acidities in solution differ from gas-phase acidities. We also understand how superacidic systems can be created and know that they protonate saturated hydrocarbons and stabilize the carbocations formed. Zeolite catalysts with their vast variety of different compositions and frameworks, but also with their rather well-defined structures, are ideal systems for studying this problem experimentally and computationally. These studies will also eventually resolve the debate as to whether or not zeolites are superacids (9).

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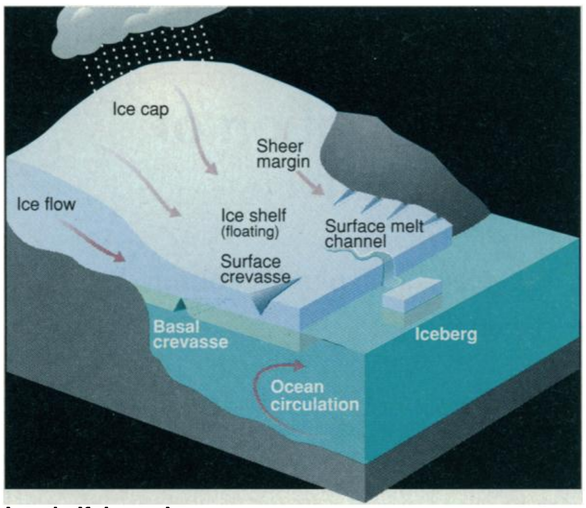
An Ice Shelf Breakup

Mark Fahnestock

Glaciers and ice sheets are controlled by the climate and must change if the conditions that led to their current configurations are changing. These ice masses exist at the interface between the atmosphere, which provides sustaining snowfall and thermal regulation, and the land, which provides a stable base and in many cases the elevation required to reach suitably cold conditions. Ice sheets and glaciers are distributed around the globe and can serve as potential indicators of past climate variability and current climatic trends. Observations of one dramatic kind of change, ice shelf collapse, are reported on page 788 of this issue by Rott *et al.* (1).



Ice shelf dynamics.

ILLUSTRATION: K. SUTLIFF

Interpretation of the climatic response of a glacier is not easy. The highly variable nature of climatic signals, combined with the wide spectrum of possible delayed responses attributable to complex ice flow, thermal diffusion and advection, and surface melt, produces a system that is in many cases not an optimal recorder of climatic events. Nonetheless, land-based ice promises to tell us about the past, and for hundreds of years in many populated alpine areas, the terminus positions of glaciers have been documented and related to climatic conditions. Satellite imagery has allowed this type of documentation to be expanded into regions that allow only limited access, where changes can go unnoticed for years. We can now study small variations over large areas and can begin to see regional trends in the varied responses of ice masses. Some of what is seen in satellite data is surprising.

Rott *et al.* describe the rapid disintegration of the northern Larsen Ice Shelf, located on the east coast of the Antarctic Peninsula. This event follows the breakup of the Wordie Ice Shelf (2) on the west side of the peninsula and the retreat of ice fronts on both sides (3). The Larsen Ice Shelf breakup was documented with satellite-borne imaging radar, which provided detailed images every few days, unhindered by the cloud cover common to this area. This frequent sampling allowed the authors to show that the main part of the disintegration event occurred over the span of less than a week. This is an extremely short period of time in a field of research that deals with gradual responses to change that take a minimum of a few years and usually require decades to centuries. But the rapidity of the disintegration highlights the difficulties that are inherent in trying to interpret this event in terms of a response to climate: certainly conditions in the area had been changing for years, but how many years, and just what triggered the final breakup? Does this represent a small change in local climate or a much larger, longer term variation?

Ice shelves are floating bodies of ice that are fed mainly by glacier ice flowing off of land, by snowfall on the surface, and in a few areas by the freezing of seawater (see figure). A typical Antarctic ice shelf is fed by one or more glaciers, fills the space between the coast and a few islands, and ends in an ice cliff that advances for a few to tens of years or longer and periodically calves icebergs, maintaining a stable, though oscillating, ice front position. Approximately half of Antarctica is bordered by ice shelves (4), ranging in size from a few square kilometers to 5×10^5 square kilometers in the case of the Ross and Filchner-Ronne ice shelves, which flank the West Antarctic Ice Sheet.

Ice shelves on the Antarctic Peninsula, which juts out of the continent toward South America, have a connection with the ocean that is shared by coastal glaciers in many regions. With the ocean as a source of moisture, relatively high snowfall in this region of Antarctica helps the balance of glaciers and ice caps. Owing to the influence of the ocean, ice in these coastal areas tends to be closer to the melting point and therefore more sensitive to slight changes in temperature than the cold ice of the interior. The dependence on temperature is especially pronounced for ice shelves (2). Extensive surface melt produces ponds of water and can enhance fracturing, as water-filled cracks can propagate through the entire thickness of the ice. Mercer (5) pointed out that ice shelves did not exist on the western side of the northern tip of the peninsula and showed that this was related to the distribution of monthly average summer temperatures. He went on to predict that the warming over the last few decades measured at stations on the peninsula should push this limit further south, causing the breakup of the northernmost ice shelves.

Extensive ice shelves are restricted to very high latitudes except on the Antarctic Peninsula. Greenland, though similar in size to West Antarctica, has only small ice shelves in the far north (6), and then only where they are supported by rapid discharge of large outlet glaciers. The lack of ice shelves in areas where there is substantial melting at the coast supports the idea that melt-induced changes in structural integrity prevent ice shelves from being stable. At

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lower latitudes, this lack of stability is well documented in the case of large tidewater glaciers, which advance down their fjords slowly, pushing a stabilizing terminal moraine shoal ahead of them, and retreat catastrophically if they thin and pull back off of that shoal into deeper water (*7*).

One possible consequence is a rise in sea level. The disintegration of the northern Larsen Ice Shelf did not directly influence sea level, however, as the ice was already floating. An ice sheet that was grounded on a bed below sea level might be susceptible to disintegration if the ice shelf in front of it were lost (*8*), but the glaciers and ice caps on the Antarctic Peninsula, which are in large part resting on beds above sea level, should not respond radically to the loss. Thus, the loss of the northern Larsen Ice Shelf is not an immediate threat to coastal communities, but rather a signal of changing conditions on the peninsula.

The meaning of the disintegration, in climatic terms, is problematic. As Rott *et al.* point out (*1*), measurements of temperature on the peninsula have indicated a warming trend over the last 40 years, and recent measurements show a warm period in the late 1980s. Was one of the recent warm periods responsible for the event, or was it caused by a much longer trend? This difficulty should not severely limit interpretation, however, as the retreat of ice shelves on both sides of the peninsula clearly indicates that the change is regional.

The complete disintegration raises a question about the origin of ice shelves: Can these ice shelves re-form under climatic conditions similar to today's, perhaps with a slight drop in temperature, or were they able to form only under the colder conditions of the last glacial period, and so represent a remnant of that climatic regime (or an artifact of the retreat from those conditions)? The answer will determine just what significance we can read into the climatic signal presented to us in the form of progressive ice shelf disintegration along the Antarctic Peninsula. If the ice shelves can re-form in a few centuries, then the signal we are seeing is possibly a small perturbation with a few-hundred-year cycle; if the ice shelves cannot re-form, even with a slight drop in temperature, then we may be witnessing an event that is unique for this area in the Holocene.

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Indeterminate Organization of the Visual System

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How is the visual system organized? The data on the anatomical subdivisions of the primate visual cortex and on the many connections among them are now so complex that it is difficult to draw conclusions about overall organization without systematic analysis. Hierarchical analysis (*1, 2*), one method for accomplishing this task, classifies connections as ascending, descending, or lateral according to their patterns of origin and termination in the cortical layers (some layers send information out and some receive information). This classification now includes connections among at least 30 areas in the monkey visual cortex and 318 pairwise hierarchical relations for these areas (*2*). In a familiar hierarchical scheme by Felleman and Van Essen (*2*), the visual areas are arranged so as to obey most of the pairwise anatomical constraints. Visual scientists make wide use of this scheme to choose cortical areas for investigation.

The number of possible orderings for 30 areas in a hierarchical ladder is large—about 10^{37}. We were interested in whether the anatomical constraints are sufficient to specify one ordering of the hierarchy out of the large number of possible orderings.

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Previous attempts to construct a hierarchy that fits these data as well as possible have relied on manual sorting. We have now developed a computer algorithm that uses evolutionary optimization to find hierarchies that have the fewest departures from a perfect hierarchy in which all the anatomical constraints are satisfied. A computational network generalizes the properties of the nodes of conventional neural nets (*3*), so that the arrangement of the nodes itself can represent the anatomical network in the real brain. Starting from randomly chosen structures, the algorithm proceeds by cumulative modification and cost evaluation of candidate hierarchies, in a process analogous to simulated annealing. The cost of any hierarchy is the number of anatomical constraints it violates (*4*).

With the most recent collation of hierarchical constraints (*2, 5*), the processor computed more than 150,000 different hierarchical structures, each with a cost of six violations (see figure). Only the limitations of the computer prevented the calculation of an even larger set of optimal hierarchies. The generation of so many optimal hierarchies answered our question: The information in the anatomical constraints cannot be expressed satisfactorily by any single hierarchical ordering. Further, conclusions drawn from considering only a single hierarchy will be misleading.

All the computed optimal hierarchies contain fewer violations than any previous hierarchy. The Felleman and Van Essen scheme (*2*), for comparison, has eight violations (*6*) and three fewer levels of visual cortical areas than any of the computed optimal hierarchies. The number of violations of the computed hierarchies—six—is remarkably low when compared with the number of violations obtained for random orderings of the areas (mean, 167 violations) and to optimized structures from shuffled constraint sets (mean, 124 violations). Only two constraint violations (FST to MSTd and MSTd to FST) remained for optimal hierarchies computed from a constraint set that excluded the 36 less reliable constraints (*2*). The primate cortical visual system is therefore surprisingly strictly hierarchical, but it is nonetheless not possible to determine the exact hierarchy.

Would further experimental data constrain a unique hierarchical arrangement of the visual areas? We considered all possible ways of filling in the 240 possible connections whose laminar direction is presently unknown. We assumed that all unknown connections exist, have laminar direction, and that these artificial data would not give rise to further constraint violations. These assumptions all aid determination of a unique ordering, but we found multiple hierarchies in all cases, even for constraint sets without any undetermined connections whatsoever. The reason for this result is that about half of the known connections (312 of 630) have been

An expanded version of this Perspective is available on the World Wide Web at <http://www.psychology.ncl.ac.uk/www/hierarchy.html>.

Further response from Felleman and Van Essen is at <http://science-mag.aaas.org/science>.