Environmental Change, Geoindicators, and the Autonomy of Nature

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ABSTRACT

Geological indicators of rapid environmental change provide a conceptual framework for assessing changes in the abiotic components of landscapes and ecosystems resulting from natural processes or human actions. The application of geoindicators to monitoring of landscape conditions, particularly in state-of-the-environment reporting and long-term ecosystem research, can help earth scientists to contribute more effectively to these interdisciplinary efforts. Geoindicators may also help to remind policymakers and the general public of the reality of natural change and the common difficulty of distinguishing it from human modifications.

ENVIRONMENTAL SUSTAINABILITY: ARE WE GETTING CLOSER?

As the millennium approaches, the most important new development in human thinking may well be embodied in the concept of sustainability, which has at its core the goal of economic, social, and environmental conditions that meet the present and future needs of people everywhere. Despite inevitable overworking, the concept requires an attempt to think and plan for the long term. This is clearly seen in recent international agreements on climate change, atmospheric ozone, forestry, and biodiversity, in which the goals may not be achievable until well into the next century and beyond.

Achieving any kind of sustainability requires a capacity to assess current conditions and trends, so that policies and practices can be tested and revised as needed. Much effort is now being devoted to developing standard economic, social, and environmental indicators with which to assess social and environmental conditions (Hammond et al., 1995; Moldan et al., 1999).

As a key part of this activity, state-of-the-environment reporting has now become commonplace. In the past decade, several hundred such reports have been published for continental regions, nations, states and provinces, and even individual cities. The general aim is to assess and report on what is happening in the environment, the significance of any changes, the reasons for changes (e.g., within the context of global climate change), and the usefulness of societal responses. Are physical, chemical, and biological pressures on the environment increasing or decreasing? If so, in what ways? Are the health and integrity of ecosystems being maintained, reduced, or enhanced?

A FAILURE OF EARTH SCIENCE

Despite the obvious importance of state-of-the-environment reporting, most published reports appear to ignore key abiotic components of landscapes and ecosystems. For example, neither the 1991 national state-of-the-environment report for Canada (Environment Canada, 1991) nor that for British Columbia (British Columbia Ministry, 1993) mention changes in ice fields and glaciers, changes that have significant implications for hydroelectricity generation, water supplies, fisheries, and outdoor recreation. Neither is there reference to seismicity, notwithstanding much public activity and expenditure on disaster preparedness in the Pacific Northwest. Despite some notable exceptions (e.g., Critical Trends Assessment Project, 1994), few state-of-the-environment reports assess the state of ground-water resources, changes in coastal or fluvial erosion and deposition, the physical condition of soils in areas of extensive ground frost, or the extent of slope instability that could lead to significant landslides and mass wasting.

For example, in the authoritative Guide to the Global Environment, the World Resources Institute (1996), in its review of major problems of rapidly growing urban areas, virtually ignores geohazards (McCall et al., 1996), whether catastrophic (e.g., earthquakes, volcanic eruptions, landslides) or slower and more pervasive (e.g., surface subsidence, ground-water contamination and depletion, sea-level change, erosion). How, for example, could one work sensibly to resolve environment challenges in and around Mexico City, Bangkok, Shanghai, Bogota, or San Francisco without recognizing the importance of seismicity, ground-water pollution, surface subsidence, or slope failure?

The report also estimates that some 34% of the world's coasts are at high risk of degradation, and an additional 17% are at moderate risk; the great majority of European and Asian coasts are in these two categories. The emphasis is on threats from coastal development rather than from natural forces: risks to coastal zones with cities or ports are "automatically" ranked as being high, as are areas where the population, road, or pipeline density is high. Little is said about the background natural processes of erosion, deposition, and subsidence. The question must be asked, Would delicate ecological niches and coastal habitats along dynamic coastlines, such as the southeastern seaboard of the United States, be stable and their organisms safe from harm if no human development were present? Innumerable studies have shown that coastal changes resulting from wave forces and longshore transport are the norm here, despite human attempts to stabilize shorelines with breakwaters and beach armour (Pilkey and Dixon, 1996). In the United Kingdom too, planners have largely failed to take into account the dynamic nature of the coastal zone (Lee, 1993).

Another direction in assessing environmental health is long-term ecosystem monitoring, usually carried out so as to anticipate change, and to contribute to sustainable management and restore ecosystem function and integrity (Risser, 1991; Leigh and Johnston, 1994). Such programs are becoming more common, both for their important contribution to state-of-the-environment reporting and for more fundamental research reasons, yet many appear to ignore or minimize abiotic components (Hughes, 1995). How can changes in ecosystems be understood without assessing the state of their chemical and physical (landscape) components and without understanding the past trends that have led to current conditions?

Geologists see very well the vagaries of nature and are learning to read its record much more carefully, but it has been an uphill battle to convince others that abiotic processes are an integral part of ecosystem and environmental behavior. This may be the result of our very long time perspective, which tries the patience of those coping with short-term problems, or it may be a question of research focus and language (Moores, 1997). In any case, the gap might be partly bridged with simple tools to assess the condition of the geological environment. How can we assess landscape change on spatial and temporal scales that are meaningful to environmental planners and the general public? What geological processes and phenomena should be monitored?

GEOINDICATORS—AN APPROACH TO LANDSCAPE MONITORING

A response to these questions has been developed by COGEOENVIRONMENT, the International Union of Geological Sciences Commission on Geological Sciences for Environmental Planning

Geoindicators *continued on p. 4*

TABLE 1. GEOINDICATORS AND SOME ENVIRONMENTAL CHANGES THEY REFLECT

Geoindicator	Change
Coral chemistry and growth patterns	Surface-water temperature, salinity
Desert surface crusts and fissures	Aridity
Dune formation and reactivation	Wind speed and direction, moisture, aridity, sediment availability
Dust storm magnitude, duration, and frequency	Dust transport, aridification, land use
Frozen ground activity	Hydrology, downslope movement, especially in active layer
Glacier fluctuations	Precipitation, insolation, melt runoff
Ground-water chemistry in the unsaturated zone	Weathering, land use
Ground-water level	Abstraction and recharge
Ground-water quality	Industrial, agricultural and urban pollution, rock and soil weathering, land use, acid precipitation, radioactivity
Karst activity	Ground-water chemistry and flow, vegetation cover, fluvial processes
Lake levels and salinity	Land use, streamflow, ground-water flow
Relative sea level	Coastal subsidence and uplift, fluid withdrawal, sedimentation, and compaction
Sediment sequence and composition	Land use, erosion, and deposition
Seismicity	Natural and human-induced release of earth stresses
Shoreline position	Coastal erosion, land use, sea levels, sediment transport, and deposition
Slope failure—landslides	Slope stability, mass movement, land use
Soil and sediment erosion	Surface runoff, wind, land use
Soil quality	Land use, chemical, biological, and physical soil processes
Streamflow	Precipitation, basin discharge, land use
Stream channel morphology	Sediment load, flow rates, climate, land use, surface displacement
Stream sediment storage and load	Sediment transport, flow rates, land use, basin discharge
Subsurface temperature regime	Heat flow, land use, vegetation cover
Surface displacement	Land uplift and subsidence, faulting, fluid extraction
Surface-water quality	Land use, water-soil-rock interactions, flow rates
Volcanic unrest	Near-surface movement of magma, heat flow, magmatic degassing
Wetlands extent, structure, and hydrology	Land use, biological productivity, streamflow
Wind erosion	Land use, vegetation cover

Note: Modified from Berger (1997).

Geoindicators *continued from p. 3*

(Berger and Iams, 1996). This approach is based on standard methods for measuring geochemical, geophysical, and geomorphological processes (e.g., Goudie et al., 1990). It aims to synthesize for any particular area all the contemporary geological changes that might be significant for environmental assessments. The emphasis is on changes that are naturally induced, with or without human input.

Geoindicators are defined as magnitudes, frequencies, rates, or trends of geological processes and phenomena that occur at or near Earth's surface and that are significant for assessing environmental change over periods of 100 years or less. Included are both rapid-onset (i.e., catastrophic) and more pervasive, slow-onset events that are generally evident within a human lifespan, whereas important but slower earth processes such as plate tectonics, basin subsidence, and diagenesis are excluded.

There are obviously numerous parameters that could be monitored, but to reduce these to a manageable number, 27 geoindicators have been identified (Table 1) and compiled from standard methods and techniques (Berger and Iams, 1996; complete checklist available on the Internet at www.gcrio.org/geo). Together they constitute a kind of landscape metric, a collection of tools for assessing landscape change in any terrestrial or coastal setting. Most can be monitored by inexpensive means, though some geoindicators, such as ground-water, soil, and surface-water quality require complex and costly analyses. Some are quite straightforward, such as shoreline position, presence and condition of desert surface crusts, or ground-water level, but others are composites of many related processes, such as karst and frozen ground activity, and volcanic unrest.

By including measures of past environmental change, such as coral growth rings and sediment sequence and compo-

Figure 1. Western Brook Pond in Gros Morne National Park, Newfoundland, a popular location for boat tours. Frequent rock falls and slides occur along the 650-m-high cliffs. What is the rate of slope failure and mass movement, and how does this affect lake levels and water quality in this oligotrophic pond? Photo courtesy of Parks Canada.

Figure 2. A coastal community where monitoring of geoindicators could assist planning. To what extent are the river channel and its streamflow and sediment load liable to change? The shoreline position has certainly been affected by postglacial adjustments (note the raised terraces). How fixed is it? How stable are the slopes above the settlement and the cliffs along the shore? Photo of Trout River, Newfoundland, by D. R. Grant, 1969.

sition, geoindicators help to emphasize the importance of the geological archive for ecosystem monitoring. This task is easier now that paleoenvironments can be deduced from ice cores, lake sediments, speleothems, and other proxies with the kind of resolution that is useful for assessing short-term changes. As Shen (1996) pointed out, such geoindicators can function as inexpensive automatic field data stations, whose record can be collected from time to time and "played back" to extract information on environmental change.

The geoindicator checklist will certainly need revision and refinement, for there are gaps and inconsistencies (Berger and Iams, 1996, p. 386–389; Berger, 1997). For various reasons, oceanic environments are excluded, as are tree rings and lichens, methane degassing, rock weathering and stresses, and geomagnetics. The checklist excludes parameters relating to nonrenewable mineral and energy resources, since changes in these are unlikely to be naturally induced within the time frame under consideration. An international project on the human contribution to global geomorphological change is currently developing indicators for this purpose (Osterkamp and Morton, 1996). Another avenue for further research concerns ways to combine or aggregate separate measures (Elliott, 1996). Instead of environmental managers having to cope with many unrelated parameters, it would be convenient to have a few simple composite indices that would convey the overall state of geological condition and change.

Figures 1 and 2 illustrate situations where geoindicators could provide guidance in environmental management. Other potential applications include modeling of landscape and terrestrial ecosystem change, assessments of ecosystem health and integrity (e.g., in forest management, wilderness areas, or mining districts), and evaluating the environmental condition of urban or industrial areas. COGEOENVIRONMENT is eager to cooperate with scientists and environmental managers anywhere using geoindicators to assess landscape changes for planning wilderness protection, forest regeneration, urban development, etc. It will, however, take some time to test the concept properly.

The use of geoindicators or, for that matter, any other approach to the assessment of environmental condition, raises the question of the relative importance of natural and human-induced actions or stresses in causing change. Dealing with this question runs directly into "anthropoblamism"—the attitude that natural environments left untouched by humans are stable and unchanging, and that it is only human actions that cause change.

ACKNOWLEDGING NATURAL CHANGE

Natural change was very much a part of the early philosophies. Taoist thought incorporated the notion of a world ever in flux. Plato's Timaeus advanced a philosophy of change through time, based on cycles in which the world is periodically destroyed by catastrophes. With the Enlightenment and the rise of determinism, however, came the idea of a universe amenable to scientific analysis, and the notion that nature was effectively stable. For example, in his influential work, Marsh (1864, p. 29) stated that where humans were not present, the only geological changes were so slow that they could be regarded "as constant and immutable," leaving nature with an "almost unchanging permanence of form, outline and proportion." In "comparatively rare cases of derangement" such as earthquakes and landslides, nature "sets herself at once to repair the superficial damage and to restore, as nearly as practicable, the former aspect of her dominion" (Marsh, 1864, p. 35).

Today, it is anthropogenic stress on the environment that is rightly the central concern, for human actions now affect much of Earth in one way or another (Meyer, 1996). However, so intent is the discussion on the harmful results of human actions on ecosystems and landscapes that natural change and its effects on land and the biosphere tend to be overlooked. The Framework Convention on Climate Change, for example, speaks of protecting the climate system for the benefit of present and future generations, and directs governments to take precautionary measures to anticipate, prevent, or minimize the causes of climate change and mitigate its effects. There is little mention that human-induced changes are superimposed on, and interact with, natural climatic variations that in the past were on occasion much more marked than those currently predicted. Neither does the more recent intergovernmental report on climate change (IPCC, 1996) make much of this obvious fact. The recognition that natural processes continue to set the biophysical context for life, as they have throughout its evolution, also appears to be ignored or downplayed in other recent international agreements. The Convention on Biological Diversity contains no statement recognizing that biodiversity is also affected by natural events and processes beyond our current capacity to predict and control.

The general conviction seems to be that if biodiversity and the biosphere are now in a "perilous state," this has been "caused by human activity" (Kim and Weaver, 1994, p. 393). From the perspective of deep ecology, "the environment created by nature is perfect as it is and has created no problems" (Drengson, 1989, p. 5). The complete marginalization of nature is neatly exemplified by the title of McKibben's (1989) popular book, *The End of Nature*, in which he argues that nature unaffected by human actions no longer exists.

Even the efforts of the International Decade for Natural Disaster Reduction and the extensive literature on natural hazards (Burton et al., 1993) do not seem to be

Geoindicators *continued on p. 6*

Geoindicators *continued from p. 5*

reflected in environmental thinking. This may be so in part because labeling as disasters natural changes such as river floods or storm-generated destruction of barrier islands implies that they are not part of the natural background, but rather surprising anomalies. In ancient times, disasters were commonly regarded as punishment by the gods for human transgressions. Now they are aberrations of nature to be compensated for by government emergency funding, insurance payments, or settlements from legal claims against those held to be responsible.

Despite the major efforts of global change research to model natural changes in climate, atmospheric chemistry, and ecosystems, the public seems to believe that if only humans would not interfere, natural change would be slow, benevolent, and predictable, and ecosystems and their organisms would always adapt without significant harm. It is only humans who cause landscape disturbances: ecosystems away from human influence, therefore, remain undisturbed. Human actions control the state of the environment, and what is needed to achieve sustainability is simply a better regard for and management of land, ecosystems, and habitats.

There is a strong ethical dimension to this worldview. "It is genuinely immoral to destroy a species or an ecosystem—a bounded, self-maintaining habitat" (Anderson, 1996, p. 182). Aldo Leopold's dictum turns up time and again: "A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends to do otherwise" (Leopold, 1968, p. 224). This makes sense when we consider human stresses on nature, but rather less when seen from the perspective of natural evolution and change. Is a wilderness landslide that blocks a fish-laden stream "wrong"? Climate warming that melts late-lying snow-beds where rare plants grow? Or a wandering bolide that smashes into Earth, extinguishing species en masse?

A landscape being overrun by desert sands, or a coastal plain drowning by rising sea levels may not be healthy in the sense of functioning well, or sustainable in the sense of lasting, but nature is rarely at rest for long, and is full of surprises and "disvalues," as Rolston (1992) termed them. "Permanence is an illusion; any balance is not only temporary but contingent on what went before" (Dickinson, 1995, p. 3). Botkin (1990) and Watson (1995) have advanced similar arguments from the perspectives of ecology and biology.

Many natural environmental changes are highly beneficial and rejuvenate soils, landscapes, and ecosystems. However, Petit-Maire et al. (1994) have described the widespread desertification of the savannas and grasslands of the central Sahara when hit by climate change some 5000 years ago. Issar (1993) traced the effect of natural environmental variations on the history of Middle Eastern societies and religions. These changes may well have been considerably slower than those now being caused by human actions. However, if the recent work on the Greenland ice cores is correct, there were very rapid swings in temperature in the last interglacial that make the predicted global warming look like child's play (Broecker, 1997). Ecosystems of that time are unlikely to have survived unscathed.

Obviously, efforts to develop a better environmental ethic and more sustainable practices of economic and industrial development must be continued and accelerated, so great is the risk of land degradation. However, defining the latter as due solely to human interference (Johnson and Lewis, 1995, p. 2) ignores the destructive power of nature. Putting all the blame on humans for the repeated deadly coastal flooding in Bangladesh, the submergence of coastal wetlands in the Mississippi delta, or massive landsliding in the mountains of southern Thailand does not seem the path to better environmental policies and attitudes (see also Schumm, 1994; Dickinson, 1995). As Passmore (1980, p. 213) pointed out, "a satisfactory philosophy of nature … must recognize that natural processes go on in their own way, in a manner indifferent to human interests and by no means incompatible with man's total disappearance from the face of the earth."

TABLE 2. RELATIVE INFLUENCE ON GEOINDICATORS OF HUMAN STRESSES AND NATURAL (NONHUMAN) FORCES

Geoindicator	Natural forces	Human stresses
Coral chemistry and growth patterns	1	1
Desert surface crusts and fissures	1	2
Dune formation and reactivation	1	2
Dust storm magnitude, duration, and frequency	1	2
Frozen ground activity	1	2
Glacier fluctuations	1	3
Ground-water quality	2	1
Ground-water chemistry in the unsaturated zone	1	1
Ground-water level	2	1
Karst activity	1	2
Lake levels and salinity	1	1
Relative sea level	1	2
Sediment sequence and composition	1	1
Seismicity	1	2
Shoreline position	1	1
Slope failure (landslides)	1	1
Soil and sediment erosion	1	1
Soil quality	2	1
Streamflow	1	1
Stream channel morphology	1	1
Stream sediment storage and load	1	1
Subsurface temperature regime	1	2
Surface displacement	1	2
Surface water quality	1	1
Volcanic unrest	1	3
Wetlands extent, structure, and hydrology	1	1
Wind erosion	1	2

Note: 1 = Strongly influenced by; 2 = may be influenced by; 3 = no substantial influence on.

DISTINGUISHING HUMAN FROM NATURAL CAUSES

It is one thing to recognize the reality of natural environmental change, and quite another, particularly after the fact, to distinguish its effects from those due to human agency. Table 2 is an attempt to show the relative importance of natural forces and human-induced stresses in causing geoindicator change (for further details see the full geoindicator checklist in Berger and Iams, 1996). For example, a particular change in the shape and dimensions of stream channels or the capacity of rivers to store and discharge sediments might be a result of dams and reservoirs, irrigation systems, and river diversions, or the consequence of rainfall and flash floods, failure of watershed slopes, or variations in the supply of source sediments. The change could also be a consequence of the internal dynamics of fluvial flow (Schumm, 1994). Ground subsidence, seismicity, and slope failure are all natural processes that can also be triggered directly or indirectly by human action.

The question of causes becomes important in current discussions about assessing environmental and socio-economic sustainability. In developing ways to assess progress, the international Committee on Sustainable Development (1995) and many other national and regional organizations are following a driving force–response–state framework, in which driving forces (stresses, limited to those resulting from human actions) on environments, policy responses, and the resulting environmental condition (state) are recognized (Moldan et al., 1997). This distinction requires that the natural component of any particular environmental change be separated from the human contribution. Interactions between human and nonhuman inputs are oversimplified (Berger and Hodge, 1998).

Parks Canada, like some other national park services, now concentrates its efforts less on management of park visitors and more on maintaining ecosystem integrity. This is "achieved when ecosystem structures and functions remain unimpaired by human-caused stresses and native species are present at viable population levels" (Woodley, 1996, p. 51). The implication seems to be that there is no loss of integrity when natural stresses impair ecosystems or when "alien" species on their own invade new territory and overrun native species. Even if the reality of natural environmental change is accepted, applying this definition in practice again necessitates that natural and human-induced change be clearly distinguished.

The difficulty in distinguishing human from natural environmental change does not make any easier the management of landscapes and urban areas, but ignoring natural forces, in attitude, policy, and practice, would seem to guarantee failure. As Botkin (1990, p. 79) argued, "It is only by understanding how nature works and applying this understanding in our management of nature that we can successfully achieve our goal: people living within nature, neither poisoning it nor destroying its reproductive capabilities."

CHALLENGING THE MYTH

Earth scientists can help to enhance the way in which environmental managers and the general public understand and accept the reality and complexity of natural landscape change. The geoindicator approach can be a helpful reminder both of the prevalence of natural fluctuations and of the difficulty of separating them from human-induced environmental change. Geoindicators may also prove to be useful tools for enhancing interdisciplinary research and communication, a way to connect with others concerned with environmental issues and problems. By focusing on important landscape changes, it may be possible to integrate geoscientific knowledge and understanding more fully into ecology, forestry, hydrology, and environmental policy and management. It should also contribute to integrated monitoring and assessment programs and help to ensure their continuation (see the Gros Morne Declaration, *GSA Today*, May 1995).

A fuller recognition of natural change has important implications for sustainable development, environmental ethics, and the way we understand wilderness and nature. It also raises some difficult questions. How can the concept of sustainability and its application be reconciled with a nature that changes—sometimes suddenly—unpredictably and without human input? How can we plan for the unpredictable, the indeterminate? Does ecosystem restoration make sense if, as Dickinson (1995, p. 7) pointed out, "cumulative Holocene environmental changes are largely so irreversible that all hopes to restore the past are vain"? Even more important, how can we acknowledge the autonomy of nature without minimizing the dangers of human-induced change? In recognizing natural environmental change, how can we effectively counter the argument that since we do not know how the world climate would be changing in the absence of human inputs, we might as well continue forcing the atmosphere as it suits us?

We need better ways to assess changes to the landscape, whatever the cause, and to identify and track trends that can at least warn of impending thresholds beyond which new policies must be adopted. Our view of the environment is strongly influenced by our understanding of human stresses, which can be managed, regulated, and legislated (taxation, lawsuits), and natural processes, which by and large cannot. Society must not only reduce unsustainable human activities but must also adjust to natural fluctuations. Continuing to ignore the importance of natural change is bound to lead us farther down the blind alleys of reductionism and determinism, of nature as machine, and of harmful human dominance over the geosphere and the biosphere.

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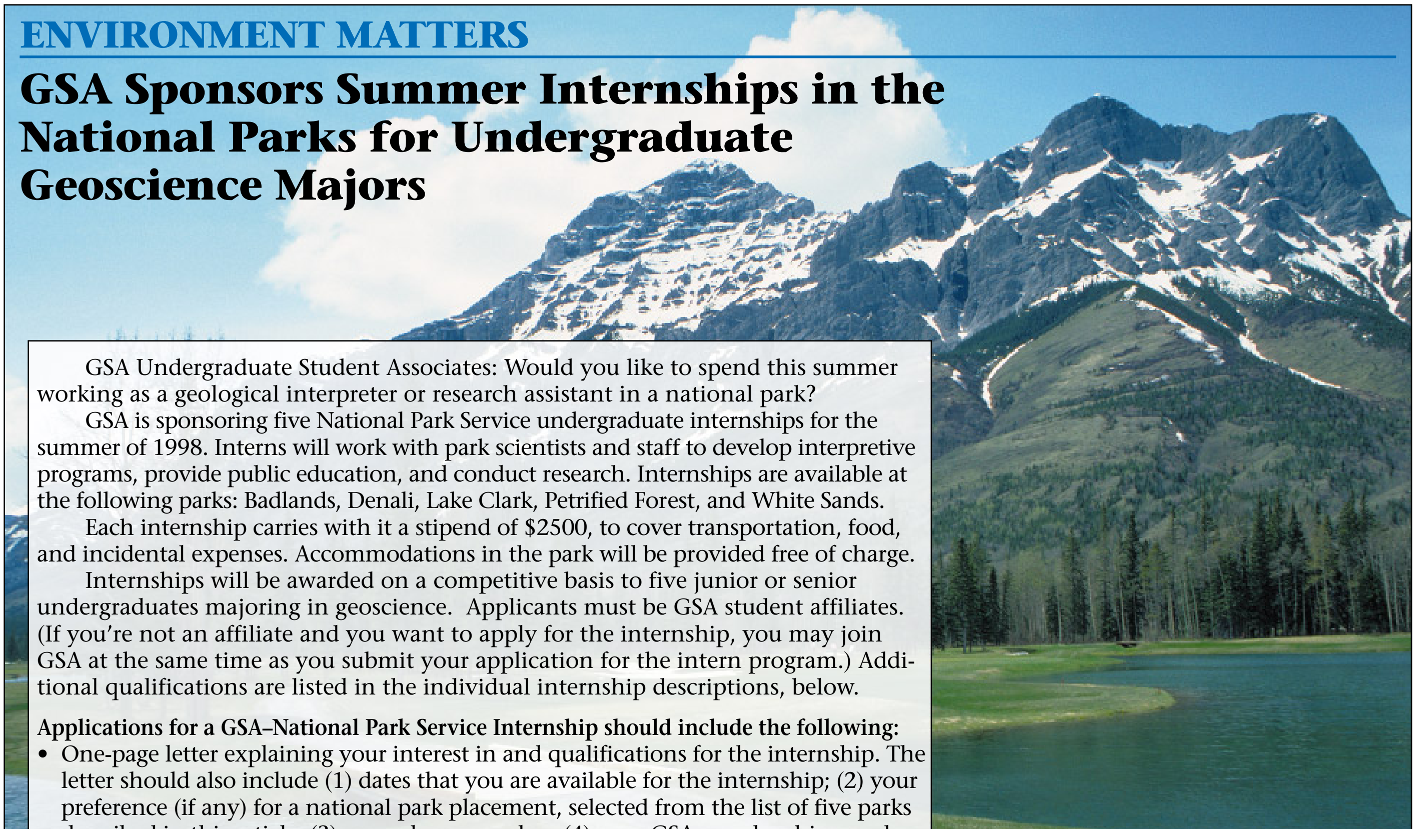

ENVIRONMENT MATTERS

GSA Sponsors Summer Internships in the National Parks for Undergraduate Geoscience Majors

GSA Undergraduate Student Associates: Would you like to spend this summer working as a geological interpreter or research assistant in a national park?

GSA is sponsoring five National Park Service undergraduate internships for the summer of 1998. Interns will work with park scientists and staff to develop interpretive programs, provide public education, and conduct research. Internships are available at the following parks: Badlands, Denali, Lake Clark, Petrified Forest, and White Sands.

Each internship carries with it a stipend of $2500, to cover transportation, food, and incidental expenses. Accommodations in the park will be provided free of charge.

Internships will be awarded on a competitive basis to five junior or senior undergraduates majoring in geoscience. Applicants must be GSA student affiliates. (If you're not an affiliate and you want to apply for the internship, you may join GSA at the same time as you submit your application for the intern program.) Additional qualifications are listed in the individual internship descriptions, below.

Applications for a GSA–National Park Service Internship should include the following:

- One-page letter explaining your interest in and qualifications for the internship. The letter should also include (1) dates that you are available for the internship; (2) your preference (if any) for a national park placement, selected from the list of five parks described in this article; (3) your phone number; (4) your GSA membership number.
- A copy of your academic transcript (unofficial is okay).
- Your resume.
- One letter of reference from a faculty member in your geoscience department. (This letter may be included with your application package in a separate, sealed envelope, with the signature of the reference across the seal, or it can be mailed separately.)

Send applications to: National Parks Internship Program,
Geological Society of America,
3300 Penrose Place, P.O. Box 9140, Boulder, CO 80301

All application materials must be received at GSA headquarters by March 1, 1998.

The five successful applicants will be notified no later than *April 15, 1998.*
For more information, call (303) 447-2020 ext. 195, or e-mail bbrown@geosociety.org

The 1998 GSA–National Park Service Internship Program is supported by generous gifts from John F. Mann, Jr., and the Shell Oil Company Foundation. This program is administered by the John F. Mann, Jr. Institute for Applied Geoscience.

Internship: Badlands National Park, South Dakota

Carved by erosion, this scenic landscape contains fossil remains of mammals, birds, reptiles, and mollusks. Studied since 1847, the White River Badlands area of South Dakota is considered to be the birthplace of the science of vertebrate paleontology. Badlands National Park receives 1.3 million visitors each year, the majority seeking education about fossil and geological resources.

Position Description: The intern will spend 75% of the time in public education work through visitor-center staffing,

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