

# Landscapes on the Edge

## New Horizons for Research in Earth Surface Processes

Chemical, physical, biological, and human processes constantly reshape Earth's surface, at scales ranging from particles to continents and from nanoseconds to millions of years. These processes form a complex network of interactions and feedbacks, but currently, these interplays are not well understood, and challenging questions face science and society: How did Earth surface processes interact to create the landscapes of today? How will changing processes shape landscapes in coming years? This report identifies nine grand challenges in this emerging field of study and proposes four high-priority research initiatives.

Over geologic spans of time, Earth's shifting tectonic plates, atmosphere, freezing water, thawing ice, flowing rivers, and evolving life have shaped Earth's surface features. The resulting hills, mountains, valleys, and plains shelter ecosystems and interact with all life, and provide a record of Earth surface processes that extends back through Earth's history. Despite rapidly growing scientific knowledge of Earth surface interactions and feedbacks, and the increasing availability of new monitoring technologies, understanding of how interconnected processes generate and degrade landscapes is incomplete. Scientists are challenged to take full advantage of the extensive archive that Earth's surface provides.

Earth surface science has helped solve practical problems such as restoring ecosystems and maintaining water supplies, and will allow scientists to anticipate and predict the effects of changing conditions, such as the impact of



future climate change on the landscapes of coastal areas or the Arctic.

In recognition of the need for a more complete understanding of processes that shape Earth's surface, the National Science Foundation requested that the National Research Council assess the fundamental questions in Earth surface processes, identify

challenges and opportunities in this area of study, and outline the research needed to meet these challenges.

New technologies now allow scientists to examine Earth's surface in greater detail than ever before. Together with an interdisciplinary approach to the emerging science of Earth surface processes, the report suggests that these developments will aid in the planning of environmental restoration efforts and will guide policy for such issues as hazard reduction and environmental protection. The report suggests focusing research efforts on

four high-priority research initiatives that will facilitate progress towards a new understanding of Earth's surface.

## Nine Grand Challenges Facing Earth Surface Processes

Analysis of the current state of Earth surface science allowed the report's authoring committee to identify nine challenges that provide opportunities for progress in this emerging field of study.

### *Earth's Surface as a Record*

#### 1. What does our planet's past tell us about its future?

Earth's landscape is a record of its own evolution—features like mountains, the heaps of sediment left in the wake of a retreating glacier, or mud at the bottom of rivers, provide a record of Earth's environmental conditions that extends back through time. New tools and techniques to analyze this extensive natural record will help scientists understand the processes that shaped Earth and predict how changing Earth surface processes will shape the landscapes of the future.

#### 2. How do geopatterns on the Earth's surface arise and what do they tell us about processes?

Geopatterns range from the branching patterns of river networks to the repeated ridges of sand dunes stretching across a desert. These patterns provide

insight into the Earth processes that shape landscapes—for example, the path of a river illustrates patterns of erosion, and the balance of nutrients in a soil can tell the tale of long-past chemical fluxes. Now, new observational tools and powerful ways to present spatial data, as in geographic information systems, can help scientists to understand how geopatterns form.

### *The Shaping of Earth*

#### 3. How do landscapes record climate and tectonics?

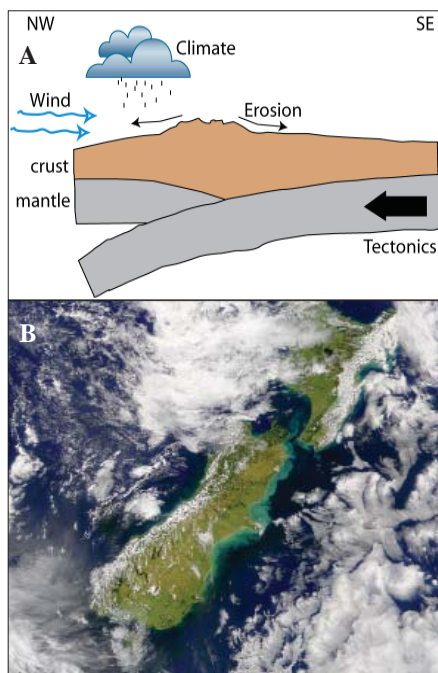
Tectonic plates, pieces of the jigsaw puzzle of Earth's crust, are hard, dense, and change slowly. In contrast, Earth's atmosphere is fluid, light, and rapidly changing. Despite these differences, the atmosphere can help shape Earth's surface, with consequences for climate, the evolution of landscapes and biological communities. This concept is illustrated in Figure 1, which shows how the movement of tectonic plates can shape the topography of a mountain range with impacts on local climate.

#### 4. How do biogeochemical reactions at Earth's surface respond to and shape landscapes?

The chemical erosion and weathering of bedrock creates soil, essential for anchoring and nourishing life, and also contributes to landscape evolution and nutrient cycles. In addition, the breakdown of bedrock feeds back to potential effects such as the chemistry of groundwater and rivers and soil nutrients content.

#### 5. What transport laws govern the evolution of the Earth's surface?

For a quantitative understanding of the impacts of factors such as climate, hydrology, geology and erosion on landscapes, a set of mathematical laws to define fundamental the rates of processes such as landslides, glacial erosion, and chemical erosion are required. These mathematical laws will allow researchers to understand the mechanics and rate of landscape change.



**Figure 1.** A mountain range is influenced by climatically controlled erosion.

A. Two converging tectonic plates form mountains, whose topography influences climate. The increased precipitation causes erosion, which can influence the shifting of tectonic plates. Image modified from Willet, 1999.

B. The topography of New Zealand's South Alps causes clouds to bank along the northwestern side of the mountain range. The increased precipitation leads to erosion, tectonic deformation and uplift. Image courtesy of the SeaWiFS project, NASA/Goddard Space Flight Center, and ORBIMAGE.

## 6. How do ecosystems and landscapes co-evolve?

How different would the Earth be if life had never evolved? Living organisms break rock into soil particles, exhaust gases to the atmosphere, and alter the chemistry of Earth's surface. The presence of living organisms can make otherwise dense and solid ground permeable, and can cause rainfall and snowmelt to enter the subsurface, influencing the form and pace of surface erosion and biogeochemical cycling, and affecting climate, hydrology, erosion and topography. An understanding of the linkages among living ecosystems, Earth surface processes, and landscapes, will be needed to fully understand Earth's changing surface.

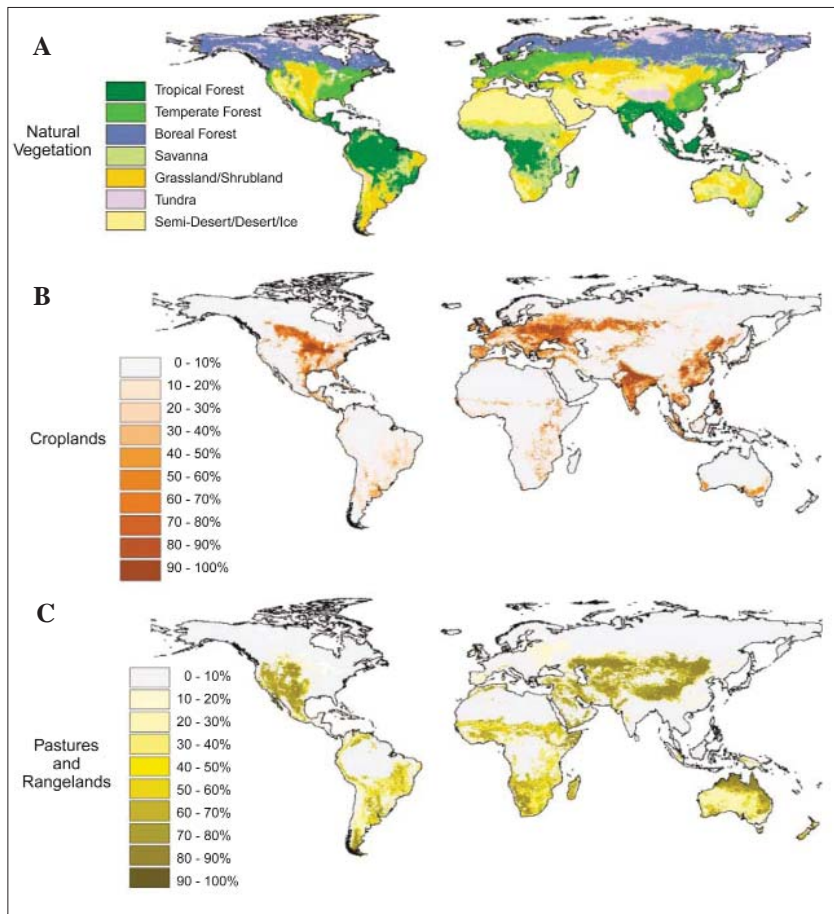
### *Changing Earth Surface Processes, Changing Landscapes*

## 7. What controls landscape resilience to change?

Geological and modern records of changing landscapes show that Earth's surface changes under the influence of drivers such as climate, plate tectonics, volcanism, and human activities—and when conditions change with sufficient magnitude and duration, landscapes can be altered irreversibly. Some changes are gradual, and others are abrupt, ranging from the millennia it takes for glaciers to move across the landscape to the seconds it takes for a landslide to occur or for a levee to fail. The conditions that lead to these landform transformations are difficult to predict, and few landscape changes have been well monitored. A comparison of neighboring landscapes affected by differing processes can provide information on the magnitude and duration of changes that alter landscapes beyond the range in which they can recover.

## 8. How will Earth's surface evolve in the Anthropocene?

The term "Anthropocene" has emerged to denote a new geologic period in which the human population dominates the Earth system. For example,



**Figure 2.** Humans have transformed much of the Earth's surface. These maps illustrate the extent of human land-use and land-cover change: A. The potential vegetation that would most likely exist in the absence of human land use. B, C. Agricultural land cover, including cropland and pastures, across the world in the 1990s. Source: Foley et al. 2005.

human-constructed dams have changed the flow of water and sediment through river networks, causing the collapse of aquatic ecosystems and erosion of deltas, wetlands and beaches. Human-induced climate change can also melt glaciers and release huge volumes of ice and water, altering water supplies and flood hazards. Understanding, predicting, and adapting to changing landscapes increasingly altered by humans is a pressing challenge which falls squarely within the purview of Earth surface science. Research on the interactions between humans and landscapes will be needed to meet this challenge.

## 9. How can Earth surface science contribute to a sustainable earth surface?

As a result of scientific understanding of the causes and cumulative long-term effects of human-induced changes, a consensus has emerged in society that at

least some disrupted and degraded landscapes should be restored or redesigned. Research in Earth surface processes brings knowledge of how major environmental drivers will affect restoration efforts and guide decision making in developing a sustainable living surface for future generations. An example comes from the Marmot Dam in Oregon, a hydroelectric dam built in the early 20th century. Environmental restoration efforts led to the removal of the dam and a stream restoration project, but when the dam was removed, sediment stored in the reservoir was rapidly mobilized, leading to a sudden, unforeseen pulse of sediment downstream. Nevertheless, salmon migrated past the dam site within several days of the removal of the dam.

### ***Research Initiatives***

To make progress in addressing the nine grand challenges, the committee suggests a collaborative approach to the emerging field of Earth surface science, integrating expertise from Earth, atmospheric, climate, ocean, biological, geographic, engineering and social sciences. In addition, the application of new technologies will fuel advances towards these four research initiatives.

#### ▪ **Interacting Landscapes and Climate**

Reaching a quantitative understanding of climatic controls on Earth surface processes, and the influence of landscape on climate over timescales

from individual storm events to the evolution of landscapes, will shed light on the connection between landscapes and climate.

#### ▪ **Quantitative Reconstruction of Landscape Dynamics across Time Scales**

Developing detailed reconstructions of the evolution of Earth's surface, based on information recorded in landscapes and in sedimentary records, will provide information on how Earth's surface has changed over various time scales.

#### ▪ **Co-evolution of Ecosystems and Landscapes**

New ways of measuring how the living and non-living worlds interact, and an increasing ability to link biological processes with changing landscapes, present the opportunity to forge a new understanding of the co-evolution of ecosystems and landscapes and to address pressing problems of future environmental change.

#### ▪ **Future of Landscapes in the Anthropocene**

Substantial advances have been made in the understanding of the range and extent of human impacts on Earth-surface systems. These advances, coupled with technological breakthroughs, opens the path to answering a fundamental and urgent question—how can we predict and respond to rapidly changing landscapes that are increasingly altered by humans?

---

**The Committee on The Challenges and Opportunities in Earth Surface Processes: Dorothy J. Merritts** (*Chair*), Franklin and Marshall College, Lancaster, Pennsylvania; **Linda K. Blum**, University of Virginia, Charlottesville; **Susan L. Brantley**, The Pennsylvania State University, University Park; **Anne Chin**, University of Oregon, Eugene; **William E. Dietrich**, University of California, Berkeley; **Thomas Dunne**, University of California, Santa Barbara; **Todd A. Ehlers**, University of Michigan, Ann Arbor; **Rong Fu**, University of Texas, Austin; **Christopher Paola**, University of Minnesota, Minneapolis; **Kelin X. Whipple**, Arizona State University, Tempe; **Elizabeth Eide** (*Senior Program Officer*), National Research Council.

The National Academies appointed the above committee of experts to address the specific task requested by the National Science Foundation. The members volunteered their time for this activity; their report is peer-reviewed and signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.



For more information, contact the Board on Earth Sciences and resources at (202) 334-2744 or visit <http://nationalacademies.org/besr>.

Copies of *Landscapes on the Edge: New Horizons for research in Earth surface processes* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; [www.nap.edu](http://www.nap.edu).

*Permission granted to reproduce this brief in its entirety with no additions or alterations.  
Permission for images/figures must be obtained from their original source.*