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INSIDE

What If the Conveyor Were to Shut Down? Reflections on a Possible Outcome of the Great Global Experiment

W. S. Broecker, Lamont-Doherty Earth Observatory, Palisades, NY 10964

ABSTRACT

Suggestions that the ongoing greenhouse buildup might induce a shutdown of the ocean's thermohaline circulation raise the questions as to how Earth's climate would change if such an event were to occur. The answer preferred by the popular press is that conditions akin to those that characterized the Younger Dryas—the last kiloyear cold snap—would return. But this extreme scenario is an unlikely one, for models suggest that in order to force a conveyor shutdown, Earth would have to undergo a 4 to 5 °C greenhouse warming. Hence, the conditions at the onset of the shutdown would be very different from those that preceded the Younger Dryas. Thus, it is unlikely that new climate conditions would be nearly so severe. Unfortunately, because no atmospheric model to date has been able to create the observed large and abrupt changes in climate state of Earth's atmosphere, we lack even the crudest road map. However, as was the case for each of the abrupt changes recorded in Greenland's ice, if the conveyor were to shut down, climate would likely flicker for several decades before locking into its new state. The consequences to agricultural production of these flickers would likely be profound.

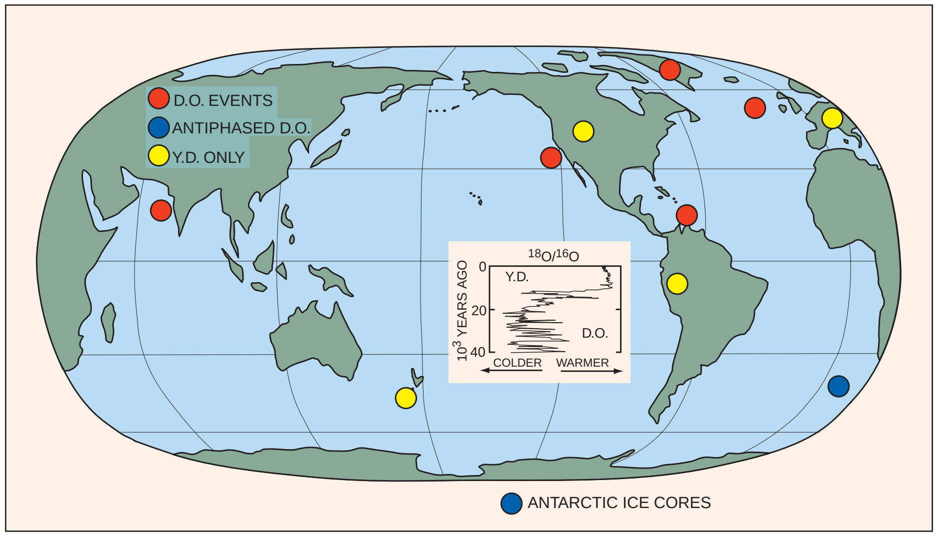

Figure 1. Map showing locations where abrupt climate changes (i.e., Dansgaard-Oeschger events) have been documented in records kept in marine sediments or polar ice (red and blue dots). Yellow dots show those locations where the last of these events (i.e., Younger Dryas) is recorded by major advances of mountain glaciers. While for most of the globe, these events are in phase, in parts of the Southern Ocean and of the Antarctic ice cap, they are clearly antiphased. This switch in phasing at high southern latitudes appears to reflect a seesawing of deep-ocean ventilation between the northern Atlantic and the perimeter of the Antarctic continent.

INTRODUCTION

Past shutdowns of the Atlantic Ocean's conveyor circulation appear to have played a key role in triggering the large and abrupt global climate changes that punctuated the last period of glaciation including the millennial duration Younger Dryas (Broecker and Denton, 1990). Modeling studies suggest that the ongoing greenhouse warming and consequent strengthening of the hydrologic cycle might trigger yet another such shutdown (Manabe and Stouffer, 1993; Stocker and Schmittner, 1997). To most science writers, this result has been construed as implying that conditions similar to those that prevailed during the Younger Dryas cold event would return. Were this analogy correct, then indeed a shutdown of the conveyor would have awesome consequences. Iceland would become one large ice cap. Ireland's climate would be transformed to that of Spitzbergen. Winters in Scandinavia would become so cold that tundra would replace its forests. The Baltic Sea would be permanently ice covered, as would much of the ocean between Greenland and Scandinavia. Further, the impacts of such a mode change would not be limited to the northern Atlantic basin; rather, they would extend to all parts of the globe (see Fig. 1). Rainfall patterns would dramatically shift. Temperatures would fall. The atmosphere would become dustier. Finally, the transition to this new state would be completed in decades, and very likely during this transition period, climate would flicker.

But is it realistic to believe that a shutdown of the conveyor a century or so from now would produce the conditions that characterized the last glacial period? The answer is very likely "no," for several reasons. The first has to do with the fact that during the Younger Dryas, Canada and Scandinavia still had sizable ice caps. The second is that the abrupt part of the warming at the close of the Younger Dryas brought climate only about halfway to its interglacial state (Severinghaus et al., 1998). The other half of the transition was more gradual, reflecting perhaps the post–Younger Dryas retreat of the residual ice caps in Canada and Scandinavia. Finally, modeling studies (Manabe and Stouffer, 1993; Stocker and Schmittner, 1997) that forecast a greenhouse-induced conveyor shutdown do so only after a substantial global warming (4 to 5 °C) has occurred. Hence, the global climate conditions prevailing at the time of the shutdown would be substantially warmer than those that existed just before the onset of the Younger Dryas. For these reasons, the analogy to the conditions that prevailed during the Younger Dryas surely constitutes a worst case scenario.

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If the climate change from Younger Dryas to present is not an apt analogy to that which would accompany a conveyor shutdown, then how might we go about estimating the consequences of such an event? As noted by some readers of my papers that warned of a possible greenhouse-induced conveyor shutdown (Broecker, 1997a, 1997b), I stopped short of presenting a specific scenario, for I was fully aware of the pitfalls associated with any such attempt.

ALLERØD–YOUNGER DRYAS ANALOGY

A less imperfect analogy to what might happen if the conveyor were to shut down is the climate change that accompanied the abrupt transition from the near interglacial conditions that prevailed during the Allerød to the cold conditions that prevailed during the Younger Dryas (see Table 1). The reasons are as follows. First, this transition represents a shutdown rather than a start-up of the conveyor. Second, the melting of the Northern Hemisphere's residual ice caps nearly halted during the Younger Dryas. Hence this analogy is flawed neither by the influence of changing ice cap size nor by that of changing sea level. But it is flawed in that the base state (i.e., the Late Allerød climate) was different from today's and even more different from that which would prevail at the time of a greenhouse-induced conveyor shutdown. Nevertheless, it is worthwhile to compare the climate of the late Allerød with that of the Younger Dryas.

The contrast between climate conditions during the warm Allerød and cold Younger Dryas is recorded in four major ways (see Fig. 2): (1) pollen and beetle remains in lake and bog sediments tell us about differences in continental temperature, (2) moraines formed during the Younger Dryas record advances of mountain glaciers, (3) planktonic foraminifera shells in marine sediments document decreases in surface ocean temperature, and (4) the oxygen isotope records kept in ice and lacustrine calcium carbonate record shifts in hydrological conditions. These records send a consistent message. Conditions during the Allerød were nearly as warm as those that characterized the Holocene. As clearly shown by pollen records, the beginning of the Bolling-Allerød marked a worldwide transition from glacial to interglacial conditions. The lapse back to cold conditions during the Younger Dryas, while documented at many localities throughout the world, has a puzzling signature. It is clearly recorded by the descent of mountain snowlines in the American Rockies (Gosse et al., 1995),

TABLE 1. CONTRAST IN PROPERTIES OF THE SUMMIT GREENLAND ICE CORES (GISP AND GRIP) DURING THREE PERIODS

	Late Allerød	Younger Dryas	Early Holocene*
Ice accumulation rate (Alley et al., 1993)	13 cm/yr	8 cm/yr	22 cm/yr
$\delta^{18}O$ of ice (Dansgaard et al., 1993)	–38 ‰	–41 ‰	–35 ‰
CH_4 content of trapped air (Chappellaz et al., 1993)	670pdb†	480pdb†	710pdb†
Dust infall rate (Mayewski et al., 1994)	Low	High	Very low

*Full interglacial conditions established.
†Parts per billion by volume.

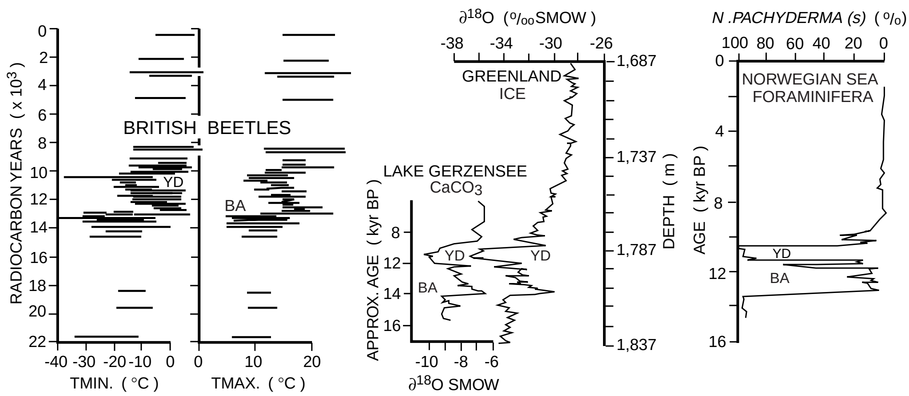

Figure 2. Records demonstrating the profound change in climatic conditions that occurred in the northern Atlantic basin between the Bølling-Allerød (BA) warm interval and the Younger Dryas (YD) cold interval. Left: temperature record based on beetle carapaces (Atkinson et al., 1987). Center: oxygen isotope records from Greenland ice (Dansgaard et al., 1993) and from Swiss lake $CaCO_3$ (Eicher and Siegenthaler, 1983). Right: abundance of the cold-loving planktonic foraminifera species *N. pachyderma* (left coiling) in the Norwegian Sea (Lehman and Keigwin, 1992).

in the Swiss Alps (Ivy-Ochs et al., 1996), in the tropical Andes (Van der Hammen and Hooghiemstra, 1995; Clapperton et al., 1997), and in the New Zealand Alps (Denton and Hendy, 1994). The oxygen isotope records in Swiss (Eicher and Siegenthaler, 1983) and Polish (Goslar et al., 1995) lakes, tropical mountain glaciers (Thompson et al., 1995) and in the Greenland ice sheet (Dansgaard et al., 1993) make clear that the hydrologic cycle in the region surrounding the northern Atlantic operated quite differently during the cold episodes (late glacial and Younger Dryas) than during the warm episodes (Allerød and Holocene). That these differences in the hydrologic cycle extended well beyond the region around the northern Atlantic is suggested by the substantially lower rate of global methane production during the Younger Dryas as recorded in ice cores from Antarctica and Greenland (Chappellaz et al., 1993; Brook et al., 1996). As the methane content of the atmosphere is set by the areal extent and temperature of the world's wetlands, these systems must on the average have been drier and colder. The dust record preserved in Greenland ice implies that storminess in the Asian deserts from which the dust has been shown to originate (Biscaye et al., 1997) must have been more intense during the Younger Dryas than during the Allerød. Finally, the benthic oxygen proxy for the deep Santa Barbara basin (Behl and Kennett, 1996) for the Arabian Sea (Schulz et al., 1998) and for the Cariaco Trench (Hughen et al., 1996, 1998) suggests major alternation in thermocline ventilation between these times. In contrast, the Younger Dryas is weakly expressed in many pollen records, giving rise to numerous claims that it didn't cause significant climate change outside northern Europe. Even in Switzerland, where the snowline descent and ^{18}O change are large and thoroughly documented, the Younger Dryas pollen change is muted. One interpretation for this seeming dichotomy is that while its impacts were global, the Younger Dryas was not simply a return to glacial state. Rather, it lacks an analog and represents yet another mode of operation of the Earth system.

One other aspect of the Allerød–Younger Dryas oscillation must be mentioned. Ice cores from the polar plateau in Antarctica reveal that the millennial-duration climate changes that punctuated the last glacial period were antiphased with respect to those elsewhere in the world (Blunier et al., 1998). During the Allerød, the ongoing warming of the polar plateau came to a halt. Then, at approximately the time of the onset of the Younger Dryas, the warming commenced once again at an even steeper rate than that in progress before the Allerød pause. Based on reconstructions of the radiocarbon content of surface ocean carbon, Hughen et al. (1996) clearly demonstrated that at the onset of the Younger Dryas, the Atlantic's conveyor circulation must have shut down, allowing newly produced ^{14}C to be backlogged in the atmosphere and upper ocean. Then, 200 years later, the backlogging ceased and the excess ^{14}C in the atmosphere and upper ocean was gradually drained back down. I suggested that this drain-down was caused by the inception of a new mode of deep water formation in the Southern Ocean, and that this new mode delivered extra heat to the Antarctic continent, reinitiating the stalled warming (Broecker, 1998).

When the difference in base conditions between those that prevailed during the Allerød and those that would prevail when the greenhouse warming has become sufficiently intense to threaten a conveyor shutdown is taken into account, then the picture looks quite different. As shown by the simplistic scenario presented in Figure 3, while conditions in the northern Atlantic basin would likely become cooler than now, for the rest of the world this change might only ameliorate part of the accrued greenhouse warming. But of course, even if the temperature change could be adequately assessed, we would still lack information regarding those aspects of the climate change which would matter the most (rainfall patterns, soil moisture, storminess, dustiness, etc.). One must keep in mind that as the physics of mode changes is so poorly understood, diagrams such as that in Figure 3 are unlikely to portray what would happen if the Earth system were to undergo a mode switch. The consequences of such a change defy prediction.

The last point to be made is that the Allerød to Younger Dryas transition was punctuated by flickers (see Fig. 4). Electrical conductivity measurements on the GISP2 ice core (Taylor et al., 1993a, 1993b) show that the onset of the Younger Dryas was marked by a period of increased dust fall onto the Greenland ice cap which lasted for about 5 years. This brief dust episode was followed by a several-year-long respite. Then came a second and a third episode each followed by respites. Finally, about 45 years after the onset of

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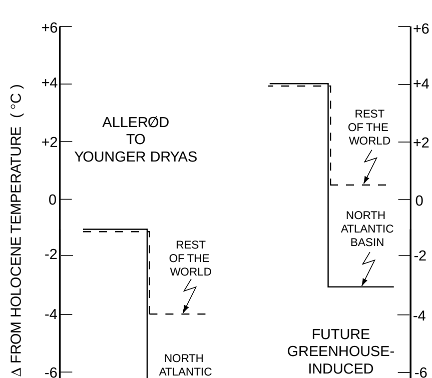


Figure 3. Simplistic scenario of possible impact on Earth temperatures of a greenhouse-induced conveyor shutdown based on an analogy to the Allerød to Younger Dryas transition, but taking into account that Earth temperatures just prior to a greenhouse-induced shutdown would be several degrees warmer than those that prevailed during the Allerød. While this change would likely cause temperatures around the northern Atlantic basin to drop below their present values, for the rest of the world, it would merely alleviate some part of accrued greenhouse warming. While seemingly comforting, this analogy says nothing regarding all-important changes in the hydrologic cycle, which would surely accompany such a mode change.

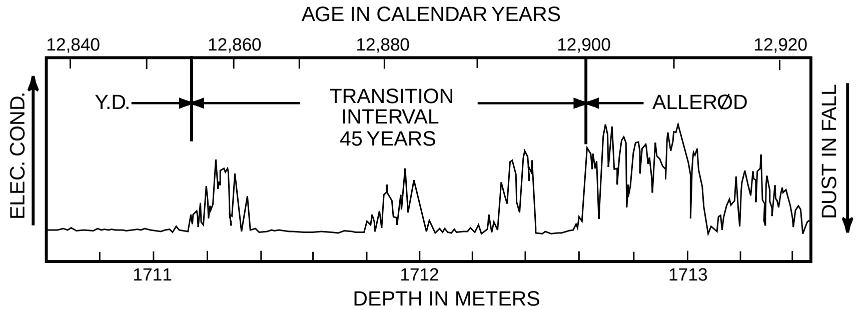


Figure 4. Electrical conductivity of the Summit, Greenland, GISP ice core measured by scraping a pair of electrodes along a fresh ice surface (Taylor et al., 1993a, 1993b). Periods of high dust fall had low conductivity because $CaCO_3$ in the dust neutralizes proton-bearing acids carried by snow. As annual layers are clearly seen, there is no question regarding duration of each episode.

Conveyor *continued from p. 3*

the first dust episode, Younger Dryas conditions locked in. As similar flickers accompanied all the Dansgaard-Oeschger (D-O) transitions, the likelihood that they would accompany a greenhouse-induced mode switch is reasonably high.

WHAT TRIGGERS THERMOHALINE REORGANIZATIONS

The trigger for the precipitous Younger Dryas cooling as first proposed by Rooth (1982) was likely the large pulse of fresh water released into the northern Atlantic as a result of the sudden switch in the outlet of proglacial Lake Agassiz from the Mississippi to the St. Lawrence drainage. This switch was triggered by the retreat of the Laurentian ice cap, which formed the northern shoreline of the lake. When the ice dam gave way, the lake surface dropped in a series of steps by about 100 m (Teller and Thorliefson, 1983). The water released flooded eastward into the northern Atlantic and presumably reduced the salinity of surface waters there to the point where deep water could no longer form. Radiocarbon dating places the timing of the drop in lake level resulting from this switch at about 11000 ^{14}C yr ago (that is, within the dating uncertainty of the time of the onset of the Younger Dryas). Confirmation comes from the record kept in Gulf of Mexico sediments, which reveals that a reduction in the input of low ^{18}O meltwater from the Mississippi occurred at close to this time (Broecker et al., 1989). I published a full account of this scenario as a popularized article entitled "The Biggest Chill" in *Natural History* (Broecker, 1987). Unbeknownst to me, the editors added the following subtitle: "When ocean currents shifted, Europe suddenly got cold." Then they went on to say, "Could it happen again?" At the time, this statement greatly annoyed me because I had carefully avoided any mention of the future in the article itself. But now in retrospect, perhaps I should forgive them.

During the course of the 50 000-yr-duration glacial period, 20 climate shifts similar to that marking the beginning of the Younger Dryas occurred. It is highly unlikely that each was driven by a sudden influx of ponded meltwater. Rather, there must have been another cause. One possibility is that these shifts were driven by a salt oscillator (Broecker et al., 1990). During times when the conveyor was off, the northern Atlantic region was extremely cold, and fresh water accumulated in the ice caps of Canada and Scandinavia rather than running off to the sea. This allowed the salinity of surface waters in the Atlantic Ocean to rise. When the density of waters in the northern Atlantic became large enough, conveyor circulation was reinitiated. Once in action, the heat released from the conveyor's upper limb caused the ice caps to recede, releasing fresh water to the Atlantic. Surface water salinities were then driven back down to that level where deep water could no longer form, causing the conveyor to shut down. Viewed in this context, one would conclude that during the Allerød, warm ice cap melting drove down the salinity of the northern Atlantic until the shutdown threshold was reached. Likely the surge of water stored in Lake Agassiz merely pushed the system over the brink; i.e., in the absence of such a surge, the system might well have reached this threshold due to the progressive reduction in salinity caused by the ice cap melting. Similarly, greenhouse-driven polar warming and strengthening of the hydrologic cycle during the coming 100 or so years may push the system over the brink once again, bringing the conveyor to a halt. As has been emphasized by many authors (see Rahmstorf, 1996), regardless of the impetus, once the conveyor is shut down, a fresh water lid forms in the northern Atlantic, temporarily locking ocean circulation into one of its alternate modes of operation.

MODELS TO THE RESCUE?

But wouldn't predictions based on conveyor shutdowns carried out in linked ocean-atmosphere climate models be more informative than analogies to past changes? I would contend that to date no model is up to the task. No one understands what is required to cool Greenland by 16 °C and the tropics by 4 ± 1 °C, to lower mountain snowlines by 900 m, to create an ice sheet covering much of North America, to reduce the atmosphere's CO_2 content by 30%, or to raise the dust rain in many parts of Earth by an order of magnitude. If these changes were not documented in the climate record, they would never enter the minds of the climate dynamics community. Models that purportedly simulate glacial climates do so only because key boundary conditions are prescribed (the size and elevation of the ice sheets, sea ice extent, sea surface temperatures, atmospheric CO_2 content, etc.). In addition, some of these models have sensitivities whose magnitude many would challenge. What the paleoclimatic record tells us is that Earth's climate system is capable of jumping from one mode of operation to another. These modes are self-sustaining and involve major differences in mean global temperature, in rainfall pattern, and in atmospheric dustiness. In my estimation, we lack even a first-order explanation as to how the various elements of the Earth system interact to generate these alternate modes. One intriguing proposal implies that excess atmospheric dust lowers the mean residence time of water molecules in the

Conveyor *continued on p. 5*

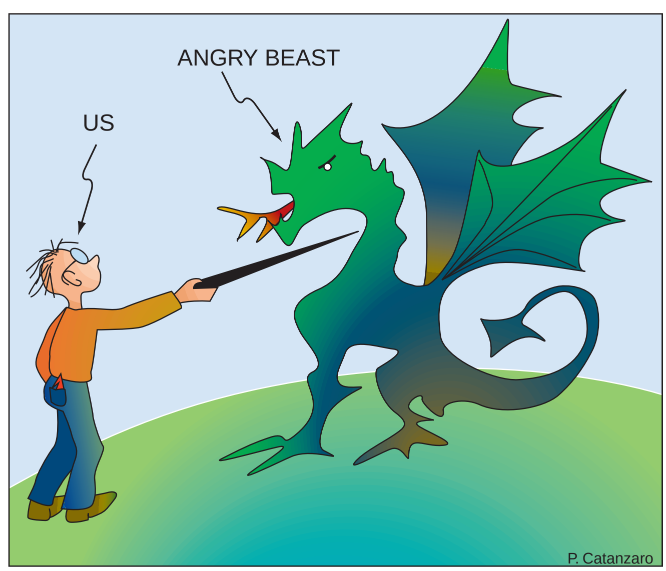
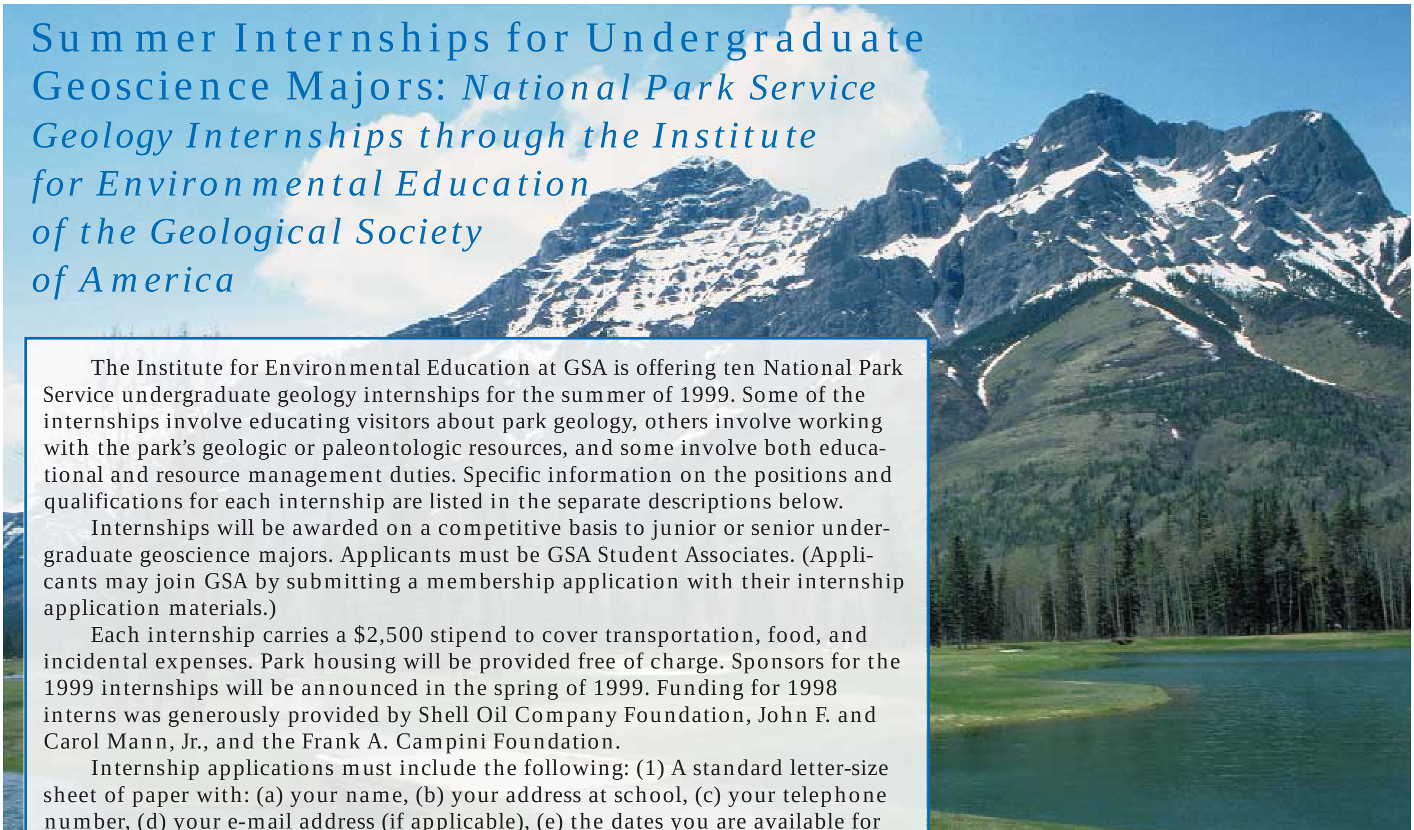


Figure 5. The angry beast. Drawing by P. Catanzaro.

Summer Internships for Undergraduate Geoscience Majors: *National Park Service Geology Internships through the Institute for Environmental Education of the Geological Society of America*



The Institute for Environmental Education at GSA is offering ten National Park Service undergraduate geology internships for the summer of 1999. Some of the internships involve educating visitors about park geology, others involve working with the park's geologic or paleontologic resources, and some involve both educational and resource management duties. Specific information on the positions and qualifications for each internship are listed in the separate descriptions below.

Internships will be awarded on a competitive basis to junior or senior undergraduate geoscience majors. Applicants must be GSA Student Associates. (Applicants may join GSA by submitting a membership application with their internship application materials.)

Each internship carries a $2,500 stipend to cover transportation, food, and incidental expenses. Park housing will be provided free of charge. Sponsors for the 1999 internships will be announced in the spring of 1999. Funding for 1998 interns was generously provided by Shell Oil Company Foundation, John F. and Carol Mann, Jr., and the Frank A. Campini Foundation.

Internship applications must include the following: (1) A standard letter-size sheet of paper with: (a) your name, (b) your address at school, (c) your telephone number, (d) your e-mail address (if applicable), (e) the dates you are available for an internship this summer, and (f) your GSA membership number (or attach your completed application for GSA Student Associate); (2) One copy of your resume; (3) One copy of your academic transcript (unofficial is acceptable); (4) One letter of reference from a faculty member in your geoscience department (the letter may be included with your application in a separate, sealed envelope with the signature of the reference across the seal, or it may be mailed separately); (5) For *each* internship you are applying for, a one-page letter explaining your interest in and qualifications for that internship; be sure to specify which internship you are applying for and to specifically address how your education, experience, and interests match the needs and requirements of that particular internship.

Send complete application materials to: Gwenevere Torres, NPS Internship Applications, Geological Society of America, 3300 Penrose Place, P.O. Box 9140, Boulder, CO 80301.

All application materials must be postmarked no later than *February 15, 1999*. Electronic submissions will not be accepted. Successful applicants will be notified by April 1, 1999. For more information, call (303) 447-2020, ext. 162, or e-mail gtorres@geosociety.org.

Dates for internships: Three months between May and the end of August 1999, except where indicated; exact starting and ending dates are negotiable.

Capitol Reef National Park, South-Central Utah

Capitol Reef National Park encloses Waterpocket Fold, a 100-mile-long monocline with dramatic sandstone arches, domes, deep narrow canyons, and steep cliffs.

Position: The park needs an intern to assist with public programs, such as geology talks, walks, slide shows, Junior Geologist events, and children's geology day camps. The intern will help staff the visitor center once a week, where one duty will be broadcasting road and weather information on the park's radio system.

Qualifications: The intern must enjoy working with the public and be comfortable speaking to a variety of audiences. Experience working with children is required, preferably with upper elementary students in an outdoor setting. Knowledge of Colorado Plateau geology is highly desirable. Introductory course work in geology is required, and course work in education is highly desirable. Personal transportation is recommended; the park is 11 miles from groceries and 75 miles from a major commercial area.

Craters of the Moon National Monument, South-Central Idaho

Craters of the Moon lies in a high desert wilderness at the edge of the Snake River Plain, an hour from Sun Valley and three hours from Yellowstone and Grand Teton national parks. The park preserves a surreal "moonscape" of rugged basalt dotted with cinder cones and cut by hundreds of lava tubes and volcanic caves.

Internships *continued on p. 6*

Conveyor *continued from p. 4*

atmosphere (Yung et al., 1996). As water vapor is the most important greenhouse gas, the resulting reduction in its inventory cools the planet. Of course, maintaining the necessary higher atmospheric dustiness would seemingly require increased storminess and decreased vegetative cover in the dust source regions. Even if it could be shown that, once created, these very different states of climate could be maintained, the question would remain as to how, in a period of just a few decades, the system is able to jump from one of these operational modes to another. In particular, if the villain is indeed a reorganization of the ocean's thermohaline circulation, how does it trigger the atmosphere to jump from one mode of operation to another? So, unfortunately, until the major deficiencies that prevent climate models from spontaneously reproducing glacial conditions and from jumping from one quasi-stable

Conveyor *continued on p. 6*

Internships *continued from p. 5*

Position: The park seeks an intern to assist with locating, mapping, and inventorying the park's volcanic caves and their geologic, hydrologic, biologic, and cultural features.

Qualifications: For this field-based internship, the intern must be able to hike for long distances over rugged volcanic terrain in extreme summer weather. Caving experience is highly desirable. Course work in introductory geology and field geology is required; mineralogy and/or igneous petrology course work is desirable. The intern must have experience working with computer databases; experience with GPS mapping and ArcView is desirable. Demonstration of strong organizational skills and the ability to integrate information from many sources are required. Personal transportation is recommended; the park is roughly 25 miles from town.

Denali National Park, South-Central Alaska

Denali's bedrock geology includes Precambrian to Tertiary rock units roughly aligned in east-west belts along the Alaska Range and capped by magnificent 20,320-foot Mt. McKinley, the highest point in North America.

Position: The park needs an intern to identify, label, inventory, and organize rock, mineral, and fossil specimens from the park and surrounding areas and to assist in developing geologic exhibits for a park visitor center. Some fieldwork may also be required for collecting samples and assisting with park projects.

Qualifications: Course work in introductory geology, mineralogy, and field geology is required, and course work in paleontology is highly desirable. The ability to work with computer databases is required; experience with GPS and/or GIS is highly desirable. The intern must be able to hike and work in remote locations and extreme weather. Field work may require tent camping in remote sites.

Florissant Fossil Beds National Monument, East-Central Colorado

Florissant Fossil Beds National Monument contains a wealth of fossils preserved in sedimentary and volcanic Tertiary rock units surrounded by high Rocky Mountain scenery. Among the fossils are petrified sequoia stumps and delicate plants, animals, and insects.

Position: The park needs an intern to assist with public education and other park duties. About 60% of the internship will be giving geology and paleontology talks and programs, leading public tours of active paleontological digs, and staffing the visitor center and museum. About 25% will be completing park projects such as preparing exhibits and bulletins, assisting with paleontological digs, collecting natural resource data, or creating new educational programs. About 15% will be participating in training opportunities in fields such as paleontology, geology, park operations, fire management, natural resource management, and/or natural history.

Qualifications: Strong written and oral communication skills are required. The intern must enjoy working with the public and must be able to present geologic information in interesting and understandable ways. Course work in introductory geology, historical geology, and paleontology is required. The intern must be able to hike and work outdoors in the extremes of mountain summer weather. Personal transportation is highly recommended; the park is about 20 miles from a small mountain town.

Dates: About May 26–August 15, 1999; the intern must attend park training in late May.

Fossil Butte National Monument, Southwest Wyoming

Fossil Butte lies within the Wyoming Thrust Belt and contains a remarkable fossil record of Tertiary freshwater fish and a variety of insects, snails, turtles, birds, bats, and plants.

Position: The park needs an intern to help with tasks related to developing a virtual fossil quarry. The intern will help collect, document, and digitally photograph fish fossils in a quarry setting, prepare and curate specimens, and compile a computer database for the collection. The intern may also travel with park personnel to do field work at other paleontological sites, depending on the intern's interests and the park's needs.

Qualifications: Course work in introductory geology and paleontology is required. Course work in biology is desirable. Experience with computer databases and/or photography is desirable. Photographic equipment is available at the park. Personal transportation is recommended in order to take advantage of the region's resources.

Conveyor *continued from p. 5*

mode of operation to another are conquered, these models have little to offer regarding the prediction of the impacts of a conveyor shutdown.

CONCLUSIONS

The fact that we are unable to provide satisfactory estimates of the probability that a conveyor shutdown will occur or of its consequences is certainly reason to be extremely prudent with regard to CO_2 emissions. The record of events that transpired during the last glacial period sends us the clear warning that by adding greenhouse gases to the atmosphere, we are poking an angry beast (Fig. 5).

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Great Sand Dunes National Monument, South-Central Colorado

Great Sand Dunes includes 39 square miles of the continent's tallest dunes—some as high as 750 feet—against a spectacular backdrop of 14,000-foot mountain peaks.

Position: The park seeks an intern to assist with all aspects of visitor education, including developing and giving geology talks and slide programs, creating a park geology pamphlet, and helping staff the visitor center. About 10% of the internship will be spent assisting staff with field projects and research on hydrogeology and dune migration.

Qualifications: The intern must have excellent oral and written communication skills, a desire to work with park visitors, and an ability to present geologic information to the public in interesting, understandable ways. Course work in introductory geology and geomorphology or sedimentology is required. Course work or experience in education is highly desirable. Field work will require the ability to hike at high altitude (8,200+ feet) in extreme summer weather. Interns must bring bedding and cooking and eating utensils. Personal transportation is highly recommended; the park is 35 miles from the nearest town.

Lake Roosevelt National Recreation Area, Northeast Washington

Lake Roosevelt stretches for 130 miles along the Columbia River behind Grand Coulee Dam. The park includes two distinct regions: Paleozoic sedimentary rocks exposed in mountains bordering the northern half of the lake and Tertiary basalt terrain, modified by huge Pleistocene flooding events, surrounding the southern half of the lake.

Position: The park needs an intern to assist with visitor education by giving campfire talks, making visitor contacts in day-use areas, participating in guided canoe trips, and helping with environmental education and Junior Ranger programs. Other projects may include revising and creating park educational materials. The intern will also assist with evening talks, children's programs, and other visitor services at the Dry Falls Visitor Center, a nearby site operated by the State of Washington.

Qualifications: The intern must enjoy working with the public and must be able to summarize area geology and present it to the public in interesting, understandable ways. Course work in introductory geology and geomorphology is required; course work in glaciology and/or volcanology is desirable. Course work and/or experience in education, communications, or other media fields is also highly desirable. The intern may be able to earn field-geology credit during the summer. Intern must bring her or his own linens. Personal transportation is recommended in order to take advantage of the area's resources.

Dates: Three months, approximately May 23 to Labor Day 1999.

Mount Rainier National Park, South-Central Washington

Mount Rainier, on the Pacific Ring of Fire, is an outstanding example of Cascade Range volcanism. Today, the volcano hosts the largest single-peak glacial system in the contiguous United States, but its history of eruptions and mudflows warrants its reputation as a significant hazard to surrounding communities.

Position: The park needs an intern to assist with visitor education. About 40% of the intern's time will be spent presenting geology programs for adults and children. About 30% will be spent staffing the visitor center and roving park trails to provide general information. The remaining time will be spent in training, program preparation, and completing park projects such as creating volcano fact sheets, helping to develop activities for an educators' guide to volcanic hazards, or writing geology training information for staff and volunteers.

Qualifications: The intern must be interested in public education, have strong oral and written communication skills, and be able to effectively convey geologic information to the public. Course work in introductory geology, and course work or experience in geomorphology, glaciology, and/or volcanology is required. Course work and/or experience in education is highly desirable. The park is located in a remote area, and personal transportation is highly recommended.

Dates: Approximately June 1 through August 31, 1999.

Oregon Caves National Monument, Southwest Oregon

Oregon Caves is located in geologically complex ophiolitic terrain in the Siskiyou Mountains. The caverns are contained in a metamorphosed Triassic reef that originally developed in a back-arc

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