Species Identification and Isotopic Analysis of Southern Ocean MPN

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By

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Certificate

This is to certify that this dissertation entitled "Species Identification and Isotopic Analysis of Southern Ocean MPN" towards the partial fulfillment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents study/work carried out by Favaz Ahammed K at Indian Institute of Science, Bangalore under the supervision of Dr. Prosenjit Ghosh, Centre for Earth Sciences, Centre for Atmospheric and Oceanic Sciences during the calendar year of 2018.

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Declaration

I hereby declare that the research work presented in the report entitled "Species Identification and Isotopic Analysis of Southern Ocean MPN" has been carried out by me at Centre for Earth Sciences, IISc Bangalore, under the supervision of Dr. Prosenjit Ghosh and the same has not been submitted elsewhere for any other degree.

Favaz Ahammed K

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To my mentor Dr. Prosenjit Ghosh, I owe it all to him. Many thanks. I take this opportunity to express my profound gratitude and deep regards for his guidance and I shall carry them a long way in the journey of life on which I am about to embark.

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Abstract

The stable oxygen isotope ratio of mixed layer planktonic foraminifera collected from tow samples along the latitudinal transect from $47^{0}49$'S to $64^{0}05$'S during summer time over the Southern Ocean. Samples were collected during the Expeditions – SOE IX and SOE X. The analysis of $\delta^{18}O$ of foraminifera together with ocean water $\delta^{18}O$ allowed deciphering the state of equilibrium -disequilibrium relationship at a particular temperatures; which varied across the latitude. We observed a subtle disequilibrium relationship on approaching the $50^{0}0$'S latitude, which may be due to secondary reservoir effect

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Chapter 1

1.1 Introduction

The abundance and isotopic ratios of oxygen in the carbonate of planktonic foraminifera have long been used as tools for monitoring surface ocean condition and temperature. This enabled understanding the shift in the atmospheric and oceanic circulation pattern through time. However, the isotopic compositions of planktonic foraminifera are commonly prone to deviate from the equilibrium condition under certain conditions; which demand more critical assessment of environmental parameters, which includes winds and nutrient supply due to upwelling [(2)]. Micro fossils are by far the most abundant of all fossils in the oceanic settings and most useful in paleo climate recorder. The sea surface temperature and the salinity condition affect growth of planktonic species which are dealt in this project.

1.2 Different water zones in Southern Ocean

Southern Ocean is divided into following zonal segment based of the temperature and salinity condition. The Subtropical zone (STZ) which is distinguished with the presence of warm water and poor nutrients are characterised by the abundant oxygen at the deeper part. It extends from 20^0S to 35^oS. The SST is normally found more than 20 °C and the Sea Surface Salinity (SSS) varies between 35–35.5 PSU. Towards south we have Transition zone (TZ) which lies between 35°S to 40°S and is characterised by a meridional gradient in all biogeochemical parameters. The SST for this zone varies from 15–20 °C, while sea surface salinity ranges between 35– 35.5 PSU. From the latitudes of 40°S to 45°S lies the third zone known as Sub-Antarctic Frontal zone (SAFZ) which is marked by the presence of Sub-Antarctic Front (SAF), where the temperature difference is 6–15 °C and the sea surface salinity ranges between 33.8–35 PSU. Further south lies the Polar frontal zone (PFZ) starting from 45°S and terminates at ~ 50°S. The SST recorded in this zone varies between 4– 9 °C and the Sea Surface Salinity is >33.9PSU. The final and farthest zone, the Antarctic zone (AAZ) is placed beyond 50°S, and characterised by a cold water with SST < 4 °C and sea surface salinity is < 33.8 PSU. (Ref: 3-5)

1.3 Seasonal Variability of Mixed Layer Depth (MLD)

Mixed Layer is the prime habitat of *G. Bulloides* and its depth varies depending on the season (summer or winter) and zones. Based on published data (Racape et al, 2010)[1] the MLD of the various zones in the Southern Ocean are as follows: STZ: 20 m in summer and 117 m in winter with temperature of 20°C and 14°C respectively. TZ: 31 m in summer and 280 m in winter with temperature of 15-20°C and 13-16°C respectively. SAFZ: 42 m in summer and 125 m in winter with temperature of 6-15°C and 5-15°C respectively. PFZ: 66 m in summer and 165 m in winter with temperature of 4-9°C and 2-5°C respectively. AAZ: 88 m in summer and 150 m in winter with temperature of less than 4°C.

1.4 Objective

The main objective of this work is to separate out MLD species from the tow samples and analyse them for the $\delta^{18}O$ composition. In addition, we analysed surface water isotopic composition of the water across the latitude. The input of temperature (SST) measured across latitude during the sailing and water composition were used to derive the expected/model equilibrium isotopic composition of carbonate found in the foramnifera. The deviation of measured composition with the expected/model equilibrium isotopic composition allowed understanding the equilibrium and disequilibrium process.

Chapter 2

Materials and Methods

2.1 Water and Plankton net sample collection during SOE IX and SOE X

For this present study, I have used seawater samples which integrates 500 m water depth in the southern Indian Ocean during Southern Ocean Expedition (SOE) IX and X as well as foraminifera from the mega plankton net. The location of water sample collection and plankton net sample collection are described in Figure 2.

Fig.1: Mega plankton net sample collection during SOE IX.

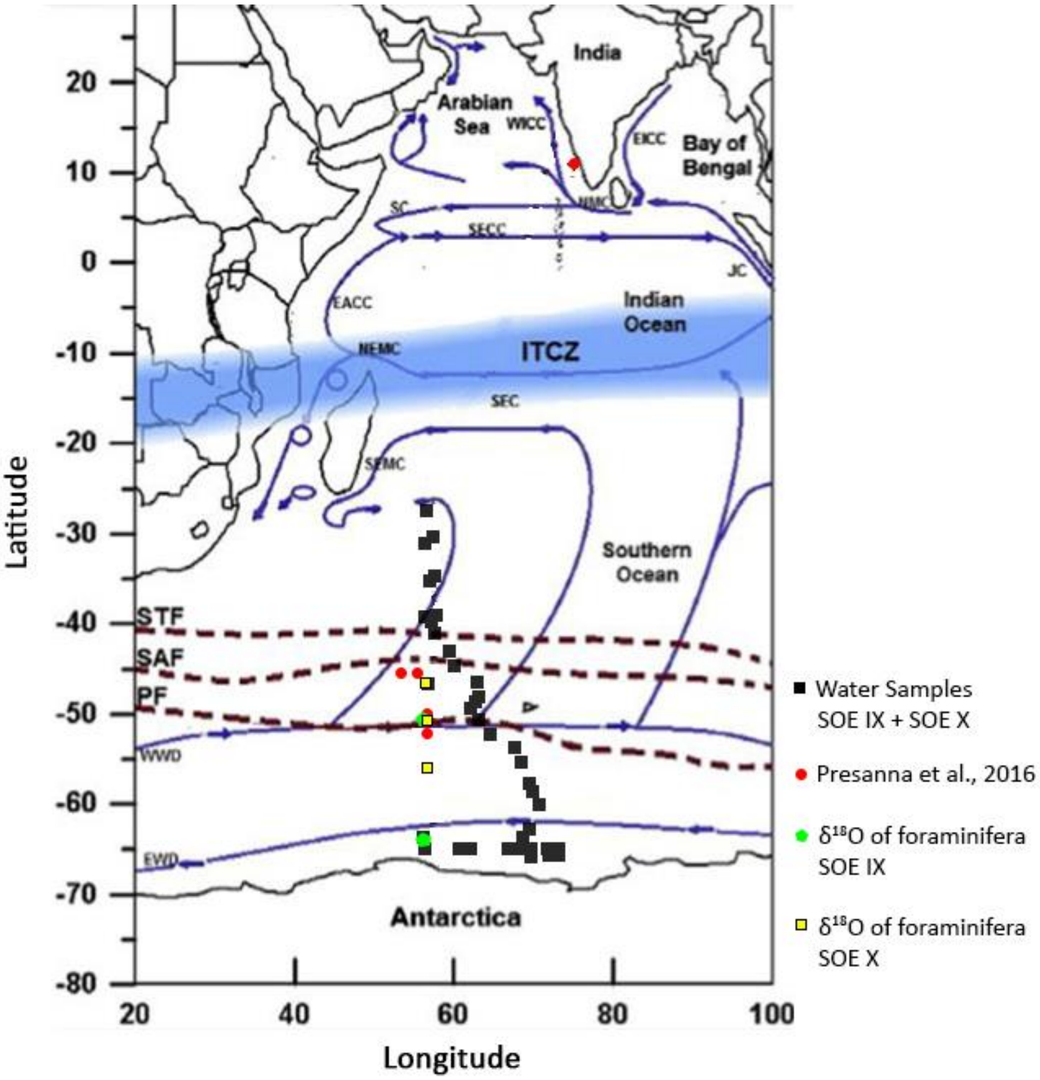


Figure 2: Sample locations (edited from Tiwari et al., 2013)

2.2 Microfaunal separation:

The phytoplankton samples were sieved over the 63-micron mesh and dried it at ~ 50°C. The dried coarser fraction was weighed and stored in plastic vials. This thesis work involves separation and identification of foraminifera from 20 tow samples collected from four stations over the latitudinal belt between 43°S to 64°S. The foraminifera were separated from the plankton tow samples by the process of sieving through 63-micron mesh. After sieving the sample were dried at 50^{0}C. The foraminifera tests were identified under binocular stereo zoom microscope with the help of World Foraminfera Database. The identified species were *Neogloboquadrina pachyderma* (both sinistral and dextral) and *Globigerina bulloides*.

2.3 Stable Oxygen and Carbon Isotope analysis

For this study we have picked as many mixed layer planktonic foraminiferal species as possible of fractions > 250-micron size and followed the cleaning procedure suggested by Barker et al.,2013. These samples were analysed for the $\delta^{18}O$ and $\delta^{13}C$ using IRMS MAT 253 interfaced with Gas bench II peripheral at Indian Institute of Science. The isotopic values are calibrated against the internal lab standard MAR J1 (Ghosh et al., 2005) (Carrara marble 1) and expressed as per mil (&) versus Vienna Pee Dee Belemnite (VPDB). The analytical precision based on repeated analysis of MAR J1 was 0.08 ‰ for $\delta^{18}O$ and 0.05‰ for $\delta^{13}C$.

2.4 Stable isotope measurement of small carbonate by Isotope dilution method

Techniques exist for quantitative stable isotope measurement of microgram samples using Keil device. We designed a new method of isotope dilution for precisely quantitative measurement of microgram of sample powder available for our experiment. The above problem can be overcome by spiking (known stable isotopic composition) with sample (unknown stable isotopic composition), which popularly known as isotope dilution. De Bievre and Debus[(12)], 1965 have explained the theoretical and practical approach of isotopic dilution analysis. The few prior isotope dilution analyses were done in OASIS lab, IISc by mixing the standard Carrara Mable 1 ($\delta^{13}C$ and $\delta^{18}O$ values are 2.03 ± 0.01‰ and -2.06 ± 0.03‰, respectively) with OMC ($\delta^{13}C$ and $\delta^{18}O$ values are -4.25 ± 0.02‰ and -8.46 ± 0.06‰, respectively) in different proportion (Fosu et al., 2018).

For the present study, I have analyzed $\delta^{18}O$ and $\delta^{13}C$ of planktonic foraminifera from SOE 10 sample using isotope dilution method

Chapter 3

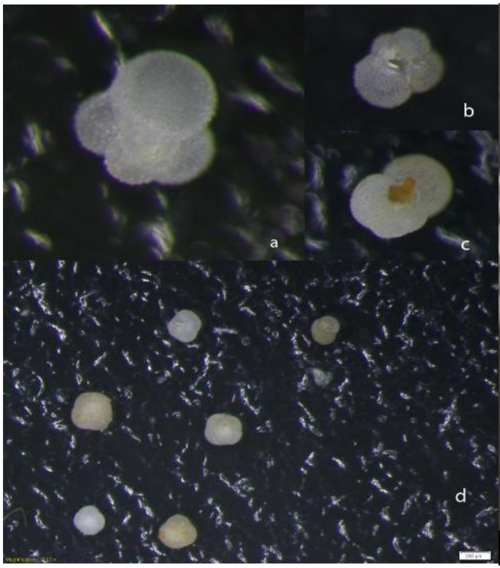
Systematics

3.1 Southern Ocean Expedition IX samples

Only 6 samples yielded enough specimens for our analysis (Table 1). Majority of the specimens were: *Neogloboquadrina pachyderma* (both sinistral and dextral) and *Globigerina bulloides*. These were initially photographed (Figure 1) under microscope and then SEM images (Figure 2) were taken for further identification.

Sl. No	Name	No of specimens	
		N. pachyderma	*G. bulloides*
1	CTD 19 (3)	7	5
2	CTD 22 (1)	4	11
3	CTD 22 (2)	11	5
4	CTD 22 (3)	45	7
5	CTD 22 (4)	32	19
6	CTD 22 (5)	4	5

Table 1 : Shows sample details and statistics of two species of foraminifera for SOE IX sample



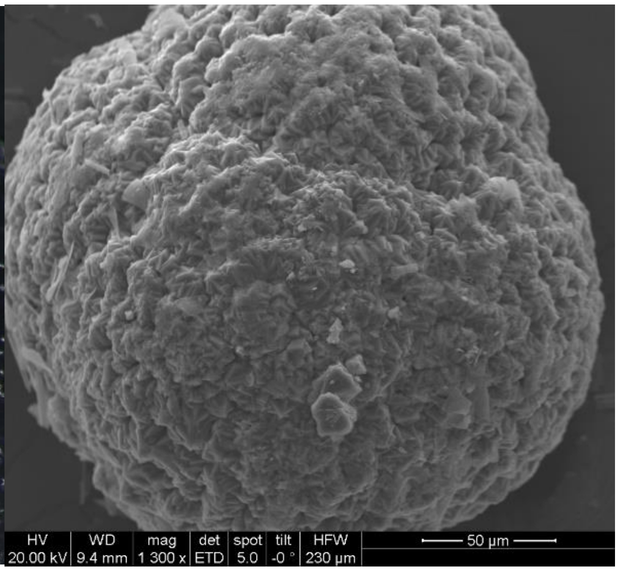


Figure 3: Image of a *G. Bulloides* specimen under binocular microscope (left)

Figure 4: SEM image of *G. Bulloides* (right)

3.1.1 Neogloboquadrina Pachyderma

Neogloboquadrina pachyderma (4-chambered) is a dominant member in the assemblages studied from the transitional to polar water masses. The depth they are found varies because it can adapt its living depth within water column and they reach maximum abundance at depths from 50 to 200m. They are characterised by calcareous wall structure with trochospiral coiling. There are two types, sinisteral (left coiling) which are found in colder waters predominantly and dextral (right coiling). The shape of the aperture also varies, and can be found from an open arc to a closed slit. They have fewer pore size with no distinct ornamentation.

3.1.2 Globigerina Bulloides

G. bulloides inhabits mainly the mixed layer, their presence has been recorded in the water column of upper 200 m. There are 3 wall structures categorised among foraminifera - Agglutinate, Calcareous or Organic. G. bulliodes has a calcareous wall structure. They are trochospiral and evolute in coiling. There is only primary aperture opening, and G. bulliodes is identified with its umbilical side aperture. Their pores are well defined by fine spores and absence of any distinct ornamentation. The oxygen isotopic ratio of foraminifera at equilibrium should depend on the oxygen isotopic composition and temperature of the ambient sea water (Prasanna et al, 2015)(1). In this work we are going to study $\delta^{18}O$ variability of mixed layer planktonic foraminifera over southern Indian Ocean with depth and latitudinal position by analysing foraminiferal test. Previous study on this topic identified isotopic disequilibrium in *Globigerina bulloides* (Prasanna et al, 2015)(1).

3.2 Southern Ocean Expedition X samples

Out of 6 sample sets, only 3 samples yielded enough number of specimens for the analysis. There were no particular species in majority of number. Specimens are identified as Orbulina universa, Globigerinoides conglobatus, Globorotalia clemenciae, Globigerinoides bulloides, Globigerina bulloides. (Figure 5)

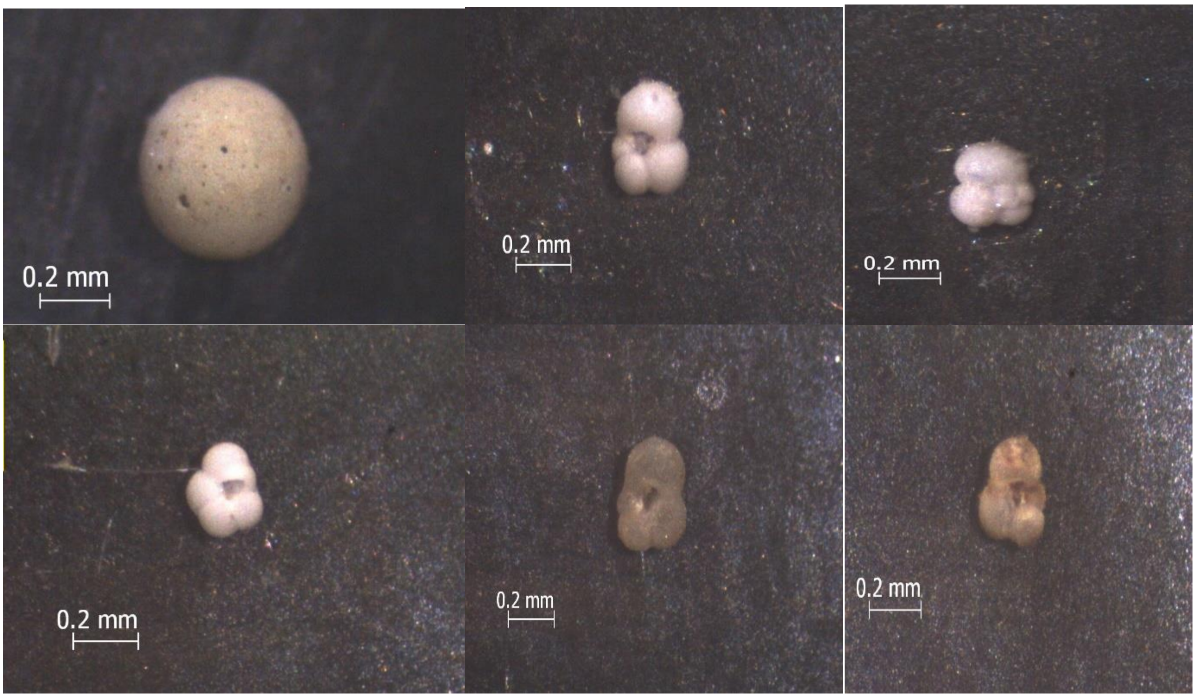


Figure 5 : Images under binocular Microscope (35x) – SOE X ; Clockwise from top – (i) Orbulina universa ; (ii) Globigerinoides conglobatus apertural view ; (iii) Globigerinoides conglobatus spiral view ; (iv) Globorotalia clemenciae ; (v) Globigerinoides bulloides apertural view ; (vi) G. bulloides apertural view

Chapter 4

Results and Discussions

4.1 Introduction

The understanding of Southern Ocean in terms of climatic and oceanographic component is rare. It plays vital role in controlling the heat budget over the ocean and atmospheric CO_2. The few attempts were done to understand present day oceanographic (1,13) and climatic settings of Southern Indian Ocean. The $\delta^{18}O$ and sea surface salinity (SSS) over the southern Indian ocean controls by Evaporation and precipitation, except the polar front (> 54°S) where $\delta^{18}O$ and sea surface salinity controlled by fresh water input from Antarctica glacier (13).

In previous works (1) it is established that beyond 40° S the $\delta^{18}O$ of foraminifera show a deviation from the predicted value due to secondary disequilibrium effect. Thus, It is necessary to understand the oceanographic variation between polar fronts and southern Indian ocean. In the present study, we deal with the spatial variability of $\delta^{18}O$ of seawater and $\delta^{18}O$ of planktonic foraminifera from the southern Indian ocean to polar front transect.

4.2 Result:

The $\delta^{18}O$ of foraminifera value ranges from -2.50 ‰ to 4.07 ‰ (table 3). The predicted $\delta^{18}O$ of foraminifera value based on Bemis et al, (10) ranges from -2.03‰ to 3.2 ‰ (table 2). $\delta^{18}O$ of water ranges from -3.45 ‰ to 0.77 ‰. The $\delta^{18}O$ of foraminifera shows drastic increase at polar fronts.

Expedition name	Location		SST (ºC)	$\delta^{18}O$
	Latitudes	Longitudes		
	-South	East		
SOE X	-26.80	57.79	25.0	-2.059
SOE X	-31.05	58.00	21.3	-0.993
SOE IX	-31.53	57.49	25.0	-2.279
SOE X	-35.24	58.20	21.0	-1.336
SOE IX	-35.38	57.50	19.5	-1.032
SOE X	-39.84	58.49	16.5	-0.332
SOE X	-39.99	57.49	16.0	-1.100
SOE X	-39.99	57.49	16.5	-0.082
SOE IX	-40.09	58.52	16.0	-0.200
SOE X	-40.18	58.80	16.0	-0.300
SOE X	-40.91	58.58	16.5	0.058
SOE IX	-41.38	59.46	16.5	-0.342
SOE IX	-43.67	61.15	17.0	-1.064
SOE X	-45.69	62.63	8.0	1.285
SOE IX	-47.02	64.00	7.0	1.308
SOE X	-47.51	57.52	9.0	0.262
SOE X	-48.07	64.35	5.0	1.465
SOE IX	-49.02	64.10	5.5	1.643
SOE X	-50.78	63.85	4.5	1.437
SOE IX	-51.05	64.17	5.0	1.805
SOE X	-53.07	65.58	4.0	2.078
SOE IX	-54.01	68.49	4.5	2.037
SOE X	-54.02	68.23	3.0	2.341
SOE X	-56.43	69.03	2.5	2.423
SOE IX	-57.40	69.29	3.0	2.351
SOE X	-58.03	70.14	2.0	1.975
SOE X	-59.05	70.12	0.5	2.489
SOE X	-59.99	71.59	0.0	2.511
SOE X	-61.06	71.14	0.5	2.369
SOE X	-61.66	70.90	0.5	2.679
SOE IX	-61.95	70.08	2.0	2.475
SOE X	-63.01	69.99	1.5	2.066
SOE IX	-64.00	68.34	0.5	3.059
SOE X	-64.01	57.42	1.0	2.548
SOE X	-65.45	62.84	0.0	2.401
SOE X	-65.49	66.99	0.0	2.641
SOE X	-65.49	70.71	1.0	1.788
SOE X	-65.51	57.85	1.0	1.718
SOE X	-65.51	74.91	0.0	2.371
SOE X	-65.51	68.81	-0.5	-0.347

SOE X	-65.52	73.84	0.0	1.831
SOE X	-65.54	72.67	-1.0	2.414
SOE X	-65.73	60.93	0.5	2.159
SOE X	-66.35	74.79	-0.5	2.463
SOE X	-66.45	73.00	-0.5	2.773
SOE X	-66.60	76.42	0.5	2.009
SOE X	-66.78	74.73	0.0	2.421
SOE X	-66.80	73.31	0.0	2.301
SOE IX	-67.96	72.54	1.5	2.046

Table 2: Predicted value of $\delta^{18}O$ of shell taken to be at equilibrium with given values of $\delta^{18}O$ of water and SST over compiled locations from SOE IX and SOE X.

Sample name	**Location**		**δ ¹³C**	**δ ¹⁸O**
	Latitude (-S)	Longitude (E)		
Prasanna et al				
SOE11-12_T	-10.27	75.22	0.58	-1.47
SOE11-12_S12	45.59	56.30	-0.21	1.21
SOE11-12_S9	45.59	53.30	-0.33	1.56
SOE11-12_S9(2)	45.59	53.30	-0.14	1.91
SOE11-12_S18	50.00	57.30	0.11	3.07
SOE11-12_S21	52.59	57.30	-0.27	2.17
SOE IX				
SOE-IX_CTD19	-64.05	57.28	-0.24	3.20
SOE-IX_CTD22(1)	-50.26	57.30	-6.26	0.47
SOE-IX_CTD22(2)	-50.26	57.30	-2.70	0.27
SOE-IX_CTD22(3)	-50.26	57.30	-1.55	1.55
SOE-IX_CTD22(4)	-50.26	57.30	-1.85	2.69
SOE-IX_CTD22(5)	-50.26	57.30	-0.61	2.08
SOE X				
SOE-X_S3	-56.98	57.50	-3.320	4.071
SOEX-_S4	-51.00	57.49	0.715	0.042
SOEX-_S5	-47.49	57.49	-0.150	-2.505

Table 3 : Calculated $\delta^{18}O$ and $\delta^{13}C$ values of foraminifera from Prasanna et al., SOE IX and SOE X.

Isotope dilution was done initially with different proportions of MARJ1 with OMC. The reproducibility of $\delta^{13}C$ and $\delta^{18}O$ for isotope dilution were 0.03‰ and 0.2‰.

Sample Name	OMC fraction	MARJ1 fraction	$\delta^{18}O$ vpdb	$\delta^{13}C$ vpdb
OASIS_CAL_1	-	-	-11.18	1.25
OMC_350_MARJ1_195	0.642	0.358	-6.221	-2.116
OMC_500_MARJ1_195	0.719	0.281	-6.684	-2.565
OMC_650	1.000	-	-8.198	-4.083

Table 4 : $\delta^{18}O$ and $\delta^{13}C$ values with respect to different proportions of MARJ1 and OMC

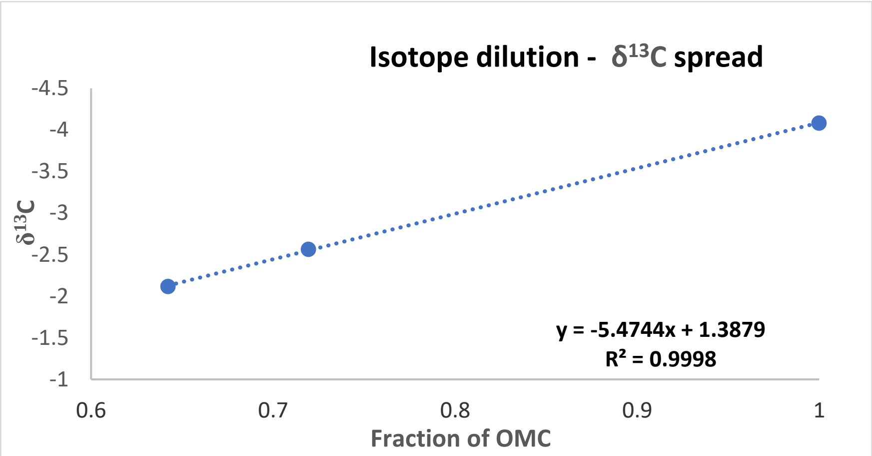


Figure 6 : Isotope dilution – $\delta^{13}C$ Spread

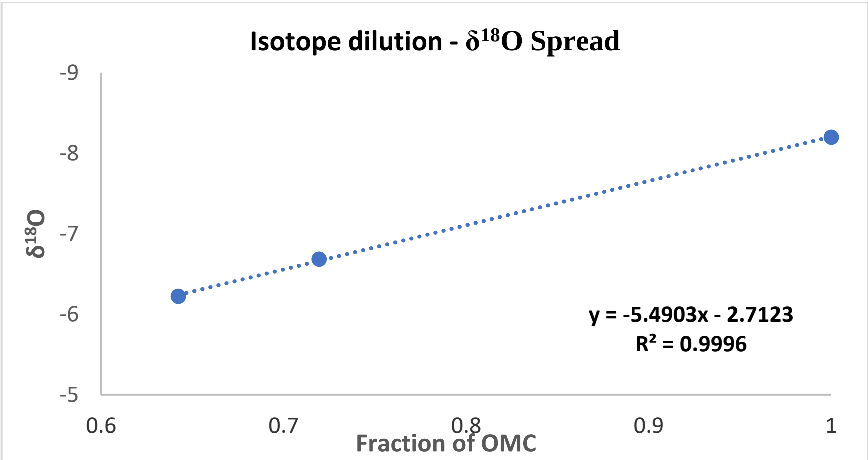


Figure 7 : Isotope dilution – $\delta^{18}O$ Spread

4.3 Discussion:

The oxygen isotopic composition of planktonic foraminifera depends on the oxygen isotope of seawater and calcification temperature. The relationship between $\delta^{18}O$ of foraminifera and reservoir given by Bemis et al, (10)

$$T\ (^{0}C) = 13.4 - 4.48 \times (\delta^{18}O_{shell} - \delta^{18}O_{water}) \qquad \text{(Equation 1)}$$

The above eqn. 1 derived based culture experiment of *G.bulloides* at 15°C to 25°C. We have derived expected $\delta^{18}O$ of *G.bulloides* over the transect using $\delta^{18}O$ of seawater and temperature based on Bemis et al, (10). The predicted $\delta^{18}O$ of *G.bulloides* shows the enriched value from polar fronts to poleward indicates cooling of temperature. We have compared measured $\delta^{18}O$ of mixed layer planktonic foraminifera from plankton samples taken during SOE IX and SOE X with predicted data. The observation is that the samples which are above the polar front follows the predicted $\delta^{18}O$ *G.bulloides* data with offset due to combined sampling of foraminifera in the present study. The observed deviation of $\delta^{18}O$ of planktonic foraminifera from the predicted value due to some reservoir influence rather than temperature and $\delta^{18}O$ of seawater. Our observation is consistent with the previous studies done over Southern Ocean (1,11,14).

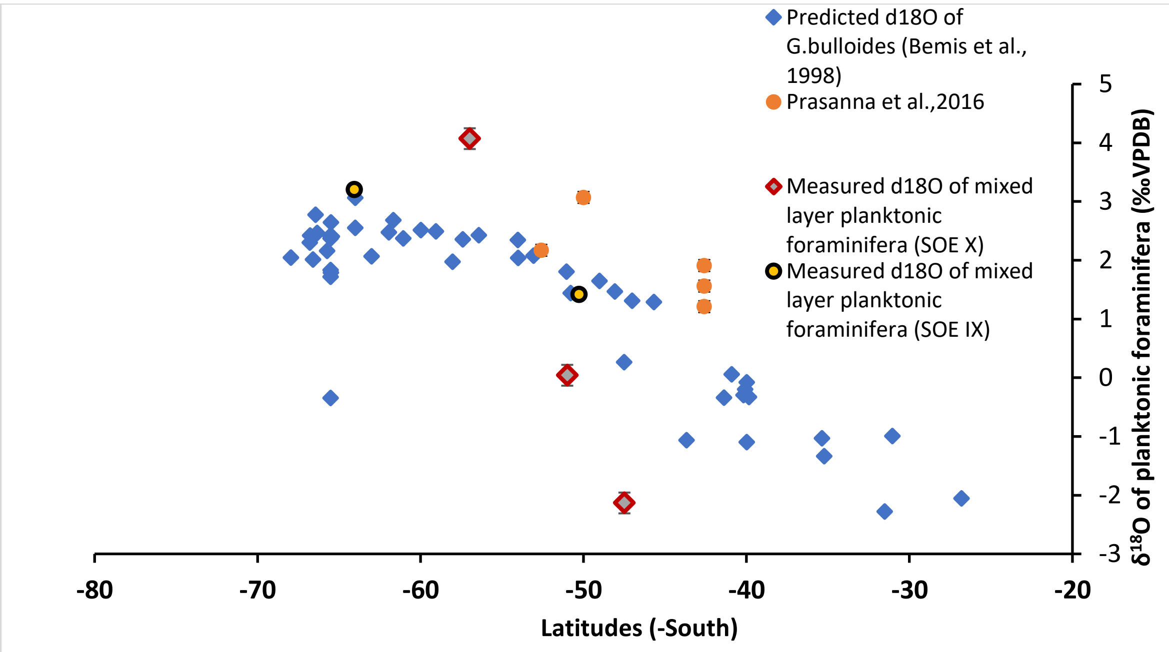


Figure 8: Graph between $\delta^{18}O$ (equilibrium and obtained) of foraminifera against Latitudes.

Combined from both expeditions this work identified species from 26 samples in the initial step. Analysed 9 (6 from SOE IX + 3 from SOE X) samples, designed isotope dilution method. $\delta^{18}O$ of planktonic foraminifera from polar fronts to southern pole depends not only on $\delta^{18}O$ of seawater and temperature, but also controlled by different reservoir parameter. With progressive southern latitudes, suffers disequilibrium effect.

Bemis et al., 1998 $\delta^{18}O$ seawater and temperature signature on $\delta^{18}O$ of *G.bulloides* can't be applicable for the basin such as less than $5^{0}C$.

4.4 Summary and Conclusion

Globigerina bulloides and *N. Pachyderma* retrieved from tow samples from two out of four locations across the Southern Ocean over the latitudinal range of 43°S to 64°S were analysed for $\delta^{18}O$ and $\delta^{13}C$ values. The measured $\delta^{18}O$ values are in good agreement with the earlier published values. Furthermore, this work positively reproduced the observation of Prasanna et al (2016) which suggests that with progressive southern latitudes the temperature established using the $\delta^{18}O$ thermometry suffer from the disequilibrium effect.

For isotopic analysis of foraminifera with fewer specimen amount (~100μg) Isotope dilution analysis can be used.

My suggestion based on present study is that the relationship between $\delta^{18}O$ of seawater over $\delta^{18}O$ of planktonic foraminifera and sea surface temperature should be studied for the region from polar front to south pole.

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