Carbonate sand deposition along the coast of southern Norway

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In spite of extensive exploitation of marine carbonate sand (as fertilizers for agricultural purposes) along the western coast of Norway, little attention has been drawn to these cool-water carbonate deposits in the geological literature. Some work has been carried out on their geochemical composition and quality as soil fertilizers (Sve et al. 1990), but there has been little work dealing with the sedimentology and sedimentation rates of carbonate sand deposits.

Carbonate sand is a designation commonly used for both carbonate sand and carbonate gravel. For convenience, we will continue to use this term even though some of the deposits have the grain size of gravels. The examined carbonate sand is bioclastic, usually composed of bivalve fragments making up more than 90 % of the sediment, with gastropods, serpulids, barnacles and echinoids in minor amounts. The calcareous red algae *Lithothamnium* is also present, but rarely in large quantities in southern Norway.

Occurrence

Cool-water, modern carbonate deposits in Europe are described from the coast of Brittany in northwestern France, from the western part of the English Channel and in Cornwall, along the western coast of Ireland and from the western and northern coasts of Scotland.

Regional mapping by the University of Bergen (Haye & Russenes 1984) and the Geological Survey of Norway (Bøe & Ottesen 1994) has shown that carbonate sand deposits occur in a narrow coastal belt with thousands of islands and skerries along the outermost part of the southern and western coasts of Norway (Fig. 1). The boundary line between areas with and without carbonate sand deposits swings into the Boknafjord near Stavanger, but is otherwise remarkably restricted to the outermost coastal belt. The sea bed within this coastal belt has an irregular relief, and commonly drops down to the fjord bottom at several hundred metres water depth. Carbonate sand deposits are normally situated between 0 and 50 metres water depth. Due to a moderate land uplift of the coastal areas after the deglaciation (Kaland 1984), carbonate sand is rarely located above sea level in southern Norway.

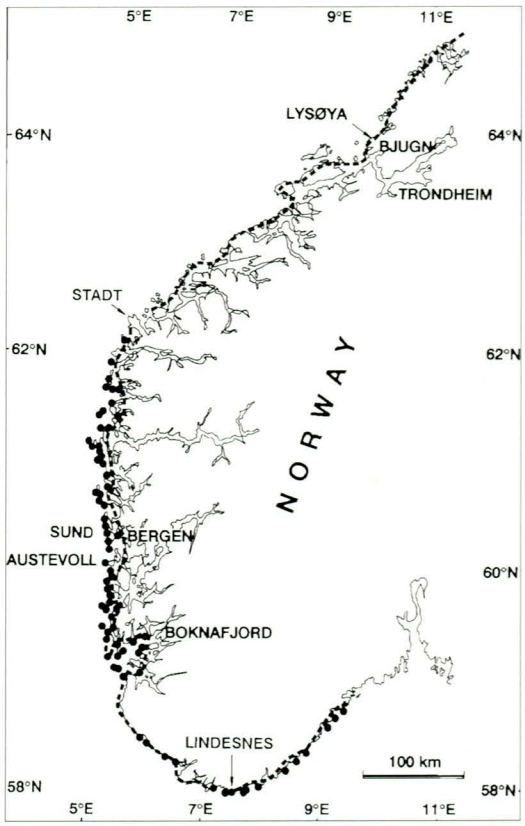

Fig. 1. Carbonate sand and gravel deposits along the coast of Norway from Lindesnes to Lysøya. The stippled line represents the approximate landward boundary of areas with large carbonate sand deposits. Dots show major carbonate sand deposits to the south of Stadt.

Methods

The mapping of carbonate sand resources by the Geological Survey of Norway has been carried out using high-resolution seismic equipment (Topas and Geopulse). Approximately 4500 profile kilometres have been acquired, and 1000 grab samples have been taken to verify the type and quality of the bottom sediments. These data, together with detailed bathymetric maps from the Norwegian Hydrographic Service, have been used to draw boundaries of individual carbonate sediment areas. In two areas along the western

coast of Norway, Sund and Austevoll (Fig. 1), carbonate sand has been sampled by vibrocoring (Grøsfjeld 1991, Bøe & Ottesen in prep.) and dated, and sediment accumulation rates have been calculated. An additional locality at Lysøya in Bjugn, Central Norway, has also been studied.

Description and results

The shoreline along the western coast of Norway faces the North Sea, and is exposed to westerly winds. There is little input of terrigenous material from major rivers to these coastal areas, and this favours the growth of lime-secreting organisms. Skeletal grains accumulate to form carbonate sand and gravel deposits. The carbonate production sites in Sund and Austevoll vary from exposed areas with a rocky substrate (resistant crystalline rocks) to more sheltered sandy zones. The commonly bare rock surface in general favours hard bottom, benthic communities, and this is also seen in the bioclastic composition, with the byssally attached *Modiolus modiolus* often as a major constituent. The predominant calcareous organisms are molluscs, but serpulids, echinoderms and barnacles also occur.

In Sund (Fig. 1), nineteen vibrocores were taken at water depths between 7 and 64 m and examined in detail (Grøsfjeld 1991). The tops and bottoms of three of these cores were dated by the ^{14}C method. The ages and computed sediment accumulation rates are summarised in Table 1 and Fig. 2. The sediment accumulation rate for core 17 was calculated to have been 57 cm/1000 years and for cores 15 and 16, 43 cm/1000 years.

In Austevoll, southwest of Bergen (Fig. 1), the carbonate sediments were mapped in 1994. Three vibrocores were taken at three different localities. The sampled sediments consist entirely of pure carbonate sand and gravel. The tops and bottoms of the cores have been dated, and sediment accumulation rates computed. The sedimentation rates vary from 35 cm/1000 years to 60 cm/1000 years, and in one case up to 130 cm/1000 years (Fig. 2, Table 2).

The locality at Lysøya in Sør-Trøndelag (Figs. 1 and 3a) comprises an almost pure carbonate sand deposit lying between 0 and 15 m above the present sea level. The locality is exposed to northwesterly winds, but is more sheltered from winds from the southwest. From this area, carbonate sand and gravel has been exploited for agricultural purposes for 60 years. The thickness of carbonate sand reaches more than 10 metres, and the deposit represents an excellent locality for stratigraphical investigations. The sedimentary succession at the back-wall of the pit is, from

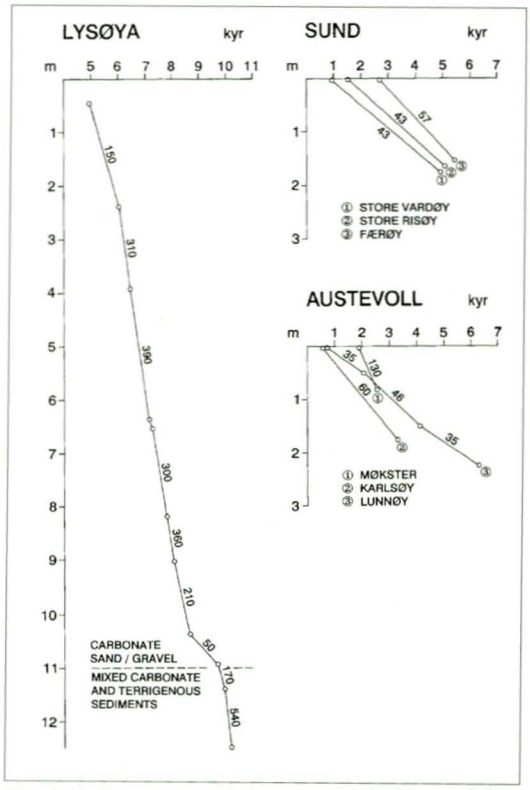

Fig. 2. Sediment accumulation rates (cm/1000 years) from Sund, Austevoll and Lysøya.

Table 1. ^{14}C ages and average accumulation rates in three cores from Sund.

Core no.	Depth (cm)	Age (14C yrs BP)	Lab. no.	Aver. acc. rate (cm/1000 yrs)
15	0-5	910± 45	T-9491	
	170-173	4895± 60	T-9492	43
16	1-9	1255± 65	T-9494	
	162-166	5075± 95	T-9493	43
17	0-1	2675± 70	T-9495	
	151-156	5410± 80	T-9496	57

Table 2. ^{14}C ages and average accumulation rates in three cores from Austevoll.

Core site	Depth (cm)	Age (^{14}C yrs BP)	Lab. no.	Aver. acc. rate (cm/1000 yrs)
Møkster	1	1930± 70	T-11461	
	82	2605± 40	T-11462	130
Karlsøy	3	600± 65	T-11463	
	173	3245± 75	T-11464	60
Lunnøy	3	665± 65	T-11465	
	50	2020± 70	T-11466	47
	147	4000± 50	T-11467	46
	223	6315± 45	T-11468	35

bottom to top:
(1). 0.5 m of glaciomarine clay with dropstones and a few mollusc fragments.
(2). A 2 m-thick transition zone with layers of non-calcareous sand and gravel with an upward increasing content of carbonate fragments (mostly molluscs and serpulids).
(3). 10 m of almost pure, stratified carbonate sand and gravel with erosive troughs up to 20 cm deep infilled with cross-bedded sand and gravel in the uppermost 3 m of the section.

The sedimentary succession is interpreted as a shallowing-upward sequence. A mollusc fragment from the clay near the bottom of the pit has been dated by the AMS method to 10,140±85 years BP (Fig. 2 and Table 3), which represents the latest part of the Younger Dryas cold period. The sediments of the transition zone above the clays were deposited during Preboreal time (10,000-9,000 years BP) (Fig. 2). Carbonate sand accumulation started in the beginning of the Preboreal, and increased throughout the period. Near this pit, another section near the top of Akimskaret (x in Fig. 3b) shows glaciomarine clay overlain by cobbles and boulders with a matrix of sandy, gravelly carbonate (Fig. 3b). The glaciomarine clay can by correlated with the clayey sediments at the bottom of the dated section measured in the pit, while the coarse deposit with cobbles and boulders is a beach deposit representing the transition from offshore to foreshore conditions at this locality. The ^{14}C method gave an age of 4,015±90 years BP (T-11167) for the shelly matrix in the beach deposit. This means that the shell production took place over a period of about 6,000 years, from about 10,000 years BP to about 4,000 years BP, when the locality rose above sea level. The carbonate sand accumulation rate at the Lysøya locality varies from 150 cm/1000 years to 390 cm/1000 year (Fig. 2).

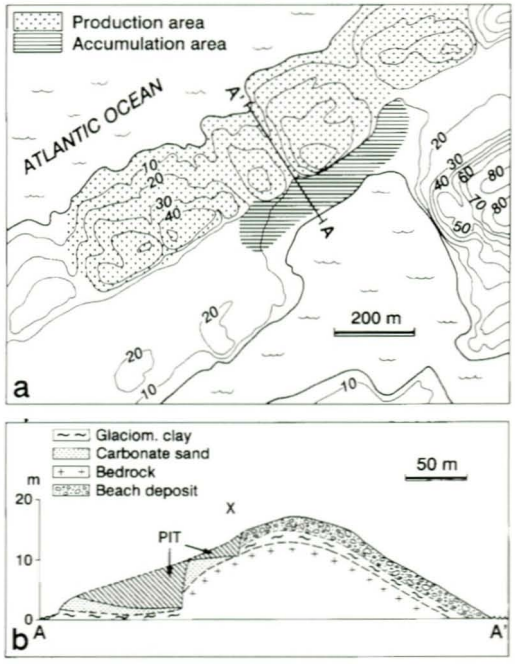

Fig. 3. a) Carbonate sand accumulation and production area at Lysøya. Altitudes are in metres above sea level. See Fig. 1 for location. b) Cross-section through Akim-skaret at Lysøya. For location see Fig. 3a.

Table 3. ^{14}C ages and average accumulation rates from the Lysøya section.

Sample no	Depth (cm)	Age (^{14}C yrs BP)	Lab. no.	Aver. acc. rate (cm/1000 yrs)
25	45	4995± 95	T-11165	
22	240	6065± 50	T-11164	150
Lys 8-88	380	6490± 90	T- 9174	310
	635	7120± 90	T- 8144	390
Lys 9-88	635	7260± 55	T- 9175	
13	820	7800±115	T-11163	300
Lys 7-88	925	8075±100	T- 9173	360
3	1040	8660± 65	T-11162	210
2	1090	9630± 80	T-11272	50
1	1140	9920± 55	T-11271	170
6	1255	10140± 85	TUa-876	540

Discussion

During the maximum of the last glaciation (ca. 20,000 years BP), inland ice covered the whole of the Scandinavian peninsula and reached the shelf edge. During this period extensive erosion occurred, and most of the older deposits in the coastal areas were removed. Thus, it was not until the end of the glacial period that conditions were suitable for carbonate production and preservation. The results obtained in our studies show that the majority of the Norwegian carbonate sand deposits are of Holocene age.

Kjemperud (1986) constructed a shoreline displacement diagram for the Bjugn/Lysøya region (Fig. 4), which makes it possible to estimate the water depths during the time of deposition of the Lysøya carbonate sand deposit. When deglaciation occurred about 12,000 years BP, the sea level was about 130 metres above the present sea level. After a period of relatively stable sea level between 12,000 and 10,000 years BP, a strong regression occurred between 10,000 and 9,000 years BP (Kjemperud 1986). Thereafter

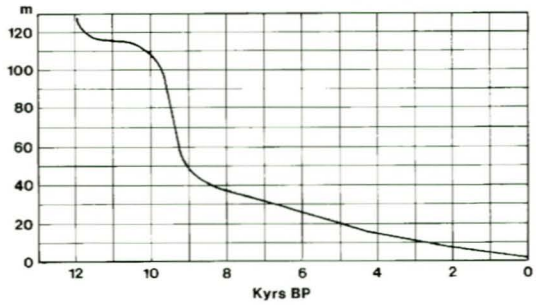

Fig. 4. Shoreline displacement curve for Bjugn. Modified from Kjemperud (1986).

the rate of regression diminished, and when extensive carbonate production by benthic carbonate-secreting organisms started at about 9,000 years BP, about two thirds of the shoreline displacement had occurred. In Fig. 3a, the production areas of lime-producing organisms are indicated. From about 9,000 years BP, the fauna was dominated by the mussel *Modiolus modiolus* and serpulids. Farrow et al. (1984) have observed from side-scan records that both live on bare rock. When extensive carbonate production started at about 9,000 years BP, the water depth in the accumulation area was about 50 m above today's sea level (Fig. 4). This means that the water depth in the production area varied between 0 and 50 m, and that the water depth decreased through the whole production period. This also implies that production took place in smaller and smaller areas, so that a constant accumulation rate in reality means an increasing carbonate production.

During the period of carbonate sedimentation, the lime-producing organisms were eroded, crushed and washed down from the production areas and deposited on the lee side of Lysøya. The water depth in the accumulation area decreased from 50 m to about 10 m. This is consistent with the occurrence of erosive troughs infilled with cross-bedded carbonate gravels in the upper 3 m of the section. During deposition of this part of the section, extreme currents through the narrow bedrock-channel Akim-skaret (which was formerly a narrow sound) (Fig. 3) generated during storms were strong enough to be erosive.

The carbonate sand accumulation rates are between 2.6 and 9 times higher at Lysøya than in Sund and Austevoll. The high rates of deposition at Lysøya might have resulted from high production rates of calcium carbonate by organisms inhabitating an extensive, shallow, offshore platform on the northwestern side of Lysøya (Fig. 3a). Farrow et al. (1984) measured sedimentation rates of carbonate sand on the Orkney shelf to be 10 cm/1000 years, and on the Scottish shelf 3 cm/1000 years. The sedimentation rates in Sund and Austevoll, on the western coast of Norway, are 4-11 times higher than the sedimentation rates on the Orkney shelf, while the sedimentation rates at Lysøya are 15-40 times higher. This difference in carbonate sand accumulation rates is due to the very efficient transport and concentration mechanisms, with high waves and strong currents, along the western coast of Norway.

Keary (1985) showed that there is a zone of high carbonate deposition along the Atlantic margin of Europe. Carbonate deposits are confined to areas which are open to the influence of undiluted Atlantic water. The results of the carbonate sediment mapping along the coast of Norway support this observation and show that a short distance to the east, where the Atlantic waters are diluted by water from other sources, carbonate sand deposits do not exist.

Acknowledgements
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