

High-latitude application of $^{87}\text{Sr}/^{86}\text{Sr}$: Correlation of Nuwok beds on North Slope, Alaska, to standard Oligocene chronostratigraphy

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ABSTRACT

Strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) calculated from three samples of benthic foraminifers and one mollusc indicate an age range from 23.8 to 27.0 Ma for the Nuwok Member of the Sagavanirktok Formation, eastern North Slope, Alaska. Previous correlations derived paleontologically (foraminifers, ostracodes, and molluscs) for the Nuwok beds have differed greatly (Oligocene to Pliocene), but strontium isotope ratios substantiate the late Oligocene age determined from benthic foraminifers. The results constitute an important test case, illustrating the effectiveness of the strontium isotope method in correlating high-latitude carbonate samples to the standard Oligocene chronostratigraphy. In addition, a sample from the Kugmallit sequence in the Beaufort Sea Edlok N-56 well provided a strontium isotope age estimate of 30.7 Ma. The Edlok sample was paleontologically correlated to just below the early/late Oligocene boundary (30.0 Ma).

INTRODUCTION

The attainment of an accurate geochronology based on precise correlations is an important step in deciphering Cenozoic Earth history of the Arctic region. This region is important because climatic changes are accentuated in the polar regions and might be the cause or effect of global oceanographic, climatic, and tectonic changes. For example, Arctic-derived, cold deep waters are a critical component in the world oceanic system. The correlation and dating of Arctic events is challenging, however, because of the general low diversity of fossil assemblages and because of possible diachroneity of the Arctic fossil record. Development of a refined biochronology is inhibited by the lack of such standard biostratigraphic indices as planktonic foraminifers, nannoplankton, radiolarians, and diatoms. Consequently, ties to standard chronostratigraphies (Berggren et al., 1985) are in many cases uncertain. At present, the only avail-

able biochronology that spans the entire Cenozoic of an Arctic Ocean region is that derived from benthic foraminifers (McNeil, 1989). This biochronology is based on last-appearance datum levels that are from a minimum of 0.8 m.y. to a maximum of 13.0 m.y. apart.

Our contribution to high-latitude geochronology focuses on application of the strontium isotope method to a part of the Cenozoic succession. Suitable sections to test the strontium isotope method at high latitudes are rare because the overall succession is dominated by siliciclastic terrigenous deposits; hence, this study is restricted to an exceptional exposure of calcareous neritic mudstones and sandstones (Nuwok Member of the Sagavanirktok Formation) on the eastern North Slope, Alaska. The methodology involves correlation of strontium isotope data from this high-latitude locality with data from well-documented Atlantic Deep Sea Drilling Project (DSDP) sites.

Questions that arise when data from Atlantic DSDP sites are compared with data from neritic sites in the Arctic Ocean are: (1) Will strontium ratios be the same in neritic waters as bathyal/abyssal waters? (2) Would Arctic strontium isotopes be sufficiently homogenized with other parts of the world ocean as they are today? (3) Are outcrop exposures affected by diagenetic overprinting of the original strontium-isotope signal?

STRATIGRAPHY AND PREVIOUS WORK

The Nuwok Member crops out on the Marsh Creek anticline at Carter Creek, Alaska (Fig. 1). It consists of shale, pebbly mudstone, and fine-

grained sandstones, and the middle part contains thin limestone beds (Fig. 2). The sediments yield foraminifers, ostracodes, and molluscs that collectively indicate that the Nuwok was deposited in a neritic environment (Detterman et al., 1975; Brouwers and Marincovich, 1988).

Previous paleontologically determined age estimates for the Nuwok Member have been based on molluscs, foraminifers, and ostracodes, and estimates have ranged from Oligocene to Pliocene for identical sample intervals with no evidence of unconformity within the member. Ages based on molluscs ("*Chlamys*" *nuwokensis* and *Arctica carteriana*) have ranged from Miocene to Pliocene (MacNeil, 1957; Brouwers and Marincovich, 1988). A Pliocene assignment was postulated on the basis of ostracodes (primarily species of *Rabilimis* and *Pterygocythereis*) and molluscs (Brouwers and Marincovich, 1988). Age assignments based on benthic foraminifers have ranged from Oligocene to Pliocene (Todd, 1957; Detterman et al., 1975; Young and McNeil, 1984; McNeil, 1989). However, previous foraminiferal identifications have been

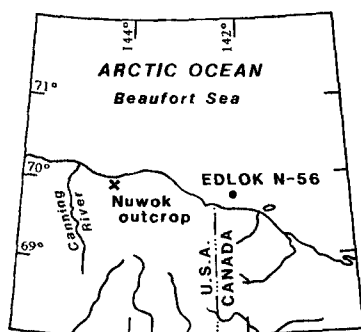


Figure 1. Location of Nuwok outcrop and Dome Edlok N-56 exploration well.

CARTER CREEK, ALASKA 69°56'45"N; 144°39'42"W

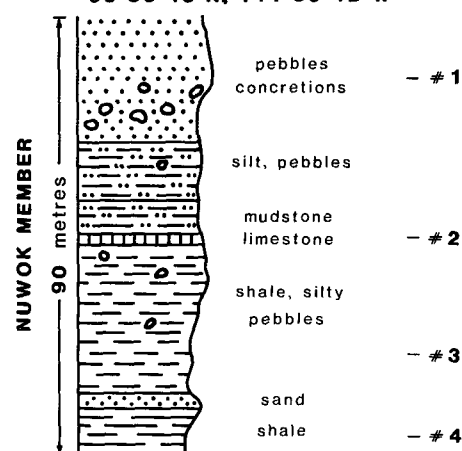
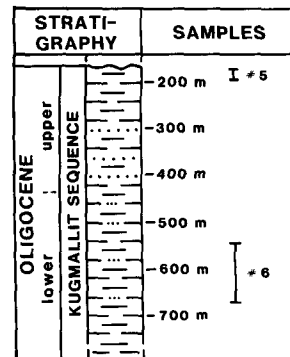


Figure 2. Nuwok stratigraphic succession after Detterman et al. (1975), and location of foraminiferal samples 1, 3, 4, and molluscan sample 2. Nuwok Member is uppermost unit of Sagavanirktok Formation. Lower members not illustrated are Paleocene-Eocene Sagwon Member and Eocene Franklin Bluffs Member.

AGE	ZONE	STRONTIUM AGE ESTIMATE (Sr 87/86)	
		Nuwok	Edlok N-56
OLIGOCENE	late	*1. 23.8 Ma (0.708270 ± 0.000007)	*5. No value obtained
		*2. 24.3 Ma (0.708253 ± 0.000028)	
	*3. 25.8 Ma (0.708198 ± 0.000012)		
	*4. 27.0 Ma (0.708157 ± 0.000018)		
early	Caneris subconicus		*6. 30.7 Ma (0.708030 ± 0.000023)

Figure 3. Isotope ratios, absolute-age estimates, and foraminiferal zonation of samples from Nuwok outcrop and Edlok N-56 well.

Figure 4. Stratigraphic succession in Dome Edlok N-56 and location of samples 5 and 6.



critically revised (McNeil et al., 1982; Young and McNeil, 1984; McNeil, 1989), and the age of the member has been narrowed to the late Oligocene because of both the near-ubiquitous appearance of *Turrilina alsatica* and the absence of pre-late Oligocene indices. Although contradictory ages have been assigned to the Nuwok beds, the age of *T. alsatica* has never been in doubt. *T. alsatica* is well documented in Oligocene and uppermost Eocene strata deposited in neritic to bathyal environments: (1) the western North Atlantic (Gradstein and Agterberg, 1982), (2) the North Sea (King, 1982), and (3) northwestern Europe (Batjes, 1958). The identification of *T. alsatica* is routine, and its evolution has been thoroughly reviewed by Revets (1987).

A problem in dating the Nuwok beds would arise if components of the fossil assemblage were reworked into the Nuwok from older sediments. This is implied by the ostracode correlations, but there is no evidence that *Turrilina alsatica* and associated calcareous benthic foraminifers are reworked. The Nuwok foraminiferal assemblage is virtually identical to the microfauna of the *T. alsatica* Interval Zone, which has been mapped extensively through the Beaufort-Mackenzie basin and has been correlated with Oligocene microfaunas of the western and eastern margins of the North Atlantic (McNeil, 1989).

STRONTIUM ISOTOPE RATIOS

Strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) were analyzed from three samples of calcareous benthic foraminifers taken from the upper and lower parts of the Nuwok member (1, 3, and 4, Fig. 2). One molluscan specimen (#2) was analyzed from the middle part of the Nuwok (see Appendix 1). The fossils of the Nuwok and their strontium isotope ratios provide independent checks on one another because the interpreted ages come from entirely different lines of evidence. The resulting strontium isotope age estimates (Fig. 3), calculated from the standard strontium isotope curve of Miller et al. (1988), are 23.8, 25.8, and 27.0 Ma (foraminiferal samples) and 24.3 Ma (molluscan sample), thus substantiating the late Oligocene assignment previously determined by benthic foraminifers. Strontium isotope values monotonically increase, and age estimates decrease up-section as expected.

An additional test was carried out on benthic foraminifers (see Appendix 1) from the Dome Edlok N-56 exploration well in the Canadian Beaufort Sea (Figs. 1 and 4). The sampled interval was paleontologically correlated (Dietrich et al., 1989) by a benthic foraminiferal last-appearance datum (*Caneris subconicus*) to be just below the early/late Oligocene boundary (30.0 Ma). The resulting strontium isotope age estimate of 30.7 Ma was remarkably similar to the paleontologically derived estimate.

The foraminiferal composition of the samples consisted of approximately 300 specimens from the species indicated in Figure 5 and illustrated in Figure 6. In terms of the foraminiferal zonal scheme for the Beaufort-Mackenzie Basin (McNeil, 1989), all of the material from the Nuwok Member comes from the *Turrilina alsatica* Interval Zone (23.7 to 30.0 Ma). Samples 5 and 6 were from the Edlok N-56 well. Sample 5 did not yield a strontium isotope ratio because of insufficient sample size or perhaps diagenetic changes. Sample 6 consisted exclusively of a thick-sutured variety of the benthic foraminifer *Melonis affine*, which has a last-appearance datum in the Edlok N-56 well in the uppermost part of the *Caneris subconicus* Interval Zone (30.0 to ~36.6 Ma); it thus could not be affected by downhole contamination typical of rotary sampled wells. Sample 2 was an articulated specimen of the mollusc *Arctica carteriana* (see Appendix 1) collected from a concretionary limestone bed within the Nuwok Member as indicated in Figure 2.

Ages were estimated from $^{87}\text{Sr}/^{86}\text{Sr}$ values by using the linear regression determined by Miller et al. (1988): age (Ma) = 20392.79 - 28758.84 ($^{87}\text{Sr}/^{86}\text{Sr}$). This regression was established from late Eocene to Oligocene strata at DSDP Site 522 in the eastern South Atlantic at 26°7'S, 05°8'W. Strontium isotope data from this section were rigorously integrated with oxygen isotopes and the magnetostratigraphic record to produce a reliable chronostratigraphy. We use the term "age estimate" for a strontium isotope correlation in order to differentiate it from a radiometric age measurement (date). In effect, this age estimate represents a strontium-isotope correlation of the Nuwok beds to our standard reference section, Site 522, which is directly correlated to the geomagnetic polarity

TAXA	#1	#2	#3	#4	#5	#6
<i>Cibicidoides eocaenus</i>					x	
<i>Cibicidoides</i> sp.				x	x	
<i>Criboelphidium ustulatum</i>	x					
<i>Elphidiella(?) brunnescens</i>	x		x		x	
glandulinids	x					
<i>Melonis affine</i>			x	x		
<i>Melonis affine</i> variety						x
<i>Nuttallides</i> sp.						x
<i>Trifarina fluens</i>			x	x	x	
<i>Turrilina alsatica</i>			x	x		
<i>Arctica carteriana</i>		x				

Figure 5. Species composition of samples used for strontium isotope analysis.

time scale of Berggren et al. (1985). The strontium isotope stratigraphic resolution for that age span was determined to be ±1 m.y. or better.

The standard regression calculated from DSDP Site 522 was tested previously on data from the eastern North Atlantic at Irish margin DSDP Sites 548 and 549. Ages determined by the standard regression were applied to strata above and below a hiatus that was estimated by using planktonic foraminifers. Accuracy of the linear regression was demonstrated by a variation of only ±1 m.y. between the strontium and plankton foraminiferal age estimates.

DISCUSSION AND SUMMARY

Strontium isotope stratigraphy relies (Burke et al., 1982; DePaolo and Ingram, 1985; and DePaolo, 1987) on the validity of the hypothesis that strontium from the land sources (generally high ratios) will be quickly homogenized (~400 yr) with sea-floor-derived strontium (generally low ratios) and that the strontium cycle will take about 4 m.y., the mean residence time of strontium in the ocean (Broecker and Peng, 1982). It has been demonstrated that changes have occurred within intervals of virtually no change (the Paleocene-Eocene) and those of very high rates of change (late Eocene-early Miocene) (DePaolo and Ingram, 1985; Hess et al., 1986). The strontium method is most applicable during these periods of relatively rapid change (DePaolo, 1987). Applications and examples of this technique include DePaolo (1986), Elderfield

with the world ocean during the past 35 m.y. or more.

In summary, strontium isotope correlations were used to resolve discrepancies in paleontological age estimates based on foraminifers, molluscs, and ostracodes from the Nuwok Member of the Sagavanirktok Formation, North Slope, Alaska. Strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) correlations from three samples of benthic foraminifers and one mollusc resulted in age estimates from 27.0 to 23.8 Ma in a monotonic series, thus substantiating the late Oligocene age predicted by using benthic foraminifers. Also, a strontium isotope age estimate of 30.7 Ma was derived from a Beaufort Sea subsurface sample paleontologically (foraminifers) correlated to approximately 30.0 Ma. The consistent and nearly identical ages derived from the uniquely different methods of benthic foraminiferal paleontology and strontium isotope correlations substantiated the effectiveness of each in dating Oligocene samples at high latitude.

APPENDIX 1. PROCEDURES, SAMPLES, AND CURATION

Procedures

The procedures used in preparation for strontium isotope analysis were identical to those outlined by Miller et al. (1988). Foraminiferal samples were sonified in distilled water for 2 s, and the mollusc sample was sonified in distilled water for 2 min to remove adhering debris. Carbonate was dissolved in 3N HCl. Standard ion-exchange techniques (e.g., Hart and Brooks, 1974) were used to separate strontium for analysis on a VG Sector mass spectrometer at Rutgers University. At Rutgers, NBS-987 is routinely measured as 0.710250. Internal precision (intran variability) on the Sector is approximately ± 0.000011 ; external precision (inter-run variability) is estimated on the basis of replicate analyses of NBS-987 and other samples (Miller et al., 1988) of about ± 0.000030 or better.

Nuwok Samples

The Nuwok samples (U.S. Geological Survey field numbers 84-EB-114 and 84-EB-115 [composite sample 1], 83-EB-105 [sample 3], and 83-EB-108 [sample 4]) were collected and processed by E. M. Brouwers in the U.S. Geological Survey ostracode laboratory in Denver by adding sodium bicarbonate to the sediment, followed by warm water, and then freezing and thawing. The fine sediment residue was discarded through a 63 μm sieve, the residue was air dried, and the microfossils were picked manually. The specimen of *Arctica carteriana* (sample 2) (U.S. Geological Survey field number 84-CP-13) was collected by C. Powell II and provided to J. R. Matthews, Jr., by L. N. Marincovich, Jr. Matthews (1989) has used the strontium age estimates to substantiate noncorrelation between the upper Oligocene Nuwok beds and lower Pliocene or upper Miocene beds of the Beaufort Formation in the Arctic Archipelago. Preservation of all the material utilized was excellent, and there appeared to be no evidence of diagenetic alteration.

Edlok N-56 Samples

Well-cutting samples from the Edlok N-56 well (Geological Survey of Canada [GSC] locality C-130896) were processed in the Institute of Sedimentary Petroleum micropaleontology laboratory in Calgary; they were disaggregated in a solution of the detergent Quaternary "O" at 60 °C on an oscillating

hot plate. The fine residue was discarded through a 75 μm sieve, and microfossils were extracted manually from the coarse residue. Preservation of all the material utilized was excellent, and there appeared to be no evidence of diagenetic alteration.

Paleontological Curation

Illustrated foraminifers are stored in the type collection of the Geological Survey of Canada, Ottawa, and are referred to by GSC type number as indicated in Figure 6.

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