ARTICLE IN PRESS

Int J Appl Earth Obs Geoinformation xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Geological remote sensing

1. Introduction

Geology is defined as the 'study of the planet Earth – the materials of which it is made, the processes that act on these materials, the products formed, and the history of the planet and its life forms since its origin' (Bates and Jackson, 1976). Remote sensing has seen a number of variable definitions such as those by Sabins and Lillesand and Kiefer in their respective textbooks (Sabins, 1996; Lillesand and Kiefer, 2000). Floyd Sabins (Sabins, 1996) defined it as 'the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter' while Lillesand and Kiefer (Lillesand and Kiefer, 2000) defined it as 'the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation'. Thus Geological Remote Sensing can be considered the study of, not just Earth given the breadth of work undertaken in planetary science, geological features and surfaces and their interaction with the electromagnetic spectrum using technology that is not in direct contact with the features of interest.

Remote Sensing has typically perhaps been more associated with satellite imagery yet there were a number of aerial systems in use during the 1940s and whilst their main mission was intelligence It also allowed us to capture wide areas of geological importance remotely. As such it is perhaps difficult to pinpoint the onset of 'geologic remote sensing science'. A keyword (topic) search on WebofScience© using 'geology' and 'remote sensing' returns 917 publications and a publication from 1966 as the first entry (Beckman and Whitten, 1966) while the first paper on geology using ERTS (Earth Resources Technology Satellite, now known as Landsat) data dates back to 1975 (Lawrence and Herzog, 1975). Some other of the early works include Baker (1975), Siegal and Abrams (1976) and breakthrough research produced by Alexander Goetz and Larry Rowan (e.g., Goetz and Rowan, 1981). Moreover early missions like SEASAT, specifically designed for oceanography, were also gaining traction in the field of geology for offshore imagery of oil slicks as early as 1978 (Evans et al., 2005).

However, the field greatly benefitted, in particular those working on optical remote sensing data, from the laboratory work that Graham Hunt (Hunt, 1977, Fig. 1) and John Salisbury (Salisbury et al., 1989) did on systematically analyzing diagnostic absorption features of all main mineral groups and rock types published in a journal called 'Modern Geology'. It is said that the band 7 of Landsat Thematic Mapper was added at a late stage of the sensor design to the Landsat Program in recognition of its use and benefit to the geological community and was lobbied for heavily. However, in doing so at this late stage, the numbering could no longer be changed hence the Thermal Infrared (TIR) band 6 features before the Short Wave Infrared (SWIR) band 7 in numbering despite its longer wavelength (Pers. Comm. Mike Abrams NASA −JPL).

Geologic remote sensing got another boost with the advent of ASTER (the Advanced Spaceborne Thermal Emission and Reflection Radiometer) in 1999. With 3 NIR (Near Infrared), 6 SWIR bands and an additional 5 TIR bands, ASTER provided the opportunity to undertake semi-quantitative mineral mapping and its forward and backward looking telescope also provided the possibility to create digital surface models. In 2005, a special issue was published in *Remote Sensing of Environment* on the use of ASTER data with the launch of this sensor considered a real milestone in space capability for the geological community (Gillespie et al., 2005).

Another milestone was the launch of the first hyperspectral instrument to image the Earth (there is also one for Mars) with Hyperion being launched on EO-1 (Earth Observing-1) in 2000. Hyperion was part of NASA's New Millennium Program and a test-bed to demonstrate spectroscopic measurements could be made from space. The sensor was really a proof of concept that relatively cheap technology could work. This had its downside in terms of complexity in preprocessing (Khurshid et al., 2006), limited signal to noise (SNR), inconsistent data quality and coverage. Yet it offered scientists the possibility to acquire imaging spectrometry data worldwide at limited cost with the data becoming publicly available in ~2008.

Since the 1980s geologists had been experimenting with field and airborne hyperspectral instruments such as NASA's AIS (Airborne Imaging Spectrometer) and AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) systems, the Canadian CASI (Compact Airborne Spectrographic Imager) system and the commercial HyMAP series, but now hyperspectral data was available to all and not only to those that could afford commercial airborne campaigns or were part of science teams on airborne missions. A classic paper comparing Hyperion data to airborne data was written by Fred Kruse (Kruse et al., 2003, Fig. 2). As we prepare this special issue, EO-1 and as such Hyperion, intended only to last a year, came to the end of its service in March 2017–17 years after launch and having achieved so much more than it was ever intended. In particular this mission allowed the thorough testing of the 13 new instruments on board with collection autonomy not seen on other satellites, as well as milestones such as detecting the first methane leak from a facility from space. Whilst powered down it will remain in orbit until 2056.

For further reading there are a number of review articles that show the history and development of geologic remote sensing (Cloutis, 1996;

http://dx.doi.org/10.1016/j.jag.2017.08.005

Int J Appl Earth Obs Geoinformation xxx (xxxx) xxx–xxx

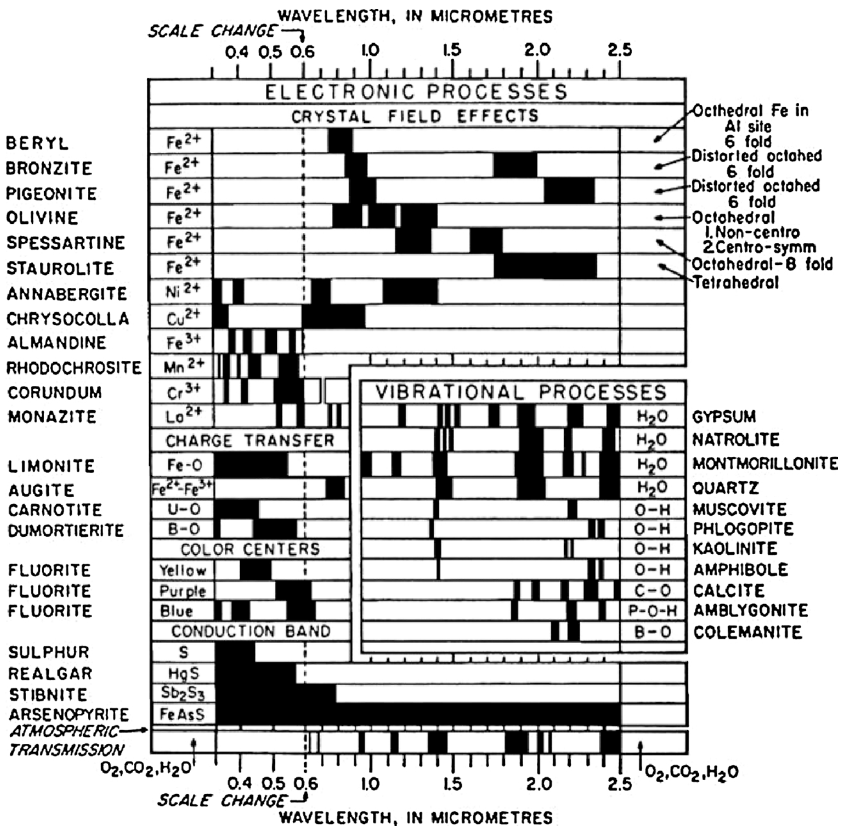

Fig. 1. Spectral signature diagram outlining the effects observed from electronic and vibrational processes in various minerals measured in the laboratory (after Hunt, 1977).

Buckingham and Staenz, 2008; Sabins, 1999; Goetz, 2009; Van Der Meer et al., 2012; Asadzadeh and Souza Filho, 2016).

So far this introduction has focused mainly on optical passive remote sensing, but there is also a vast community of geologists working with radar, also known as Synthetic Aperture Radar (SAR) data. This technology, prevalent since the early 1990s, has a number of advantages as an active

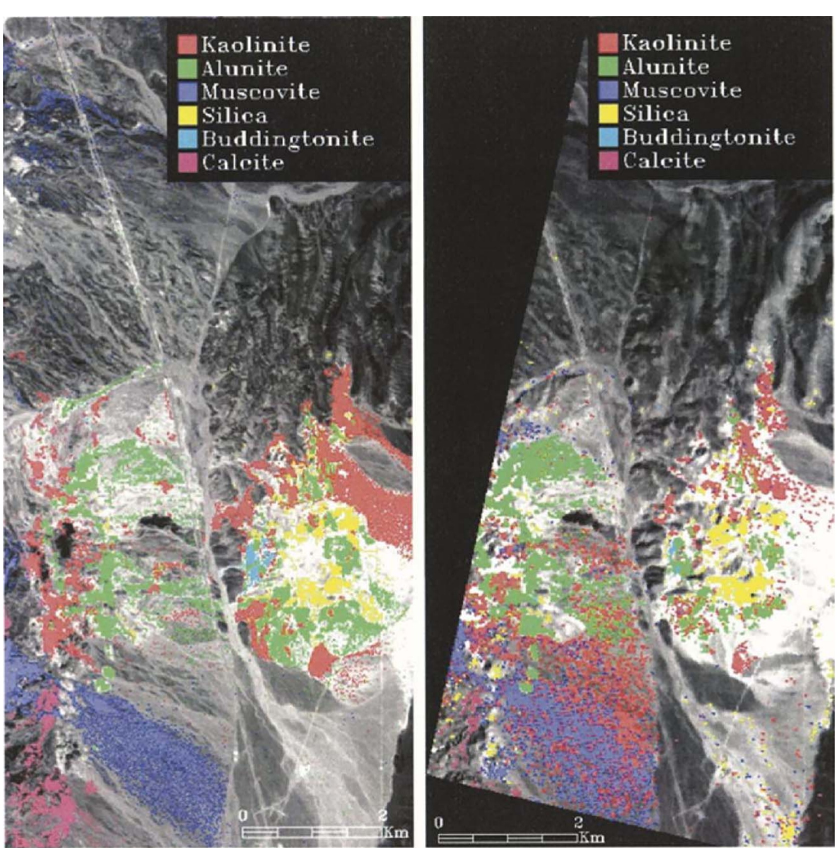

Fig. 2. Mineral maps for (left) AVIRIS and (right) Hyperion across Cuprite NV, USA. Coloured pixels show spectrally predominant mineral at concentrations greater than 10%. After (Kruse et al., 2003).