Key Questions and Challenges in Dynamic Earth Processes, Natural Resources, and Hazards linked to Geologic and Soil Surface Composition

Description

This white paper discusses the major questions in landscape sciences addressed through surface compositional studies. Earth's dynamic surface processes cause land surface change due to erosion, degradation, and desertification, lead to concentration of natural resources, and create landscapes susceptible to natural or human-influenced hazards.

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Key Questions and Challenges

This white paper discusses major questions in geological sciences addressed through surface compositional studies. These questions and challenges are described in three broad areas, (1) dynamic earth processes that result in land surface change, (2) location and availability of natural resources and (3) impacts on society from natural and human-influenced hazards. ***Major challenges synergistic to all three areas include identification of surface materials on a global scale, understanding how rapidly surfaces are changing and establishing metrics of change prior to and after catastrophes or other unique events.***

Land Surface Change

The global land surface is experiencing unprecedented change, and yet both the rate and extent of severe land degradation is only poorly understood. Understanding and quantification of the spatial distribution of soil surface properties is important as it contains valuable information about organic matter, soil degradation processes, crust formation, salinity, runoff, infiltration and many other hydrologic and earth surface processes. Soil resources play a fundamental role for assuring food security. The interface between rock weathering, soil formation and the biosphere is often referred to as the "critical zone" where living organisms interact in ways that regulate natural habitats and determine the availability of life-sustaining resources such as food and water. We need a better understanding of which processes drive land degradation and how well mitigation processes are working. At small scales, digital soil mapping, combining geo-statistics, terrain analysis and remote sensing, has been successful in delivering up-to-date soil information. This is especially important in understanding long-term trends as vegetation species composition and growth cycles are strongly linked to soil characteristics. Also on a small scale, remote sensing technologies have been utilized to monitor and evaluate agricultural tilling practices that preserve soil nutrient content and reduce the need for soil amendment and impacts on water quality.

Still, challenges exist for larger scale assessments (greater than 10,000 sq. km), the most critical of which is availability of satellite remote sensing instruments capable of characterizing soil mineral and nutrient composition. Existing broadband satellite multispectral instruments such as Landsat lack sufficient spectral resolution that will allow us to distinguish soil minerals from one another, or from organic materials and cover vegetation with which they are often associated.

In Alaska and other high-latitude arctic regions, the state and condition of permafrost (frozen organic soils) is another critical issue because of the potential release of methane gas, which is an even more potent greenhouse gas than carbon dioxide. Although the older Landsat sensors have had single thermal infrared bands capable of measuring surface temperature (critical to monitoring the active layers of permafrost zones), the spatial resolution (i.e. ~120 meters/pixel) have always been poor for monitoring permafrost thaw and thermokarst formation at the landscape scale.

Natural Resources- Energy and Minerals
Scientists, policy makers, and other stakeholders rely on accurate assessments of resource availability, location and quantity in order to make predictions of economic growth, energy supplies, and sustainable societies. Natural resources, including minerals for the built environment, fossil and renewable energy, are critical to the US economy.

Surface bedrock and soil exposures contain a variety of minerals, including clays, which have variable physical and chemical properties. Certain clay minerals are indicative of processes that help to form mineral resource deposits and can lead us to new energy resources. Some minerals can occur in pure enough forms to give them value as industrial minerals that are used extensively as building and roofing materials. Understanding the source and distribution of these minerals within urban landscapes is critical to understand the effects of urban expansion such as the creation of urban heat islands. Accurately monitoring changes in global surface temperature requires an understanding of surface compositional changes at thermal wavelengths (emissivity).

Exploration for and development of strategic mineral resources requires detailed mapping of surface cover over large areas in order to target high priority prospects or areas of interest. Despite potential for mineral development, other remote areas, such as high latitude lands like Alaska, remain largely under explored. Because of their remoteness, short observation season, vegetation cover, and poor illumination, modern spectroscopic instruments are needed to identify and map surface indicators of resources. As compared to modern hyperspectral sensors, the Landsat series lacks the ability to discriminate mineral types, mineral chemical compositions, and vegetation changes. A global inventory of resources using surface composition as a vector to those resources does not yet exist.

Natural and Man-Made Hazards
Whether hazards such as floods, wildfires, landslides and human caused accidents and activities have consequences that are serious or are truly catastrophic, depend on whether they have been anticipated and what preparations and societal readiness exist. Satellite monitoring after events can rapidly classify regions of highest priority for intervention, cleanup and remediation. In particular, slope stability and susceptibility to landslide depends upon the mineral composition, soil cohesion among other parameters. A separate white paper deals explicitly with volcanic eruptions and their impact on society, so we focus here on other types of hazards and understanding the scope and scale of their impacts.

In particular, information on which locations are susceptible to hazards such as landslides and floods need to be identified and linked to the land surface compositional characteristics. In case of a natural disaster, which areas affected, how severely and how this information can be provided for short-term coordinated emergency response is crucial.

Soils are altered by fire in complex ways. The type of clays in soils has been shown to have large impacts on erosion and slope failures. Although existing satellite remote sensing technologies have capability to categorize burn severity, they lack the ability to directly sense soil mineral composition pre- and post-fire. This type of information can be used to improve modeling of catastrophic debris flows by increasing understanding of surface factors that influence erosion, including post-fire ash/char deposition, soil clay content, and post-fire cover of vegetation likely to survive and plants likely to experience delayed mortality.

The *Deepwater Horizon* oil spill catastrophe highlights potential risks associated with extraction of petroleum resources in difficult or inaccessible locations and the need for rapid, large-scale surface compositional assessments associated with clean up operations.

Understanding potential effects of land use history is vital to managing soil and water quality. For example, historical mining has left many watersheds vulnerable to mobilization of mine waste through annual snowmelt, cataclysmic events such as fire, storms, or retaining pond breaches. Remote sensing applications used to identify mineralogy and soil chemistry, or even shifts in vegetation that could be associated with trace-metal contaminated soils, can help identify watershed regions that should be prioritized for remediation.

Common Major Challenges in Surface Change, Resources and Hazards

Establishing a global inventory of surface geologic and soil composition: Although the Landsat suite of satellites has monitored the Earth's land surface since the 1970s, these sensors do not have sufficient spectral fidelity to map fundamental surface compositional properties associated with lithology, soil and surface alteration of rocks. ***An imaging spectrometer system can provide data consistent with the Landsat continuity mission and provide a wealth of new exploratory and applications research related to compositional mapping. This sensor should have contiguous channels in the VSWIR (0.4 to 2.5 μm) and sufficient channels in the TIR (7.5 to 12 μm) to separate surface material emissivity from temperature.***

Identifying the rate of surface change of these materials: Land surface change, impacts of naturals hazards, extent of effects of natural resource development depend on mapping surface compositional change over time in order to understand rates of change. ***A repeat cycle roughly consistent with existing Landsat acquisitions is needed.***

Pre- and post-event characterization: Providing a global inventory of surface composition and frequent repeat observations will provide the required baseline to establish areas susceptible to hazards, how they have changed during events, and areas for immediate response and action following events.

Why are these challenges/questions timely to address now with respect to readiness?

- There is tremendous synergy with modern, recently launched commercial imagery at both the satellite and surface scale (e.g. World View 3, UAS and drones).
- Low cost field and commercially-available airborne instruments are widely available and providing new methods of satellite validation.
- Surface impacting events such as landslide, earthquake, drought, wildfires are common and potentially increasing in frequency due to climate change.
- Current satellite sensors are aging, have calibration issues and don't take advantage of technological advances in imaging spectroscopy that would maximize surface compositional information.
- NASA's sustainable land imaging program dates back ~30 years and can continue with enhanced fidelity and capability.
- There is synergy with new or recently launched missions (SMAP, NEON).
- Advances in 'Big Data' Computing (on-board processing capabilities).
- Modern multi-sensor data fusion capability (imaging plus topographic data from lidar for example).
- Social media and outreach is more prevalent, disaster response on the ground can include new tools and materials, including engagement with citizen scientists.

Why are space-based observations fundamental to addressing these challenges/questions?

- Global accessibility and continuity
- Climate research requires global measurements
- Global surface boundary conditions are needed for global models
- Space offers cost-effective data acquisition
- Allows temporal/spatial observations and variability
- Crosses political boundaries where access may be difficult
- Enables mapping of geopolitically unstable regions.
- Allows diurnal cycle observations
- Provides repeatability (frequency, seasonality)