Lithological mapping with spectral remote sensing

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Summary

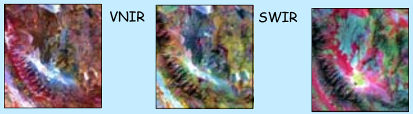
Rock, soil, and vegetation composition can be mapped using passive multispectral visible/near-infrared (VIS/NIR) scanners. Additionally, the thermal infrared (TIR) can be used to map differences in silica and carbonate content in rocks and soils. A variety of methodologies were used to map out different units, including: spectral angle mapping, spectral mixture analysis, and supervised classification techniques. The different units were mapped as layers of the final produced map. It is critical to understand the processes that form desert surfaces to develop a model for predicting desert terrain conditions. Remote sensing is an important tool for both understanding these processes as well as provide inputs for predictive geomorphic surface evolution models. These inputs, which describe surface composition / condition, include maps of: 1) rock/soil types, 2) vegetation cover and, 3) surface roughness. These surface characteristics are also important factors in determining trafficability and dust generation from military operations. We have drawn on examples from earlier studies that illustrate the state of the art. Data are from Landsat TM and airborne simulators TM-001 and TIMS, and also from ASTER.

History

The field of reflection spectroscopy was invented in the 1960s in order to identify minerals, and early efforts led by J. B. Adams soon applied it to problems of mineral and lithologic mapping on the Moon and then Mars. On Earth the first civilian efforts at multispectral imaging from space were organized around mapping vegetation, but pioneers such as Alex Goetz and Larry Rowan soon applied Landsat MSS data to mapping in hydrothermally altered zones. Improvements suggested by their work underlay the development of Landsat TM, with its extra bands, and by the early 1980s true "hyperspectral" VNIR/SWIR airborne imagers such as AVIRIS. This instrument was developed explicitly for lithologic mapping and mineral identification. The *Joint Geosat-NASA-JPL Test Case Report* (1983) summarizes the field well.

Also in the 1980s, Anne Kahle and Larry Rowan recognized that multispectral thermal data acquired by NASA's airborne NS-001 Thematic Mapper Simulator could be used to map rocks based on their siliceous mineral content, rather than hydrous minerals and secondary Fe oxides. By 1984, Gillespie and colleagues at JPL showed that multispectral thermal images were capable of generating accurate rock-type maps and even in distinguishing alluvial fans based on relative age as well as parent lithology. The relative dating was based on chemical and mechanical weathering. This was done in 1984 in a region of diverse lithologies (carbonates and silicates) at near Trail Canyon and Blackwater Wash in the Panamints and the results are summarized in this poster (right).

Gillespie, Bud Burke, Jennifer Harden, Fred Fischer, and others then applied spectral imaging to the compositionally similar granitic fans on the western side of Owens Valley, showing that relative dating there too was feasible, and that distinctions among different granite outcrops could be made spectrally, even in the presence of weathering products. Mohammed Sultan, Ray Arvidson, and others from Washington University showed in Egypt that parent compositions could be distinguished, even in the presence of heavy desert varnish.



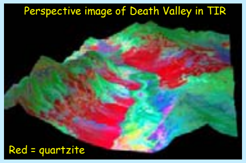
Full-spectrum ASTER images of Saline Valley, CA, about 40 km across. Different spectral windows reveal different information about a landscape: the VNIR image reveals mostly vegetation (red) and Fe oxides (weathering); the SWIR image shows hydration and clay mineralogy; and the TIR image shows fundamental silicate mineralogy (quartzose rocks are red, basalts are cyan or bluish, and carbonates are greenish).

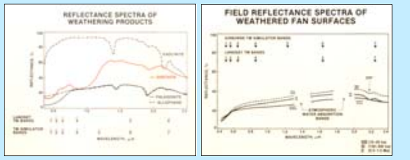
In the 1990s, studies by Fred Kruse, Larry Rowan, Tom Cudahy, and many others extended the range of regions mapped with spectral images, and also the gamut of techniques used. One major innovation was the development by John Hackwell and colleagues at The Aerospace Corporation of an airborne hyperspectral thermal infrared scanner, so that the full optical spectrum was then covered by experimental spectral imagers.

Lithologic mapping is regarded as solved in considerable degree by most remote-sensing practitioners. The application is, in general, routine, and canned protocols exist to do most of the algorithmic work in packages such as ENVI. However, in geological studies the devil truly is in the details, and specific case studies always seem to generate new challenges. For work in desert terrain analysis, and for trafficability studies there, these are the challenges to be met.

Approach

There are two basic approaches to lithologic mapping. The most commonly used is grounded in petrology and mineralogy, and searches image spectra for the presence of specific absorption bands characteristic of minerals, and generates mineral maps that must then be generalized to infer lithologies and make rock-type maps. The other approach is grounded in geological mapping and uses photo interpretation and whole-spectrum analysis to delineate units, which are then identified using specific spectral features. Although these two approaches may seem to the casual observer to differ only trivially, the differences are real in a practical way and the two approaches may actually produce different maps. The reader interested in pursuing this more fully should consult Adams and Gillespie (2006), *Remote Sensing of Landscapes with Spectral Images* (Cambridge).





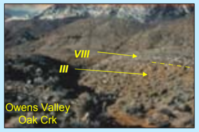
Fan Surface VIII is ~15 ka old; III is ~250 ka; and II is >500 ka. Triangles show the spectral bands for the Landsat Thematic Mapper (TM) scanner and NASA's airborne TM simulator NS-001. From Gillespie et al. (1986).

Surface III - ~250 ka

Surface VIII - ~15 ka

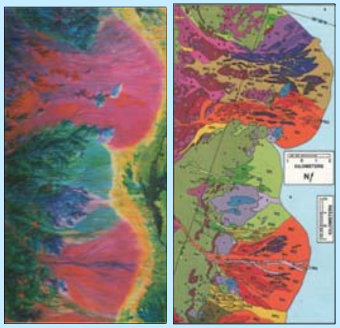
Surface II (~500 ka) appears reddish or brown. Most granitic boulders have disintegrated. Vegetation is less dense than on other fans.

Surface VI (~40 ka) is intermediate in character between surfaces III and VIII, but vegetation is the same.

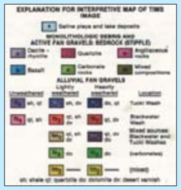


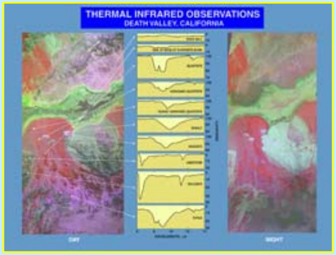
Lightly weathered, bouldery Surface VIII (~15 ka) burying reddish III (~250 ka). Granitic clasts of III are less weathered than on II.

Spectral response to weathering of soils appears to be concen-trated in the medium sand fraction shown here. Grain coatings containing amorphous FeOx and hydrous clay pre-cursors reduce reflectance in the visible and SWIR spectral regions, respectively. The Owens Valley study is from Gillespie et al. (1986).



Airborne TIR TIMS image of Death Valley (left) and interpretive map made from it (right).

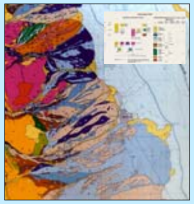




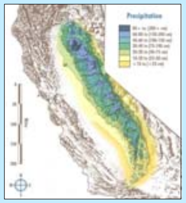
Day (left) and night (right) airborne TIMS images of Death Valley showing geological units and related TIR emissivity spectra.

Airborne multispectral TIR images from TIMS are usual for mapping in regions of complex lithology such as Death Valley, CA. Here is shown the eastern piedmont of the Panamint range (Trail Canyon on the south; Blackwater & Tucki washes on the north). Not only are silicate and carbonate well-distinguished, but different silicate minerals as well. The map differentiates alluvial unites on the basis of age, parent composition, and chemical and mechanical weathering processes and products. Also shown are common spectra and their occurrence in day/night TIR images. After Gillespie et al. (1984).

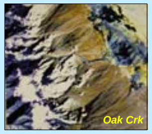
TM image, Owens valley fans



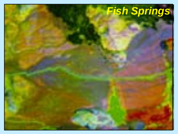
Interpretive map of fans and bedrock



Mean annual precipitation in California



TM image, natural color



TM image with exaggerated colors: reddish = older soils

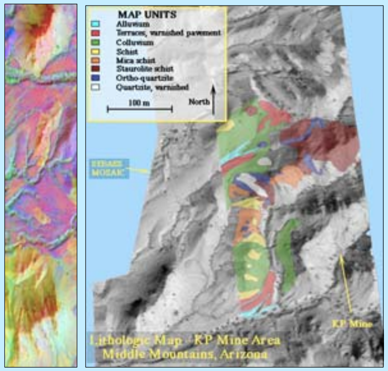
Air photo of moraines, Bishop Creek. Moraines and associated fans weather similarly.

The spectral basis for lithologic mapping of fans of uniform granitic composition is shown in the slides in the Approach section, above. TM and TM simulator images were used to map 8 units of alluvial fans on the west side of Owens Valley in an experiment to determine how extendable local calibration could be. Provided annual precipitation was similar (map of California), fans over a 200-km transect could be treated the same. Ternary diagrams show schematic basis for spectral mapping (left) and the dispersion of fan units according to age for different bands. Example from Gillespie et al. (1986).

After Mushkin et al. (2004) & Mushkin (2006)

Compositional mapping of Quaternary sediments using ASTER SWIR (1.6 – 2.4 mm), Namalzah Hills landslide, Gobi desert - SW Mongolia. Top: view south from location (1) showing the SW corner of the ~10X10 km landslide block and its source area ~5km up-hill at the front of the Gichigniy mountain range. Heavily varnished desert pavements with <1% vegetation cover comprise the surface of the landslide block. Left: ASTER false color composite of the Namalzah Hills. Right: ASTER SWIR ratio image enables distinction between alluvial surfaces of different compositions and form the basis for the compositional map (not shown here).

Hyperspectral TIR imaging,
Yuma Proving Grounds, Arizona



The mapping approaches discussed above for multispectral imaging have been applied to hyperspectral images (e.g., Kirkland *et al.*, 2002) The example here, from Gillespie et al. (1997), shows an application to mapping alluvial fans in Yuma Proving Grounds. SEBASS TIR data courtesy of The Aerospace Corporation.

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