

Relationship of Ice Crack Morphology of the Southern Greenland Ice Sheet to Iceberg Calving in the North Atlantic

Mr. Brian Campbell, Elizabeth City State University
Ms. Sharain Halmon, Elizabeth City State University
Lloyd Mitchell Ph.D., M.P.H., R.S., Elizabeth City State University

Abstract

In an effort to understand the influence of ice crack geomorphology on the on iceberg calving, 142 images of newly calved icebergs were analyzed using a newly developed crack classification system. Classification began by placing each iceberg's primary crack onto a classification grid containing eight categories. The eight categories were: Linear (being straight or slightly curved), Lightning (stair stepped at right angles), Arched (a slow definite curve), Multi-Arched (having one or more arched crack), Married (combining two or more of any category), Honeycomb (a field of uniformed shaped cracks), Jagged (sporadic, random resembling lightening with out straight angles) , and Other (any geometry that does not conform to the above categories). Additionally, all iceberg images were subjectively classified into one of these six categories; baby bergs (the size of a small vehicle) small berges (the size of a small house) medium bergs (the size of a large house or small building) large bergs (the size of a large building or skyscraper) and mega berges (greater than the size of a city or small state). We have also chosen to differentiate the icebergs studied from a shipping hazard standpoint, to this end Babybergs, as well as surface ice chunks, and ice floe chunks, were not included in this study. Additionally in preparation for this study researcher made preliminary contact with several organizations such as the international ice patrol, NASA, IPY and other organizations that are concerned with the tracking and monitoring of iceberg calving and migration. Results of data analysis showed: 100% (n=8/8) Mega bergs calved from linear cracks. 87.5% (n=14/16) large icebergs calved from linear cracks with the remaining 12.5% (n=2/16) calving from lightning cracks. Of the medium icebergs

50% (n=32/64) calved from linear cracks with 15.63% (n=19/64) calving from lightning cracks and 12.5% (n=8/64) calving from married cracks. Of the small icebergs (n=54), which were the most difficult to visualize, 68% (n=37/54) showed calving from married with arch(es) or married with jagged or other cracks , 12.96% (7/54) calving form jagged cracks, 7.40% (4/54) calving from lightning cracks, with the remaining percentages calving from other crack types. The conclusion of this study indicates that linear cracks have been identified as the primary crack type for mega bergs as well as the majority of large bergs. The occurrence of a linear primary crack decreases with the size of the ice berg.

1. Introduction

Our world is dominated by water, for the duration of human existence we have congregated to the water as a source of life, and a mode of transportation. All of the world's major cities are built on the major waterways and lakes that transect the continents. For generations, we have studied water's liquid form. Through the study of the changing and the navigation of the world's ocean currents, we have developed a close relationship with liquid water and it properties. Still a full third of the earth's water is found in it solid form frozen within glaciers.

2. Data collection

Glaciers, which will play a large part in our study, are categorized primarily

by the area that they cover. The smallest form known as Alpine Glaciation refers to the localized snow caps that are found on mountains and at high altitudes, such as in the rocky of western America, and the Himalayas. Continental Glaciation is the term given to instances in which large bodies of land are completely consumed by the by a glacier during all or most of the year. The most widely studied occurrence of this is on the Greenland sub-continent where from the month of November through the warming season in April the glacier extends into the ocean off its cost for miles. The third and largest type of glaciation is found at the pole in the form of planetary ice caps. On earth, these glacial masses span thousands of miles from the poles to the edge of the Arctic Circle at 66.33 degrees latitude north and south. The Antarctic ice cap covers 12.5 million square kilometer and contains over 7 million cubic miles of ice (Elbert) accounting for nearly 70% of the worlds fresh water.

2.1 Glacial Movement

Glaciation occurs as precipitated ice in the form of snow and sleet amass over the glaciers center. Eventually the weight of the ice at the center of the mass begins to force the body of the glacier down and out. The glacier, as it is forced outward, flows along the valleys and slopes of the host mountain range seeking lower elevation. The solid ice is able to flow because of a thin layer of water that remains beneath the glacier acting as a lubricant, and because of its structural composition. The solid ice of a glacier is composed of small microscopic particles of ice. As the ice particles are compressed, they begin to slide over around and between one

another in a slow but continuous forward progression. The fastest moving glacier in recorded history is found on Greenland's western coast, the Quarayaq Glacier advances at a pace of 20 - 24 meter per day.

2.1.1 Seasonal calving

All glaciers on earth follow a growth thaw seasonal pattern. In the winter months while the temperatures remain at a sufficient level. The accumulation of snow and ice cause glaciers to expand. In many cases the expanding glacier will exceed the limits of the continental host body and flow out to spread across the surface of the ocean. These oceanic ice masses are referred to as ice sheets or ice tongues depending on the area that each cover. An ice tongue refers to an ice peninsula; these peninsulas, which can grow to be hundreds of miles in length, are thin by comparison, measuring 10 to a hundred miles across. As an ice sheet extends into the ocean it is acted upon by forces which over time will erode and batter the ice sheet. The forces that act against the ice sheet can be tidal, atmospheric, or related to the shear weight or buoyancy of the ice sheet. As the temperature warms, either by the changing of the seasons or by changes in latitude, the ice begins to thaw further weakening its structural integrity. When the integrity of ice can no longer withstand the forces that are acting against it is said to reach the point of failure, at this point a portion of the ice sheet or ice tongue will slough off into the ocean, forming an iceberg. This process is referred to as calving.

Calving season occurs mainly during the warmer summer months between April and July. During this time Greenland's ice sheets produce hundreds

of icebergs of varying sizes each year(IIP).

2.2 Area of Study



Figure 1

Greenland was chosen for this study because of this activity and its proximity to the North Atlantic trade routes. Greenland's southern coast lies just north of the 50 degrees latitude with its most northern settlement placed just south of 80 degrees latitude, representing some of the most northern human settlement on earth. The weather in Greenland is sub-polar, with average temperatures falling below freezing for most of the year. Meteorological conditions in Greenland are greatly affected by the North Atlantic Current, and a steady southwesterly wind that blows down from the poles. Most of Greenland's human settlements are found on the warmer western coast, which receives more daily sun, and thus has a more active calving season.

2.2.1 Ice

In preparation for this study, the researcher also took a look at the structural properties of ice. In researching this area, it was found that there are twelve forms in which ice can be found. The definition of these forms is dependent on the pressure and temperature at which it formed and the impurities that can be found within.

Each of these twelve stages show a different level of structural integrity and molecular stability.

Most of the world's ice is found in two of the twelve categories, cubic ice and hexagonal ice, named for the structure of the molecular bond that is formed on solidification. The first cubic ice is the preferred state for ice particles measuring less than a nano-meter in length at very low pressure. This form of ice is found primarily in the upper atmosphere where these conditions are stable. The second, hexagonal ice is the preferred form for ice found at surface pressure, thus it is considered the natural form for ice. The structure of these forms of ice is relatively unstable when compared to the rest of earth's solids, and can vary drastically with slight changes of pressure. This instability comes from a combination of ice's high solidification temperature and the loosely uniformed way that the molecular bonds are formed. The molecular stability of ice increases with the pressure at which it forms, with Ice 12 being of the highest pressure and most stable. However due to the instability of ice's molecular bond it is difficult to sustain a sample of ice twelve outside of laboratory conditions. It was evident that the uniformed structure and the weak molecular bonds insure that no matter the form ice took it would be structurally brittle.

Humans first became interested in the structural integrity of ice during WWII when a study was launched to determine whether it was feasible to use icebergs as air craft landing strips in the North Atlantic. It was found during this study that the structural integrity of ice on a large scale was insufficient to facilitate a landing strip. It was also found that on a large scale the size of the composing particles, and the impurities held within

the ice could drastically change its tensile strength. For instance, the addition of wood chips was able to increase the integrity of ice to that of concrete. Schulson(1999),

3. Methodology

The first stage of research was a period of broad scope data collection. During this stage, the team members became familiar with the areas of study and the terms, theories, and processes involved with glaciations. Also during this stage, team members made initial contact with several organizations that have come to be affiliated with the monitoring of iceberg calving and migration, including the International Ice Patrol(IIP) the International polar year (IPY) and Eco-photo explorers (EPE). Additionally contact was made with organizations such as NASA, and the EROS Data Center (EDC), which contain the nations database of satellite imagery spanning the last decade from 1996-2006, which we had chosen as our research period.

The satellite databases were reviewed along with images from the Webpages of several amateur and professional photographers. Satellite and photographic images were selected from those amassed, to be visually examined against a set of outlined parameters. The parameters were used to find icebergs that would be suitable for study. Out of the images that were analyzed, from them 142 newly calved icebergs were identified for study. The ice bergs used were qualified as newly calved based on the extent of surface erosion, seasonality of the image, or accompanying text.

After identification was completed, the chosen icebergs were sorted by size into one of five categories; baby bergs, and small, medium, large, and mega bergs, and as was stated in the abstract those that qualified as baby bergs were discarded as harmless from a shipping stand point.

Each ice bergs that was included in the study was given a identifying number if one had been preassigned either by a government agency it was used however for some of the smaller bergs studied it became necessary for a team member to assign one.

The primary crack of each of the subject icebergs was identified through visual inspection of file photos. From these observation we derived the percentage of each shape of primary crack within each size category. The resulting statistical information was used to determine the



Figure 2

relationship between primary crack and the calved icebergs.

4. Results

The results of the data analysis showed that there was a direct relation between the linearity of an icebergs primary crack and the potential size of the iceberg. The largest class the Mega-bergs were calved exclusively by linear cracks, and the smallest classification the small-bergs containing no bergs that calved from a linear crack. The ratio of a

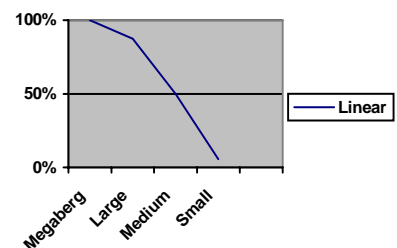


Figure 3

linear primary crack slowly decreased in a smooth arithmetic slope as the bergs reduced in size. Non-linear primary cracks at present calving crack off decrease as the berg size increases. Total length of primary crack at crack off may be the most significant factor in large berg and mega berg calving

It was also found that there is a relationship between linear cracks and a sudden break. This was found through the analysis of the secondary crack (those that form and fail after the initial calving) all of which were linear in nature. This uniformed cracking is due to the weakly bonded but uniformed structure of the ice molecules which readily break along set axis's. the progress of our study was limited both by the amount of time that was available for the study and the limited amount of preexisting information. To aid in the continuance of the project a standard classification system for ice sheet cracks needs to be created and accepted by glaciologists, to increase the availability of useable information.

5. Recommendations for further study

It is recommended by this team that future attempts should be made to continue collaboration with the EROS Data Center to expand access to the GIS images of Ice Sheets, and other geographical sites.

This will allow for the expansion of project imagery data base and strengthen classification system for future research teams.

The analysis of the ice snouts be pursued in order to identify historical ice berg calving as it relates to annual meteorological processes.

With this accumulated information as a starting point the next phase of

the project will be to develop a iceberg calving prediction model through the application of primary crack research crack patterns.

6. References

International ice patrol, 2004: *Data Archives*, retrieved from http://www.uscg.mil/lantarea/iip/General/data_archive.shtml on the date of March 28, 2006

Eco-photo Explorers (2005), *The Icy Landscape*, retrieved from <http://www.ecophotoexplorers.com/default.asp> on the date of March 25, 2006

T Devitts, (2003) *Massive Antarctic Iceberg Breaks in Two*. Retrieved from <http://www.news.wisc.edu/archives.php> on the date of march 26, 2005

D. Pendick, (2003), *ice and icebergs*, retrieved from <http://www.pbs.org/> on the date of April 1, 2006

M.Chaplin (2006), *Water Structure and Mechanical Behavior*, retrieved from <http://www.lsbu.ac.uk/water/index.html> on the date of april1, 2006

Iceberg. (2006). *Encyclopedia Britannica*. Retrieved from <http://www.britannica.com/eb/article-65700> on the date of April 1 , 2006 , from Encyclopedia Britannica Premium Service

E. M. Schulson(1999),*The Structure and Mechanical Behavior of Ice*, retrieved from <http://www.tms.org/pubs/journals/JOM/9902/Schulson-9902.html> on the date of April 1, 2006.

CBC (2005), *Ice Tongues and Ice shelves* retrieved from <http://www.thewe.cc/weplanet/poles/antarcti/iceshelv.html> on the date of april 1,2006

Chylek P. ; Box J.E ; Lesins G. (2006),
Global Warming and the Greenland Ice
Sheet. Retrieved April 11, 2006

From Ingenta Connect Website:
<http://www.ingentaconnect.com/content/ku/clim/2004/00000063/F0020001/05140445>

The Climate of Greenland (2006). A part
of [The New York Times Company](#).
Retrieved from About, Inc. Website:
<http://weather.about.com/library/world/blworld-greenland.htm?terms=Southern+Greenland>