Surface Geology Reconstruction Through Integration of Active and Passive Remotely Sensed Data*

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Abstract

This paper presents the first preliminary results of a 3-year R&D project led and funded by Eni with the aim of supporting the development of an innovative methodology based on the integration of remotely sensed data and field geology. The complete set of remotely and locally sensed data is:

● Passive data of high and medium resolution satellite multispectral data, and hyperspectral airborne imagery;

● Active data of low to medium resolution satellite C and L band radar data, and airborne X and L band radar data;

● Surface geology, spectral data, mineralogical analysis, acquired over a well defined test area in the Dolomites (NE Italian Alps), characterized by the outcropping (with different type of soil coverage) of sedimentary, volcanic and volcanoclastics lithologies.

Further acquisitions in deserted areas are planned for the next project phase in North Africa. The development of proprietary processing algorithms and spectral libraries will be a key result to be achieved. The elaboration of a comprehensive surface geological model based on integration of ground data, spectral signatures, image textures and physical properties of radar data would be part of the routine set of activities during early phases of exploration onshore projects.

Mapping Lithology Using Aerial Hyperspectral Data

Following a separability analysis phase carried out on *in situ* hyperspectral data, which has highlighted some important issues for the thematic mapping of outcrops (Pompilio et al., 2009; Pompilio et al., 2010), the focus of work using optical remote sensing data has become the geolithological mapping of outcrops in the study area (Alpe di Siusi, Trentino-Alto Adige, Italy). The recognition of geological features through remote sensing has been traditionally circumscribed to two applications: 1) the recognition of shapes and physical characteristics of the landscape, as obtained from satellite images, orthophotos and DEM derived from other remote sensing techniques, and 2) the recognition of the surface mineralogy based on hyperspectral imaging techniques.

The purposes of this work, for what concerns the optical remote sensing dataset, are centered on geolithotypes recognition. These recognition capabilities are based on the reflectance characteristics of rock materials as a function of the presence of certain chemical species, in particular of certain negative and positive ions present in the rock (Hunt and Salisbury, 1971; Farmer, 1974). A traditional geological map is therefore not reproducible from remote sensing because it usually exploits and takes advantage of a wide range of knowledge and correlations, stratigraphic, structural, and geometric information which can be derived only from direct survey on site.

The geolithotypes mapping consists in the characterization of the outcrops of the area which has been carried out using both supervised classification methods (Villa et al., 2011), based on data derived from hyperspectral *in situ* campaigns and MIVIS aerial data (September 2nd, 2010), and from unsupervised classification methods in the context of analysis of mapping capabilities for different geolithotypes assessing hyperspectral data classification derived solely from remote sensing without a priori knowledge of the spectral characteristics of the geological targets.

All classifications were carried out on atmospherically corrected data (Richter, 2009) and have been performed masking only the rock and soil outcropping areas not covered by shadows, in order to focus on clustering and classification of those areas where the geological features are visible on the surface. Geolithotypes classifications have been performed using three different techniques of unsupervised classification and three different techniques for supervised classification. The supervised algorithms used for this mapping are the Spectral Angle Mapper (SAM), the Minimum Distance (MD) and the Spectral Feature Fitting (SFF), while the unsupervised approaches exploit Self-Organising Maps (SOM), ISODATA clustering, and Minimum Noise Fraction transform (MNF). The decision to use such different approaches is justified by the need to evaluate the pros and cons of different techniques (image-based or knowledge-based) with regard to their transferability to other situations even less known and controlled than the study area.

All in all and taking into account the intrinsic limitations of the overall approach, we can conclude that the application of remote sensing techniques to outcrops geolithotypical classification on the study area (Alpe di Siusi) has given satisfactory results so far.

Moreover, given the pros and cons of the tested approaches, we can consider that a hierarchical classification that establishes the different methods, based on their best performance and integration of information from other sources (thermal properties of rocks, DTM derived from LiDAR, georadar and aerial SAR data), as for example some literature recently begun to take into consideration (Chen et al., 2010), could be an optimal solution for enhancing the contribution of remote sensing data and techniques to geolithotypes mapping in carbonatic basins.

Mapping Lithology Using Synthetic Aperture Radars

Another technology under investigation in the frame of GEOSAT is Synthetic Aperture Radar (SAR) 2D and 3D imagery. A SAR system is basically constituted by a radar sensor transmitting and receiving electromagnetic waves as it is flown onboard a moving platform like an aircraft or a satellite. Platform motion allows synthesizing a virtual antenna, as long as several hundreds of meters in the airborne case or several kilometres in the spaceborne case, resulting in the possibility to yield images of the targets response to the impinging waves with a spatial resolution on the order of 1 meter. This provides sensitivity to relative permittivity and surface roughness, therefore bringing information about electromagnetic and morphological features of the targets. Moreover, depending on the frequency, electromagnetic waves may be able to penetrate dense vegetation layers down to the ground making it possible to investigate physical properties of the ground even in the presence of dense forest. Finally, modern SAR sensors are capable of operating with different combinations of wave polarization (i.e. different directions of the electric field associated with the wave). Especially at low frequencies, different polarizations exhibit different sensitivities to target features which helps the extraction of target features. For all these reasons, SAR imagery appears to have the capability to complement measurements from LIDAR or hyperspectral sensors, possibly revealing new insights about lithological exploration through remote sensing.

The data collected so far in the frame of the GEOSAT project consists of more than 60 airborne polarimetric SAR images acquired over the Italian Dolomites. The SAR sensor has been built and operated by MetaSensing. Data analysis is being carried out by Politecnico di Milano. The frequency of operation has been chosen to be 1310 MHz (L-Band). Such a choice allows the usage of compact hardware equipment while granting good penetration capabilities.

References

Bamler, R., and P. Hartl, 1998, Synthetic aperture radar interferometry: Inverse Problems, v. 14, p. R1-R54.

Chen, X., T.A. Warner, and D. Campagna, 2010, Integrating visible, near-infrared and short-wave infrared hyperspectral and multispectral thermal imagery for geological mapping at Cuprite, Nevada: a rule-based system, International Journal of Remote Sensing, v. 31/7, p. 1733-1752.

Curlander, J.C., and R.N. McDonough, 1991, Synthetic aperture radar: systems and signal processing: John Wiley & Sons Inc., New York, USA, 647 p.

Farmer, V.C., 1974, The infrared spectra of minerals: Mineralogical Society Monograph, Mineralogical Society, London, United Kingdom, 539 p.

Gaffey, S.J., 1986, Spectral reflectance of carbonate minerals in the visible and near-infrared (0.35-2.55 microns): calcite, aragonite, and dolomite: American Mineralogist, v. 71, p. 151-162.

Hunt, G.R., and J.W. Salisbury, 1971, Visible and near infrared spectra of minerals and rocks, II Carbonates: Modern Geology, v. 2, p. 23-30.

Pompilio, L., G. Pedrazzi, E.A. Cloutis, M.A. Craig, T.L. Roush, 2010, Exponential Gaussian approach for spectral modeling: the EGO algorithm II. Band Asymmetry: Icarus, v. 208, p. 811-823, doi:10.1016/j.icarus.2010.03.020.

Pompilio, L., G. Pedrazzi, M. Sgavetti, E.A. Cloutis, M.A. Craig, T.L. Roush, 2009, Exponential Gaussian approach for spectral modeling: the EGO algorithm I. Band saturation: Icarus, v. 201/2, p. 781-794, doi: 10.1016/j.icarus.2009.01.022.

Richter, R., 2009, Atmospheric/Topographic Correction for Satellite Imagery: DLR report, DLR-IB 565-01/09, Wessling, Germany.

Tebaldini, S., and F. Rocca, 2010, Forest structure from longer wavelength SARS: Geoscience and Remote Sensing Symposium (IGARSS), 2010 IEEE International, 25-30 July 2010, p.158-161.

Villa P., M. Pepe, M. Boschetti, R. De Paulis, 2011, Spectral Mapping Capabilities of Sedimentary Rocks using Hyperspectral Data in Sicily, Italy: Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS 2011), Vancouver, 24-29 July, 2011.

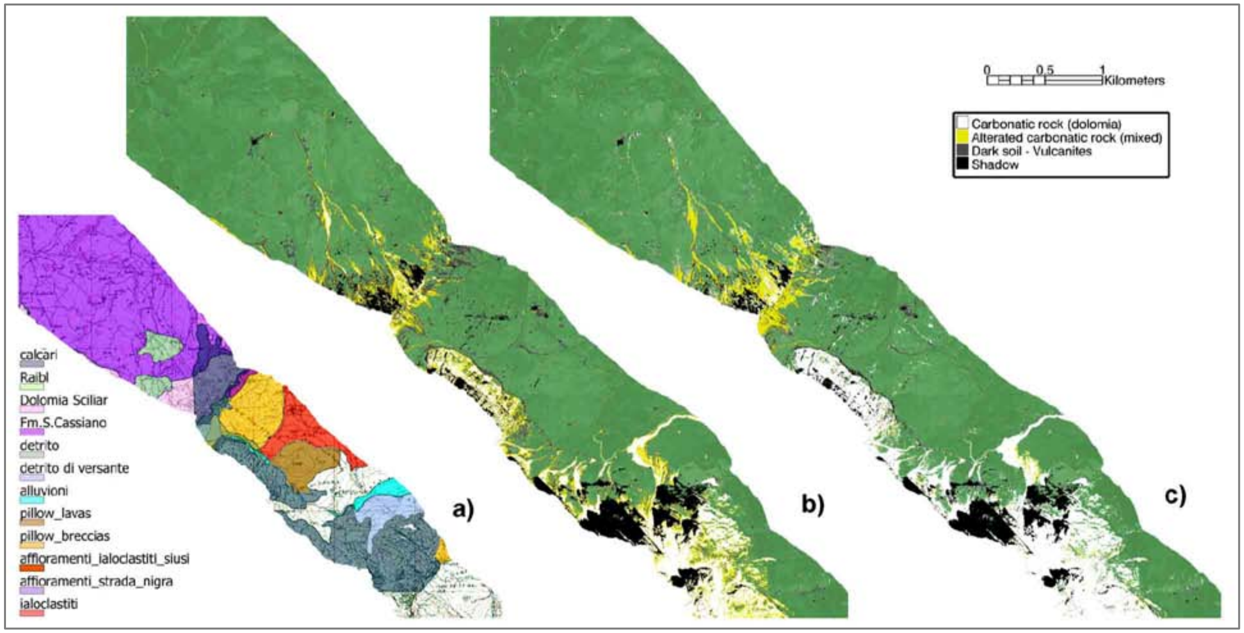

Figure 1. Geolithological maps derived from MIVIS hyperspectral data using supervised approach, Minimum Distance Classifier (b), and unsupervised approach, SOM (Self-Organising Maps) (c). On the left, the geological map of the study area (Alpe di Siusi, Trentino-Alto Adige, Italy) used as reference (a). In green shades vegetated areas are depicted.

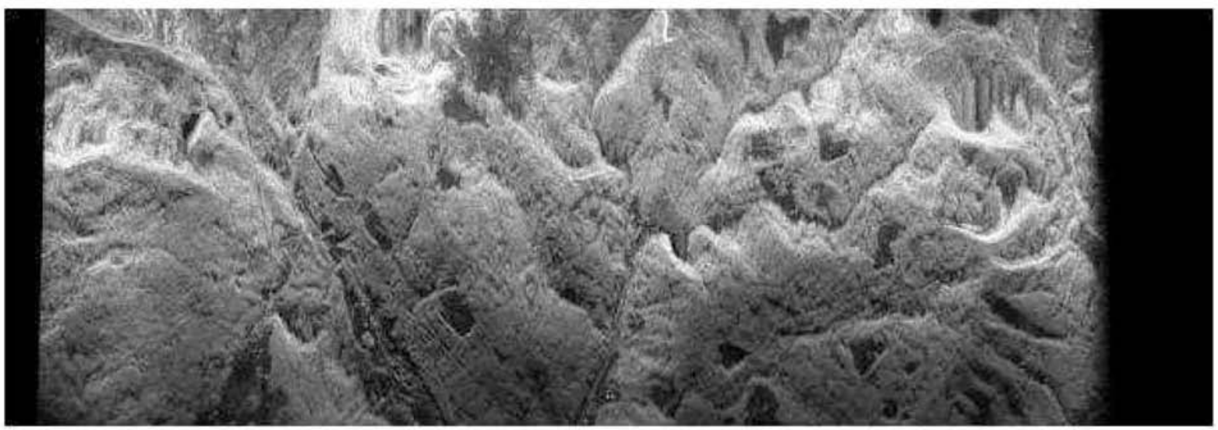

Figure 2. L-Band SAR amplitude image collected over the Catinaccio, Northern Italy.