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# Physical Properties of the US ITASE Firn and Ice Cores from South Pole to Taylor Dome

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**Final Report for Period:** 06/2009 - 05/2010

**Submitted on:** 07/20/2010

**Principal Investigator:** Meese, Debra A.

**Award ID:** 0538494

**Organization:** University of Maine

**Submitted By:**

Meese, Debra - Principal Investigator

**Title:**

The Physical Properties of the US ITASE Firn and Ice Cores from South Pole to Taylor Dome

### Project Participants

#### Senior Personnel

**Name:** Meese, Debra

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

**Name:** Baker, Ian

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Dr. Baker's involvement thus far has been minimal since we don't have any samples back from the field. However, he has been involved in working with students on developing the SEM methodology. His involvement will increase in April/May when we have the samples.

**Name:** Mayewski, Paul

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Dr. Mayewski served on Nicole Spaulding's committee and is the Chief Scientist for the program.

**Name:** Hamilton, Gordon

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Dr. Hamilton served on Nicole Spaulding's committee and was a member of the field party.

#### Post-doc

**Name:** Obbard, Rachel

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Rachel is doing CT imaging on ITASE firn to compare to SEM images.

#### Graduate Student

**Name:** Spaulding, Nicole

**Worked for more than 160 Hours:** Yes

**Contribution to Project:**

Ms. Spaulding is a graduate student at the University of Maine, funded under this project. She has been reviewing previously published grain size data/methodologies and comparing them techniques. She has also been developing the methodology on the SEM on old ITASE samples. Now that we have a series of photographs, she's working with the data and new interpretation methods.

**Name:** Sneed, Sharon

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Ms. Sneed completed the chemistry for the co-registration of elemental chemistry, soluble chemistry, SEM and properties.

**Undergraduate Student**

**Name:** Johnson, Brooke

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Brooke has assisted doing stratigraphy in the cold room and transferring data to the computer.

**Technician, Programmer**

**Name:** Sieg, Katherine

**Worked for more than 160 Hours:** No

**Contribution to Project:**

Ms. Sieg recently completed her MS working on SEM analyses of Siple Dome sections. She has assisted in training and provided oversight in obtaining the appropriate machined parts for the new cold stage on the SEM.

**Other Participant****Research Experience for Undergraduates****Organizational Partners****University of Washington****U.S. Army Cold Regions Research and Engineering Laboratory****University of Maine**

There are several ITASE grants at the University of Maine, including this one, but we are all working together on the same set of cores and sharing data.

**Dartmouth College Thayer School of Engineering****Other Collaborators or Contacts**

I've been in contact with Sepp Kipfstuhl at the Alfred Wegner Institute regarding his work on firn and CT studies. We had many discussions at the Firn Workshop at Dartmouth College with numerous international colleagues.

**Activities and Findings****Research and Education Activities:**

We have perfected the techniques of using the SEM for grain size rather than the traditional method, where firn sections are altered by the use of the often toxic fillers required when using a universal stage. A new cold stage, which required designing and machining new parts, that was accomplished by Dartmouth Engineering students, has worked well.

Specific activities include:

Imaging of samples from 8 cores from 2006 and 2007 field seasons.

Collection of c-axis orientation patterns.

Collection of misorientation patterns.

Collection of EDS chemistry for 2007 samples.

Collection of Micro CT images of several samples.

Stratigraphy for ITASE cores

**Findings:**

We have shown shown that the 'standard' methodologies for working on firn, particularly the more porous firn from the shallower depths, have most likely been erroneous. The SEM photographs bear no resemblance to the thin sections that have been produced using aniline or dodecane as a filler. Many have suspected that any kind of sample preparation that involves attaching a section to a glass slide and/or using a filler changes the structure of this very fragile material, which appears to be the case. As the density increases, the appearance of the SEM images and the traditional sections do not appear to be as significant.

Grain sizes using the SEM and digital imaging software are smaller than those found using more traditional methods and the deviation increases with depth. This may be due to several factors. A filler and/or mounting a thin section on a glass slide will likely artificially increase grain size. This result may also indicate the assumptions of rectangular geometry in the calculation of area becomes increasingly invalid with depth. We believe that our new numbers are more accurate as pixel counting makes no geometrical assumptions.

Geographically, grain size decreases inland, indicating that grain size is temperature dependent, as has been previously reported.

Fabric and texture analyses are more accurate and performed automatically with the ECM, allowing data collection in the finest grained samples. Fabric analysis to 90 m showed only one section in one core (06-1) with a weakly aligned orientation at 90 m. In addition to obtaining c-axis orientations, with electron back-scattered diffraction, misorientation angles are also obtained which the type and extent of stress, strain and deformation in the samples.

Although SEM analysis will not provide soluble chemistry, elemental analyses of particles or impurities can be determined indicating provenance. As expected, potassium, chlorine, sodium and calcium are found in greater abundance in samples collected closer to the coast. Silica, calcium and aluminum are more indicative of dust and as expected, dust sources vary between East and West Antarctica.

Factor analysis of elemental impurities from SEM analysis provides climate data including variations in air mass trajectories. As these determinations can be made at high resolution (sub-centimeter) it may be possible to accurately compare the chemistry of continuous stratigraphic layers, such as those traced with GPR, in cores from distal locations. These applications would contribute greatly to the understanding of the spatial and temporal changes in environmental and climate conditions throughout Antarctica.

Characterization of internal surface volume (SV) showed that the progression from firn to ice is not entirely linear, as would be observed if only grain size or porosity were considered. Further investigation of changes in SV with depth may add to the understanding of the processes of firn densification and metamorphism in the ice sheet.

The high degree of clustering of poles in sample 06-1-97 and the inclusion of a great number of low angle misorientations indicate sub-grain formation. Sub-grains are not typically expected to form in the shallow parts of the ice sheet, however visual evidence of sub-grain formation was found in samples as shallow as 50 m. These findings indicate that SEM and EBSD are valuable techniques for investigations of strain in the shallow parts of ice sheets.

The morphology and microstructural location of impurities is dependent upon the elements present. As was determined in previous studies (Cullen and Baker, 2001; Obbard and others, 2003; Barnes and Wolff, 2004; Rosenthal and others, 2007; Iliescu and Baker, 2008), the formation of filaments was found to require the presence of marine species; whereas bright white spots contained both marine and continental species. Not reported elsewhere is the characterization of filament tufts; which require the presence of continental (dust) species for their formation.

Continuous trace element chemistry has recently been completed (however not yet analyzed) on 0.5 m of core and will be compared to the elemental analysis, grain size and texture data. Additionally, we are in the process of detailed statistical analyses of the elemental, impurity type, detailed chemistry, texture and fabrics.

#### **Training and Development:**

Nicole Spaulding, the graduate student working on the project, first started working on ITASE samples from the first series of traverses as an undergraduate at CRREL. Nicole participated in the 2007-2008 traverse and was clearly an integral part of the team. She is now pursuing her Ph.D. in the Climate Change Institute at the University of Maine.

Two University of Maine undergraduates have worked with Nicole and myself on stratigraphy as well as a high school graduate.

Katherine Seig, a Dartmouth graduate student, worked with Nicole on the SEM imaging. Two other Dartmouth graduate students worked on designing and implementing the new cold stage and sample holders for the SEM.

Rachel Obbard, a Dartmouth post-doc has been working on the micro computer tomography on several ITASE samples.

Sharon Sneed, a Ph.D. candidate in the Climate Change Institute at the University of Maine completed the chemical analyses.

### **Outreach Activities:**

Poster 'Firn and Ice-Core Close-Ups' at the Climate Change 21 Choices for the 21st Century October 23-24 2009 at the University of Maine

Climate Change Institute Science Day at the University of Maine. Tours and Demonstrations for Middle and High School Students.

Nicole Spaulding is a Master's student working on the project. Nicole gives several talks each year to visiting elementary, middle school and high school students.

Several undergraduates and graduate students have worked on various aspects of the project from stratigraphy to designing parts for the SEM.

### **Invited Talks:**

4-D structure of snow?. Baker DOE workshop on Characterization of materials and damage in four dimensions, Annapolis, MD, 16&#8208;19 August, 2009.

Advanced Microstructural Characterization of Snow, Firn and Ice, I. Baker, IACS-IAMAS-IAPSO Joint Assembly, Montr?al, Canada, 19-29 July, 2009.

Studies of Natural and Artificial Ice, I. Baker, Australian Nuclear Science and Technology Organization, Australia, May 1st, 2009.

Studies of Natural and Artificial Ice, I. Baker, University of Sydney, Australia, April 28th, 2009.

Characterization of Seven East Anantarctic Ice Cores Using Scanning Electron Microscopy, N. Spaulding, D. Meese, I. Baker, P. Mayewski, Gordon Hamilton, Hal Borns Symposium, University of Maine, May 2009.

Studies of Natural and Artificial Ice, I. Baker, British Antarctic Survey, Cambridge, U.K., August 14th, 2008.

Advanced Microstructural Characterization of Firn, I. Baker, Workshop on the Microstructure and Properties of Firn, Dartmouth College, NH, March 10-11th, 2008.

Microstructural Characterization of Snow Firn using SEM/EDS/EBSP, I. Baker, R. Obbard, D. Iliescu and D. Meese, 2007 Annual TMS meeting, Orlando, FL, Feb. 25th-March 1st, 2007.

Advanced Electron Microscopy Techniques for Studying Firn and Ice Cores, I. Baker, R. Obbard, D. Iliescu, K. Sieg, D. Meese, M. Albert, Arctic Science Summit Week, Dartmouth College, Hanover, NH, March 14th - 20th, 2007.

### **Other talks:**

Microstructural Characterization of Snow and Ice, I. Baker, R. Obbard, S. Chen, R. Lomonaco, N. Spalding, D. Meese, Materials Science and Technology 2009, Pittsburgh, PA, October 25- 29th, 2009.

Advanced Microstructural Characterization of Firn, I. Baker\*, S. Chen, R. Lomonaco, R. Obbard, D. Iliescu, N. Spalding and D. Meese, Materials Science and Technology ?08, Pittsburgh, PA, October 5-9th, 2008.

Advanced Microstructural Characterization of Firn, I. Baker, S. Chen, R. Lomonaco, R. Obbard, D. Iliescu, N. Spalding and D. Meese, Materials Science and Technology ?08, Pittsburgh, PA, October 5-9th, 2008.

Scanning Electron Microscopic Characterization of U.S. ITASE Firn/Ice, N. Spalding\*, D. Meese, I. Baker, P. Mayewski and G. Hamilton, ITASE Synthesis Workshop, Castine, ME, 2-5 Sept. 2008.

On the use of Scanning Electron Microscopy to Characterize Firn/Ice Cores, N. Spalding, D. Meese and I. Baker, 2008 16th Hal Borns Symposium, U. Maine-Orono, ME, May8th-9th, 2008.

Determination of Polar Firn/Ice Core Physical Properties Using Scanning Electron Microscopy, N. Spaulding, D. Meese and I. Baker, Poster at

the Workshop on the Microstructure and Properties of Firn, Dartmouth College, NH, March 10-11th, 2008.

Advanced Electron Microscopy Techniques for Studying Ice and Firn Cores, I. Baker, K. Sieg, N. Spaulding and D. Meese, Proceedings of the 10th International Symposium on Antarctic Earth Sciences, University of California- Santa Barbara, CA, August 26th-31st, 2007.

Determination of polar ice core physical properties using scanning electron microscopy, N. Spaulding, D. Meese and I. Baker, 15th J. Louis Agassiz Symposium, U. Maine-Orono, ME, May 10 th -11th, 2007.

Determination of polar firn/ice core physical properties using scanning electron microscopy, N. Spaulding, D. Meese, I. Baker, poster at the 37th Annual Arctic Workshop, Skaftafell, Iceland, May 2nd - 5th, 2007.

### **Journal Publications**

Baker, I., R.W. Obbard, D. Iliescu and D. Meese, "Microstructural Characterization of Firn", Hydrological Processes, p. 1624, vol. 21, (2007). Published,

Baker, I., K. Sieg, N. Spaulding and D. Meese, "Advanced Electron Microscopy Techniques for Studying Ice and Firn Cores", Proceedings of the 10th International Symposium on Antarctic Earth Sciences, p. , vol. , (2007). Published,

Baker, I., R.W. Obbard, D. Iliescu and D. Meese, "Microstructural Characterization of Firn", Proceedings of the 63rd Eastern Snow Conference, p. , vol. , (2006). Published,

Spaulding, N., D.A. Meese, I. Baker, P.A. Mayewski, G. Hamilton, "A New Technique for Firn Grain Size Measurements", Journal of Glaciology, p. 1, vol. 55, (2010). Published,

Spaulding, Nicole; Meese, Debra; Baker, Ian, "Characterization of Four East Anatarctic Firn/Ice Cores Using A New Imaging Technique", Journal of Glaciology, p. , vol. , (2010). In final author review prior to submission,

### **Books or Other One-time Publications**

### **Web/Internet Site**

**URL(s):**

[http://gcmd.nasa.gov/getdif.htm?meese\\_0538494](http://gcmd.nasa.gov/getdif.htm?meese_0538494)

<http://www2.umaine.edu/USITASE/science/scienceimp/discipl.html>

**Description:**

### **Other Specific Products**

**Product Type:**

**Teaching aids**

**Product Description:**

Poster presented at 37th Annual Arctic Workshop May 2-5, 2007. Nicole Spaulding, Debra Meese, Ian Baker, Determination of polar firn/ice core physical properties using scanning electron microscopy

**Sharing Information:**

Poster was presented at workshop. Poster is on display in the Climate Change Institute at the University of Maine and shown on tours.

**Product Type:****Other inventions****Product Description:**

Designed cold stage and sample holders for ECM.

**Sharing Information:**

Limited use, only applicable to those using same ECM and doing cold work.

**Contributions****Contributions within Discipline:**

We have developed the first technique to observe the microstructure of firn without disturbing the structure using fillers or requiring the section be mounted on a glass slide. We have also measured a- and c-axes and measured misorientation angles providing information on stress, strain and deformation. These are the first data on misorientations in firn, showing some interesting relationships. It is believed that by extending this technique from the surface firn into deep ice, greater information can be obtained on the deformation history of the ice.

Elemental chemistry was obtained on various particulates or impurity types observed in the firn. This data is very exciting as it is showing the location within the structure various impurities are located and the properties of different impurity types. This will now be compared to the soluble chemistry, just recently completed to determine if a correlation exists between the insoluble and soluble chemistry in a given sample.

We are revolutionizing physical properties research on firn and are providing a greatly expanded view of firn properties.

**Contributions to Other Disciplines:**

This may have application to other material sciences including mineralogy, metals and ceramics.

This project is an interdisciplinary combination of glaciology and engineering that is not commonly seen, where most interdisciplinary research is between the different sciences.

**Contributions to Human Resource Development:**

One high school graduate, two undergraduates, one graduate student, one recently matriculated MS student, a Ph.D. candidate, and a postdoc (all but one are female) have been involved with the project. Additionally, several engineering students at Dartmouth have been involved with the design and machining of the parts required for the new cold stage for the SEM.

This project is a combination of glaciology and engineering and is providing students with interdisciplinary research that is not commonly done, where most of interdisciplinary work is between the different sciences rather than a field such as engineering.

**Contributions to Resources for Research and Education:**

The new cold stage for the SEM is off-the-shelf. The design of sample holders and other pieces that were designed for this project will be available to others who wish to use this technique.

**Contributions Beyond Science and Engineering:****Conference Proceedings****Categories for which nothing is reported:**

Any Book

Contributions: To Any Beyond Science and Engineering

Any Conference