Teacher Guide for *Ice Core Records – From Volcanoes to Supernovas*

Ice Core Investigation Summary:

This investigation is an application of absolute and relative dating techniques – a skill taught within many science disciplines. Students examine the seasonal/annual nitrate record and use information from known Icelandic volcanic eruptions to date their unique signatures. Data is also provided for known volcanic eruptions from other latitudes which can be used throughout the activity to date major conductivity and nitrate spikes to further refine and date time locations along the core. Solar proton data, including the Carrington superflare and the Dalton and Maunder Minima are used to date both solar activity and unique solar events.

Using the seasonal nitrate cycles and the volcanic eruptions that they have labeled on the ice core strips, students search for unlabeled nitrate anomalies that could correlate to the Tycho and Kepler supernova events of 1572 and 1604, respectively. The final task for students is to search for evidence of an anomaly that could be correlated to the Cassiopeia A (Cas A) supernova and determine the date of the event. After reading the possible evidence from other sources for dating the Cas A supernova, students can decide for themselves which date, if any, they support. The teacher may challenge their students to date and label other anomalous spikes, including the RDS-220 H-bomb detonation and the Tunguska event, which appear in the ice core data.

The GISP2 H-core contains suspected supernova events, and there are other research projects that support the correlation of nitrates with supernovas; however, within the scientific community there are those who disagree. Controversial science is great science; often, serendipitous discoveries that cross disciplinary boundaries produce years of additional research, analysis, investigation and debate before a final consensus is reached. Sometimes there is no one definitive answer unless other supporting evidence is found. This investigation provides a more realistic view of how science sometimes works. The GISP2 H-core also contains nitrate anomalies that are as yet unidentified and not correlated with any known terrestrial or extra-terrestrial event – providing teachers the opportunity for student research projects. The power of *Ice Core Records – From Volcanoes to Supernovas* is that it does not provide all the answers; it is an open-ended inquiry into possibilities.
NOTE: This activity will take from 3-4 classroom periods, depending on the length of the class. Ideally, one class period each for labeling and discussing volcanic events, solar proton events, and supernova events.

Using the Background Information Segments:

1. The Science within the Core:
This investigation includes concepts relating to cryology, chemistry, meteorology and astronomy. Teachers can use the investigation as a springboard to any of the associated sciences or as an application after the content has been introduced in the classroom. Ice cores, like tree rings and ocean sediments are proxies – preserved physical characteristics from the past used to reconstruct conditions and events further back in time to construct a reliable record of the Earth's history. The wet and dry deposition of materials onto the ice sheets in the Polar Regions are useful in reconstructing the past and involves local and global climatology, atmospheric physics and chemistry, radiation and ionization.

The Scientific Evidence within the Ice Core Record **(5 pages)**
This segment gives more detailed information about the ice core data, liquid electrical conductivity, Icelandic volcanoes, the nitrate record, solar proton events, and the Tycho and Kepler supernovas. The student ice core handout includes all the information that students need to complete the investigation; however, teachers may elect to download this segment to provide additional information for their students to read, either before beginning the investigation or after. **NOTE:** The last paragraph gives the probably date in the ice core for the Cassiopeia A event and would need to be eliminated if the students have the handout before the investigation.

2. Connections to History:

There are interesting and rich historical connections during the timeframe represented in the core – including the first ice core data from Greenland, Icelandic volcanism, the historical sunspot record, the lives of Tycho Brahe and Johannes Kepler, John Flamsteed the First Royal Astronomer, and King Charles II of Great Britain The core is embedded within a historical context of changing world views and paradigm shifts. The background information segments provide a historical context and perspective of the individuals and/or locations related to the investigation. The associated histories help illuminate science as an extension of the prevailing culture of the times.

Teachers may elect to address any or all of the historical segments themselves, or team up with a history teacher. There are 5 Background Information segments that address specific interesting topics. Teachers can download any or all of the segments as student handouts, or use them for their own edification. If a team-teaching approach is possible, the history teacher can use the segments as a starting point for a more in-depth history lesson. The Background Information segments relating to historical connections are:

Icelandic Volcanoes and the Greenland Ice Sheet Connection **(2 pages)**
This segment highlights Iceland's geographical location and history of volcanism, and the first study of snow/ice strata in Greenland – including the death of Alfred Wegener, famous for the theory of continental drift.

The Historical Sunspot Record **(3 pages)**
This segment highlights the discovery, research and controversy involving sunspots, including John of Worcester, Thomas Harriot, David and Johannes Fabricius, Christoph Scheiner, and Galileo. A prominent misconception – that Galileo discovered sunspots – is addressed.

The Astronomers Tycho Brahe and Johannes Kepler **(5 pages)**
This segment describes the fascinating stories involving Tycho Brahe and Johannes Kepler – their personal lives as well as their working relationship. From Tycho Brahe's duel that resulted in his metal noses to the controversy surrounding his death and the two exhumations of his remains to Johannes Kepler's thief of Brahe's data, and writing the first science fiction book which almost resulted in his mother being burned at the stake as a witch – these two personalities lived in a time of tremendous changes. They also individually observed and studied a Type Ia supernova event which is named for them.

John Flamsteed and the Cassiopeia A Supernova Event **(1 page)**
This segment presents the evidence for the possible observation of the Cas A supernova remnant by John Flamsteed – the first Royal Astronomer at the Greenwich Observatory.

King Charles II and Cassiopeia A **(2 pages)**
This segment presents evidence based upon the works of 17^{th} century poets and historians found in the archives of the Yorkshire Museum that contain various descriptions related to a bright object that appeared in the sky on the birthday of King Charles II. The researchers, Lunn and Rakoczy, theorize that the King Charles II event may have been the Cas A supernova.

Summarizing the Evidence **(2 pages)**
This is a summary of the GISP2 H-core data, the possible John Flamsteed observation, and the literature discovered at the Yorkshire Museum – all related to possible dates for the Cas A supernova event.

Using the Ice Core Investigation Materials in the Classroom:

The 10-page **Student Ice Core Records Investigation** includes all the information and instructions necessary for students to complete the investigation. The **Using the Background Information Segments** above describes their individual connections to the investigation, and teachers may elect to download any or all of the segments for student use; however, they are not necessary for the completion of the investigation.

The **Volcanic Eruptions Data Tables** and the **Solar Proton Events/Supernova Data Tables** are the same tables that are included with the Student Ice Core Records Investigation handout. Teachers may elect to download one 10-page handout per team; however, since each team member needs to use the data tables, and each individual team is using different data tables – the volcano data tables and the solar proton event data tables are available as separate downloads. For a large classroom, this lessens considerably the number of handouts that need to be distributed.

Before the investigation can be used, the **Student Ice Core Data Worksheet** needs to be downloaded and printed. The worksheet contains the entire 415-year ~8000-sample ice core data sectioned into 4 individual strips. Each section contains ~2000 samples. The activity is designed for four groups of students (Team 1, Team 2, Team 3, and Team 4) to each work with one of the ~2000 sample sections. In order to have the ice core sections large enough for students to identify individual conductivity and nitrate spikes and label them, the worksheet needs to be printed in a large format. An optimal size would be 24 inches by 24 inches; however, 20 inches by 20 inches is also a workable size. The worksheet is then cut into the 4 individual sections. If the strips are laminated and non-permanent thin markers are used, the strips can be used multiple times and will not have to be downloaded and printed again. If there are 4 students in a group, with each group working with one section of the ice core data, one worksheet is enough for 16 students and two worksheets for 32 students, etc. The number of worksheets needed depends on individual class sizes and the number of students assigned to each group.

It is also necessary to download and print in the same size format the **Ice Core Data Worksheet Labeled** version of the worksheet. This works as the "answer key" for the Icelandic and mid-latitude volcano locations and dates. There are 2 ways to use the labeled ice core strips. The labeled worksheet can be cut and laminated the same way as the student worksheet, and when the students are done they can use the strips to compare the labeled and dated events with their results; in which case the same number of labeled worksheets would need to be printed as student worksheets. Teachers may elect to print one labeled sheet, cut out the four individual sections, and tape them all together in one long, continuous ice core strip for the entire classroom to use. There is both a black and white and a color version of the labeled worksheet.

The ice core strips were sectioned into 4 strips for ease of use in the classroom. However, the entire ice core strips are also available for download in 4 versions – black and white labeled and unlabeled, and color labeled and unlabeled. If teachers elect to have the full length strips printed, they would have to be either 80 or 96 inches long.

NOTE: Since each team is only working with one quarter of the entire ice core record, then only Team 4, the group working on the deepest section of the core that includes the possible supernova nitrate spikes, will have a result for these events. The remaining groups will not be able to participate. Teachers may elect to have larger groups work with all 4 sections of the ice core so all the students can participate in determining if there are correlations with anomalous nitrate spikes and supernova events. Also note that the labeled worksheet does NOT have any of the supernova events labeled. The students have to defend their decisions about identifying spikes and determining dates for Tycho, Kepler and Cas A – especially Cas A which may not have been observed and therefore the date is not known, unlike the Tycho and Kepler supernovas. The nitrate anomaly correlation to supernova events is suspected, but not definitive. Teachers may elect to have students perform a web search for this topic. One research project in Antarctica shows evidence for a nitrate spike correlation for the Vela supernova. The research paper is posted at http://www.physics.mcgill.ca/~cliff/papers/Icecore.pdf.

Additional information for the two significant nitrate spikes that students are instructed to research and label at the end of the investigation is located at:
RDS-220 hydrogen bomb (http://en.wikipedia.org/wiki/Tsar_Bomba)
Tunguska Event (http://science.nasa.gov/science-news/science-at-nasa/2008/30jun_tunguska/)

Assessment:

This investigation is constructed as a long-term or final classroom project and the task specific scoring rubric has been constructed to enable educators to assess student performance. Student performance is scored in two categories – content understanding and communication skills. This provides the opportunity for students to not only present their ice core dating results, but also their understanding of geochemical cycles, related science core content, absolute and relative dating techniques, and how different science disciplines interconnect and scientists work together to construct understanding.
The following task specific scoring rubric addresses four different levels of student performance in understanding and communicating the Ice Core Records results.

Task Specific Scoring Rubric

Content Understanding	Communication
4pts- Students have correctly identified all Icelandic volcanoes, mid-latitude volcanoes, and solar proton events using absolute and relative dating techniques for the conductivity and nitrate signals in the ice core data and correlated the Tycho, Kepler and Cas A supernova events with anomalous nitrate spikes.	4 pts- Students describe in detail using correct scientific terminology and language how geochemical cycles produce the conductivity and nitrate records that are deposited in the Greenland Ice Sheet, and how historical events are used to determine absolute dates so that other events can be identified with relative dating techniques. Information is clearly understood by the listener and does not sound as if it was copied from the website (is in the students' own words.)
3 pts- Students have correctly identified all Icelandic volcanoes, and the majority of mid-latitude volcanoes and solar proton events using absolute and relative dating techniques for the conductivity and nitrate signals in the ice core data and correlated the Tycho and Kepler supernova events with anomalous nitrate spikes.	3 pts- Students generally describe, using some correct scientific terminology and language, how conductivity and nitrate records become incorporated into the Greenland Ice Sheet, and how absolute and relative dating techniques are used to date events in the ice core record. Information is generally understood by the listener and in most cases, does not sound as if it was copied off the web site.
2 pts- Students have identified at least half of the Icelandic, mid-latitude volcanoes , and solar proton events and using absolute and relative dating techniques for the conductivity and nitrate signals in the ice core data and correlated the Tycho and Kepler supernova events with anomalous nitrate spikes within a 10-year error. There may be minor errors and/or some omissions.	2 pts- Students partially describe in general terms how the conductivity and nitrate records become part of the ice core record, and that absolute dating of known events allows for relative dating of other events. Information may be unclear to the listener or may sound as if it was copied from the web site.
1 pt- Students have identified at least one quarter of the Icelandic and mid-latitude volcanoes, and solar proton events. Techniques of identification and correlation may be missing or contain major errors.	1 pt- Students attempt to describe in simple words that conductivity and nitrates become part of the ice core record and can be used to date specific events. Information is vague and/or confusing to the listener and may sound as if it was copied from the web site.
0 pts- Blank, irrelevant, or mostly incomplete.	0 pts- Mostly incomplete, missing, or incomprehensible

Connecting to the Next Generation Science Standards (NGSS), National Science Education Standards and Benchmarks:

Teachers can select the focus of the Ice Core Records investigation to address one or more of the National Science Education Standards and/or Benchmarks for Science Literacy. The strongest connections to the national science standards include key concepts from Science as Inquiry (Content Standard A), Physical Science and chemical reactions (Content Standard B), Earth and Space Science geochemical cycles and evolution of Earth (Content Standard D), and History and Nature of Science – science as a human endeavor and the nature of scientific knowledge (Content Standard G). Summaries of the key concepts, as described within the standards, are listed below along with several key concepts from Benchmarks for Science Literacy Project 2061.

Next Generation Science Standards (NGSS)
http://www.nextgenscience.org/search-standards-dci

Performance Expectations:

HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

HS-ESS1-1: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation

HS-ESS2-2: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Science and Engineering Practices:

Developing and Using Models
Develop a model based on evidence to illustrate the relationships between systems or between components of a system. **(HS-ESS1-1)**

Analyzing and Interpreting Data
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. **(HS-ESS2-2)**

Disciplinary Core Ideas

PS1.B: Chemical Reactions
In many situations, a dynamic and condition-dependent balance between a reaction and reverse reaction determines the numbers of all types of molecules present. **(HS-PS1-6)**

PS3.D: Energy in Chemical Processes and Everyday Life
Nuclear Fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. **(secondary to HS-ESS1-1)**

ESS2.A: Earth Materials and Systems
Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. **(HS-ESS2-2)**

Cross-cutting Concepts:

Scale, Proportion, and Quantity
The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs**. (HS-ESS1-1)**

Cause and Effect
Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. **(HS-ESS2-2)**

NATIONAL SCIENCE EDUCATION STANDARDS (Grades 9-12)
http://www.nap.edu/openbook.php?record_id=4962&page=173

1. CONTENT STANDARD A – SCIENCE AS INQUIRY

Six fundamental abilities and concepts that underlie this standard are addressed in the *Ice Core Records* investigation:

Formulate and revise scientific Explanations and Models Using Logic and Evidence:
Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.

Recognize and Analyze Alternative Explanations and Models:
This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.

Communicate and Defend a Scientific Argument:
Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

Understandings about Scientific Inquiry:

1. Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.

5. Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

6. Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

2. CONTENT STANDARD B – PHYSICAL SCIENCE

Chemical Reactions:

3. A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.

4. Chemical reactions can take place in time periods ranging from the few femtoseconds (10^{-15} seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species.

3. CONTENT STANDARD D – EARTH AND SPACE SCIENCE

Geochemical Cycles:

2. Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

The Origin and Evolution of the Earth System:

3. Interactions among the solid earth, the oceans, the atmosphere, and organisms have

resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years.

4. CONTENT STANDARD G – HISTORY AND NATURE OF SCIENCE

Science as a Human endeavor:
2. Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

Nature of Scientific Knowledge:
2. Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.

3. Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

BENCHMARKS FOR SCIENCE LITERACY PROJECT 2061 (Grades 9-12)
http://www.project2061.org/publications/bsl/online/index.php?home=true

1. THE NATURE OF SCIENCE

- In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to a better understanding of how things work in the world but not to absolute truth. 1A/H3bc*
- Sometimes, scientists can control conditions in order to obtain evidence. When that is not possible, practical, or ethical, they try to observe as wide a range of natural occurrences as possible to discern patterns. 1B/H3*
- New ideas in science are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many investigators. 1B/H7
- Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise. Although each discipline provides a conceptual structure

for organizing and pursuing knowledge, many problems are studied by scientists using information and skills from many disciplines. Disciplines do not have fixed boundaries, and it happens that new scientific disciplines are being formed where existing ones meet and that some subdisciplines spin off to become new disciplines in their own right. 1C/H4

- Scientists often cannot bring definitive answers to matters of public debate. There may be little reliable data available, or there may not yet be adequate theories to understand the phenomena involved, or the answer may involve the comparison of values that lie outside of science. 1C/H9** (SFAA)

4. THE PHYSICAL SETTING

The Structure of matter:

- An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules. 4D/H7b

10. HISTORICAL PERSPECTIVES

Displacing the Earth from the Center of the Universe:

- Johannes Kepler, a German astronomer, worked with Tycho Brahe for a short time. After Brahe's death, Kepler used his data to show mathematically that Copernicus' idea of a sun-centered system worked well if uniform circular motion was replaced with uneven (but predictable) motion along off-center ellipses. 10A/H4*
- Writing in Italian rather than in Latin (the language of scholars at the time), Galileo presented arguments for and against the two main views of the universe in a way that favored the newer view. His descriptions of how things move provided an explanation for why people might notice the motion of the earth. Galileo's writings made educated people of the time aware of these competing views and created political, religious, and scientific controversy. 10A/H6*

- Tycho Brahe, a Danish astronomer, proposed a model of the universe that was popular for a while because it was somewhat of a compromise of Ptolemy's and Copernicus' models. Brahe made very precise measurements of the positions of the planets and stars in an attempt to validate his model. 10A/H7**

Moving the Continents:

- Early in the 1900s, Alfred Wegener, a German scientist, reintroduced the idea of moving continents, adding such evidence as the underwater shapes of the continents, the similarity of life forms and land forms in corresponding parts of Africa and South America, and the increasing separation of Greenland and Europe. Even with this evidence and the realization that the earth was old enough for this to have occurred, very few contemporary scientists adopted Wegener's theory because he lacked a plausible mechanism for the movement of continents. 10E/H2*
- In the 1960s, scientists noted that earthquakes occur much more frequently in certain areas, that the rock around mid-ocean ridges is progressively older the farther it is from the ridge, and that this gradient is symmetrical on either side of the ridge. This evidence, coupled with a scientifically sound physical explanation for how continents could move,

transformed the idea of moving continents into the theory of plate tectonics. 10E/H3*

11. COMMON THEMES

Constancy and Change:

• Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change. 11C/H4
• The present arises from the conditions of the past and, in turn, affects what is possible in the future. 11C/H6*

• It is not always easy to recognize meaningful patterns of change in a set of data. Data that appear to be completely irregular may be shown by statistical analysis to have underlying trends or cycles. On the other hand, trends or cycles that appear in data may sometimes be shown by statistical analysis to be easily explainable as being attributable only to randomness or coincidence. 11C/H9** (SFAA)

12. HABITS OF MIND:

Values and Attitudes:

• In science, a new theory rarely gains widespread acceptance until its advocates can show that it is borne out by the evidence, is logically consistent with other principles that are not in question, explains more than its rival theories, and has the potential to lead to new knowledge. 12A/H3** (SFAA)
• Scientists value evidence that can be verified, hypotheses that can be tested, and theories that can be used to make predictions. 12A/H4** (SFAA)
• Curiosity motivates scientists to ask questions about the world around them and seek answers to those questions. Being open to new ideas motivates scientists to consider ideas that they had not previously considered. Skepticism motivates scientists to question and test their own ideas and those that others propose. 12A/H5*