Middle Weichselian interstadial sediments in Sogndalsdalen, western Norway

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At Kollsete 380 m a. s. l., Sogndalsdalen, a 20 cm thick bed with gyttja silt has been recorded beneath 3 m glaciolacustrine silt and 5–6 m till deposits. The gyttja silt is supposed to have been deposited during the initial phase of a glacial lake located laterally to an advancing valley glacier. The sedimentation of the gyttja silt was succeeded by the deposition of a glaciolacustrine silt and a lodgement till. The pollen assemblage in the gyttja silt reveals open, treeless vegetation. An Arctic/alpine climate is confirmed by the insect fauna and plant macro fossils. Two radiocarbon age estimates of the gyttja, > 39 200 BP and 43 800 BP, indicate an interstadial of Mid Weichselian age. Correlations with the Bø interstadial (about 40–60 ka BP), and Sargejokha interstadial (35–60 ka BP) are suggested.There is also a discussion of correlations with other Mid Weichselian localities.

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Introduction

This paper reports the first identification of a site of Mid-Weichselian age from the inner fjord areas of western Norway. So far several sites of probable Mid Weichselian age have been recorded on the west coast, e.g. Sunnmøre (Mangerud et al. 1981a, Landvik & Mangerud 1985, Landvik & Hamborg 1987, Larsen et al. 1987, Valen 1995, Valen et al. 1996); Fjøsanger (Mangerud et al. 1981b); Karmøy (Andersen et al. 1983) and Jæren (Andersen et al. 1981, Sejrup 1987, Larsen & Sejrup 1990, Stalsberg et al. 1999, Larsen et al. 2000) as well as in southern inland Norway; Sorperoa, Gudbrandsdalen (Bergersen 1989, 1991, Bergersen et al. 1991); Brumunddal (Helle et al. 1981); Åstdalen (Haldorsen et al. 1992); Folldalen (Thoresen & Bergersen 1983) and Rokoberget (Rokoengen et al. 1993). Vorren (1972) described a core from a basin at Kroken (Figure 6) with proposed interstadial sediments. A review of Weichselian interstadials is given in Mangerud (1991a, b, c).

A major deglaciation in central eastern Norway during the Early Weichselian is generally accepted (Mangerud 1991 a, b, c), whereas a continuous ice sheet is supposed to have covered the Scandinavian mountains during the Mid Weichselian (Andersen & Mangerud 1989, Donner 1995). However, the subtill sediments at Kollsete close to present glaciers support a considerable deglaciation during Mid Weichselian (Thoresen & Bergersen 1983; Haldorsen et al. 1991; Rokoengen et al. 1993a,b; Olsen 1995, 1997a,b; Olsen & Grøsfjeld 1999).

Study site

The location of the Kollsete site (UTM930956) in Sogndalsdalen is shown in Figure 1. A road section in a steep moraine slope 380 m a.s.l. 15–20 m above the valley bottom revealed layers of till above glaciolacustrine silt and organic sediments (Figs. 2 and 3). Another section with subtill sand some 50 m further north in the same moraine slope was described by Kvalvågnes (1979).

Sogndalsdalen has a relative relief of about 400 m (Figure 1). In general, the valley sides are steep with a discontinuous cover of till and avalanche material (Aa 1982). At Kollsete, the slope is more gentle with relatively thick till deposits. The dominant bedrock is Precambrian gneiss, but Cambrosilurian phyllites are exposed in both valley sides (Bryhni et al. 1986).

Lithostratigraphy

Description and interpretation

Unit D (Figure 3) is a 8–10 cm thick dark grey sand layer lying directly upon bedrock. Some 2–3 mm thick clastic silt dikes penetrate the sand. The dark sand D is interpreted as in situ weathered bedrock.

Unit C (Kollsete gyttja silt) is a 20 cm thick layer of brown silt containing thin sand-lenses. Loss on ignition at 550 °C on 6 samples is in the range of 1.2–5.8%. No diatoms and only a few macrofossils have been found. Two conventional radiocarbon age estimates have been

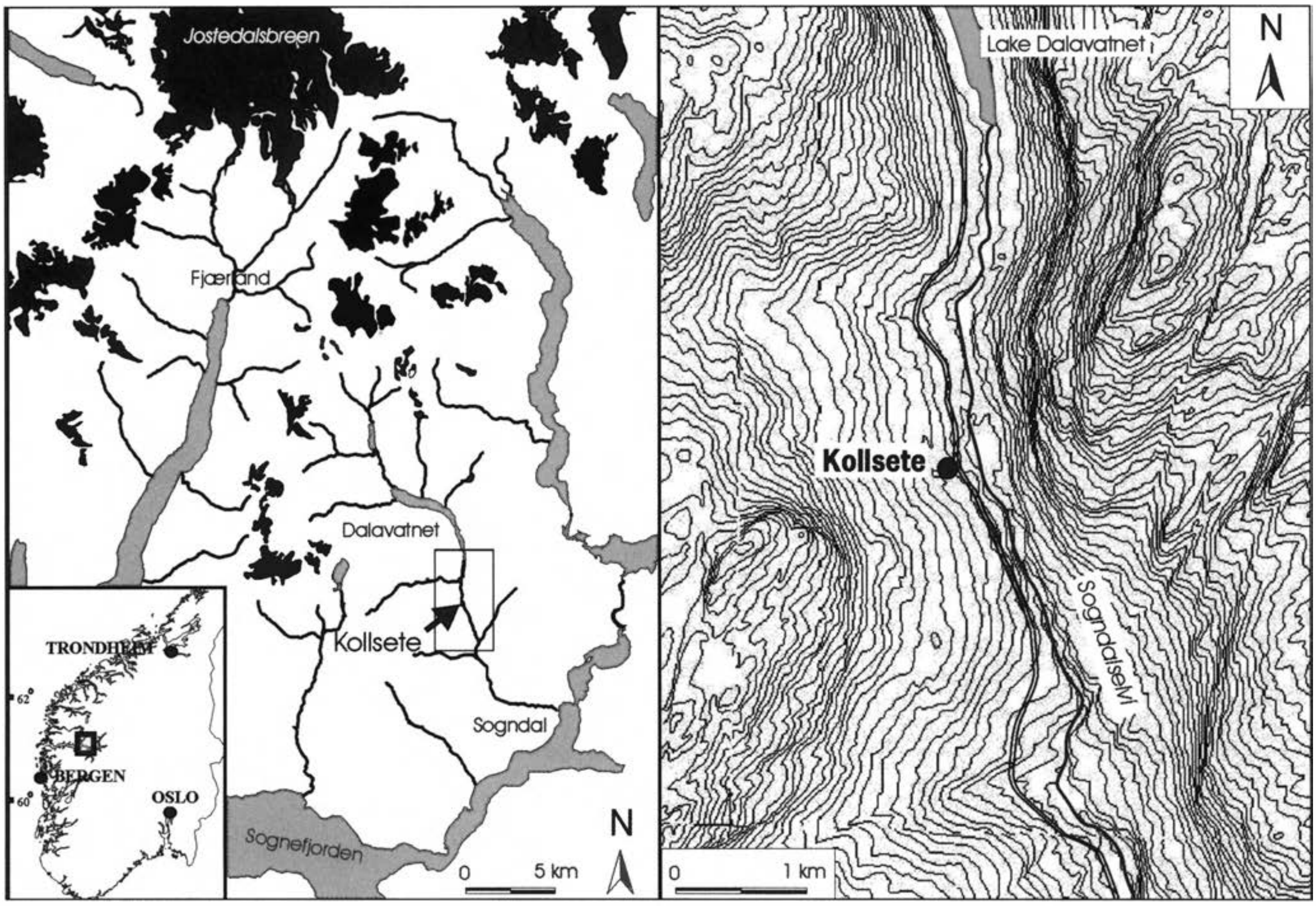

Figure 1. Location map and topographic map of the Kollsete area. The contour interval on the map to the right is 20 m. (Aa & Sønstegaard)

performed. The upper boundary of unit C is very uneven, and occasionally vertical (Figure 2).

The gyttja silt, unit C, is interpreted as a lake sediment, probably glaciolacustrine, although no diatoms, water plants or algae have been recognized. Since the gyttja silt is underlain by a weathered bedrock surface, a considerable time span under subaeril conditions must have elapsed before the lake came into existence. Our interpretation is that the organic material is allochthonous and was deposited during the onset of a glacial lake

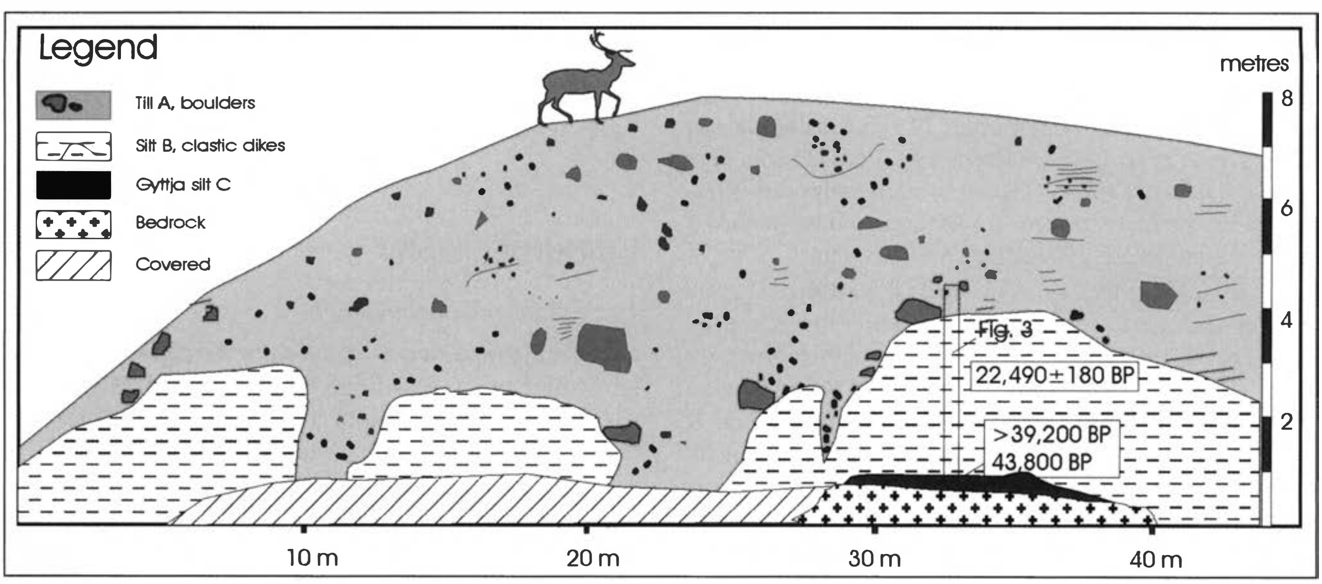

Figure 2. The section at Kollsete. (Aa & Sønstegaard)

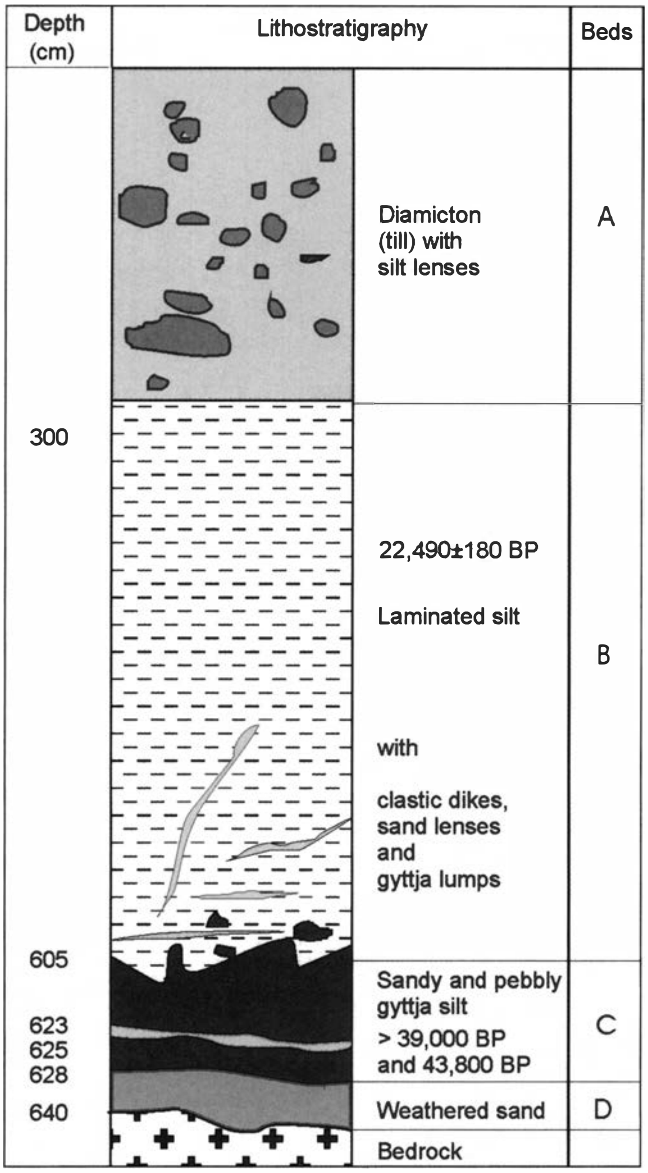

Figure 3. Stratigraphy of the sediments at Kollsete. (Aa & Sønstegaard)

phase, as validated by the high silt content and the very few macro fossils. Two conventional radiocarbon age estimates of the NaOH-soluble part of bulk samples from the silt gyttja unit C gave >39.2 ka BP (T-11143A) and 43.8 ka + 3.7/–2.5 ka (T-13211A), respectively (Table 1).

Unit B (Kollsete silt) consists of silt with laminae and layers from 1 mm to 6 cm thick, 1 cm being the most common. Lenses of sand and some clastic dikes are present in the lower part. Small pieces of brown silt derived from unit C occur at the bottom of this unit. The silt in unit B is interpreted as a glaciolacustrine sediment, too. This was deposited during a later phase of the glacial lake. The disturbance of the laminated silt seems to have been negligible (Figure 2). No diatoms were found in the silt. A bulk AMS age estimate of the upper part of the glaciolacustrine silt B yielded 22490 ± 180 BP (Table 1).

Unit A (Kollsete diamicton) is a sandy diamicton (till) up to 7 m thick containing boulders, mostly rounded, with largest diameter close to 1 m, although blocks with diameter 20–30 cm dominate. According to glacial striae measured on adjacent bedrock exposures (Aa 1982), till A seems to have been deposited in a SSE direction, parallel to the direction of the section.

The irregular and partly vertical A/B boundary is probably a result of partial liquifaction of silt B, causing subsidence of till A into silt B, as corroborated by some size sorting within the subsided till structures and inclined laminae in unit B close to the steep boundaries. Due to the liquified structures, till A is supposed to have been deposited during the initial stage of the glaciation, while silt B still was unconsolidated.

Fossils

Five samples were prepared by the HF method for pollen analysis (Figure 4). Spectrum no. 4 and 5 are bulk samples from gyttja silt C, spectrum no. 2 and 3 are sampled from the top of gyttja silt C, whereas spectrum no. 1 is from the upper part of silt B, 40 cm beneath the B/A boundary. The pollen percentages were calculated from the sum of pollen, whereas the spore percentages were calculated from the sum of pollen + spores.

No diatoms were found in the subtill silt B and silt gyttja C sediments. The absence of diatoms most likely is the result of complete chemical dissolution, and is an argument in favour of an old age of the sediments i.e. pre Late Weichselian (S.K. Helle, pers. comm. 1997).

Regarding insects, Geoffrey Lemdahl recorded a pronounced Arctic fauna in the gyttja silt C. He also identified some plant remnants of *Selaginella selaginoides* and *Dryas octopetala.* However, the fossils were seriously damaged and corroded.

Climate and vegetation

The pollen content of spectrum 2 and 5 from gyttja silt C, reflects an open, treeless tundra vegetation dominated by grasses (*Poaceae*) and other herbs, mainly *Asteraceae* and *Rumex/Oxyria*, together with *Dryas octopetala* and *Selaginella selaginoides* as verified by macro remnants. *Pinus* pollen usually are overrepresented in tundra diagrams since pine trees are great pollen producers and *Pinus* pollen are easily transported by the wind. Therefore the extremely small amount of *Pinus*, 6 of a total of 1399 identified pollen grains, combined with low values of *Betula*, including *Betula nana*, suggest that the whole area was treeless, probably down to sea level, implying a forest limit that was at least some 800 m lower than today.

A deteriorating climate towards the end of the interglacial (spectrum 1 and 2) might be postulated from the decline of *Betula* pollen, *Cryptogramma Crispa* and *Polypodiaceae* spores, and increasingly grass-dominated vegetation.

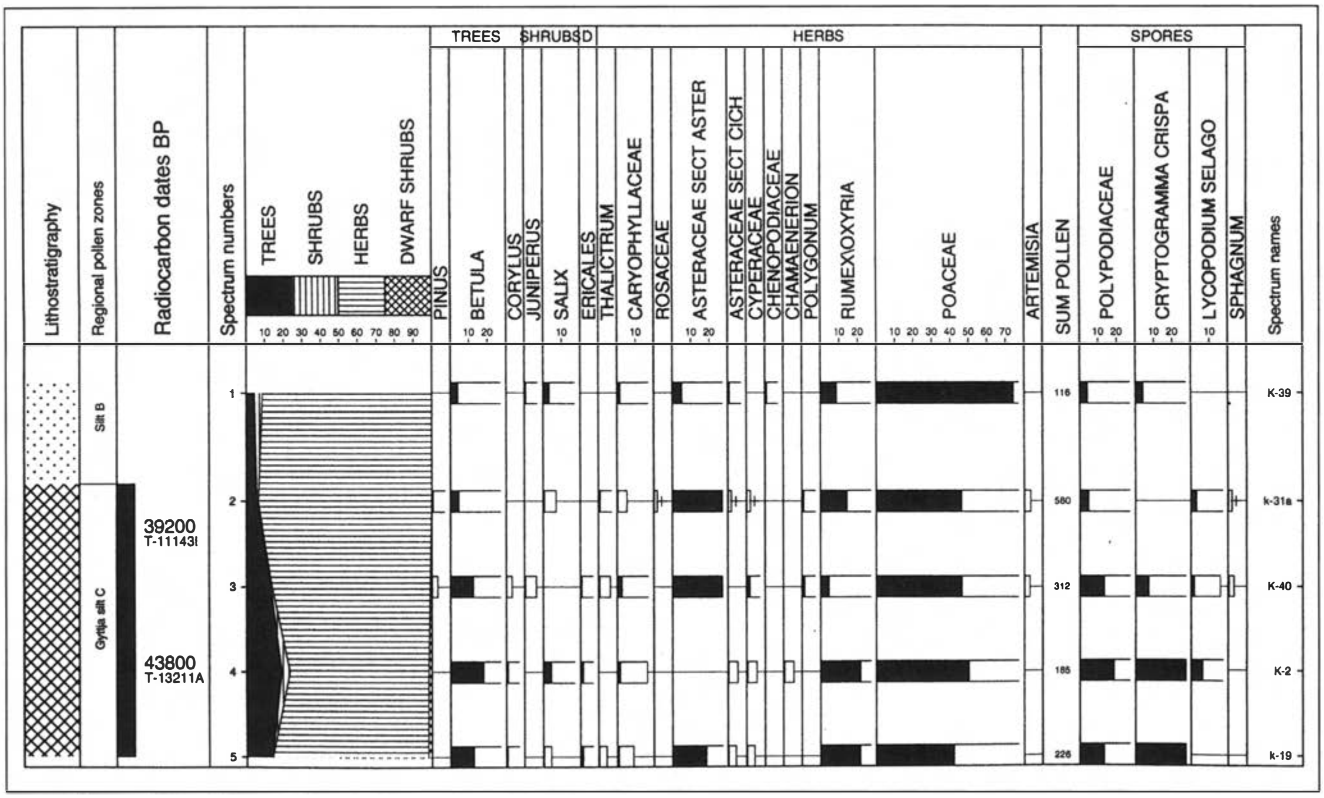

Figure 4. Pollen diagram from Kollsete. (Eivind Sønstegaard)

Radiocarbon age estimates

Dating results are given as average age ± one or two standard deviations. Only small gas amounts were evolved from the samples T-11143A and T-13211A, and the dates might be considered as minimum ages. Most probably the measurements indicate the age of the gyttja deposits to be older than the Ålesund interstadial (S. Gulliksen pers. comm. 1998).

In general such old samples are sensitive to contamination. At the actual site the organic sediments, however, should be preserved by several metres of low permeable sediments above. The stratigraphic position of the dated sediments is also clear. But there is a chance of contamination from both old and young carbonate dissolved in the groundwater moving at the rock surface.

An AMS age estimate of the NaOH-insoluble part of a bulk sample of the upper unoxidized part of the glaciolacustrine silt B yielded 22490 ± 180 BP (Table 1). The chance of contamination is less for this sample, since only the insoluble fraction was dated. Due to the very small amounts of organic matter, this date should not be overestimated. The dates are uncertain, but the oldest must be regarded as most reliable. Far more organic material was available compared to the 22.5 ka date where the dating material was almost sterile silt, and consequently the uncertainty of the last date might be larger. The first conventional dating result of the silt gyttja B was >48.6 ka. A larger sample, approx. 2 kg, of this silt gyttja was later redated to >39.2 ka.

Discussion

A glaciation curve of western Norway, revised from Mangerud (1991a,b,c), denotes one early upper Weichselian interstadial, the Hamnsund interstadial (ca. 24.5 ka BP), and two Middle Weichselian interstadials, the Ålesund/Sorperoa interstadial (ca. 30–40 ka BP) and the Bø interstadial (ca. 40–60 ka BP). Although some proxy data,

Table 1: ^{14}C age estimates from the subtill sediments at Kollsete

Lab. ref.	Unit	Age ± 1 σ	Age ± 2 σ	Fraction	Material
T-11143 A	C	>39200	>35700	soluble	silt gyttja
T-13211 A	C	43800+3700/–2.500	43800+10800/–4500	soluble	silt gyttja
UtC 6046	B	22490+-180 BP		insoluble	silt

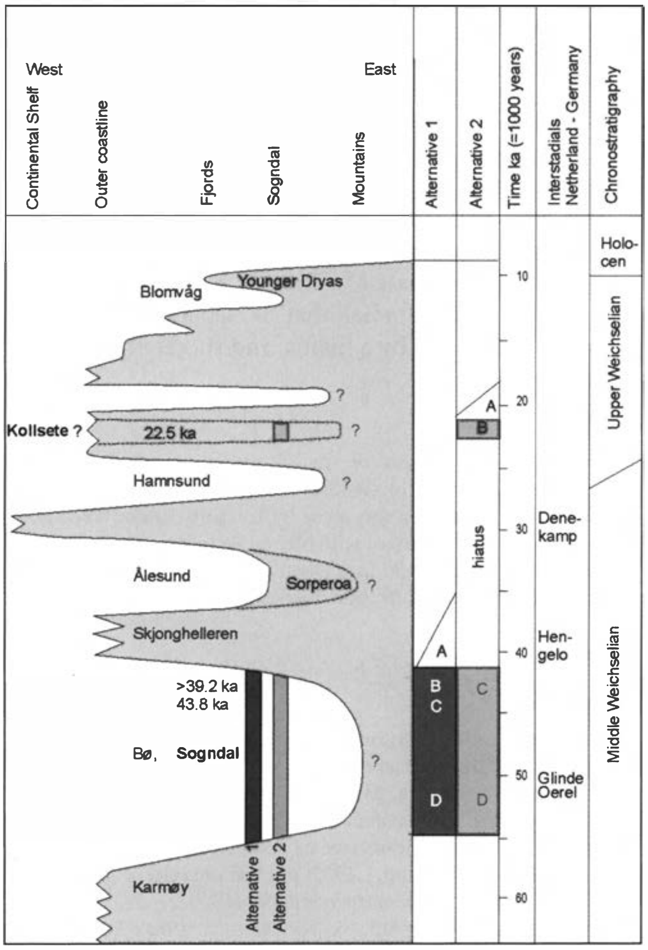

Figure 5. Schematic glaciation curve for the Mid and Upper Weichselian from the coast to the mountain areas of western Norway (modified from Valen et al. 1995). (Aa & Sønstegaard)

e. g. amino acid analysis, from the Bø site indicate a higher age, substage 5c (Larsen & Sejrup 1990), we here assume the Bø interstadial to be of Mid Weichselian age (Baumann et al. 1995). The Middle Weichselian interstadials in northwestern Europa (Denekamp, Hengelo, Glinde/Oerel) are characterized by cold climates as revealed by tundralike treeless vegetation in contrast to the forested Early Weichselian interstadials Odderade and Brørup (Mangerud 1991a). Therefore, pre Late Weichselian forested interstadials in Norway, e.g. the Brumunddal interstadial, are supposed to be of Early Weichselian age. Due to the high radiocarbon age estimates, and the seemingly total absence of a forest vegetation during the ice-free period of Sogndal, we limit the discussion of its age to Mid Weichselian.

The in situ weathered rock surface D implies terrestric environment and a barren rock surface exposed to subaeril weathering for a long time, probably several thousand years. The gyttja silt unit C and silt unit B are supposed to be glaciolacustrine formations. Theoretically there is a possibility that the former lake was dammed by a landslide. However, a glacial dammed marginal lake during a valley glacier advance in Sogndalsdalen is much more reasonable. A constriction of the valley downstream of the locality indicates the possibility of the formation of such a temporary glacial lake. Our preferred interpretation (Figure 5, alternative 1) is that the gyttja silt C consists of terrestric soil and humus that were eroded and deposited into the glacial lake during the early lake phase. Afterwards there has been a gradual shift to pure minerogenic glaciolacustrine sedimentation until the glacier advanced and deposited till A. Accordingly the C and B units have probably been deposited within a rather short time at the very end of an interstadial. The lithostratigraphic record supports a continuous development from the weathering of the bedrock surface D, succeeded by the glacier advance and the deposition of the glacial lake sediments C and B and finally the lodgement till A (Figure 5, alt. 1).

However the radiocarbon age estimates of units C and B lead to a possible course of event with 2 interstadials (Figure 5, alternative 2): The oldest represented by the weathered rock D and the gyttja silt C of age 39 ka BP or more, and a younger interstadial, represented by the silt B dated to 22.5 ka BP. In that case the two interstadials are separated by a hiatus between C and B excluding one or more glaciations.

This alternative will support the age estimates.The problem is that no traces of hiati or discordances have been observed in the field. The age estimate of the oldest interstadial at Kollsete, > 9.2 and 43.8 ka BP, leads to a correlation with the Bø interstadial (Andersen et al. 1983). The later deglaciation of Nordsjøen at ca. 19–22 ka (Sejrup et al. 1994, Larsen et al. 2000) corresponds to the youngest interstadial at Kollsete (22.5 ka BP). Possible correlatives could also be the Hamnsund interstadial (Valen 1995), or one of the major ice recessions at 17–21 and 24–28 ka BP, respectively (Olsen 1997a, b).

A third possibility could be that the subtill sediments represent one extremely long-lasting glacial lake phase (43–22.5 ka). This interpretation would also corroborate the age estimates, but is abandoned due to both glaciological and sedimentological reasons. It is not presented on Figure 5.

Still another possibility might be that the subtill sediments represent a late Weichselian interstadial at 22.5 ka BP. In that case the two age estimates from unit C are too old, perhaps due to the effect of hard water. We regard this as a less probable alternative, and it is not illustrated on Figure 5.

Figure 6 is a paleogeographic map displaying the glaciated areas in south Norway during late Preboreal. Kollsete was deglaciated during mid or late Preboreal. End moraines 5 km upvalley are dated to 9000 BP (Eik & Kvalsvik 1998). It seems likely that the ice-sheet extension was nearly the same during the Middle Weichselian interstadial represented by the Kollsete sediments. Obviously the inner fjord areas of western Norway were deglaciated as the Kollsete site is located in a tributary valley 380 m a.s.l. not far from present glaciers. A correlation with the Bø interstadial (Andersen et al.1983) and the oldermost interstadial at Skorgenes (Larsen & Ward 1992) means that the

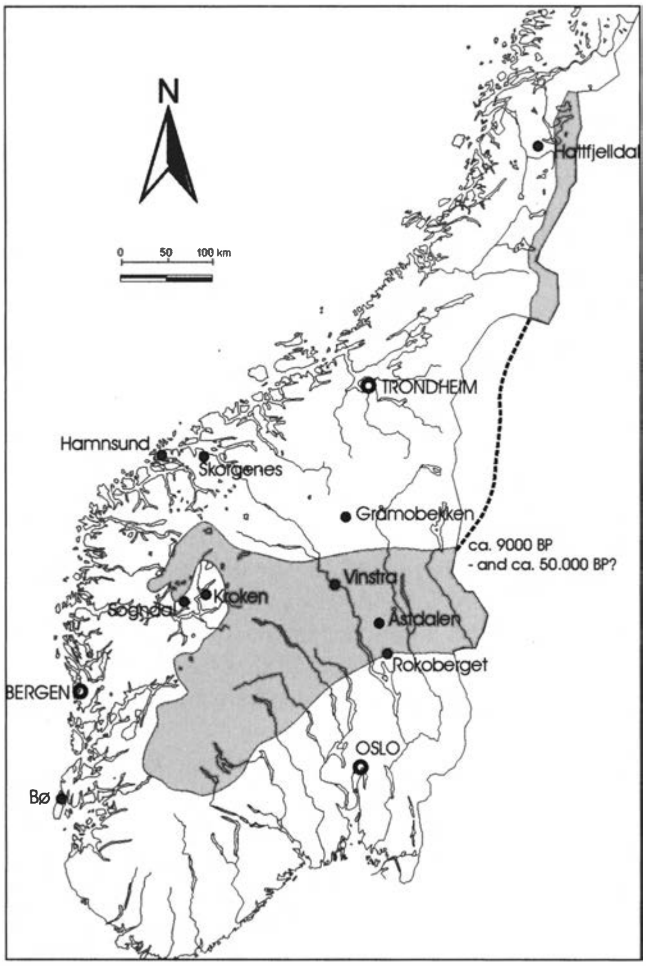

Figure 6. A map of southern Norway with possible Middle Weichselian interstadial sites indicated. The shaded glaciated areas of late Preboreal 9 ka BP are modified from Andersen & Karlsen 1986. The glacier extent at Sogndal interstadial has probably been nearly the same. (Aa & Sønstegaard)

coast and fjord areas in western Norway were deglaciated. In addition, a number of dates are obtained from the inland areas, for instance Sorperoa (Bergersen et. al 1991), Folldalen (Thoresen & Bergersen 1983, Olsen 1997a, b) and Rokoberget (Rokoengen et. al 1993a, b). Rapid shifts of the ice extension during the isotope stages 2–4 are reported by Dokken & Hald (1996) and Olsen (1997a). If contemporary, the interstadials at Folldalen and Sogndal indicate that only some mountain areas were glaciated.

Conclusions

The stratigraphy at Kollsete shows a development from an interstadial to a glacial phase. On the basis of the lithostratigraphic record, and the radiocarbon age estimates of > 39.2 ka, ca. 43 ka, and 22.5 ka BP we have made two alternative interpretations:

1) Alternative 1 suggests one Middle Weichselian interstadial at Sogndal correlated with the early Middle Weichselian Bø interstadial. In that case the date of 22.5 ka BP has to be rejected.
   The pollen content of the dated sediments shows arctic vegetation with grass tundra. The cold climate was also confirmed by the insect assemblage and some plant macrofossils.
2) The ^{14}C age estimate of silt B (22.5 ka) might suggest a younger interstadial that is separated from the oldest (>39.2 ka) by a hiatus, and succeeded by a glacial phase.

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