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GENTLE SLOPING QUATERNARY GEOLOGICAL UNITS WITH DAIS 7915 HYPERSPECTRAL DATA

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ABSTRACT

Gentle sloping terrains along the margins of fluvio lacustrine systems include morphological features related to landscape development under changing climate conditions, mainly during Quaternary times. At the headwater catchment areas of large rivers, such sedimentary and morphological record systems reflect water availability changes giving valuable clues to the paleogeographical evolution.

DAIS 7915 hyperspectral spectrometer data have been used to map Quaternary geological units on the piedmont of a Precambrian mountain massif hosting a tertiary basin in central Spain. Thematic mapper imagery has given a regional geomorphological and geological background to locate sedimentary sources of the piedmont surface. This piedmont surface is mainly formed by alluvial fans, whose distal areas present terraces associated with the main river and peatlands prograding through fan's drainage incision transverse to the axial fluvial system. To the south, and not related to this piedmont, also appear on gentle slopes some remains of evaporite deposits corresponding to high flood stages. The spectral behaviour of a complex mixture of geological detrital materials is explained both in terms of mineralogy, lithology and sedimentary meaning. Endmembers from the imagery have been identified and various hyperspectral image processing methods have been experienced. Laboratory spectra from geologically meaningful target sites have contributed to the selection of endmembers.

Spectral Angle Mapper digital mapping procedures are used as most useful to identify and map Quaternary geological units. Presence or absence of carbonate, presence of detrital phylosillicates on drainages, and saline minerals on mudflats are the main minerals responsible for the spectral features of the mapped piedmont geological units.

INTRODUCTION

The Las Tablas de Daimiel Natural Park frames a lake at the head of the river Guadiana draining to the Atlantic, settled in the large plain of La Mancha in central Spain (fig.1). This continental dry plain is subject to a Mediterranean dry, semi-arid climate with dry summer and winter and relatively short rainy seasons in fall and spring. Periods of drought are recurrent within the lapse of five years. It is a wetland with a linear morphology associated to alluvial river flats and hollows, resulting from the overflooding of the rivers Cigüela and Guadiana, joining and developing the Tablas, and the natural discharge of the underlying aquifer, through upwelling water at locations termed "ojos" (eyes). The study area is located on the northern transition from the mountains and the floodplain of the Cigüela river, carrying silty and evaporitic sediments from Tertiary and Triassic gypsum materials underlying the upstream river course. The floodplain is formed by silty and clay sediments with organic matter and gypsum.

The recent sedimentological record of the quaternary deposits in the area points to recent harsh paleoenvironmental conditions (2500-2300 years before present) with diminishing humidity and lowering of groundwater levels (García Antón et al, 1986). Intensive use of groundwater for cereal crop irrigation has produced a serious descent on the groundwater level and coverage, an already irreversible environmental problem. Today the Tablas de Daimiel has forgotten the times when it was an upwelling groundwater area to become a big pool of artificial water inflow (Llamas, 1988).

The study of the actual pattern of landforms informs about the natural processes, which are active in the present and have been active in the recent past. The area at the foot of the southern slope of the Montes de Toledo (central Spain) records sedimentary processes on different environmental settlements. Eroded material from the mountain catchments accumulates on alluvial fans, forming a transitional environment between mountains and plains. The distal areas of alluvial fans are associated with fluvial terraces developed at various stages of incision of the river channel. A wetland settled in the valley hosts deposits from an unevenly flooded area in an open-lake system related to fluvial and palustrine environments. Hyperspectral image analysis helps to outline geomorphologically the different units suggesting relative ages in landscape evolution. Spectral information can define the mineralogy of the units and qualify the geological processes through climate mineralogical markers present on the sediments (Riaza et al, 2003).

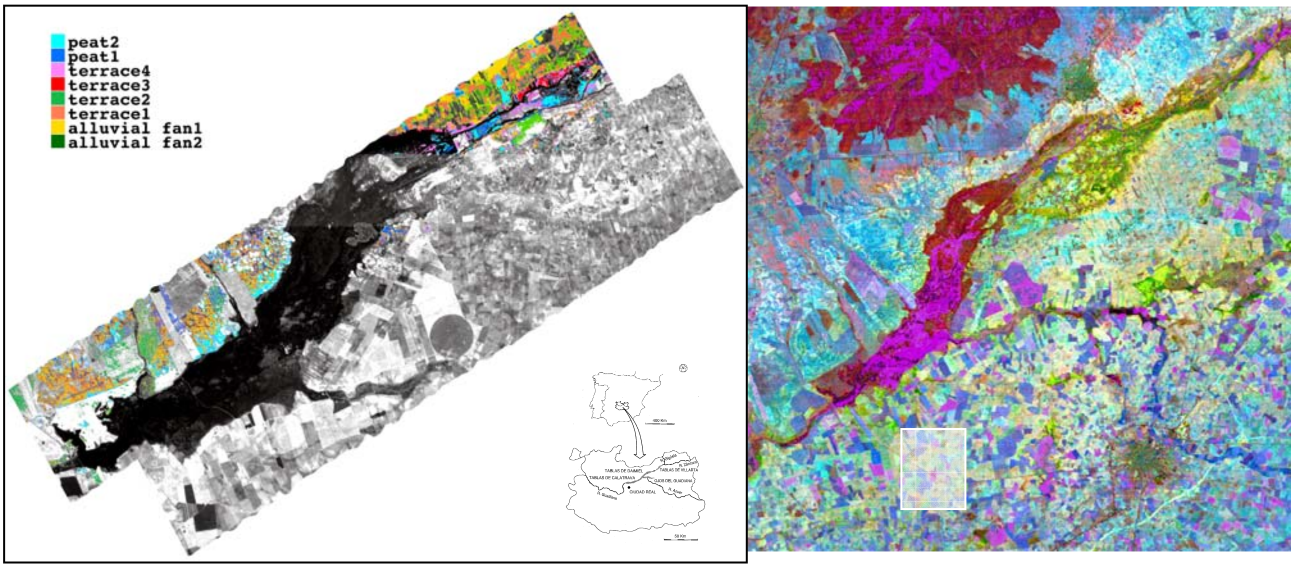

Figure 1: Geological map compiled from DAIS images on the northern and steeper slope of the Tablas de Daimiel wetland (central Spain). Thematic mapper: false colour composite with principal component 6 (red), minimum noise fraction transform 1 (green) and principal component 4 (blue) computed from the six VNIR channels.

The authors have mapped alluvial fans using broadband imagery in the visible and near infrared wavelength ranges (Garcia Meléndez et al, 2000). Previous work on the comparatively flat southern shore of the Tablas de Daimiel wetland (Riaza et al, 2003) using hyperspectral data has orientated image processing on the lacustrine and palustrine Quaternary geological units. Studies on soil properties related to humidity changes produced by variable groundwater availability have been done in nearby areas (Whiting et al, 2001). Algorithms developed for hyperspectral image processing have been used on well-known test areas using a reduced number of minerals as endmembers (Kruse et al, 1996). Geomorphic units of the same age as our study area are spectrally described based on soil properties (Batchily et al, 2003). However, none of those studies attempts to produce a summarizing map digitally elaborated from hyperspectral imagery based on the spectral properties of soils exposed on the geomorphic surfaces, nor to trace spectrally the geological processes involved which can be recognized telling the recent history of the area as suggested by landscape.

METHODS

DAIS 7915 (VIS-NIR-TIR) hyperspectral Spectrometer data were recorded on July 2000, with a 5 m spatial resolution. Preinterpretative image processing was performed for inner-instrument noise and atmospheric effects (Riaza et al, 2003). Only the 72 channels in the visible and nearinfrared have been used for this study.

Field spectra were collected for thematic analysis on geologically selected targets to be used for interpretative image processing with a GER Spectrometer. Laboratory spectra were run on field soil samples using a Perkin-Elmer Lambda 9 Spectrometer provided with an integrating sphere in the visible and near infrared wavelength ranges. Non-consolidated rock samples were dry-sieved before measurement.

X-ray diffraction analysis was performed on selected non-consolidated rock samples to confirm field observations regarding mineralogical contents.

Image processing was conducted using ENVI hyperspectral modules and reference spectral libraries. Hyperspectral mapping followed well-known image processing procedures (Kruse et al, 1997).

Vegetation, water and basic land use units have been mapped to restrict the areas of exposed soil, where mineralogical image processing exploration has concentrated (Riaza et al, 2003). A regional geological context through thematic mapper imagery helped the identification of alluvial fans, which are only scarcely present on DAIS images. They also give clues to the general trend of fluvial terraces.

Hyperspectral image processing procedures to identify endmembers geologically significant in the area include Minimum Noise Fraction Transforms, Pixel Purity Index, n-dimensional visualizer (Kruse et al, 1997), apart from more conventional exploration methods such as Principal Component Analysis, and Maximum Likelihood Classifier. Field spectra from selected sites were used with the Spectral Angle Mapper and Linear Pixel Unmixing algorithms to produce individual maps leading to summarizing geological outlines.

RESULTS

Maps have been compiled (fig.1) and the spectral features of the geological units are explored, both on DAIS imagery, field spectra and laboratory spectra on field samples collected at sites suggested by DAIS imagery.

Geological units through laboratory spectra

The spectral features described on laboratory spectra correspond only to wavelength ranges covered by DAIS data, excluding spectral features within the atmosphere water vapour absorption wavelength ranges.

Laboratory spectra have been measured on soil samples from sites suggested by digitally elaborated maps from DAIS images. From the study of the data, four terrace levels, two stages of fan development and two peatland units can be differentiated. The laboratory spectra show a progressive decrease on carbonate content from alluvial fans to young terraces, disappearing completely on modern terraces and peatland units rich on organic matter (fig.2A) Intermediate terraces display iron oxide features, not present on the modern terraces.

Terrace 1 and 2 show iron bearing minerals absorption features as well as certain amount of carbonate content, and a relatively high overall reflectance.

Terrace3 is a unit with low overall reflectance, lacking iron bearing minerals features and saline minerals, of light yellowish brown colour. The overall reflectance is lower than the older terraces. There is a sligt suggestion of the presence of saline minerals, which does not account for the low overall reflectance.

The spectral response of terrace4 is dominated by saline minerals absorption features. The presence of saline minerals is diagnosed by a 1.743 µm absorption and a deep absorption shifting from

1.911 µm to 1.94 absorption on the ascent 4 µm. A clear narrow at 2.275 µm absorption on the ascent from the OH bearing typical 2.2 µm absorption is added. It is also associated to high overall reflectance. Such comparatively topographically high mudflat slope with saline minerals can be a remnant from the last time that the lake waterlevel reached that height, before the maximum desiccation state prior to the artificial water feeding. This unit shows a well-displayed spatial coverage on the imagery in comparison with the older terraces.

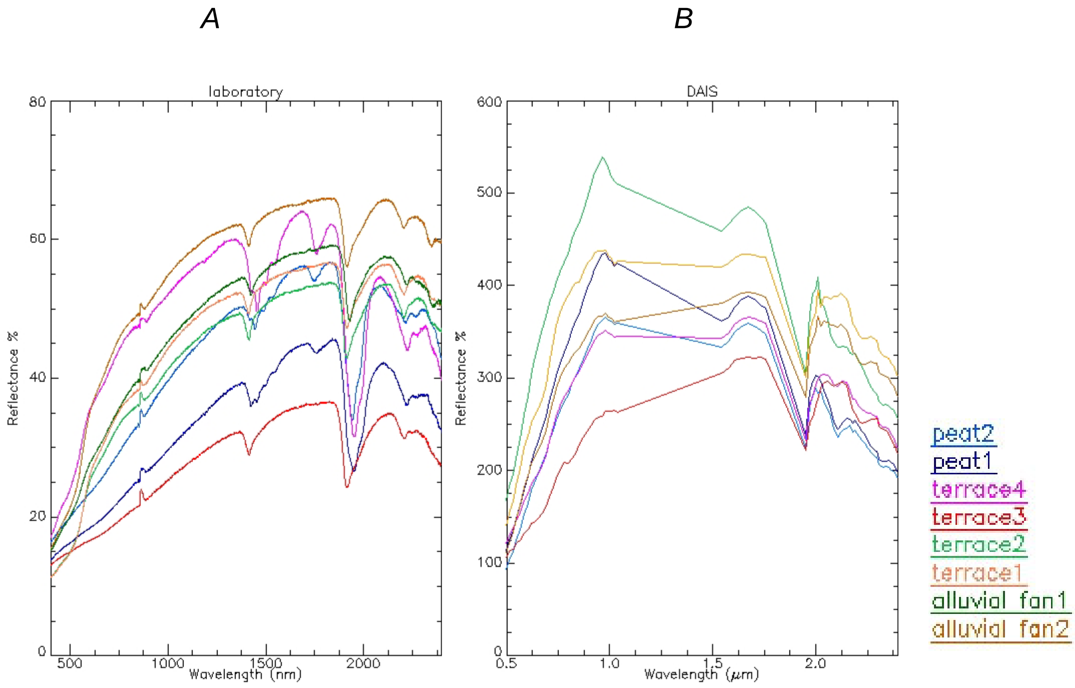

Figure 2: A: Laboratory Spectra from field nonconsolidated rock samples using a Perkin Elmer Lambda 6 Spectrometer on mapped geological units; B: Z profiles from DAIS images from areas representing mapped geological units using Spectral Angle Mapper.

The terrace4 may be the last exposed remnant of the mudflat shore belt suffering repeated floods and evaporation, due to presence of saline minerals. It is likely that the terrace4 is recently deposited, once the wetland has reached the maximum desiccation stage before it was artificially fed with water during the last 30 years. The presence of saline minerals and the steady spatial occurrence in the imagery along a continously displayed belt than the remaining terraces can explain this late deposition event.

The Red Holocene sands underlying the mapped units outcrop occasionally along the alluvial plain between the artificial water channel and the nowadays river channel, covered by peat deposits. The two mapped peat units show topographical and mineralogical relationships. The presence of more abundant organic matter lowers the overall reflectance and softens the diagnostic spectral features of the minerals present. Even then, peat units display clearly the presence of saline mineralsboth on absortion features and overall reflectance. Saline minerals absorption features are emphasized on the younger peat2 unit.

Most striking on the peat units absorption features is an absorption at 1973 nm, and a shift from the 1911 nm minimum to 1953 nm with an inflexion on the climbing branch between 1970-1987 nm. Diversity of associations of saline minerals not clearly understood can account for the diverse spectral response.

The alluvial fan units show high overall reflectance probably due to the presence of quartz and carbonate. The oldest fan unit 1 displays smoothed carbonate absorptions in comparison with the younger alluvial fan. It may be the consequence of an initially lower carbonate precipitation, or to former carbonate suffering wash-out processes diminishing its presence on the sediment.

Spectral trends can be identified depending on the relative age of the deposits of fluvio-lacustrine origin.

The most recent units, outcropping close to the river channel, show a straighter response on the visible, and an absorption at 2.00 µm which softens with increasing steepness of the visible response when units get older. A smooth absorption between 0.58 µm y 0.72 µm and a shy shoulder between 0.80-0.85 µm occurs on the spectra when the geological units age, due to the occurrence of iron oxides.

Loss of carbonate from the older terrace1 through younger units until terrace4 is shown by progressively smoothed 2.3 µm absorptions.

An absorption at 2.2 µm appears and deepens when the age of the units increase, showing emphasized expressions on terrace4 and peat2. This is due to the presence of phyllosilicates as detrital in the sediments coming from the Palaeozoic outcrops of the Schist Greywacke Complex from the northern ridges. The presence of carbonate on the two upper and most recent units with peat development and palustrine processes is shown by a 2.3 µm subtle minimum.

Geological units spectral behaviour on DAIS 7915 imagery

DAIS images reflect the spectral changes described for laboratory spectra on the visible, related to increase of iron bearing minerals absorptions as geological units age (fig.2B). The decrease of carbonate in the NIR on terrace units is not clearly shown by the imagery.

Terrace1 and terrace3 (plus alluvial fan1) show a shoulder between 2.2 µm and 2.3 µm, accompanied by emphasized iron bearing mineral absorption features. Peat1 and peat2 units display an absorption at 2.10 µm, also suggested on terrace4. Palustrine processes may be responsible for this absorption features, but laboratory spectra do not record simmilar absorptions.

Some miscalibration of the third DAIS detector may account for those features, which cannot be easily related to spectral responses from corresponding laboratory spectra, nor to known absorption features related to known minerals present on the mixture. Possible miscalibration effects on geological image spectral evaluation has been avoided through comparison with DAIS spectra from landuse maps previously compiled from the imagery. The role of spatial resolution can also be responsible for spectral discrepancies between laboratory spectra, field spectra and imagery (Riaza et al, 2004).

However, mapping through image processing has been very efficient (fig.1A) using hyperspectral image processing tools. Therefore, geological spectral variation is recorded in the imagery allowing an accurate spatial record of geological features consistent in terms of geological processes through quantitative and qualitative mineral changes, even when miscalibration or poor performance of the sensor is not able to show them faithfully as spectra.

CONCLUSIONS

The spectral features of the geological units mapped with hyperspectral data respond to mineralogical changes due to sedimentary and post-sedimentary processes. Relative age relationships are established and confirmed by semi quantitative estimations of mineral contents suggested by emphasized or softened diagnostic spectral features.

Lowering in carbonate content is spectrally traced through all geological units as an indicator of increasing young age both on terrace deposits and alluvial fans.

Iron bearing absorptions measure the length of time of exposure to the atmosphere under dry conditions. The presence of iron bearing mineral absorptions indicates medium age fluvial terraces, disappearing with the increase of environmental humidity favouring the development of peat and organic matter on the bottom of the valley. Softened iron absorptions are shown on the older peat deposits, suffering comparatively longer exposures.

OH bearing minerals absorptions suggest young peat deposits and alluvial fans with detrital phyllosilicates, which have not had time to degrade under water.

Geological spectral variation is recorded in the imagery allowing an accurate spatial record of geological features consistent in terms of geological processes through quantitative and qualitative mineral changes, even when miscalibration or poor performance of the sensor is not able to show them faithfully as spectra.

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