Ocean and Climate Change Institute
Final Report Summary

Project Title and PI(s):

The Increase of Particle Flux in the Deep Canada Basin: Provenance, Resilience, and Implications

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What were the primary questions you were trying to address with this research? (Or, if more appropriate, was there a hypothesis or theory that you were trying to prove or disprove?)

In order to test our hypothesis that the central Arctic Ocean is poised for a change in carbon export we plan to reinstall time-series sediment traps in the deep Canada Basin as part of the existing the Beaufort Gyre Observing System (BGOS) program. Examination of the first 2 years of the sediment trap deployments (2004-5; 2007-8) indicated that fluxes to the deep Canada Basin were extremely low, suggesting a virtually non-existent biological pump. During both deployments, the flux was dominated by laterally supplied particulate material from the continental margins during late winter, as indicated by old radiocarbon ages and high abundances of fine-grained lithogenic minerals. However, samples collected during the 3rd year when ice coverage was reduced significantly we observed a 2-fold increase in annual particle flux, with the highest mass flux peaks during the summer. This increased particle flux delivered to the deep basin may have been triggered by an activation of the biological pump fueled by increased surface ocean productivity, consistent with our hypothesis, but there are alternative explanations. Unfortunately our NSF proposal was not funded to continue the program and we had to remove the sediment traps from the BGOS project which is still continuing. We are actively pursuing to reinstall the sediment traps and answer basic questions regarding the functionality of the Arctic carbon cycle and provenance using Nd isotopes. Are the additional particles derived from fresh biological production from overlying waters or from material laterally transported from the several arctic shelves? Are the increased fluxes an ongoing resilient trend, or an anomalous event resulting from other factors? Irrespective of these findings, we consider it imperative to continue these sediment trap deployments in order to assess whether, and how, the Arctic Ocean carbon cycle is changing. Here, we plan to continue sediment trap deployments for 2 additional years

What were your primary objectives and describe your work plan to achieve these objectives?

Objectives: Our funding request from the ARI focuses on 2 objectives:

1. We propose to collect 2 additional years of sediment trap samples (2010-2011; 2011-2012) in order to establish whether the observed increase in particle flux in 2008-9 is a resilient feature.

We will redeploy sediment traps on 2 existing BGOS moorings (mooring A and mooring B; both traps will be deployed at 3000 m). These additional time-series samples will provide crucial data

for assessing whether there has been a shift in the behavior of the biological pump. The availability of these sample sets will be used to bridge the current observation gap, and will be used in conjunction with results from measurements on the samples currently in hand in order to leverage further support from NSF-OPP to continue biogeochemical flux observations and provide further justification for sustaining the BGOS beyond 2013, when it is currently scheduled to end.

2. We propose to explore new geochemical tracers for assessing the provenance of margin-derived particulate matter intercepted in the deep Canada Basin.

In order to establish the provenance of this laterally transported material, we propose to exploit anticipated differences in the Nd isotopic composition of particles emanating from the dominant terrestrial source (the Mackenzie River) versus those entering the basin via the Chukchi Sea which entrain marine organic matter. This anticipated difference in isotopic composition is based on the geologic age of rocks eroding from and contributing to lithogenic mineral loads emanating from these different regions. Our Arctic sediment trap samples contain large amounts of clay minerals which are ideal to test this method and we anticipate that the isotopic contrast will be sufficient to establish the provenance of this material.

Work Plan:
The timing and outcome of the WHOI-ARI call for proposals is such that, if successful, we will be able to install sediment traps this coming field season (Sept 2010) in order to insure only a 1-year gap in the particle flux time-series and extend the sediment trap study for a further 2 years (until 2012). In addition, we will be able to immediately initiate an assessment of the Nd isotope method on the sediment samples that are already in hand. We plan to use findings from our current NSF project, together with the acquisition of new time-series particle flux samples, and a demonstration of the effectiveness Nd isotopes as a particle provenance tracer in order to justify additional support from NSF-OPP in order to build upon and sustain biogeochemical flux studies in the Arctic Ocean.

Work Execution:
We were able to successfully deploy 2 sediment traps on the BGOS moorings in the 2010-2011 year and 3 sediment traps for the 2011-2012 year at all 3 BGOS locations A, B, D. A total of 105 sediment traps samples were collected and now stored at WHOI. Processing and analyses of all samples for mass flux; particulate organic carbon (POC), particulate inorganic carbon (PIC) and Al were conducted.
Selected Sediment Trap samples (24) were processed and analyzed for 24 Nd analyses representing all seasons at all 4 BGOS locations A, B, C, D.

What have you discovered or learned that you didn't know before you started this work?
We have observed that the high flux during the "reduced ice condition" year 2008-2009 was not observed during the 2 following years (2010-11, 2011-12) where ice conditions resumed "normal ice coverage". To our surprise, the high fluxes during year 2008-2009 did not contain high concentrations of carbon due to increased productivity but rather it was due to an increase in the lithogenic component indicating more lateral inputs during reduced ice conditions. Another unusual observation showed that at all 4 locations the maximum mass flux at each site during

each year occured during the annual maximum ice cover. Concurrent with this observation are decreases in the integrated annual component fluxes from the coastal site locations to the inner basin locations along with increased concentrations of POC and PIC and decreased concentrations of Al. This is also an unusual finding to have higher POC concentrations in the center of the basin. This systematic component change from the outer basin, which is closest to the coast, to the inner basin may indicate a unique transport mechanism within the Canada Basin which could be altered by changes in sea-ice concentration as observed at Site A.

Nd isotopic results allow us to make several conclusions regarding provenance of sediments entering the Canada Basin and accumulating in the sediment traps. The source of trap material is not homogenous. We believe that two sources are involved, at the east weathered old Canadian Shield and young basaltic material in the west. Assuming that sediments from two rivers draining to Canada Basin, Mackenzie (143Nd/144Nd=0.511932, Nd=19.5 ppm) and Colville (143Nd/144Nd=0.512358, Nd=29.5 ppm) characterized composition of end member material we can calculate contributions from both sources. Majority of trap samples carry around 70-80% material from Mackenzie, only few samples have high contributions from Colville around 60%. The highest contributions from Colville is apparent in sites A and B during spring time, however in site D during the same season signal from Mackenzie is dominant. It is obvious that there is a temporal variation in Nd isotopic signal during a single year and from year to year. In addition we observe spatial variation, as material collected at different sites is rather heterogeneous (compare for example site A and D).

What is the significance of your findings for others working in this field of inquiry and for the broader scientific community?

Our most recent observations from multiple year time-series sediment traps demonstrate the uniqueness of the biogeochemical functionality of the Arctic Canada Basin. The changes that we have observed in the deep basin are counterintuitive to other ocean basins in low latitudes. This observed systematic component change from the outer basin, which is closest to the coast, to the inner basin may indicate a unique transport mechanism within the Canada Basin which could be altered by changes in sea-ice concentration as observed at Site A.

What is the significance of this research for society?

It has been predicted that anthropogenically-driven climate change will have far more rapid and amplified consequences for the Arctic relative to other regions, and there is compelling evidence that marked changes are indeed already underway. Two of the most blatant manifestations of this change are a reduction in sea-ice cover and destabilization of permafrost soils, both of which will likely alter the Arctic carbon cycle. Destabilization of the permafrost and attendant shifts in the hydrologic cycle will release vast quantities of reduced carbon and associated nutrients to the marginal while decreased sea ice cover will markedly affect physical processes and marine primary production. In particular, we can expect both enhanced and an offshore extension of marine productivity. However, the fate of this carbon (i.e., remineralization versus burial), as well as the extent to which the deep basin waters and underlying sediments will sequester carbon in the face of rapidly changing hydrographic and biogeochemical conditions, remain unknown. We have hypothesized that these changes will trigger increased productivity and particle export in oligotrophic central Arctic Basins.

What were the most unusual or unexpected results and opportunities in this investigation?
Another observation shows that at all 4 locations the maximum mass flux at each site during each year occurs during the annual maximum ice cover. Concurrent with this observation are decreases in the integrated annual component fluxes from the coastal site locations to the inner basin locations along with increased concentrations of POC and PIC and decreased concentrations of Al. This systematic component change from the outer basin, which is closest to the coast, to the inner basin may indicate a unique transport mechanism within the Canada Basin which could be altered by changes in sea-ice concentration as observed at Site A.

What were the greatest challenges and difficulties?
Our field and lab programs are maintained by experts who are experienced, proficient, and enthusiastic and have always successfully executed our work plans. Our major challenge has been to acquire ample funding to continue the program.

When and where was this investigation conducted? (For instance, did you conduct new field research, or was this a new analysis of existing data?)
This project was conducted on the Canadian Ice Breaker LSST Laurent during cruises 2010 - 2012 during deployment and recovery of the BGOS mooring at locations A, B, D. We incorporated sediment traps into moorings supported through an existing NSF-sponsored physical oceanography observation program in the central Canada Basin in collaboration with Canadian oceanographers at the Institute of Ocean Sciences. The Beaufort Gyre Observing System (BGOS) program consists of an array of autonomous moored hydrographic instrumentation including moored profilers and we have taken advantage of this program by deploying our sediment traps on mooring A at 3000m for multiple years, as well as on other moorings within the array, thus reducing our cost significantly.

What were the key tools or instruments you used to conduct this research?
We used WHOI McLane Sediment Traps (21cup), WHOI JY Ultima 2 ICP-OES for Si and Al analyses, MC-ICPMS Neptune at the WHOI ICPMS facility for Nd isotopes analyses, WHOI IEC Coulometer for PIC analyses and WHOI Perkin Elmer CHN elemental analyzer 2400 for C and N analyses.

Is this research part of a larger project or program?
Yes – Our sediment trap program is part of the NSF sponsored Beaufort Gyre Observing System (BGOS). We incorporated sediment traps into moorings supported through an existing NSF-sponsored physical oceanography observation program in the central Canada Basin in collaboration with Canadian oceanographers at the Institute of Ocean Sciences. The Beaufort Gyre Observing System (BGOS) program consists of an array of autonomous moored hydrographic instrumentation including moored profilers and we have taken advantage of this program by deploying our sediment traps on mooring A at 3000m for multiple years, as well as on other moorings within the array, thus reducing our project cost significantly.

What are your next steps?

We are in the process of submitting a proposal to NSF-OPP in December 2013 which focuses on organic carbon cycling in the deep Arctic Ocean: chemoautotrophy or lateral advection, with additional scientists Ben Van Mooy and Chris German.

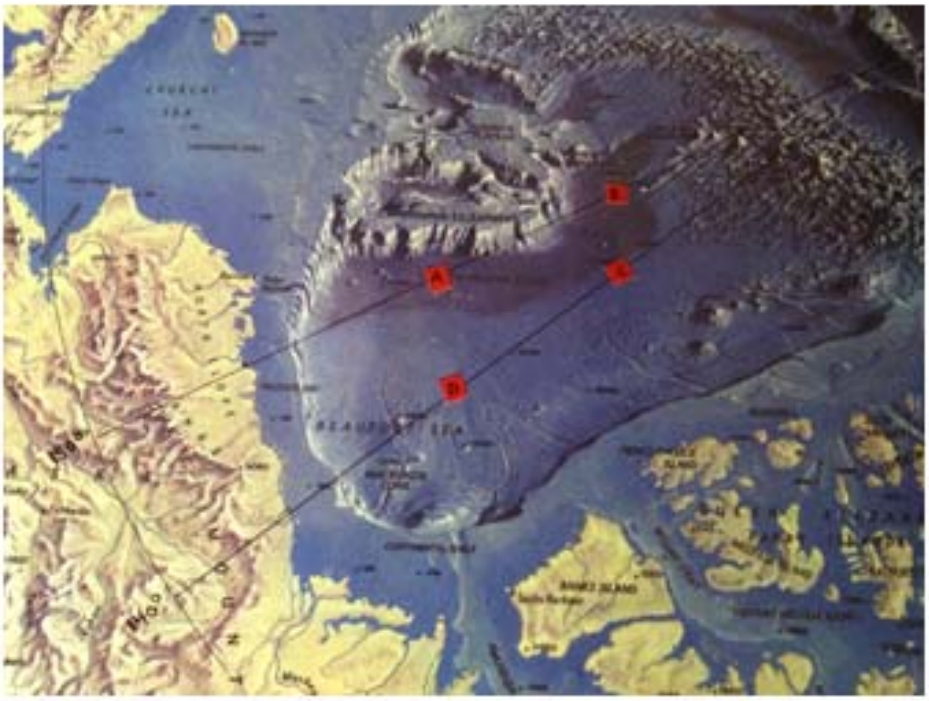
In recent decades, the Arctic Ocean's Canada Basin has seen both rapidly decreasing summer sea ice coverage and freshening of surface waters. Heretofore it is not known how these changes will translate to the dark basin below, where the fate of organic carbon exported from surrounding marine and terrestrial sources is decided. To accurately predict the response of the Arctic Ocean to climate change, and potential feedbacks through carbon sequestration/release, we therefore need a better understanding of the biotic and abiotic processes controlling carbon cycling in the Arctic Ocean. Here, we therefore propose to investigate the flux, sources and fate of organic carbon within the interior of the Canada Basin.

Specifically, we propose to quantify the relative importance of chemoautrophy, lateral advection, heterotrophy and methanotrophy in the water column of the central Canada Basin. We will use archived samples from moored sediment traps that have been collecting the vertical and lateral export flux of particles at two locations in the Canada Basin since 2007. We propose complementary analysis of Nd isotopes and fatty acid $\delta 13C$ and δD values to constrain the sources and flux of organic carbon in the interior of the Canada Basin.

The outcome of our project will be a refined understanding of carbon sources and fate in the deep Arctic Ocean. Eventually, this will allow predicting whether the deep

Arctic Ocean will act as a source or sink of atmospheric CO2 in the face of future global warming. To do so, we believe there is a clear need to maintain a biogeochemical presence in the Canada Basin and intend to use the results of this project to lay a strong foundation for a full NSF proposal to both continue the moored sediment trap program and to collect samples that will allow the use of compound-specific radiocarbon analysis on fatty acids.

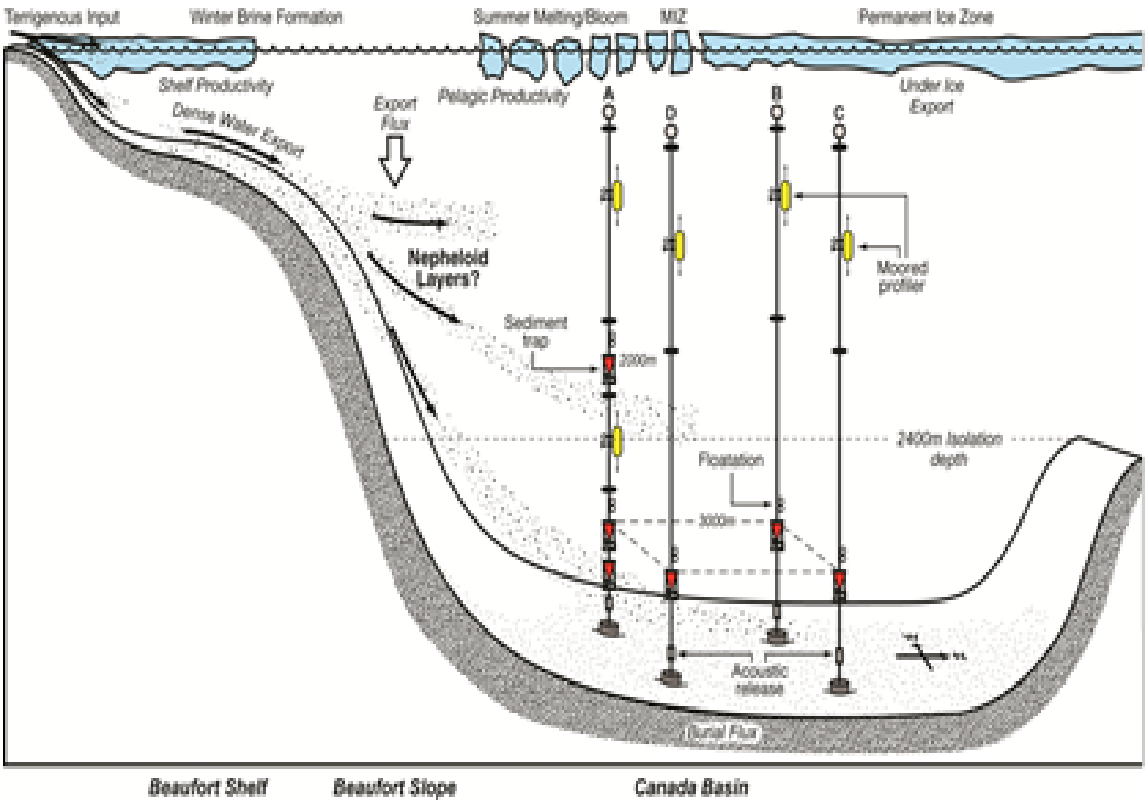
Please provide photographs, illustrations, tables/charts, and web links that can help illustrate your research.



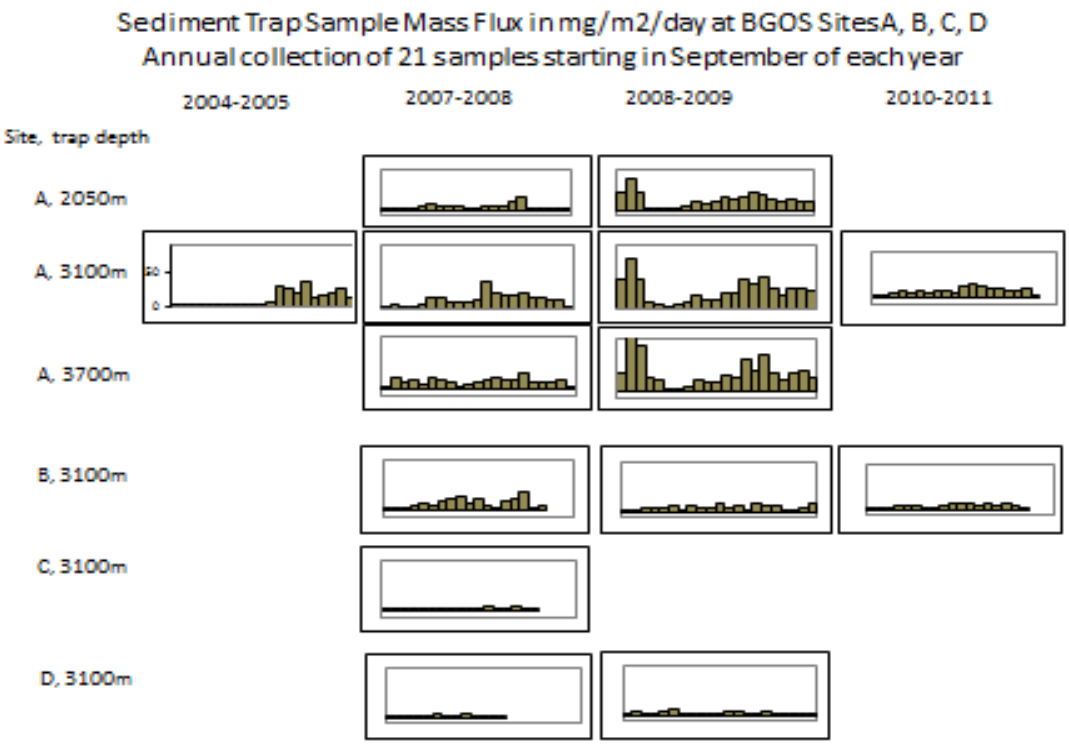
Sediment Traps sites in the Canada Basin:

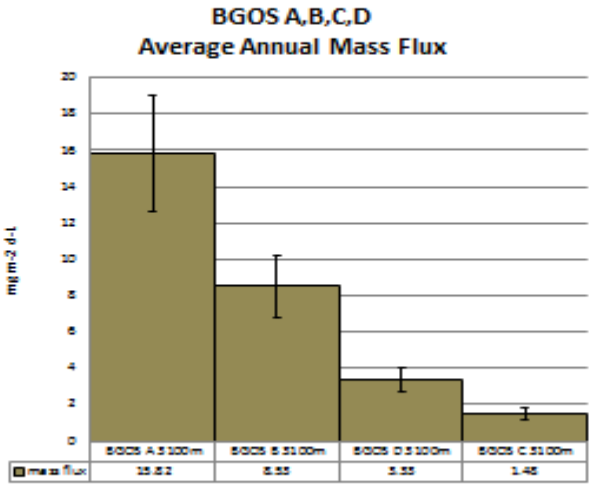
Sites A and B located on longitude 150W, water depth 3825m, 2821m respectively

Sites D and C located on longitude 140W, water depth 3518m, 3722m respectively



Sediment trap mooring diagram showing relative trap positions and proposed processes.



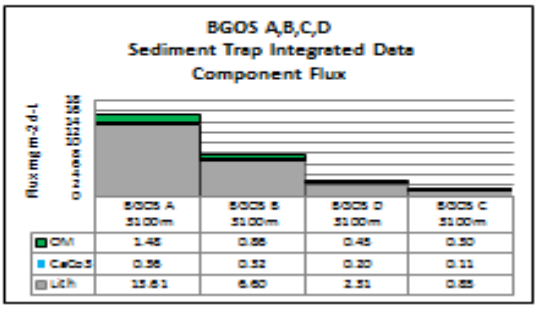


Section 1

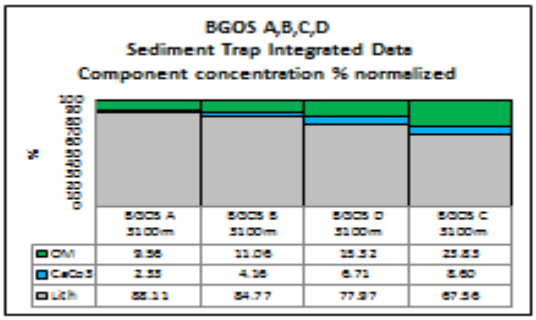
Decrease in IAA mass fluxes from A, B, D, C.

20% RSDs for mass flux interannual variability.

Detailed RSDs are presented in later figures.

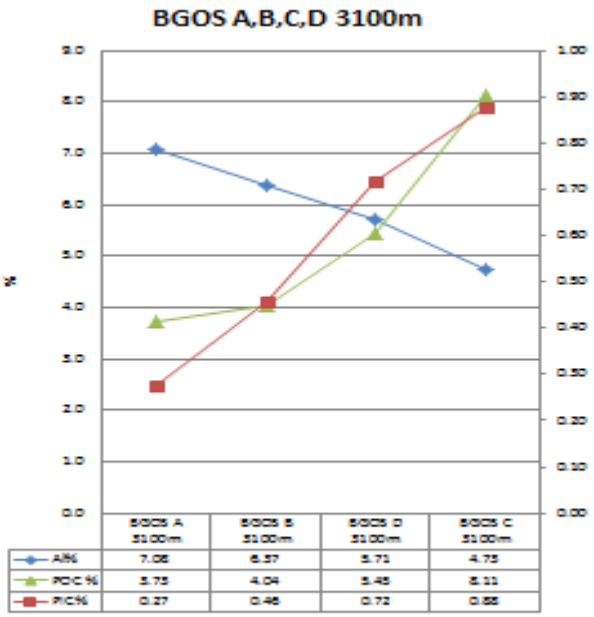


Decrease in component lAA fluxes from A,B D,C



Decrease concentration of Lith From A,B,D,C

Increase concentration of OM and CaCO3 from A,B,D,C



POC, PIC and AI concentrations at sites A,B,D,C

POC concentrations increase at site C to 8.11% and PIC to 0.88%

This may be an indicator of a sorting mechanism the lithogenic and biogenic materials.

Summary of observations from sediment trap sample data

- Intercomparison of sites A, B, C, D integrated annual average (IAA) fluxes, concentration, and ratios:
  - On the 150 longitude transect – decrease of fluxes and component fluxes from sites A to B
  - On the 150W longitude transect- decrease in fluxes and component fluxes from sites D to C
  - Decrease in mass fluxes and component fluxes from A, B D, C.
  - Increase in Al concentration from A,B,C,C
  - Decrease in POC and PIC concentration from A,B,D,C

- Interannual variability of fluxes and concentration at sites A 3100m (4 years) and site B 3100m (3years)
  - At site A anomalous high flux year was recorded in 2008 during low ice concentration in the Arctic
  - Detailed RSDs are reported from site A ranging up to 20% with 2007 year included.
  - Increase in Al concentration in recent years at site A, not observed at site B.
- Time Series data at site A depths 2005, 3100m, 3700m during 2007 and 2008.
  - Component fluxes are similar at all depths and increase with depth.
  - Anomalous fluxes at Site A are rapidly transmitted from 2000m to 3700m.
  - No anomalous time series were observed at site B

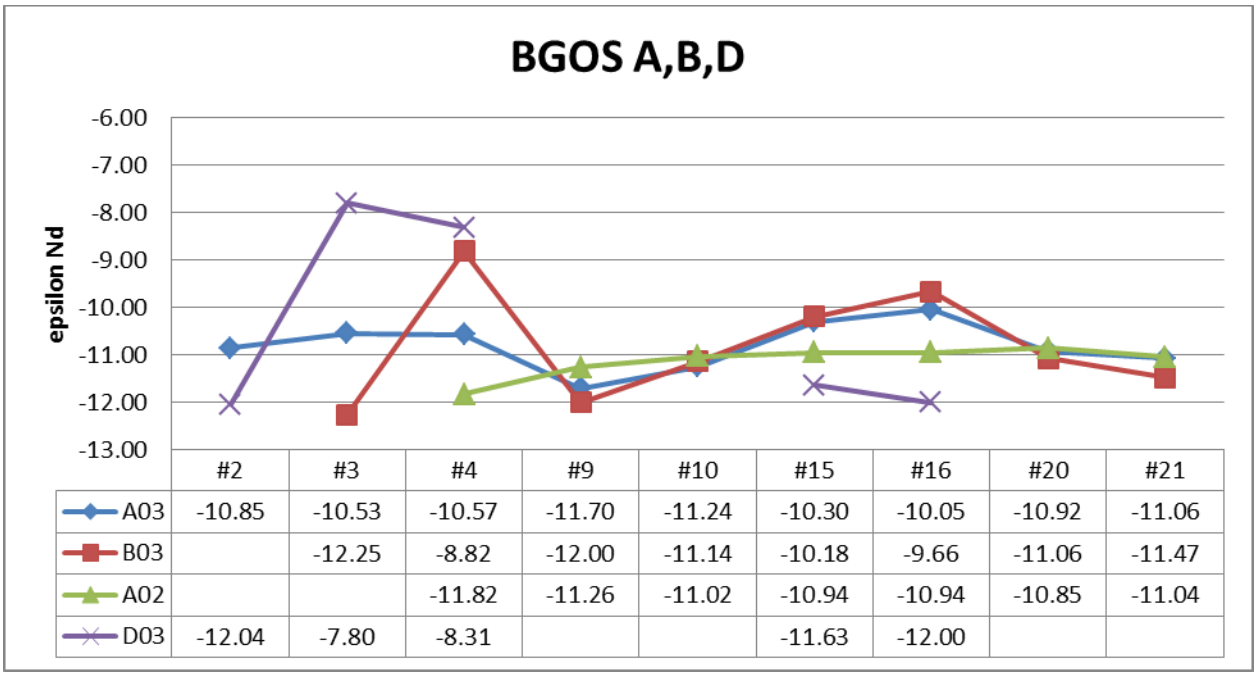
Nd Analyses

	SITE	% Al	143Nd/144Nd	epsilon Nd	Nd ppm
BGOS 03 moring A 3100m #2 <1mm	A03-2	7.90	0.512082	-10.85	28.65
BGOS 03 moring A 3100m #3 <1mm	A03-3	8.34	0.512098	-10.53	30.71
BGOS 03 moring A 3100m #4 <1mm	A03-4		0.512096	-10.57	29.10
BGOS 03 moring A 3100m #9 <1mm	A03-9	7.56	0.512038	-11.70	25.06
BGOS 03 moring A 3100m #10 <1mm	A03-10	8.10	0.512062	-11.24	24.99
BGOS 03 moring A 3100m #15 <1mm	A03-15	8.41	0.512110	-10.30	31.00
BGOS 03 moring A 3100m #16 <1mm	A03-16	8.42	0.512123	-10.05	30.37
BGOS 03 moring A 3100m #20 <1mm	A03-20	7.46	0.512078	-10.92	26.73
BGOS 03 moring A 3100m #21 <1mm	A03-21	7.09	0.512071	-11.06	26.03
			ave	-10.80	

	SITE		143Nd/144Nd	epsilon Nd	Nd ppm
BGOS 03 moring B 3000m #3 <1mm	B03-3	8.07	0.512010	-12.25	24.49
BGOS 03 moring B 3000m #4 <1mm	B03-4	6.81	0.512186	-8.82	24.83
BGOS 03 moring B 3000m #9 <1mm	B03-9	5.82	0.512023	-12.00	21.55
BGOS 03 moring B 3000m #10 <1mm	B03-10	6.19	0.512067	-11.14	21.10
BGOS 03 moring B 3000m #15 <1mm	B03-15	7.09	0.512116	-10.18	28.02
BGOS 03 moring B 3000m #16 <1mm	B03-16	7.30	0.512143	-9.66	27.22
BGOS 03 moring B 3000m #20 <1mm	B03-20	7.38	0.512071	-11.06	21.36
BGOS 03 moring B 3000m #21 <1mm	B03-21	7.38	0.512050	-11.47	21.17
			ave	-10.82	

	SITE		143Nd/144Nd	epsilon Nd	Nd ppm
BGOS 02 moring A 3100m #4 <1mm	A02-4		0.512032	-11.82	22.58
BGOS 02 moring A 3100m #5 <1mm	A02-5	6.41	0.512061	-11.26	23.11
BGOS 02 moring A 3100m #11 <1mm	A02-11	7.12	0.512073	-11.02	23.91
BGOS 02 moring A 3100m #15 <1mm	A02-15	6.86	0.512077	-10.94	25.07
BGOS 02 moring A 3100m #16 <1mm	A02-16	7.10	0.512077	-10.94	24.77
BGOS 02 moring A 3100m #20 <1mm	A02-20	7.78	0.512082	-10.85	25.26
BGOS 02 moring A 3100m #21 <1mm	A02-21		0.512072	-11.04	23.43
			ave	-11.12	

	SITE		143Nd/144Nd	epsilon Nd	Nd ppm
BGOS 03 moring D 3000m #2 <1mm	D03-2	7.31	0.512021	-12.04	34.01
BGOS 03 moring D 3000m #3 <1mm	D02-3	7.82	0.512238	-7.80	32.48
BGOS 03 moring D 3000m #4 <1mm	D03-4	7.82	0.512212	-8.31	25.80
BGOS 03 moring D 3000m #15 <1mm	D03-15	6.86	0.512042	-11.63	27.29
BGOS 03 moring D 3000m #16 <1mm	D03-16	6.95	0.512023	-12.00	27.31
			ave	-10.35	



	#2	#3	#4	#9	#10	#15	#16	#20	#21
A03	-10.85	-10.53	-10.57	-11.70	-11.24	-10.30	-10.05	-10.92	-11.06
B03		-12.25	-8.82	-12.00	-11.14	-10.18	-9.66	-11.06	-11.47
A02			-11.82	-11.26	-11.02	-10.94	-10.94	-10.85	-11.04
D03	-12.04	-7.80	-8.31			-11.63	-12.00		