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Environmental well-being: the contribution of geoscience

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Abstract: Economic and social problems and issues need to be set within the wider context of the environment, not the other way around, as traditional in public policy. Although knowledge of the composition and dynamics of the Earth's surface are fundamental to environmental planning and management, geoscience data and concepts are commonly ignored. One way for geoscientists to contribute to sustainability is through the application of geoindicators, a concept developed recently by the IUGS Commission on Geological Sciences for Environmental Planning. Geoindicators can help to assess changes in ecosystems and landscapes from some earlier condition. They focus on earth processes that can induce significant change in terrestrial environments in less than 100 years. Geoindicators can help to counter the common belief that nature left alone is stable and unchanging and that only humans perturb some sort of natural balance. Failure to recognize the importance of natural change can lead to environmental policies that miss the mark by attempting to manage changes that cannot or should not be stopped.

THE ENVIRONMENT — TWO CHALLENGES TO EARTH SCIENCE

The environment may be defined loosely as the entire web of biophysical interactions that determine the relationship between life and the planet Earth. Or one might take the broader view that the environment is nature itself, the living and non-living world that existed long before the advent of Homo sapiens and that is now increasingly modified, stressed and influenced by human actions. Broadly speaking, the environment is what exists beyond the window. It comprises the landscape, that visible geographic entity of rock, soil, water and vegetation, and the animals, plants and other organisms that live on or move through it. The environment also includes unseen physical and chemical components and conditions — temperature, air and water content, wind and sunshine — that collectively determine the conditions for life. From this broad perspective, I see two major challenges to geoscience.

The first concerns ways to check the health and condition of the world around us. Though it is obvious that neither society nor the economy can exist without a biophysical context — the geosphere, the environment — it is traditional in public policy to view the environment as a sub-set of the economy and society. Decision-makers in government and industry have long regarded the environment as merely one externality in the economic system, the continued functioning and improvement of which is regarded as the ultimate goal in development. This way of looking at the world pervades public thinking and action. Thus, news of a decrease, however temporary, in economic growth rate causes more concern than raging wildfires that destroy invaluable habitats and reduce the quality of the air we breathe, or than massive reductions in marine biodiversity due to overfishing.

Economic health is commonly measured according to Gross National (or Domestic) Product which, like other broad economic indicators, generally ignores environmental considerations such as soil and water pollution and the drawing-down of natural resource "capital" through mining. The billion-dollar clean-up of the Exxon Valdez oil spill added immensely to the economic accounts of Alaska, in part because the value of the environmental damage was not deducted from the plus side of the balance sheet. When the last fish taken from the sea adds another dollar to GNP, one can see the danger (and the stupidity) of depending on economic growth as the primary measure of the health of a nation. A first challenge to geoscience is to contribute to the task of assessing the health of nations and the condition of the environment by incorporating parameters that deal with the geological processes that determine the physical basis for ecosystems.

One of most important and urgent missions for science today is to provide the understanding of nature and of the environment that we need to make our home on Earth a more sustainable one. Is the environment fragile and vulnerable, and does environmental disaster loom ahead? Or is it resilient and robust, able to absorb human inputs without significant reduction to its structure and function? A second challenge to geoscientists is to clarify the relative roles of human and non-human natural processes in determining the state of the environment.

WHAT IS ENVIRONMENTAL GEOSCIENCE?

Broadly speaking, environmental geoscience is the study of those aspects of the non-living physical environment that are affected or influenced by earth processes and human activity. Among the many practical contributions of environmental geoscience to society are:

- finding and helping to develop sources of groundwater for domestic, industrial and agricultural use;
- determining the natural levels of toxic elements in soils, water and sediments so as to establish standards for pollution control and monitoring;
- identifying stable sites for engineering works and waste disposal, avoiding landslide hazards, and surface collapse or subsidence, related for example to active karstification or overpumping of groundwater;
- studying volcanoes and seismicity in order to understand the risks involved and to warn of impending eruptions and earthquakes;
- advising on building codes that prevent development of unstable or hazardous areas;
- helping in the remediation of contaminated land by identifying sources of pollution and leakage and by applying geological materials such as diatomite to extract contaminants from groundwater;
- minimizing harm to the environment while exploring for and extracting minerals and fossil fuels; and
- mapping and regulating onshore, coastal and offshore areas for waste disposal, pipeline and cable routes, and oil and gas production facilities.

In North America and Europe, where industrial and urban clean-ups employ a growing number of geologists, a major focus is on point-source pollution and waste sites, using hydrogeological and geophysical techniques to identify sub-surface conditions and geological materials, such as bentonite, for waste containment. Problems involving soils and surface and groundwater are especially important. Farmers and rural dwellers in Europe, North America, and many other regions have to cope with the contamination of water supplies by fertilizers and other soil additives. The extent of soil and water pollution in the former Soviet Union and elsewhere from the careless disposal of toxic wastes is still being revealed. Indeed, "chemical time bombs" may result when harmful wastes accumulating in otherwise stable places in soils or sediments are suddenly released because of lowering of the groundwater table, accelerated erosion, or melting of frozen soils. In many crowded megacities, especially in developing countries, residents face life-threatening water shortages, unstable ground conditions, or earthquake-induced injury and property damage, in part because of poor construction codes and inadequate housing. There are also problems that arise from natural change, slowed or speeded up by human actions, such as the threat to coastal communities from shoreline erosion and inundation from rising sea level. Basic research is also important, as in working out the record of climatic and other changes in the environment, especially over recent centuries, and developing new ways to integrate geological risks and hazards into national planning.

Knowledge and understanding of the composition and dynamics of the Earth's surface are fundamental to effective planning and management of the environment. Too often, however, earth science data and concepts are ignored in environmental decisions and policies (Berger and Hodge, 1998). For example, the Brundtland Report, "Our Common Future," which has been so important to current environmental thinking with its message on sustainability, took almost no account of natural earth processes. I think it is fair to say that the wealth of information and expertise that exists in the various fields of geoscience is not properly utilized, and that this is at the expense of society.

COGEOENVIRONMENT

In one response to this situation, the International Union of Geological Sciences established in 1990 a Commission on Geological Sciences for Environmental Planning. The main goal of COGEOENVIRONMENT is to contribute to more effective planning and management of the physical environment. Like many non-governmental scientific groups, it works on a shoe-string budget. Its main asset is a worldwide and ever-expanding network of members, who contribute on a volunteer basis, primarily by correspondence, and who are linked by a twice-yearly newsletter.[1] The Commission sponsors and supports many meetings, conferences and training courses, including GEOSEA 98, and it is always interested in suggestions for practical activities.

One of the Commission's first tasks was to produce a brochure for government officials and the general public on the role of the geosciences in environmental planning. This has been twice reprinted in English, and Russian and Chinese versions have been produced, with other translations in preparation. A second major activity was the development and publication of the geoindicator concept, described below. A new working group on medical geology is now gaining momentum. Its main task is to produce a book explaining the importance of geology in health and disease in humans and animals. It will show the importance of metals, minor and trace elements in the environment — neither too much nor too little — in determining the quality of life, including the sources and pathways for both essential and harmful organic and inorganic components.

SEEING THINGS TOGETHER

Environmental geoscience, as seen by the Commission, brings together knowledge and experience from many different areas, including engineering geology, Quaternary and Pleistocene geology, geomorphology, glacial geology, paleoecology, hydrogeology and physical geography. It also draws heavily on geochemistry, hydrology and geophysics. Indeed, the traditional- and artificial-boundaries between these and other fields frequently make it difficult to tackle environmental problems more effectively. Environmental problems are commonly described as if they occur in isolation, with the implication that they can all be readily managed by standard engineering or other approaches. It makes little sense to see minerals simply as nature's resources for the taking, if their extraction and processing has harmful effects on the environment. Neither can we see the addition of fertilizers and pesticides to agricultural lands as completely beneficial, when run-off into stream and infiltration into aquifers reduces the quality of surface and groundwater. Geoscientists increasingly take the integrated view that the Earth is a system and that one event or process affects another, sometimes with a ripple-like effect throughout the whole system. Thus, volcanic emissions to the stratosphere can influence the global climate, the chemistry of surface water, and indirectly the regional diversity of animal and plant life.

It is all very well to talk about holistic approaches to the environment. It is quite another thing to represent a multidimensional system and to describe it in terms that the public can readily understand. Sophisticated mathematical and computer models that deal with the flow of water through the geosphere and its innumerable chemical and physical interactions with rocks, soils, and the atmosphere are certainly useful. However, in communicating these to decision-makers and to the public, one needs, at some point, to explain geological data and conclusions in a visual form. A recent example of what can be done is the wall poster and geological map developed recently by the Geological Survey of Canada to illustrate the urban geology and landscape of Vancouver, British Columbia (Clague *et al.*, 1998).

GEOSCAPE Vancouver (GSC Open File 3309) sets out, on a wall poster for the general public, the main geoscience issues relevant to the residents of this fast-growing city on the low-lying delta of a major river, bordered by the sea and mountains, and set in a terrain that is seismically and volcanically active. The principle used in the GEOSCAPE poster is to concentrate on familiar issues of interest to the public, including floods, groundwater quality, aggregate resources, landslides and avalanches, earthquakes, and volcanic eruptions. The poster uses digital elevation models and block diagrams to bring out the all-important third dimension. Short written descriptions use non-technical language.

GEOMAP Vancouver (GSC Open File 3511) is also aimed at non-geoscientists, such as educators, planners, environmental consultants and the large geotechnical community. A simplified geological map is superimposed on a shaded-relief map and emphasizes each geological unit on the basis of physiographic setting and physical properties. The main map is accompanied by smaller-scale maps that bring out the spatial distribution of earthquake ground-shaking, liquefaction susceptibility, flood hazard, landslides, and aquifer contamination susceptibility. Similar maps and posters could be useful elsewhere to explain to non-geoscientists complex, multi-facetted geological and landscape systems.

[1] For more information including contact addresses, see the IUGS website: www.iugs.org.

ASSESSING ENVIRONMENTAL HEALTH — GEOINDICATORS

Defining environmental health is not easy, but it is generally agreed that greenhouse-gas forcing of the climate, severe erosion of topsoil, and reductions in biodiversity are bad for the integrity and functioning of the geosphere. From the social viewpoint, stability is desirable and beneficial, but we know that ecosystems need disturbance from time to time in order to maintain or renew their functions. Even if we cannot define health, we should be able to measure departures from previous conditions, such as the extent to which a landscape has been changed from some wilderness condition undisturbed by humans.

Many attempts are now being made to establish simple and readily-understood indicators that identify stresses on ecosystems. To indicators of biological and atmospheric condition, can now be added geoindicators, developed by COGEOENVIRONMENT (Berger and Iams, 1996; Berger 1997 and see www.gcrio.org/geo/title). These are measures of abiotic earth processes that can induce significant change in terrestrial ecosystems and environments in less than 100 years, whether or not human stresses are involved.

Geoindicators describe variations in erosion, deposition, geochemical and geophysical properties of soils and water, sea levels, permafrost and karst activity, as well as seismicity, volcanicity and other significant parameters. They are high-resolution measures of dominantly abiotic, short-term changes in the landscape, and they measure both catastrophic events and those that are more gradual but evident within a human life-span. Twenty-seven geoindicators have been identified to monitor and assess geological changes in fluvial, coastal, desert, mountain and other terrestrial areas (Table 1) and compiled using a standard checklist format (Table 2). Many geoindicators can be used through paleoenvironmental research to unravel trends over the past few centuries and longer, thus providing important baselines against which human-induced and natural stresses can be better understood.

Table 1. Geoindicator list.

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

Geoindicators may be useful for assessing the geological aspects of global change, climatic or otherwise (Jones, 1993). Indeed, one might recognize two constituencies that would use geoindicators, one that needs to assess environmental sustainability on a broad scale (national or larger), the other that is responsible for the management of smaller-scale jurisdictions and environments, such as urban regions and national parks. Note that geoindicators that assess soil, surface water and groundwater quality reflect the common emphasis on suitability for human use, with much less attention paid to the extent of the resource. As defined, they do not deal with changes in stocks of non-renewable earth materials consumed by society (minerals, fossil fuels). Resource extraction and utilization are not geological processes but human actions on earth materials, most of which do not undergo natural change on the geoindicator time scale.

Geoindicators may help to integrate dynamic geological parameters with biological, climatic and other measures important for tracking changes in environmental health and condition and for testing the usefulness of existing policies. Geoindicators may also help to counter the common belief that nature left alone is stable and unchanging and that only humans perturb some sort of natural balance. Earthquakes, landslides, eruptions, and widespread flooding, which can transform urban, rural and

Table 2. Checklist format.

NAME of geoindicator. Note that some are single parameters (e.g. shoreline position, streamflow) and others are aggregated (frozen ground activity, soil quality).
BRIEF DESCRIPTION: How does it relate to geological processes and phenomena?
SIGNIFICANCE: Why should it be monitored, and how are changes in it liable to affect agriculture, forestry, environmental health, human settlements, and other societal issues?
HUMAN OR NATURAL CAUSE: To what extent can it distinguish natural from anthropogenic change?
ENVIRONMENT WHERE APPLICABLE: In what general landscape settings would it be used?
TYPES OF MONITORING SITES: What specific locations?
SPATIAL SCALE: Over what area would monitoring be done, and to which larger scale might it be aggregated?
METHOD OF MEASUREMENT: How is it measured in the field, and what lab and other techniques are involved?
FREQUENCY OF MEASUREMENT: How often should monitoring take place, so as to establish a useful time series and baseline trend?
LIMITATIONS OF DATA AND MONITORING: What important difficulties are there in acquiring field or lab data and in applying results to environmental assessment?
APPLICATIONS TO PAST AND FUTURE: How can it be applied to paleoenvironmental analysis, and what predictive potential has it?
POSSIBLE THRESHOLDS: What limits that once crossed could result in significantly different conditions or threats to human health and biodiversity?
KEY REFERENCES
OTHER SOURCES OF INFORMATION
RELATED ENVIRONMENTAL AND GEOLOGICAL ISSUES
OVERALL ASSESSMENT: Importance for assessing environmental condition and sustainability.

wilderness landscapes, are thus regarded as anomalies (disasters), rather than a part of the natural background. Failure to recognize the importance of natural change can lead to environmental policies that miss the mark by regarding nature in the absence of humans as unchanging and everywhere benevolent.

APPLYING GEOINDICATORS IN THE HUMID TROPICS

It may be useful to consider three examples where a geoindicator-based analysis could be useful for tackling environmental issues in the humid tropics. In each situation, there is the capacity for significant geoindicator change within a time frame of weeks, seasons, or years.

It is customary for new urban or mine developments to carry out a standard environmental impact assessment to establish the potential effects on groundwater, soils, vegetation, wildlife, and a range of other environmental components. The relevant geoindicators for a mine site and transportation corridor would include groundwater and surface water quality, soil and sediment erosion, and soil quality. In addition, there could be direct or indirect effects both on land and near shore (at the shipping facility) on sediment sequence and composition, streamflow, stream channel morphology, and stream sediment storage and load. It would be important to establish not only the present baseline condition of these parameters but also their trends over the recent past, using a range of paleoenvironmental techniques, such as coring sediments in nearby lakes and wetlands, and determining the isotopic content of groundwater in the unsaturated zone. Past trends might indicate the direction in which change would occur without additional land disturbance. Forecasting likely environmental impacts is one thing, actual monitoring to determine both compliance with agreements and what changes are actually occurring is quite another, and it is important to establish a means of assessing any future changes in relevant parameters.

Many coastal stretches are subject to dynamic changes in shoreline morphology and position, resulting from the erosion accompanying a severe wave climate, rapid subsidence due to groundwater overpumping, or sediment deposition. Many variations have been recorded in patterns of near-shore and offshore erosion and deposition and in the morphology of estuaries and back-shore and lagoonal wetlands. These are the result of both natural and human actions, such as the mining of coral reefs and placer tin dredging. To what extent are heavy minerals in beach placers being depleted?

Are some being renewed from nearby off-shore deposits? What is the effect on marine life and coastal water quality of contaminated sediment transported to the sea by nearby rivers? To what extent can the past record of coastal change, as read for example from beach rock and littoral sediment deposits, provide a guide to present and future condition? The establishment of coastal monitoring programs at selected sites would provide much useful data to answer such questions.

In the past decade or two, the character of many parts of Southeast Asia has been altered by rapid cutting of forests. There is much evidence of impacts on the plant diversity, if not on the soil organisms and small animals that formerly existed in these areas. But what has been the effect on soil quality (chemistry and texture), groundwater level, surface water runoff and infiltration, and soil and sediment erosion, particularly on hillsides? Is there a unidirectional change in soil fertility? It is changes in these areas that have been found to be most important in temperate rainforest clear-cuts. Indeed in British Columbia and Washington state, the widespread clearing of old growth forests on steep hillsides has been responsible for accelerated soil erosion, increased stream sediment transport, and loss of habitat for anadromous fish. In Sri Lanka, the recent intense replanting of barren slopes with pine trees (a non-native species) is a large-scale experiment in ecosystem manipulation that could provide an opportunity to obtain basic scientific information on the effect of afforestation on soil, groundwater, and slope processes. A series of transects from unforested to forested patches should establish the extent of any change in geoindicators.

THE AUTONOMY OF NATURE

Geoindicators can help to draw attention to the importance of rapid environmental change that is not caused by human actions. It is common in public discussion and policy to forget that nature, however much influenced by industry, agriculture, and urbanization, is still independent and autonomous (Berger, 1998; Berger and Hodge, 1998). There is no doubt that human actions have affected much of the earth in one way or another, from climate to water quality, from soil erosion to species extinctions. However, so intent is the discussion on the harmful effects of human actions that scant mention is made of natural change and its effects on land and the biosphere. Many environmental writers and activists today have forgotten the ancient warning of Heraclitus that everything is in flux, that one cannot step twice into the same river. There is a common belief that the environment would be stable and benevolent if only humans did not interfere with and force natural processes.

Recent international agreements on the environment appear to be strangely silent on the fact that natural processes continue to set the biophysical context for life, as they have throughout its long evolutionary history. It is not obvious from the Climate Change Convention, for example, that human-induced changes are superimposed on, and interact with, natural climatic variations (e.g. El Niño), which in the not very distant past were more marked than those currently predicted (Broecker, 1997, 1999). I can find no clear indication in the Convention on Biological Diversity that biodiversity is affected not only by hunting, over-fishing, and the conversion of wilderness into developed land, but also by natural events and processes beyond our capacity to predict and control. The great outcry against alien species (introduced by humans into areas where they did not previously exist) rarely acknowledges that organisms have always migrated from one place to another in response to environmental stresses and opportunities.

The problem here is the implication that diversity, integrity and beauty are lessened only by human stresses, and that harmful natural processes are not worthy of mention since they can supposedly all be managed. To what condition should damaged ecosystems be restored if nature is ever-changing? When considering basic human rights to potable water, clean air, uncontaminated soil and food security, should we not also recognize that natural processes may make environments unsuitable for clean air (volcanic gases), soils may not be healthy for agriculture where there are high natural background contents of toxic elements, and that food security may be compromised by prolonged droughts and intense El Niño events?

The general "anthropoblamist" view is that human actions are the only important determinant of the state of the environment, and that what is needed to achieve sustainable environments is simply a better regard for and management of land, ecosystems, and habitats. If only people would not interfere, natural change would be gradual, 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.

When the central Sahara was hit by climate change 5000 years ago, vast stretches of savanna and grasslands, some rich in biodiversity, were degraded and destroyed. Humans and some animals survived by migration, but life became impossible for the fresh-water fish and plants that abounded there. Their habitats disappeared, and it is only their fossilized remains that bear witness to former healthy ecosystems (Petit-Maire, 1994). It is well-established that geological landscape change exercised important controls on the development of societies and religions in the Middle East (Issar, 1993; Neev and Emery, 1995), and in early China (Stanley and Chen, 1996).

These changes may well have been considerably slower than those now being caused by human actions. However, evidence is mounting of climatic instability during the Holocene: the proxy climate data extracted from the earth archive (lake sediments, glacier layers, coral and tree growth rings) show clearly that natural climate variability over the last 10,000 years is much greater than that revealed by the instrumental record. Ocean sediment cores show that water temperatures during the past 3,000 years have varied by more than 3°C, with some changes being more rapid than 0.25°C per decade, faster even than the IPCC predictions for the next century. If the recent work on the Greenland ice cores is correct, there were very rapid swings in temperature during the last inter-glacial that make the predicted global warming look like child's play (Broecker, 1997). The transition from the end of the Pleistocene (Younger Dryas) to the start of the Holocene appears to have occurred over a 40 year period when the temperature warmed as much as 7.5°C, and there were also rapid changes in wind speeds, precipitation and sea-ice cover (Taylor *et al.*, 1997; Broecker, 1999). New studies of Arctic paleoenvironments show that from 1840 to 1950, the region warmed on average 1.5°C (1°–3°) from the preceding Little Ice Age (Overpeck *et al.*, 1997). Ecosystems of these intervals are unlikely to have survived unscathed.

How best can we emphasize the importance of natural change to decision- and policy-makers and to the public in general? One way is to demonstrate repeatedly and systematically the many ways in which abiotic landscape components can change in magnitude, intensity or direction on a time-scale meaningful to individuals and to society. We need to be able to identify and track changes in ecosystems and landscapes and to communicate these in terms that policy-makers and the general public can understand. The geoindicator approach may help here by focussing attention on the geological processes and phenomena that should be monitored. So, as you travel through the landscape, ask yourself what environmental components might be changing significantly on a human time-scale, and decide how you would monitor and communicate such changes to environmental managers and the general public.

SUMMARY

All life exists against a moving natural background that makes sustainability in the sense of stasis, equilibrium and harmony not always possible to attain. What we can do is to reduce careless and rapacious human actions. 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. But putting the blame entirely on humans for deadly coastal flooding in Bangladesh, degradation of land in Honduras resulting from a severe hurricane, or widespread destruction due to earthquakes in central Colombia does not seem the path to better environmental policies and attitudes. If you think I am exaggerating the public ignorance of natural change and the dark side of nature, watch the news media regularly for a week for items and statements heaping blame on humans for the vicissitudes of nature. You will find them aplenty.

We cannot switch off natural change, whether this affects climate or coastal systems, or results from bombardment from space. We need to find better ways to reduce human stresses while recognizing the autonomy of nature, the other side of the human-nature relationship. At the heart of the matter are some fundamental questions. How can we plan for the indeterminate, the unpredictable? To what extent should we intervene in (manage) naturally changing environments, and to what extent should we restore ecosystems that have been degraded, whether by human or natural agency? In searching for answers, geoscience has a major role to play, and this is one of the most important areas for future research and application.

REFERENCES

BERGER, A.R., 1997. Assessing rapid environmental change using geoindicators. *Environmental Geology*, 32(1), 36–44.

BERGER, A.R., 1998. Environmental change, geoindicators, and the autonomy of nature. *GSA Today*, 8(1), 3–8.

BERGER, A.R. AND HODGE, R.A., 1998. Natural change in the environment: A challenge to the pressure-state-response concept. *Social Indicators Research*, 44, 255–265.

BERGER, A.R. AND IAMS, W.J. (Eds.), 1996. *Geoindicators: assessing rapid environmental change in earth systems*. A.A. Balkema, Rotterdam, 466p.

BROECKER, W.S., 1997. Will our future ride into the greenhouse future be a smooth one? *GSA Today*, 7(5), 1–7.

BROECKER, W.S., 1999. What if the conveyer were to shut down? Reflections on a possible outcome of the great global experiment. *GSA Today*, 9(1), 1–7.

CLAGUE, J.J., TURNER, R.J.W. AND GROULX, B.J., 1998. Reinventing the geological map: making geoscience more accessible to Canadians. *Geoscience Canada*, 24, 161–172.

ISSAR, A.S., 1990. *Water shall flow from the rock — Hydrogeology* *and climate in the lands of the Bible.* Springer-Verlag, Berlin, 213p.

JONES, D.K.C., 1993. Global warming and geomorphology. *The Geographical Journal* 159, 124–130.

NEEV, D. AND EMERY, K.O., 1995. *The destruction of Sodom, Gomorrah, and Jericho. Geological, climatological and archaeological background.* Oxford University Press, New York, 175p.

OVERPECK, J., HUGHES, K., HARDY, D., BRADLEY, R., CASE, R., DOUGLAS, M., FINNEY, B., GAJEWSKI, K., JACOBY, G., JENNINGS, A., LAMOUREUX, S., LASCA, A., MACDONALD, G., MOORE, J., RETELLE, M., SMITH, S., WOLFE, A. AND ZIELINSKI, G., 1997. Arctic environmental change of the last four centuries. *Science*, 278, 1251–56.

PETIT-MAIRE, N., PAGE, N. AND MARCHAND, J., 1994. *The Sahara in the Holocene.* Paris: Unesco, Map at 1:5,000,000.

STANLEY, D.A. AND CHEN, Z., 1996. Neolithic settlement distributions as a function of sea level-controlled topography in the Yangtze delta, China. *Geology*, 24(12), 1083–1086.

TAYLOR, K.C., MAYEWSKI, P.A., ALLEY, R.B., BROOK, E.J., GOW, A.J., GROOTES, P.M., MEESE, D.A., SALTZMAN, E.S., SEVERINGHAUS, J.P., TWICKLER, M.S., WHITE, J.W.C., WHITLOW, S. AND ZIELINSKI, G.A., 1997. The Holocene-Younger Dryas transition recorded at Summit, Greenland. *Science*, 278, 5–827.

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