Time Dependence of Organic Matter Decay and Mixing Processes in Framvaren, a Permanently Anoxic Fjord in South Norway

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Abstract. Three different layers have been identified in Framvaren, which has a maximum water depth of 184 m. One oxic layer above the redoxcline at 18–20 m. One anoxic layer from 20 to 100 m which is occasionally ventilated by a flow over the sill (which has a depth of 2.5 m), and finally a stagnant layer below 100 m. Using the release rate of silica from the bottom and measurements of the concentration of HTO it is possible to make some calculations on the annual volume of interleaving in the layers 25–50 m, 50–75 m, and 75–100 m together with the advective flows. Reliable values of the sulfide concentration were obtained by precipitating and weighing HgS together with careful protection of all anoxic water samples with argon. The light yellow color of the precipitate in the depth range 25 to 80 m indicates that the occasional ventilation will cause such reactions as 0.5O2 + H2S → S(colloidal) + H2O. The elemental sulfur, being stabilized with HS−, is set free upon the precipitation of HgS. The new data for the concentration of sulfide give an acceptable stoichiometry for the decay reaction of organic matter. This is not the case with the data of Yao and Millero. The mean values for the concentrations of ammonium and phosphate agree with the new data of Yao and Millero. The mol/mol C/N ratio of 10.1 found in trapped material by Naess and coworkers (1988) agrees with the stoichiometry of the dissolved constituents, i.e. C/N = 9.92 ± 0.45. A denitrification reaction is suggested to explain the high values of C/N. The vertical diffusion coefficient at 100 m calculated from the depth profile of silica was 0.92 × 10−6 m2 s−1 which lies in the range of values given by Frøyland. Finally, the 14C age of the total dissolved inorganic carbon (Ci) in the water below 90 m was about 1600 years indicating a bioproduction in the period 8000 years B.P. to A.D. 1853 when a channel was opened between the fjord outside (Helvikfjord) and Framvaren.

Key words: Framvaren fjord, anoxic waters, sulfide, tritium, silica, mineralization and ventilation rates, carbon isotopes

1. Introduction

Recently Yao and Millero (1995) have given an account of the chemistry of the anoxic water in the Framvaren fjord, which is situated in south west Norway inside
the town of Farsund. The fjord is described in their introduction as well as by Skei (1983,1988). The fjord is permanently anoxic with a sill depth of 2.5 m and a basin depth of 184 m. The surface layer of the fjord down to the redoxcline at 18–20 m is characterized by a decrease in oxygen and an increase in salinity. The temperature of the surface water varies between 2 and 19 °C depending on the season (Skei, 1986). Below 100 m the sulfide concentration (St) increases to 5–8 mm. Since many years the fjord has been the site for intensive studies, and in 1988 a special volume of *Marine Chemistry* (No. 23) edited by Skei and Dyrsen, was published on anoxic basins as a result of a workshop in Farsund.

At the end of May 1995 we carried out new investigations of the fjord. To avoid oxidation of the hydrogen sulfide all flasks for water samples were filled with argon and argon was used to protect the water from air when the GoFlo samplers were emptied. The sulfide concentration was determined by precipitation of HgS with oxygen-free mercury(II) chloride. New determinations of total dissolved inorganic carbon have been carried out. Unpublished determinations of tritium (HTO) and carbon-14 (H\(^{14}\)CO\(_3\)) from samples taken in July 1992 will also be used to emphasize the three water masses (layers): The oxic surface layer down to the redoxcline at 18–20 m, the anoxic layer between 20 and 100 m which is subjected to entrainment and interleaving of water entering from Helvikfjord over the shallow sill according to Stigebrandt and Molvaer (1988), and finally the stagnant sulfidic bottom water from 100 m to the bottom. The inner part of the fjord was also sampled in our May 1995 investigation; the inner basin has a sill depth of 20 m and a depth of 100 m.

Comparisons of the concentrations of sulfide, phosphate, ammonium, silica, and total dissolved inorganic carbon with new data and previous mean concentrations from 1979 to 1985 (Skei 1986) will be made. We shall also present an attempt to quantify the process of entrainment, interleaving and advection in the depth range of 25 to 100 m. The carbon-14 data will be fitted to the postglacial history of the fjord. The chemistry of the redoxcline will be treated in a subsequent article.

2. Methods

The sampling in 22–25 May 1995 was carried out by a people from AMK and NIVA. As mentioned above oxidation of hydrogen sulfide was prevented by frequent use of argon as a protecting gas. Earlier samples for the determination of tritium and carbon isotopes were collected on 12 July 1992. The samples were collected at stations F1 and F2 (Skei, 1988) in the deepest parts of the two basins.

The carbon isotopes were determined with the tandem accelerator at the The Svedberg Laboratory at the University of Uppsala, Sweden.

Tritium was measured by electrolytic enrichment and low-level gas counting as follows: The sample water was treated with Na\(_2\)O\(_2\) to oxidize hydrogen sulfide and other reducing compounds. It was then distilled at least two times. Tritium-free NaOH was added to 275 ml of the distillate and the solution was electrolyzed until 6 g of water remained. This procedure resulted in a 40 fold tritium enrichment.