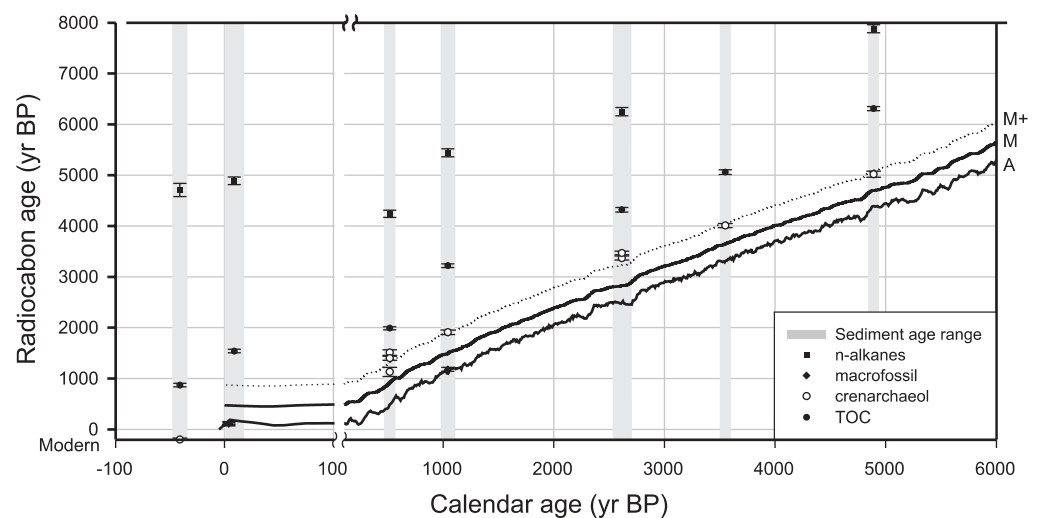


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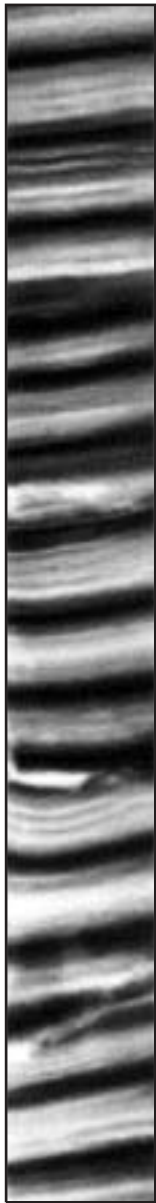
Radiocarbon dating is based on the principle that ^{14}C atoms created from ^{13}C in the atmosphere by solar radiation are taken up by organisms, which after their death exhibit an ever decreasing radiocarbon content due to radioactive decay. The introduction of accelerated mass spectrometry (AMS) in the early 1990's greatly reduced the amount of carbon required to analyze natural radiocarbon to below 100 μg , and it became possible to determine the radiocarbon age of isolated molecular remains of algae, plants and micro-organisms, so-called biomarkers. This may be of special value in cases where dating is not or hardly possible with e.g. wood or shell pieces. Our study is the first one dedicated to this possibility, as this newly developed technique has so far mainly been used for tracking carbon sources, another useful application of compound-specific radiocarbon analysis. For instance, the main source of marine derived organic carbon is dissolved bicarbonate, which is on average several centuries old, while organic carbon deposits on land may be several millennia of age. The total organic carbon fraction (TOC) of a sediment is normally a mixture of both marine and terrestrial remains, and this makes TOC useless for dating purposes.

In this study, supported by ALW, we analysed sediments from the Saanich Inlet, a Canadian fjord. The water mass inside Saanich Inlet is anoxic in the bottom part, due to an under-water sill at the entrance which prevents exchange of this bottom water with open sea. Because of this, larger animals can not live at or in the fjord sediment, and thus the record of yearly deposited light and dark layers is preserved. By counting these layers, similar to tree-rings, an accurate dating over the last 6000 yr. was obtained for this sediment. Five sediment subsamples



Radiocarbon ages of TOC, land-plant derived n-alkanes, two macrofossils (a seed and a leaf), and crenarchaeol, derived from marine microorganisms, plotted against sediment calendar ages, together with the calibration curves derived from the literature. A: Atmospheric calibration curve. M: Marine calibration curve. M+: Marine calibration curve corrected for a local 'reservoir effect'. Note the change of scale at 100 yr calBP. Because of clarity, not all measured biomarkers are plotted.

were selected, from which several biomarkers (organic compounds with known origin) were isolated. The isolation was for a large part performed using a specially developed preparative HPLC (liquid chromatography) method, so that larger and more polar compounds could be isolated then is traditionally done using gas chromatography. The isolated biomarkers on which radiocarbon dating was performed were derived from photoautotrophic plankton, from marine Crenarchaeota (a microorganism that ubiquitously occurs in the ocean), and from land plants. For comparison, the TOC fraction was also dated. The main result was that the biomarkers derived from the marine Crenarchaeota could be easily isolated in relatively large quantities and that their calibrated radiocarbon ages agreed well with the independently determined sediment ages. In the future, this method can thus be used as an alternative or extension for radiocarbon dating of marine sediments. Radiocarbon dating using phototrophic plankton gave vari-



able results. This is most likely due to the fact that phototrophic plankton grow in the surface waters, which are highly influenced by seasonal changes in air-ocean CO₂ exchange and by fresh water inputs that may also have varying radiocarbon contents. The radiocarbon ages of the biomarkers derived from land plants were several thousands of years older than the sediment, and this clearly influenced the age of the TOC. Moreover, the age difference between this terrestrial biomarker and the sediment increased towards more recent times. This can be related to an ever increasing age of the soils at the environs of the fjord, which started to develop after the termination of the last ice age.

Laminated and anoxic fjord sediments are in general very suitable for biogeochemical research, because they often contain well-preserved high resolution palaeoclimatic and palaeo-environmental records. To investigate this, two Norwegian fjords were sampled, i.e. the small Kyllaren fjord, located north of the city Bergen, and the larger Drammensfjord, a side fjord of the Oslofjord, which was visited during a cruise of the RV Pelagia during 1998.

Concentration profiles spanning approximately 400 years were obtained for a large suite of biomarkers extracted from Kyllaren fjord. Together with the stable carbon isotopic compositions of some of these biomarkers, it could be shown that this fjord is susceptible to natural eutrophication. Because the water exchange is reduced to a large extent by the sill between the fjord and the open sea, incoming nutrients are trapped and are intensively recycled, including CO₂. The building of a bridge annex dam in 1950 enhanced this effect. Due to the increase of trapped nutrients, more planktonic growth occurred, which also resulted in a rise of the level below which water column anoxia prevails, resulting in an almost completely anoxic basin.

In the Drammensfjord, eutrophication was also clearly recognisable from the biomarker profiles. At the onset of the industrial revolution around 1850 the logging industry expanded, resulting in a higher load of wood chips and pulp in Norwegian waters. The amount of plankton-biomarkers increased gradually, related to the increased supply of nutrients coming out of the wood pulp. However, almost immediately specific biomarkers derived from the plankton species *Botryococcus braunii* disappeared from the sedimentary record. This indicates that this plankton species is sensitive to eutrophication, probably because they are outcompeted by faster growing algae that can profit better from increased nutrient levels. Because *Botryococcus braunii* is a fresh water species, the occurrence or lack of its remains in a marine sediment was until now generally linked to variations in the supply of fresh water to a marine system. The results just described show, however, that the occurrence or lack of *Botryococcus braunii* may also be caused by a change in the trophic state, and not necessarily by a change in the actual input of fresh water.

Photograph of a 15 cm section of the laminated sediment from Saanich Inlet. The white layers are deposited during summer, due to calcareous plankton. The dark layers are deposited during winter, and consist mainly of silt and clays.