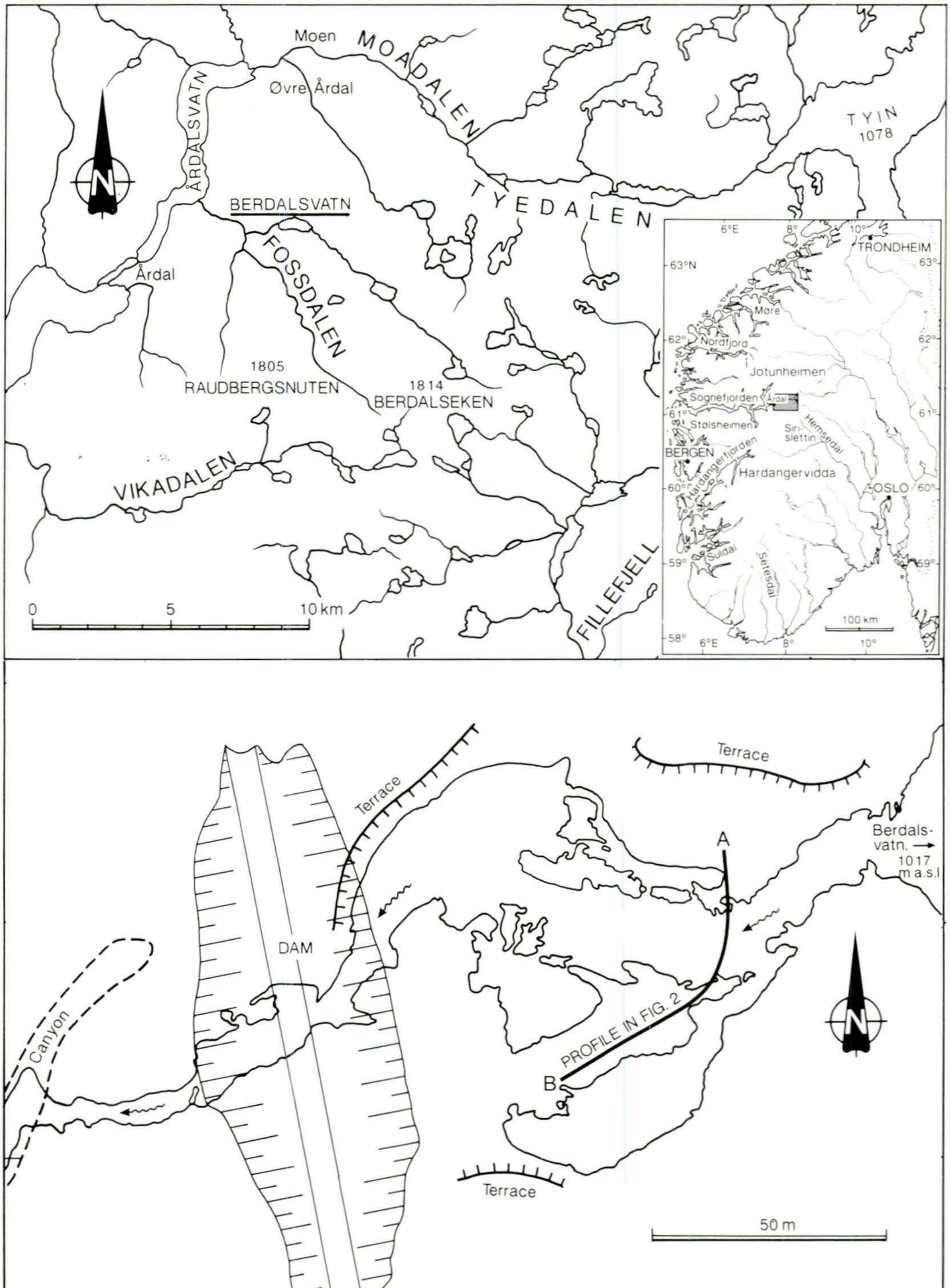

Fig. 1. Location maps of southern Norway, the Årdal - Fillefjell area and the study site at the outlet of Berdalsvatn.

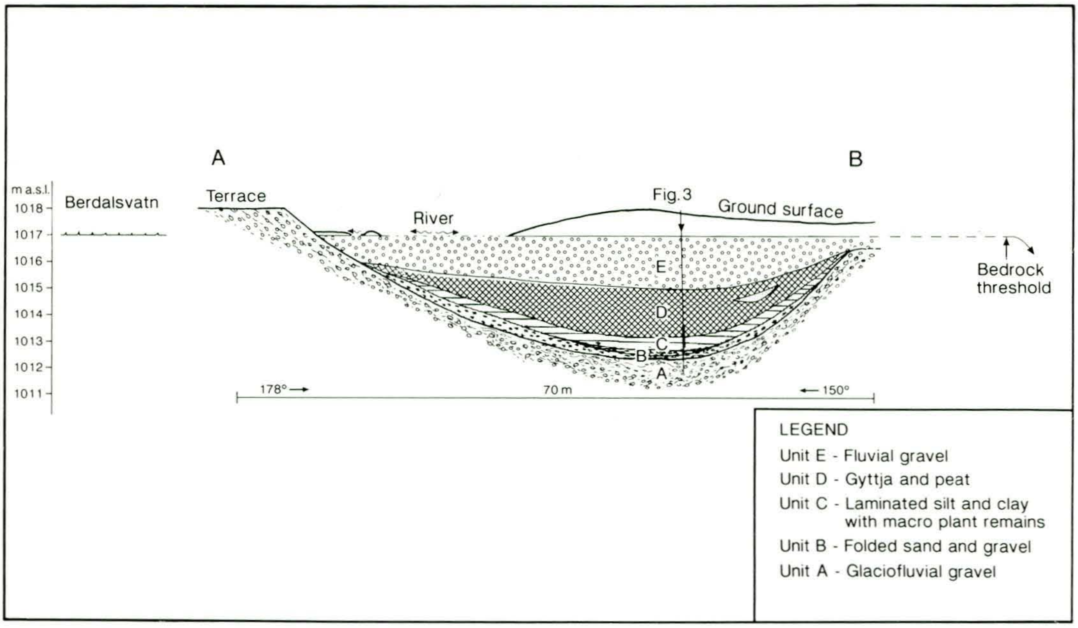

Fig. 2. Longitudinal profile through the studied section at Berdalsvatn. Note that the figure is not drawn to scale.

(now excavated) were recognised. The terraces were interpreted as having been deposited laterally from a downwasting glacier in the Berdalsvatn basin towards the end of the deglaciation (Nesje & Rye 1985, 1987).

Study site

During excavations, a 70 m-long and up to 5 m-high section was exposed (Fig. 2). The sediments were deposited in a depression in gravel (Unit A, Fig. 3) upstream from a bedrock threshold at the outlet of Berdalsvatn. Along the northern valley side, the gravelly deposits were terraced, the surface of the terraces being 1-3 m above the lake/river level before excavation.

Lithostratigraphy

Unit B consisted of a 20 cm-thick horizon of folded silt and clay with single grains mostly of gravel size (Fig. 3). Unit B was overlain by a 30 cm-thick, laminated, silt-and-clay unit with single particles mostly of gravel size, interbedded with macroscopic plant remains dominated by *Betula nana*-sticks and mosses (Table 1) (Unit C). Four metres below the sediment surface a gradual transition to a ca. 2 m-thick gyttja (lower part) and peat (upper part) (Unit D) was recognised. On top of the section there was a 2 m thickness of gravel (Unit E).

Loss-on-ignition

Loss-on-ignition analysis, according to the procedure described by Sønstegaard & Mangerud (1977), showed that the organic content in Unit C was less than 5% (Fig. 3). At the transition to the overlying gyttja (Unit D), however, the organic content increased to 10-15%. At 380 cm below the surface the organic content increased to ca. 30%. In the depth interval 365-375 cm, loss-on-ignition decreased to about 20%. Between 360 and 375 cm depth the organic content increased to ca. 40%.

Lithostratigraphic interpretation

The depression in the gravelly material (unit A) along the described profile (Fig. 2) is interpreted as a kettle hole, formed by either a downwasting ice mass or a stranded iceberg upstream of the rock threshold at the outlet of Berdalsvatn.

The folding observed in unit B was probably syngenetic, caused by either glaciotectonism (minor readvance or ice-marginal fluctuation?)

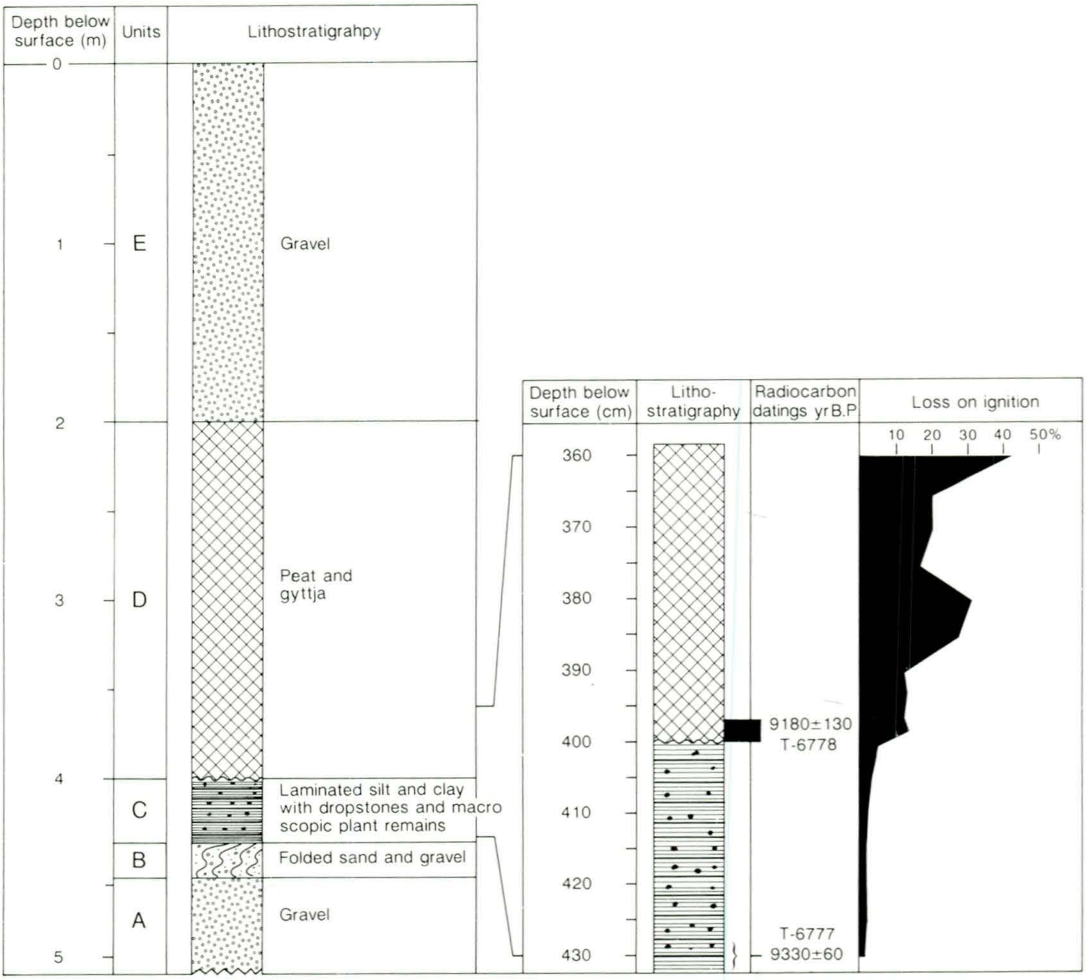

Fig. 3. Lithostratigraphy, radiocarbon dates and lossonignition from the studied section.

or slumping processes. Unit C, consisting of laminated silt and clay, is interpreted to have been deposited from suspension in a glacier meltwater stream. The single grains of gravel size in Unit C, interpreted to have been deposited as dropstones from melting icebergs, may suggest a contemporaneous ice-marginal position in the Berdalsvatn basin. The gradual transition from unit C into the overlying gyttja and peat (Unit D) most probably represents the termination of glacial meltwater transport into the Berdalsvatn basin. Unit D represents a period of organic deposition before a 2 m-thick fluvial gravel (Unit E) was deposited by the outlet river from Berdalsvatn (Fig. 1).

Radiocarbon dating

Macrofossil plant remains in laminated silt and clay from the base of Unit C (Fig. 3) were collected for radiocarbon dating. The plant fragments were sieved from the minerogenic material and dried at 120°C for two days. The submitted sample consisted of ca. 80% *Betula nana*-sticks and the remaining part of terrestrial and aquatic mosses (Table 1). The NaOH-soluble fraction (58.7 g) was dated to 9330 ± 60 yr B.P. (T-6777) (Fig. 3, Table 2).

A 3 cm-thick sample of gyttja (loss-on-ignition ca. 13 %) was collected for radiocarbon dating from the base of the gyttja and peat (Unit D). The insoluble fraction was centrifuged

Table 1. Identified macrofossil plant remains from Unit C in the section at Berdalsvatn.

Mosses
Drepanocladus exannulatus
D. fluitans
D. uncinatus
Calliergon sarmentosum
Philontis sp.
Hygrohypnum sp.
Rhacomitrium sp.
Polytrichum norvegicum
Marsupella sp./*Gymnomitrion* sp.

Vascular plants
Dryas octopetala
Salix polaris

Trees
Betula nana

before precipitation. The NaOH-soluble fraction (13.6 g) yielded a date of 9180 ± 130 yr B.P. (T-6778) (Fig. 3, Table 2).

Discussion of the radiocarbon dates

Since the bedrock surrounding the site is dominated by syenittic gneiss, the samples are considered to be little influenced by the hardwater effect. However, as the basal sample (T-6777) may include small fragments of autochthonous aquatic mosses (e.g. *Drepanucladus fluitans,* Table 1), these may have been influenced by a hardwater effect in the glacial meltwater (e.g. Sutherland 1980). The metagabbro east of Berdalen (Koestler 1983) may be a potential source for 'old' carbon in the glacial meltwater. Since the dated sample consisted of about 80% of *Betula nana*-sticks, this effect is, however, considered neglible.

Younger dates on the insoluble fraction are commonly ascribed to downward penetration by *Isoëtes* roots (Olsson 1974, Kaland et al. 1984). Allochthonous organic material eroded and washed into the kettle hole may give dates which are too old. Organic material of allochthonous origin influences both the soluble and the insoluble fractions (Donner & Jungner 1973, Olsson 1979). However, the dated organic macrofossil plant material most likely represents the first flora established at the site during or just subsequent to the melting of the dead ice which occupied the kettle hole at the outlet of Berdalsvatn. Allowing for some time between the regional deglaciation, melting of the dead ice occupying the kettle hole, and the initial production of dateable material (e.g. Sutherland 1980), the area may have been deglaciated at least some decades prior to the older date. The date of 9330 ± 60 yr B.P. (T-6777) is therefore considered to be relatively close to the minimum age for the time of the regional deglaciation of the Berdalsvatn area.

The date 9180 ± 130 yr B.P. (T-6778) may indicate the age of the initial phase of increased organic productivity in the lake surroundings, as a response to the generally improving climate during the Preboreal/Boreal transition (e.g. Andersen 1980). However, as the two radiocarbon dates overlap within one standard deviation, the age difference may not be statistically significant. A calculation of the sedimentation rate in the period between the two radiocarbon dates is therefore impracticable.

Radiocarbon dates obtained along Sognefjorden (Fig. 1) and other fjord regions of western Norway indicate that the mouths of the tributary valleys and fjords were deglaciated during the Early Preboreal Chronozone (Klovning 1963, Klovning & Hafsten 1965, Anundsen & Simonsen 1967, Rye 1970, Vorren 1973, Bergstrøm 1975, Aarseth 1980, 1988, Aa 1982, Sivertssen 1985, Rye et al. 1987). In the Stølsheimen area to the south of the outer Sognefjord area (Fig. 1), however, local ice caps occupied the mountain plateau throughout the entire Preboreal Chronozone (Aa & Mangerud 1981), where outlet glaciers formed frontal deposits at the heads of the tributary fjords (Rekstad 1909, Kyrkjebø 1953, Carlsson

Table 2. Radiocarbon dates from the section at the outlet of Berdalsvatn.

Depth (cm)	Material	Loss-on-ignition	Sample weight	Age B.P.	$\delta^{13}C$	Lab.no.
428–431	Macroscopic plant remains	≈100%	58.7 g	9330 ± 60	+26.0‰	T–6777
397–400	Gyttja	ca. 13%	13.6 g	9180 ± 130	+25.9‰	T–6778

1960, Aarseth 1980, Aa & Mangerud 1981). Based on radiocarbon dates of 8640 ± 120 (T-3224A) and 8600 ± 250 (T-3487A) obtained from the high-lying mountain areas (980-1030 m) between Suldal and Setesdal (Fig. 1), southwestern Norway, Blystad & Selsing (1989) suggested that this region was deglaciated by 8800 years B.P.

From the central mountain region of southern Norway only a few deglaciation dates have been reported. So far, the oldest one is an accelerator mass spectrometry date of 9235 ± 145 (Ua-685) from Sirislettin, Hemsedal (Fig. 1) (S. O. Dahl, unpubl. data).

The date 9330 ± 60 (T-6777) from the excavated section at the outlet of Berdalsvatn is, therefore, the oldest deglaciation date so far reported from the inner and central mountain regions of southern Norway. The dates from Berdalsvatn are, however, in close accordance with deglaciation radiocarbon dates obtained from adjacent regions of western Norway.

Summary

Radiocarbon dating of macrofossil plant remains intercalated in laminated deglaciation sediments deposited in a kettle hole at the outlet of Berdalsvatn, northeast of Årdal, inner Sogn, yielded an age of 9330 ± 60 yr B.P. (T-6777) on the NaOH-soluble fraction. Allowing for some time between the regional deglaciation, melting of the dead ice occupying the kettle hole, and sufficient organic production for dating purposes, the mountain plateau east of Årdal may have been deglaciated at least some decades prior to the actual date. T-6777 is the oldest deglaciation date so far reported from the inner and central mountain regions of southern Norway.

Initiation of gyttja accumulation in the studied kettle hole, dated to 9180 ± 130 yr B.P. (T-6778), marks the end of glacial meltwater transport from a wasting glacier in Berdalen, as a response to a generally improving climate in southern Norway from the Preboreal/ Boreal transition.

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