Icebergs as Climate Change Indicators

SCUBAnauts International

MASTERNAUT PROJECT

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Abstract

This project aims to analyze the size, shape, and types of Antarctic icebergs to see if they can serve as an early warning sign of a regional change in temperature and thus a sign of climate warming. Due to the extraordinary costs associated with deploying and maintaining scientific instrumentation in the Antarctic, this study utilized volunteer iceberg surveyors to help determine if icebergs can be a cost-effective tool to identify early signs of warming temperatures. These volunteer ice surveyors took observations of over 250 icebergs on the west side of the Antarctic Peninsula. Pinnacle and Dry Dock icebergs were found most commonly in the warmer Northernmost region, whereas Tabular and Wedge icebergs were more commonly seen in the cooler Southernmost regions. Icebergs with a scalloped wavy texture were also found most commonly in the warmer Northernmost region, whereas a broken texture was found more common in the south. With these results in mind, future studies can more easily prioritize the northernmost region's for continued measurements using advancing scientific equipment to expand understanding of climate warming in the Antarctic as a whole.

Introduction

Within the Antarctic Peninsula, temperatures are warming at 6 times the global average; increasing ~2.5°C between 1950 and 2000. (Davies, 2021). Annual mean temperatures are continuing to increase. (Davies, 2021). Changing pressure patterns result in flow anomalies, with cooling over East Antarctica and warming over the Antarctic Peninsula. (Davies, 2021). Due to the flow anomalies causing the Antarctic Peninsula to warm, it is important to see if there are warning signs that might pinpoint affected areas of warming in the Antarctic Peninsula. If these signs can be identified, then they can be used in other regions to see if they too, are experiencing warming temperatures. This project aims to establish a technique to see if icebergs can be used as a cost-effective tool to identify early signs of warming.

There are many different shapes of icebergs; the Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE) aims to standardize these shapes into 6 distinct classes (Figure 2-1). The classes include:

- **Tabular Iceberg**: A flat-topped iceberg. Most show horizontal banding.
- **Domed Iceberg**: An iceberg that is smooth and rounded on top.
- **Pinnacled Iceberg**: An iceberg with a central spire or pyramid, with one or more spires.
- **Wedged Iceberg**: An iceberg that is rather flat on top and with steep vertical sides on one end, sloping to lesser sides on the other end.
- **Drydocked Iceberg**: An iceberg that is eroded such that a U-shaped slot is formed near or at water level, with twin columns or pinnacles.
- **Blocky Iceberg**: A flat-topped iceberg with steep vertical sides.

Researchers found that the temperature of meltwater determines the shape of the ice, due to the water's density dependent on temperature. (Buchanan, 2022). By linking the molecular-scale effects underlying water's density anomaly to the macroscale flows that imprint the surface, these results show that the morphology of melted ice is a sensitive indicator of ambient temperature(Weady, 2022). This project hypothesizes that warmer and colder regions of the Antarctic Peninsula will have differing iceberg types. Changes in warming can be identified by an increase or decrease in the sightings of particular iceberg types.

Figure 2-1.

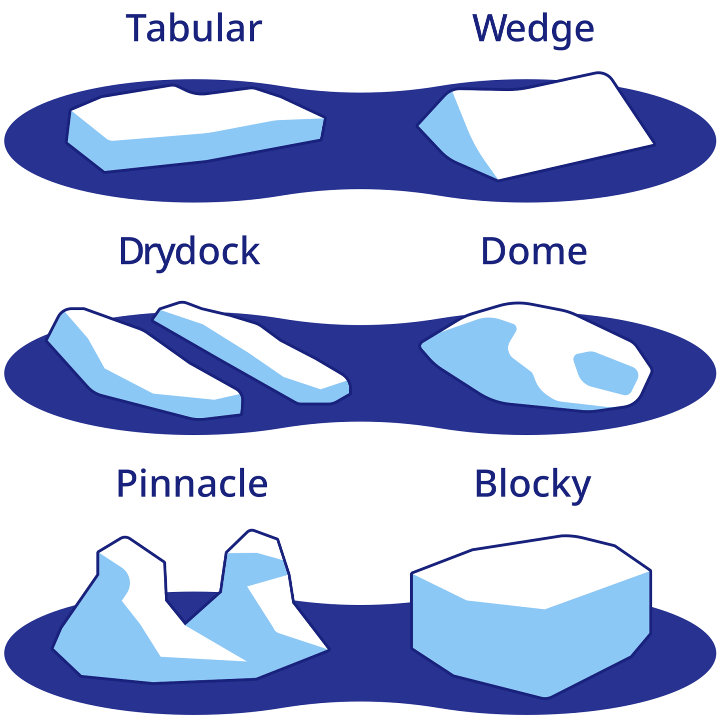


Fig. 2-1. Visual representation of the 6 classes of icebergs. Photo courtesy of Romain.

Methodology

This project was conducted along the west coast of the Antarctic Peninsula in six different locations, with two surveys conducted per day, once in the morning and once in the afternoon for a total of three days; 28 FEB 2024-01 MAR 2024. All surveys were completed in broad daylight. The study sites were:

- Palmer Science Station (64 46.4’S, 064 03.4’W)
- Paradise Bay (64 53.5’S, 062 52.8’W)
- Useful Island (64 52.5’S, 062 53.4’W)

- Foyn Harbour (64 32.1 S, 062 00.1’ W)
- Palaver Point (64 32.5’S, 061 57.1’W)

The study sites can be split up into 3 regions; Northernmost, Middleground, and Southernmost. Northernmost includes Foyne Harbor and Palaver Point, Middleground includes Palmer Station, and Southernmost includes Paradise Bay and Useful Island. These geographic regions were determined based on relative distance from the South Pole (figure 3-1).

Figure 3-1. Map of study sites

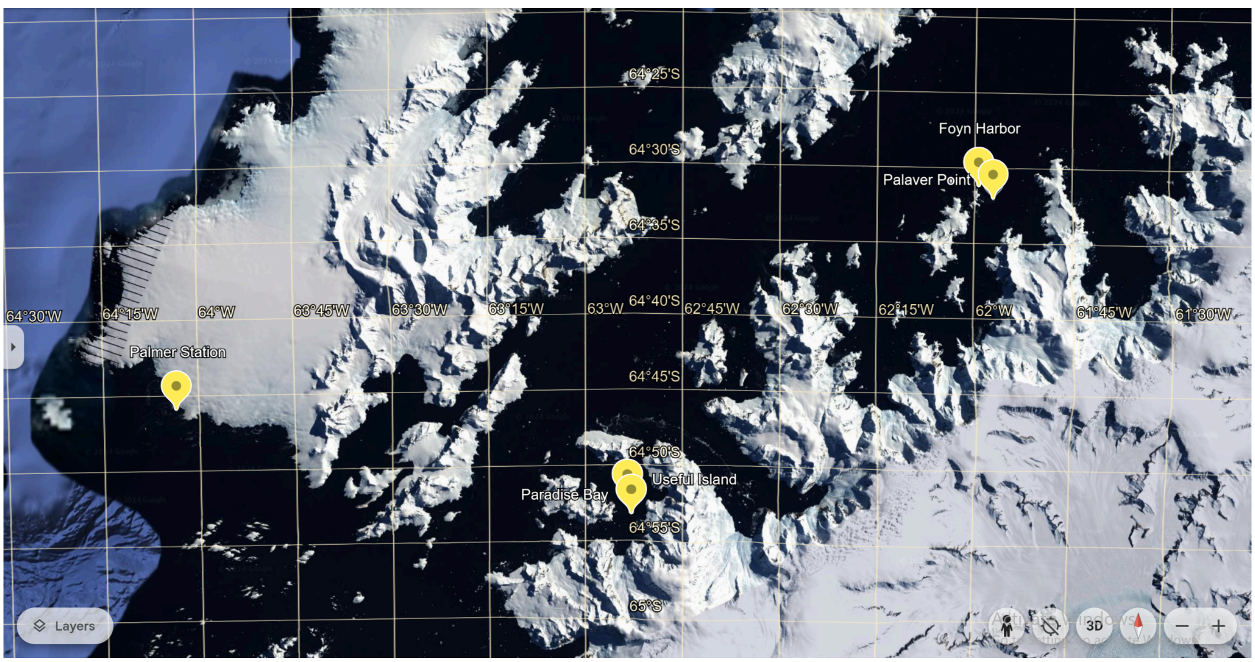


Fig. 3-1. Map of study sites (yellow pins) on the Antarctic peninsula. North oriented at the top of the figure. Photo from Google Earth.

At each location, a team of 13 volunteer iceberg surveyors took observations using the survey sheet in Appendix 2-1 and collected data from the deck of the expedition ship the M/V Orteilius. Volunteers stood on either side of the ship and attempted to collect data on 20 icebergs. Due to competing shipboard tasks and projects, survey times or lengths were not standardized.

The survey sheet included observations on the iceberg's size, class, color, texture, whether it appeared stranded (in shallow water), and any notes or particular remarks on the iceberg. To determine the iceberg's size, surveyors used references to gauge the size of the iceberg, i.e. a football field. To determine the iceberg's class, descriptions from MANICE Chapter 1, Paragraph 5, Part 2: "Shapes of Calved Ice of Land Origin" were used. At the end of each survey day, the group of volunteer ice surveyors would discuss the icebergs and their notes, and then the data was entered into a spreadsheet. Data was then converted into pivot tables and analyzed by comparing two factors in a bar graph; Class vs. Location and Texture vs. Location. Due to the short notice to train the volunteers and the duration of the data collection portion of the project, accounting for experience and bias was difficult, but was taken into consideration. All surveyors were trained at relatively the same time and all had no prior experience. To account for surveyor training bias, volunteers were asked to take photos and review them with the team before the final iceberg type was recorded.

Results

Due to the high likelihood of duplicates, all of the data collected was gathered into a spreadsheet and arranged into a pivot table and then a bar chart (Figure 4-1). The pivot table used for the bar charts used the percentage of locations to help account for the possibility of duplicate icebergs. See tables 4-1, 4-2, 4-3, and 4-4.

Table 4-1. Number count of Class ID

	Class ID						
Site Name	Blocky	Dome	Dry Dock	Pinnacle	Tabular	Wedge	Grand Total
Foyne Harbor	4	3	2		1	3	13
Palaver Point	6	1	3	5		3	18
Palmer Station	9	1	5	2	3	10	30
Paradise Bay	29	8	8	10	20	30	105
Useful Island	24	8	6	7	19	31	95
Grand Total	**72**	**21**	**24**	**24**	**43**	**77**	**261**

Table 4-1. Number count of Class ID (Columns) by Location (Site Name) (Rows). Possible skewed data not used for the Bar Chart (Graph 4-5).

Table 4-2. Percentage of Class ID

	Class ID						
Site Name	Blocky	Dome	Dry Dock	Pinnacle	Tabular	Wedge	Grand Total
Foyne Harbor	30.77%	23.08%	15.38%		7.69%	23.08%	100.00%
Palaver Point	33.33%	5.56%	16.67%	27.78%		16.67%	100.00%
Palmer Station	30.00%	3.33%	16.67%	6.67%	10.00%	33.33%	100.00%
Paradise Bay	27.62%	7.62%	7.62%	9.52%	19.05%	28.57%	100.00%
Useful Island	25.26%	8.42%	6.32%	7.37%	20.00%	32.63%	100.00%
Grand Total	**27.59%**	**8.05%**	**9.20%**	**9.20%**	**16.48%**	**29.50%**	**100.00%**

Table 4-2. Percentage of Class ID (Columns) by Location (Site Name) (Rows). Data used for Bar Chart (Graph 4-5).

Table 4-3. Number count of Texture

	Texture			
Site Name	B	S	W	Grand Total
Foyne Harbor		7	6	13
Palaver Point	3	7	8	18
Palmer Station	9	12	9	30
Paradise Bay	31	40	34	105
Useful Island	34	31	30	95
Grand Total	**77**	**97**	**87**	**261**

Table 4-3. Number count of Texture (Columns) by Location (Site Name) (Rows). Possible skewed data not used for the Bar Chart (Graph 4-6).

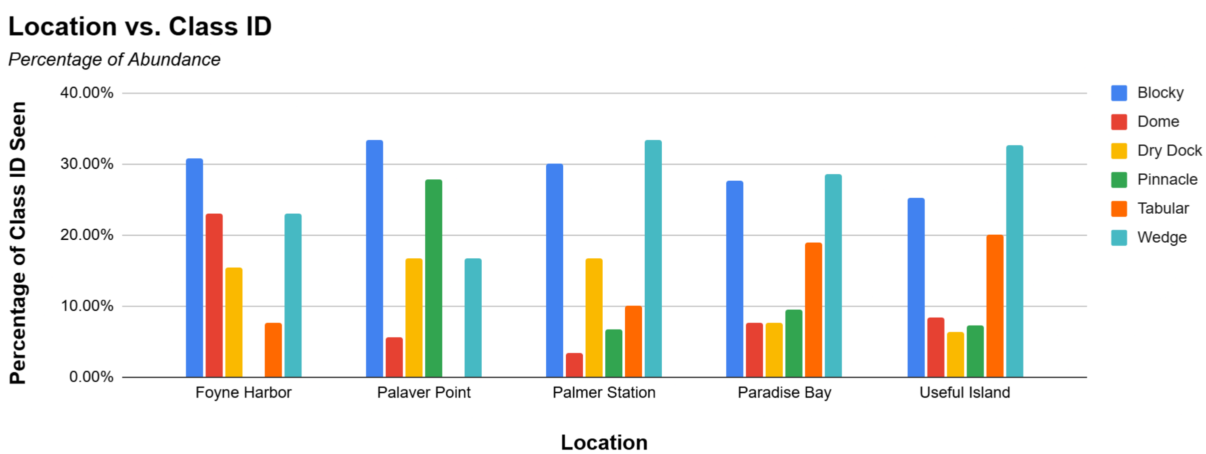
Table 4-4. Percentage of Texture

	Texture			
Site Name	B	S	W	Grand Total
Foyne Harbor		53.85%	46.15%	100.00%
Palaver Point	16.67%	38.89%	44.44%	100.00%
Palmer Station	30.00%	40.00%	30.00%	100.00%
Paradise Bay	29.52%	38.10%	32.38%	100.00%
Useful Island	35.79%	32.63%	31.58%	100.00%
Grand Total	**29.50%**	**37.16%**	**33.33%**	**100.00%**

Table 4-4. Percentage of Texture (Columns) by Location (Site Name) (Rows). Data used for Bar Chart (Graph 4-6).

A total of 261 Icebergs were recorded across all sites. The Wedge class was the number one class reported throughout 75% of the sites and appeared at every site, making up 29.5% of the overall class types. This was followed by Blocky, which also appeared at every site and made up 27.59%. Tabular was the third most common but did not appear at Palaver Point and only made up 16.48% of the total. Pinnacle and Dry Dock were tied for fourth at 9.20% of the total, but Pinnacle did not appear in Foyne Harbor, whereas Dry Dock appeared in all. Finally, Dome was the least common throughout all sites, making up a mere 8.05% of the count, yet it also appeared in every site.

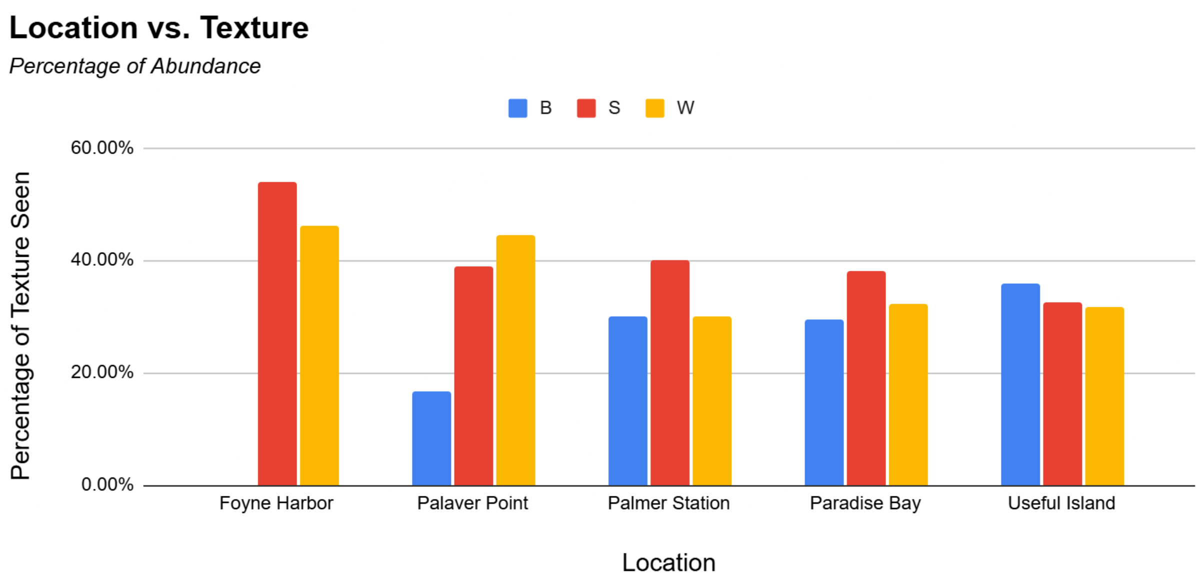
Graph 4-5. Location vs. Class ID



Graph 4-5. Percent Class ID types across all five study site locations. A complete compilation of all surveyor's data in all locations.

Smooth was the texture reported most throughout 75% of the sites, and appeared in every site and made up 37.16% of the total making it the overall highest-sighted texture. Wavy was the second texture most reported and made up 33.33% of the total. Broken was the third and did not appear in Foyne Harbor, but made up 29.5% of the total. (Graph 4-2)

Graph 4-6. Location vs. Texture



Graph 4-2. Percent textures across all five study site locations. B-Broken (Blue), S-Smooth (Red), W-Wavy (Yellow). A complete compilation of all surveyor's data in all locations.

Discussion

To better understand the impact of temperature differences on icebergs, the study sites were divided into three regions. Temperatures decrease the closer you get to the South Pole, therefore the Northernmost locations can be assumed to have the warmest average temperature and the Southernmost locations with the coldest. This is because studies done by Cambridge University have shown that there is a temperature decrease of approximately 0.84°C per degree of latitude southward. (Martin, 2017) It is expected that the Middleground will have temperatures somewhere in between.

Blocky and Wedge class icebergs are the most common types of icebergs overall. This is likely because of their simple geometric shapes and how easily ice can take on this shape at any temperature. Palaver Point seems to have a larger amount of Pinnacle icebergs than any other location. It is important to recognize that skewed data and duplicate icebergs could cause this by falsely inflating the reported observations. However, due to higher temperatures (i.e. quicker melting), it is easier for the iceberg to form one or more pinnacle spire(s). This is because the cold liquid nearest the ice surface is denser than the warmer water further away and sinks, drawing in warmer water from above, melting the upper zone faster, and causing the upright pinnacle to form (Buchanan, 2022). Throughout the Northernmost locations, the fourth most common class to be seen is the Dry Dock class, which is the third most common class to be seen at the Middleground. These results may be skewed since Dry Dock icebergs can be mistaken or similarly classified to Pinnacle icebergs that are lower in the water column.

Figure 5-1 Shapes of ice affected by temperature

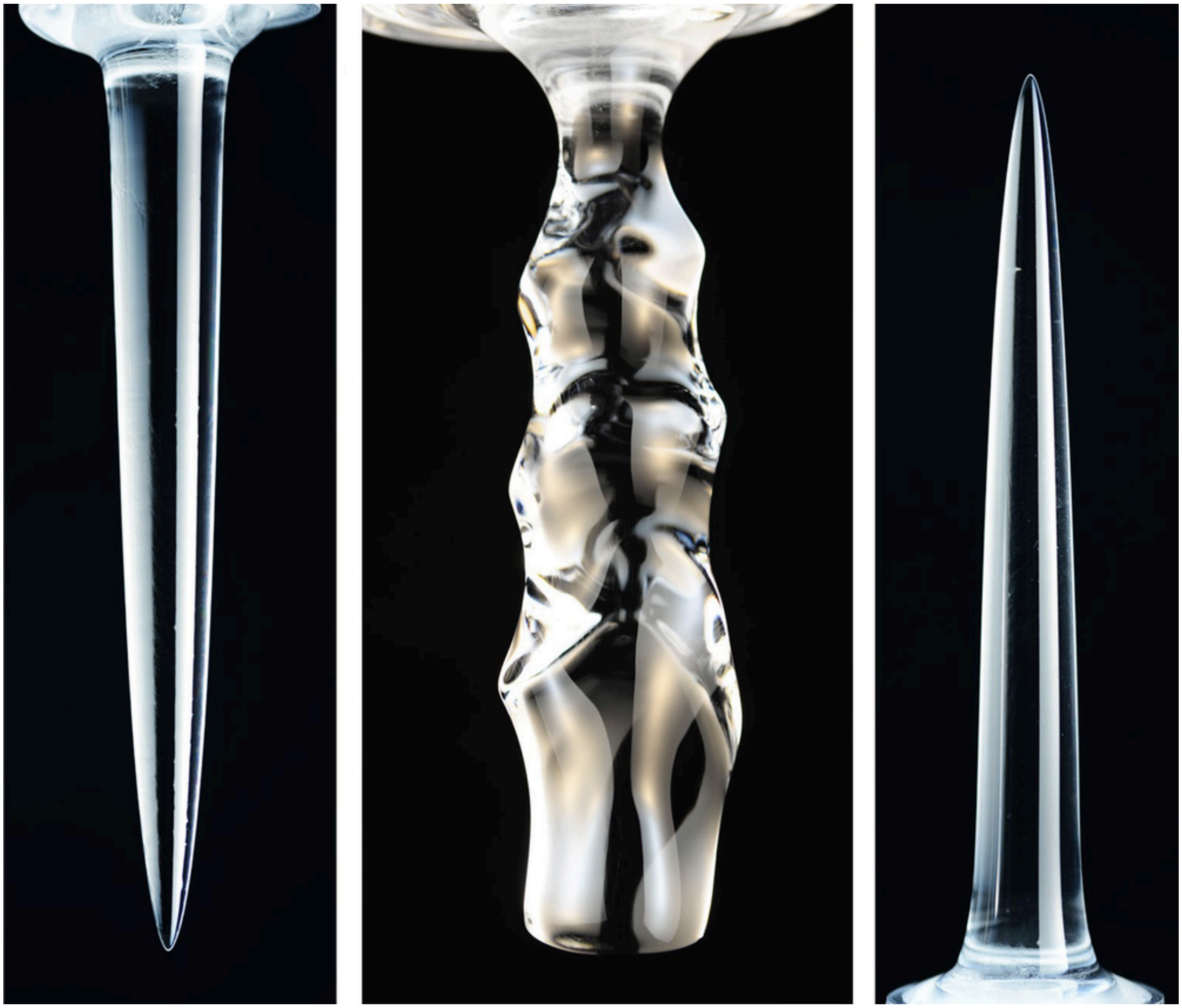


Fig. 5-1. The temperature of the water bath determines the shape of a melting cylinder of ice: 4 °C (left), 5.6 °C (center), and 8 °C (right). Photos courtesy of Department of Physics, New York University, New York, New York 10003, USA.

Pinnacle and Dry Dock class icebergs appear to occur more often in the Northernmost locations. This could be because the warmer mean temperatures are causing the uneven melting seen in the figure above (Fig. 5-1). This is important to note, because knowing where these icebergs appear more commonly could aid with ship navigation since both Pinnacle and

Dry Dock are easier for ship navigators to see at night. The distinct shape can not easily be mistaken for a glacier due to their distinct spires making them a useful tool. By identifying regions with a large number of Pinnacle and Dry Dock icebergs further south, researchers can use that as a sign and concentrate temperature measurements in that region to see if it has increased.

The texture of an iceberg also seems to be linked to geographic location, as broken textures are seen more often in the Southernmost region and smooth textures are seen more often in the Northernmost region. This could be caused by the iceberg's inability to melt and smooth out causing a more broken appearance further south in the colder temperatures. Smooth was the most abundant texture making up 37.16% of the total. This may be because surveyors were taking data from the deck of the ship at a great distance from the iceberg. This distance may cause rough or wavy textures to appear smooth leading to biased data. However, the wavy textures were the most spotted texture after smooth. This may be because the meltwater is likely denser than surrounding water in some places and less dense in others, leading to more complex flows. Simulations conducted by the University of New York showed that colder, less dense water near the ice surface flows upward, while warmer, denser water, millimeters away, flows downward. A vertical row of vortices forms as these opposing flows move past each other. These “convection rolls” carve the wave-like pattern of melting because they bring warmer liquid against the ice surface. (Buchanan, 2022)

Spire-type icebergs seem to appear in warmer temperatures. To further support this conclusion, future experiments should be conducted in the Arctic as it is a comparatively more tropical climate than Antarctica to see if a more abundant amount of Pinnacle and Dry Dock icebergs appear. More research should be conducted in areas closer to the south pole (such as East Antarctica and the McMurdo Sound area), to see if fewer Pinnacle and Dry Dock appear. If this is shown, then it will strengthen support of the conclusions, whereas if the adverse results are shown, then it will help further the understanding of the impact of temperature on icebergs beyond this limited study.

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Citations

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- **"'Shapes of Calved Ice of Land Origin.'" *Manual of Ice (MANICE)*, 2016.**

Appendices

Iceberg Survey Sheet:

Name: Date/Time: Site (Name and Lat/Long): Site Name:
Lat:
Prior Night's Wind Conditions: Long:
Site Features (Channel, Harbor, etc.):
Location on ship: Bow, Port, Starboard, Stern, Bridge

# of Icebergs	Size	Class ID	Color	Texture	Stranded	Notes/Remarks
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Size: S, M, L / Class ID: Tabular (flat top), Wedge (incline), Drydock (connected underwater), Dome (round top), Pinnacle (1 or more spires), Blocky (misc. blocky shape) / Color: White and Blue, Black, Green / Texture: Wavy, Smooth, Broken / Stranded: Close to shore, estimated to be stranded on the bottom answer with yes or no.

Filled Out Iceberg Survey Sheet Example:

Name: Sarah Vinson Date/Time: Feb 28 2024 11:45 AM Site (Name and Lat/Long): Site Name: Palmer Station
Lat: 64° 46′ S
Long: 64° 03′ W

Prior Nights Wind Conditions:

Site Features (Channel, Harbor, etc.): Harbor glacier nearby Location on ship: BOW, PORT, STBD, ~~STRN~~, BRDG

# of Icebergs	Size	Class ID	Color	Texture	Stranded	Notes/Remarks
1	M	Blocky	W + B	Broken	N	
2	L	Wedge	W+B	Wavy	N	
3	L	Dry Dock	W+B	S	N	
4	S	Tab	W+B	S	N	
5	M	DryD\Pin	W+B	S	N	
6	L	Dry Dock	W+B	S	N	
7	M	Dry Dock	W+B	Wavy	N	
8	M	Wedge	W+B	S	N	
9	S	Block	W+B	Wavy	N	
10	L	Block	W+B	S	N	
11	S	Wedge	W+B	Broken	N	
12	L	Tab	W+B	S	N	
13	L	Block	W+B	Wavy	N	
14	M	Wedge	W+B	Wavy	Y?	
15	M	Tab	W+B	S	~~N~~ Y	
16	M	Pin	W+B	Wavy	Y	
17	L	Block	W+B	Wavy	~~N~~ Y	
18	M	Wedge	W+B	Wavy	N	
19	L	Block	W+B	S	N	
20	L	Block	W+B	Broken	N	

Size: S, M, L / Class ID: Tabular (flat top), Wedge (incline), Drydock (connected underwater), Dome (round top), Pinnacle (1 or more spires), Blocky (misc. blocky shape) / Color: White and Blue, Black, Green / Texture: Wavy, Smooth, Broken / Stranded: Close to shore, estimated to be stranded on the bottom answer with yes or no.