# IMAGING SPECTROSCOPY DATA USED FOR GEOLOGICAL AND ENVIRONMENTAL ANALYSIS IN EUROPE

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**Abstract.** During the EISAC Campaign carried out in May/June 1989 six european countries were flown with the GER Scanner and the Metric Camera on water and land test sites for oceanographic, hydrologic, vegetation and soil spectral studies. Atmospherically corrected GER-II Imaging Spectrometry data acquired during the EISAC Campaign are employed for the spectral analysis of vegetation growing over a former waste deposit in Southern Bavaria. Spectral anomalies were observed in the vegetation cover which are likely to be attributed to the buried material. The result of a scene classification based on the spectral signatures shows a correlation with infill structures on the formerly open site. Geochemical sampling over the site revealed high heavy metal concentrations as a probable source for the spectral differences. This environmental application of imaging spectrometry data with new quantitative evaluation methods could reduce extensive ground surveys and be of economical interest if developed to an operational state.

The Almaden testsite (Spain) was selected for the spectral analysis of soil and vegetation in a mediterranean environment, taking account of the soil spectral characteristics dependent on the geological situation. A parallel field survey comprised field spectroscopy measurements, soil sampling and vegetation inventory. Results of spectral classification analyses of GER airborne data for the differentiation of soil surfaces with variable mineral content are demonstrated.

Keywords: Imaging Spectrometry, atmospheric correction, vegetation anomalies, waste deposits, geology

## I. APPLICATION FOR ENVIRONMENTAL RESEARCH

### A. Introduction

Regarding the number of old, unprotected waste deposits (e.g. in Germany about 50,000), and the environmental threats related to many of these sites, new methods have to be found to reduce the costly and time consuming ground surveys. Reflectance data derived from high spectral and spatial resolution Imaging Spectrometers provide a new physical parameter in the analysis of these sites. The spectral response of the vegetation cover on and near to the deposit is examined for signatures which could be related to the influence of stress caused by the buried material. Possible applications are the long term monitoring of sites, detection of leakages or the planning of ground surveys based on the delineation of spectrally anomalous areas.

### B. GER-II Spectrometer Data Evaluation

#### 1. The GER-II Imaging Spectrometer

The GER 63 channel spectrometer (also known as the GER Airborne Scanner) from Geophysical Environmental Research Corp., New York, consists of three spectrometers which view the ground through the same aperture via an optoelectronic scanning device. A rotating Kennedy cube scanner scans a line of 512 pixels perpendicular to the flight track with a scan angle of 45° to either side of the flight direction. The incoming radiation of a ground pixel is split and sent to three spectrometers, each with a separate line detector array, giving a total of 63 spectral bands through the visible (VIS), near- and shortwave infrared (NIR, SWIR) between 0.47 $\mu$m and 2.45 $\mu$m. The specifications of the spectrometers are listed in Table 1. The digital resolution of the data is 12 bit with a dynamic range of 16 bit which makes gain changes over varying terrain conditions unnecessary. An instantaneous field of view (IFOV) of 3.3 mrad was selected for all test sites which leads to a pixel size of 10 m at 3000 m flight altitude. The swath width for this aperture size and the same altitude is 6 km. Dark currents are automatically subtracted from the signal by incorporation of dark object calibration plates in the scanner.

| Spectro-meter | spectral coverage [$\mu$m] | spectral bands | sampling interval [nm] |
|---|---|---|---|
| 1 | 0.47 - 0.84 | 31 | 12.3 |
| 2 | 1.40 - 1.90 | 4 | 120 |
| 3 | 2.00 - 2.45 | 28 | 16.2 |

**Table 1: Spectrometer specifications of the GER Scanner.**

## 2. Atmospheric correction

Prior to the atmospheric correction some pre-processing steps including a roll correction and electronic time constant correction were carried out. These steps and the calibration procedure are described in more detail elsewhere (Ref.1,2).
An atmospheric correction was applied to convert the digital numbers (DN) in all channels to reflectance values. The atmospheric modelling is based on the LOWTRAN-7 model which calculates atmospheric transmittance and background radiance over a very broad wavelength region, based on the geometrical configuration between sun, target and observer (Ref.3). The model incorporates multiple scattering which is important in the VIS/NIR region and provides a series of standard atmospheres, including aerosol types and ozone profiles.

For the investigated GER-Scanner scene, the atmospheric data was derived from the $12^{00}$ UT radiosonde of the nearest meteorological station. The measured atmospheric parameters included pressure, air temperature and humidity up to an altitude of 15 km. This data was fed into the LOWTRAN-7 model and supplemented with default values of a midlatitude standard atmosphere up to an altitude of 100 km. The aerosol type and visibility were determined iteratively by constraining the reflectance values of dark targets to positive values.

The results of the LOWTRAN run are the input for the DLR developed model SENSAT-3 (SENSor-Atmosphere-Target) which relates planetary albedo to ground albedo on a per-pixel basis (Ref.4). The model SENSAT takes account of the sensor characteristics and the viewing geometry. As the viewing geometry changes over 90° during a scan, the LOWTRAN/SENSAT calculations are performed in small angular steps. In the VIS/NIR wavelength region the atmospheric modelling included a correction of the adjacency effect. This correction takes account of the reflected and scattered radiation entering the sensor from pixels in the neighbourhood of the actual target.

After atmospheric correction multitemporal datasets or data of different sensors are comparable. Even for single scenes of a sensor it is useful to eliminate the atmospheric influence. The corrected airborne data only depends on the surface properties and can therefore be directly compared with ground spectroscopic measurements.

### C. Investigation of a Waste Deposit Test Site

The atmospherically corrected data of a GER-Scanner scene, recorded in the course of the European Imaging Spectrometry Airborne Campaign 1989 (EISAC 1989, Ref.1) under excellent weather conditions, was used for a spectral analysis of an old vegetation covered waste deposit.

#### 1. Site Description

The examined waste tip in Southern Bavaria was opened in 1899 and served as a disposal site for communal and industrial waste. After the site was closed in 1949, the main part was used for agricultural purposes. At that time no protective measures were taken to prevent leakage of waste material into the surrounding environment. The site covers an area of about $1km^2$. A field survey during the EISAC-campaign showed that the site only has little topography and that the main part was equally dense covered with corn (rye) of the same height and maturity. This corn stand was further investigated (test site).

#### 2. Spectral Analysis and Scene Classification

Though the test site looked apparently homogeneous, spectral differences were observed in the atmospherically corrected GER-Scanner data. Averaged spectra of all 63 channels were extracted at different positions in the corn stand on the waste deposit. The corn spectra exhibit differences in reflectance which are in the range of 3% for the VIS and SWIR and up to 5% in the NIR wavelength region (Fig.1). It was found that reflectance increases across the test site. The spectral differences in the corn stand will be referred to as 'vegetation anomalies in the following, whereby the unmarked spectrum in figure 1 is "normal" (no vegetation anomaly) on a relative scale. The increasing reflectance values in the VIS and SWIR wavelength range in relation to the normal spectrum were associated with vegetation anomalies of increasing strength. Such a spectral behaviour was found in another study due to the influence of heavy metals (Ref.5).

Based on the four corn spectra in figure 1, a classification of the whole scene using the least noisy 55 channels was made on a per pixel basis. Four different class values, representing the four vegetation anomalies of different strength, could be assigned to a pixel. A pixel of the low-pass filtered image was marked as belonging to a certain vegetation anomaly class if all its spectral points fell into the range of one standard deviation below and above the corresponding classification spectrum. Otherwise the pixel was rejected. In the case of multiple assignments, a matchscore based on the average deviation of the pixel from the matched anomaly spectra was used as a criterion in the class assignment. The result of the classification, i.e. the spatial distribution of the anomaly classes is shown in figure 2.

This figure includes 2 aerial photographs, acquired in October 1941 and 1943. The photographs reveal the infill structures at a time when the site was still in use. It is noticeable that the distribution of the pixels belonging to the "strong" vegetation anomaly class correlates with infill structures of the open site, as the comparison with the old aerial photograph shows, whereas the "no" anomaly class is found in areas where no infill marks are noticeable. This correlation, the results of the field survey and the fact that the site is not sealed strongly suggests that the buried material causes the spectral differences.

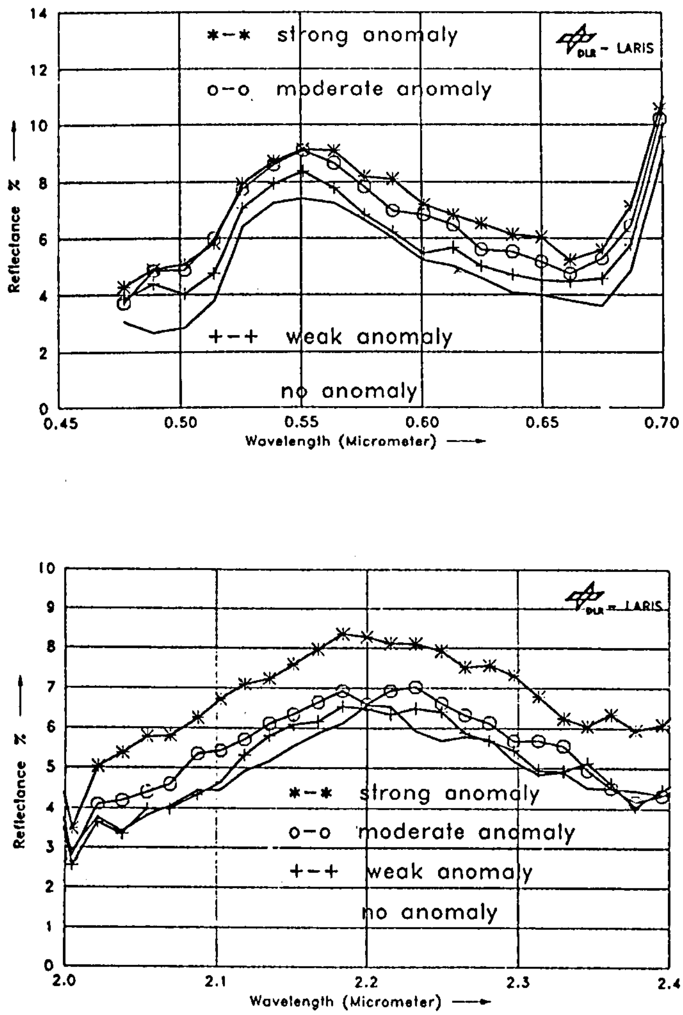



**Figure 1. Average reflectance spectra from four different locations on the testsite displaying spectral anomalies in the corn stand**
above: VIS wavelength range
below: SWIR wavelength range

**Figure 2. Scene classification of the vegetation anomalies on the recultivated waste deposit area**
**blue**: no anomaly class, **light blue**: weak anomaly, **[ see slide 7]**
**dark green**: moderate anomaly, **red**: strong anomaly class.
2 Aerial photograph of the open site in October 1941 and 1943. The infill structures show a correlation with the distribution of the "strong" anomaly class (British Crown Copyright, RAF photograph).

D. Geochemical Sampling

This year samples of soil and vegetation were taken on the test site and analysed for heavy metal concentrations. It was found that heavy metal concentrations on the waste deposit are substantially higher compared to a reference field near the site, as well for soil as for vegetation samples. Figure 3 shows the concentrations of metals Lead, Copper and Zinc in soil samples taken along a profile in the "high" anomaly area (P1 to P12), on various other locations on the site and two samples taken from a reference field (P16 and P17) outside the infill area. This data supports the suggestion, that the material present is responsible for the differences in the observed spectral signatures. Physiological plant material analyses are planned for the next growing season, which should yield more information regarding the presence and influence of stress effects.

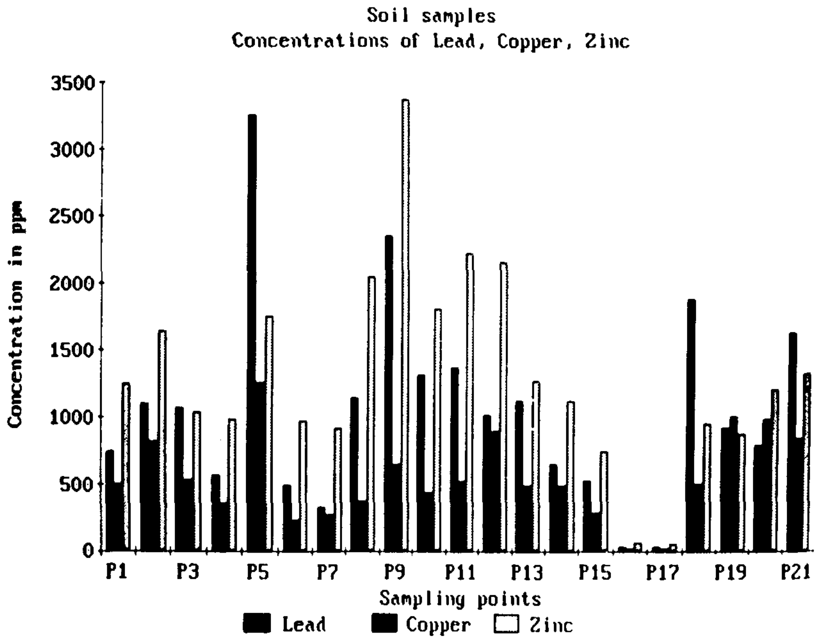



**Figure 3. Concentrations of heavy metals in soil samples**
Samples P16 and P17 are taken from a reference field near the waste deposit and show considerably smaller heavy metal concentrations. Allowed maximum concentrations in soils are as follows: Zinc: 300 ppm, Lead and Copper: 100 ppm.

## E. Conclusions

The high spectral resolution GER-Imaging Spectrometer is a useful tool for environmental studies. In this application the vegetation cover over an old waste deposit was analysed for spectral anomalies. This remote sensing method could be employed as a fast, non-destructive way of delineating spectrally anomalous areas as an input for specific ground surveys. Atmospheric modelling is the step that leads from a qualitative to a quantitative analysis of the data and will be important in the intended analysis of multitemporal spectral data.

# II. APPLICATION FOR EXPLORATION AND SOIL/VEGETATION STUDIES

## A. The Almaden Test Site

The test site is located in the Central Iberian Zone of Spain. It has an extension of approx. 10 x 15 km² covering the central part of a NW-SE trending anticline consisting of precambrian sedimentary rocks and partly outcropping granitic intrusives. Contactmetamorphic influence of the granitic cupolas is displayed in the contact zone of the surrounding sedimentary boundary (see figure 4).

The topography in the investigation area is moderate with a smoothly undulated morphology and maximum altitude differences of 160 m. The region is characterised by typical mediterranean vegetation forming an irregular pattern of cultivated (oat, olive tree plantations) and uncultivated areas. Due to cultivation cycles of several years large areas are fallow land, grassland and pasture, while areas of more expressed morphology with partly outcropping rocks and thin soil layers are not cultivated; those areas are mostly covered by garigue, macchie, and/or oak trees.

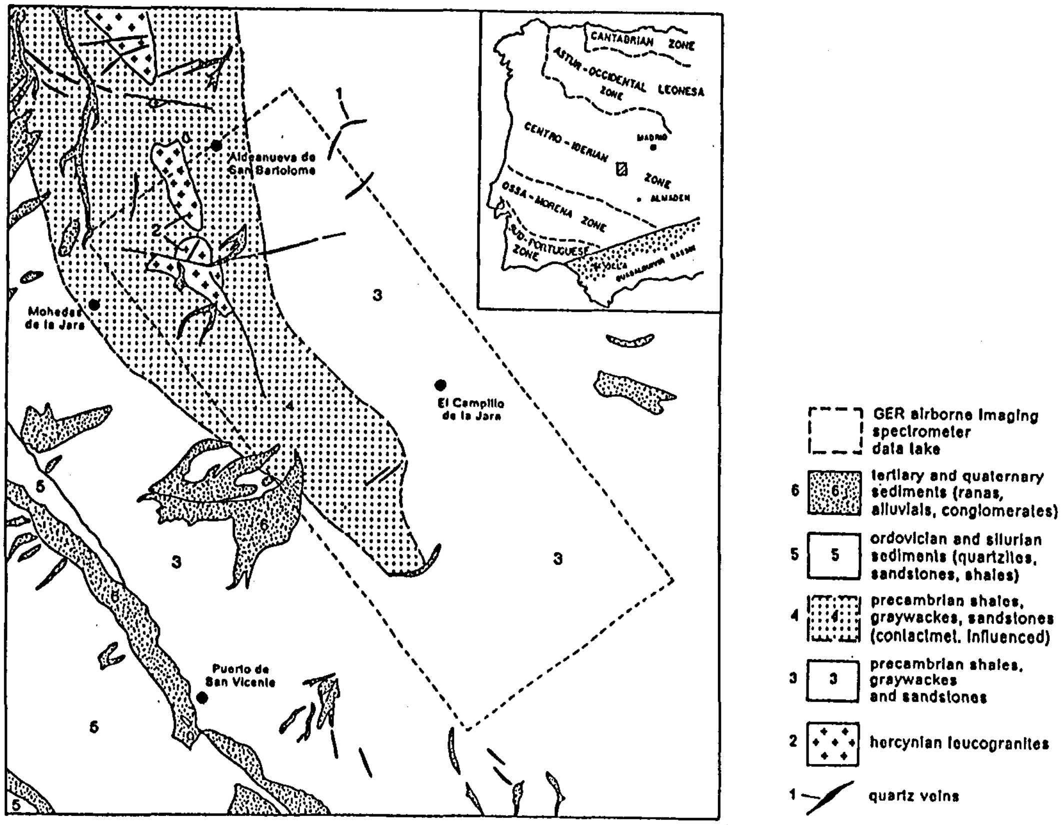



**Figure 4. Geological sketch map of the Almaden testsite**
(based on the geological map sheet No. 15-27 (682), 1:50 000)
Scale approx. 1 : 128 000

Soil spectral analyses have already been carried out in the framework of the Raw Materials Programme funded by the European Communities for mineral exploration purposes (Ref. 6). The aim was to delineate suboutcropping granitic cupolas (with possible mineralisations in their roof zones) coming near the topographic surface according to their contactmetamorphic influence on the sedimentary formations.

The observed variations in mineral composition in those altered areas are spectrally displayed by increasing relative reflectance intensity in the shortwave infrared wavelength range and strong 2.2 $\mu$m and 2.35 $\mu$m absorption depths.

## B. Field Survey

During a three day ground survey spectral field measurements have been carried out at 22 locations in the test site. Three GER IRIS spectroradiometers covering the 0.4 - 2.5 $\mu$m spectral range were used for field spectroscopy measurements of bare soil and vegetation covered targets over outcropping granites, contactmetamorphic influenced and non influenced precambrian series. The vegetation analysis included an estimation of the percentual vegetation coverage discriminating between green and dry vegetation, indication of the average plant height and determination of vegetation types and land use (Ref. 6).

C. GER Airborne Data Evaluation

GER airborne scanner data have been obtained from the central part of the investigation area with outcropping granites, precambrian sediments and the contactmetamorphic influenced contact zone (see figure 4). The area is mostly covered by various transition stages of grassland/pasture and macchie/garigue vegetation.

The GER preprocessed airborne data were first corrected for atmospheric and adjacency effects. These calculations allowed a conversion into relative reflectance values which are comparable to ground measurement data. Due to atmospheric inhomogenities during the flight in the Almaden test site, however, an additional correction had to be applied: relative reflectance spectra obtained on ground truth targets during the field campaign were selected and compared to reflectance spectra retrieved from GER image data of the corresponding locations. Based on the resulting spectral differences between ground and image data, correction factors have been calculated for each GER image band. They were used for the calculation of a calibrated GER image.

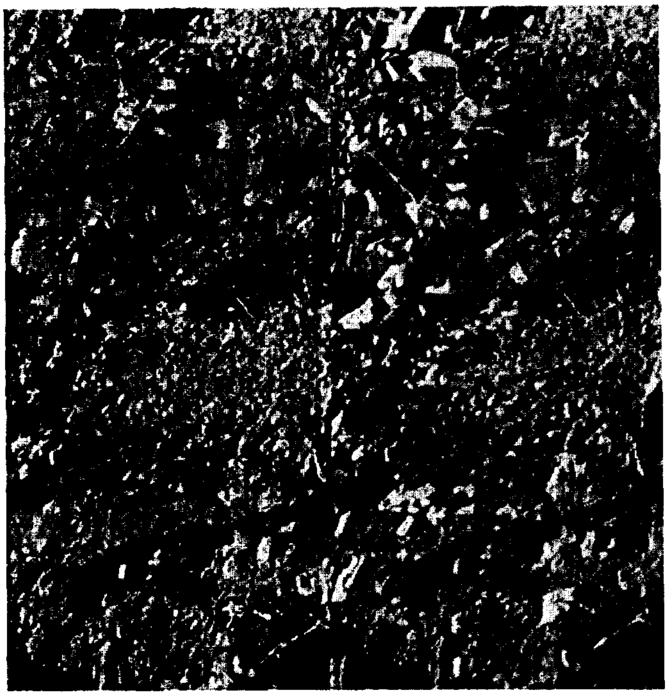
D. Results

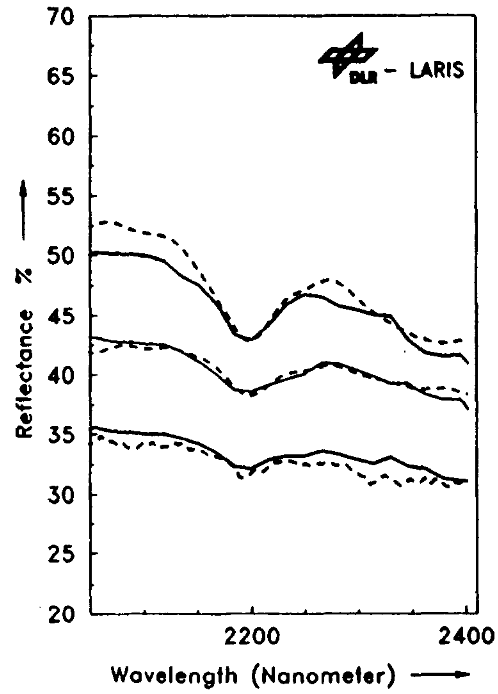
First analyses of GER airborne scanner data were concentrated on the spectral charcteristics of bare soil targets / ploughed arable land. Based on GER airborne spectra a classification analysis has been carried out, taking account of the spectral response of 55 GER scanner bands (see I.C.2), (Ref. 2).

Figure 5b shows an RGB natural colour composite of the GER image using band 15 at 650 nm (red), band 7 at 551 nm (green) and band 2 at 489 nm (blue) center wavelengths. Bare soil targets are characterised by high intensities. GER band 15 (650 nm) was used in figure 5a with the classified bare soil targets marked by red, green and blue colours. Soil targets with high intensities in the SWIR and strong 2.2 $\mu$m absorption bands are displayed by red colours. Those areas are mainly occurring over outcropping granites. Soil targets with medium intensity in the SWIR and less pronounced 2.2 $\mu$m absorption features are displayed by green colours and are located close to the outcropping granites and in contactmetamorphic influenced areas, while the spectra of blue coloured targets are characterised by low SWIR intensities and very weak absorption bands.

Soil spectra calculated from GER airborne scanner data and ground spectra measured with the IRIS Mark IV spectroradiometer during the field survey at the corresponding targets are presented in figure 5c. The colours in the diagram correspond to the classified soil targets in figure 5a. In contrast to an unsignificant spectral variation in the VIS/NIR (see figure 5b) the soil spectra are well differentiated in the SWIR wavelength region.

GER airborne scanner spectra from various Almaden vegetation cover types are shown in figure 6. Due to an inhomogeneous vegetation distribution within the test site, however, spectral variations of equivalent vegetation types dependent on different soil types could not be noticed yet.






a b c

**Figure 5. Classification of GER Airborne Scanner Data (Reventon) [see slide 8]**
a) black & white = GER band 7 (551 nm); red, green, blue = bare soil targets with different spectral signatures (see c)

b) RGB natural colour display, GER band combination: 18=687 nm (red), band 7=551 nm (green), band 2=489 nm (blue); all bare soil targets are characterised by high intensities in channel 2, 7 and 18.

c) SWIR wavelength range of soil spectra, selected as a basis for the classification (see a). Spectral differences (albedo, absorption depth) are caused by variable mineral content. Solid lines: reflectance spectra retrieved from GER airborne scanner data; dotted lines: field spectra of the corresponding target, acquired with the IRIS Mark IV spectroradiometer during the simultaneous ground truth.

## E. Conclusions

GER airborne scanner data is regarded to be very useful for soil / vegetation studies. Soil surfaces with even small mineralogical variations could be differentiated according to their spectral characteristics in the SWIR wavelength range. GER airborne scanner spectra of different vegetation types display noticeable variations in the VNIR and/or SWIR. Statistical spectral analyses are limited due to the small size of fields, the irregular pattern of cultivated and uncultivated areas and missing bare soil targets in some regions of the Almaden testsite. The relationship between geology and vegetation cover has to be examined in detail by further spectral anlysis.

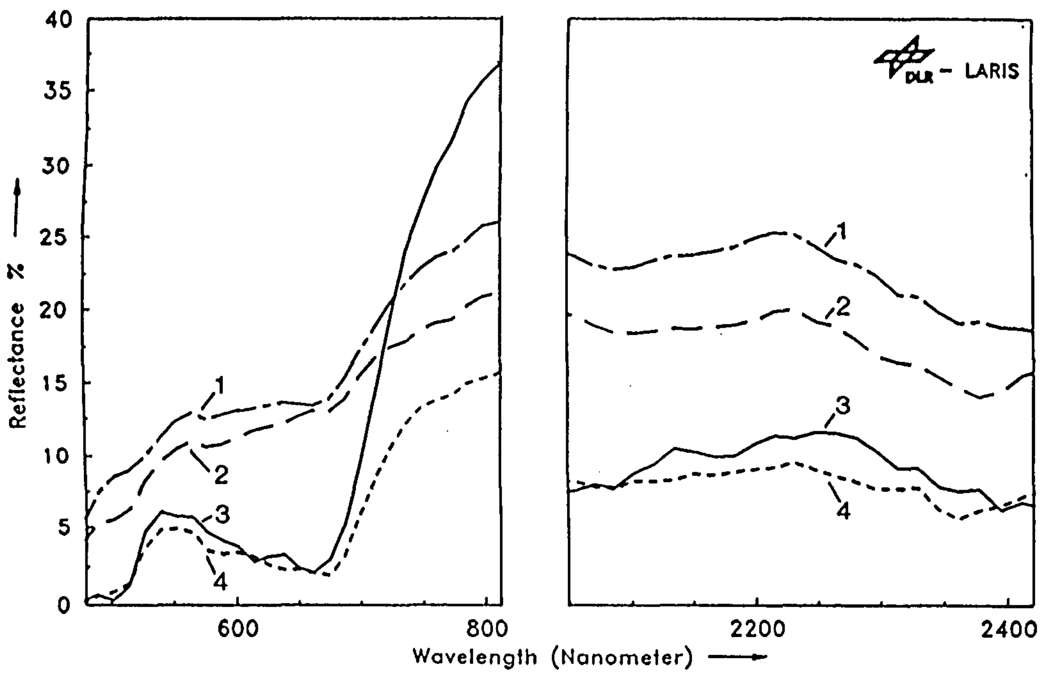



**Figure 6. Reflectance spectra calculated from GER airborne data representing various vegetation cover types**
1 = grassland, 2 = ripe oat,
3 = damp vegetation, 4 = cistus ladanifer macchie

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