USING SPECTRAL MIXTURE ANALYSIS OF AVIRIS HIGH DIMENSIONAL DATA FOR DISTINGUISHING SOIL CHRONOSEQUENCES

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ABSTRACT

Soil surface dating techniques are presently imprecise without expensive excavation and lab analysis. Remote sensing with airborne spectrometers offers the potential to survey large areas quickly and inexpensively. Age information from remote sensing imagery when combined with proper geomorphic interpretation may be useful for soil mapping, geologic interpretation, and ancient climate research. The study site, a glacial moraine at Pine Creek, Owens Valley, California, USA was chosen because approximate age information could be inferred from known glacial history. We used a spectral mixture analysis to compress 172 bands of AVIRIS data into five endmembers. Fraction images for well-developed soils and for undeveloped soils were compared to sites with approximate age information from soil profile development indexes and geomorphic interpretation.

Results to date indicate a good correlation ($r^2 > 0.9$) between soil profile depth and soil profile development index. Also the data suggest that differences in soil development index are related to age of the surface. Good correlations ($r^2 > 0.9$) were found between fraction image, brightness values and soil age class. Further study is required to more precisely establish the ages of tested surfaces and to relate surface age to color values in enhanced color composite imagery of three fraction images.

INTRODUCTION

Surface dating techniques are desired for soils mapping, geologic interpretation and establishment of ancient climate regimes. Geologic history can be partially interpreted from geomorphic relations, radio-isotope data and soil profile data. However, the interpretation is uncertain when carbon is not present in the soil profile and excavation of soil pits is time consuming and expensive. We have investigated the relationship of the spectral reflectance pattern of the surface with the age of the surface. If age could be estimated from surface characteristics, airborne spectroscopy holds promise for rapid survey of large areas by remote sensing from aircraft or spacecraft. Our work is based on field observations of soil surface darkening with age in arid regions. Two mechanisms are suggested for this darkening: varnishes developing on rock surfaces, and "bio-turbation" (the bringing to the surface of soil from 10 to 20 cm down in the profile by small rodents and insects burrowing in the soil).

STUDY AREA

We selected a study area in the Owens Valley, California, USA, near Pine Creek. The area is characterized by a large glacial moraine that has been formed and modified by several periods of glaciation over the past two million years (Fig. 1). This area was selected because the glacial history is relatively well known and rough age control was provided by geomorphic interpretation (Fig. 2). Three major age classes have been tentatively identified in the study area. Some of the lateral fans were formed during a glacial period occurring approximately 150 thousand years ago when the glacier extended to the nose of the current moraine. Other lateral fans were deposited later, approximately 50 to 60 thousand years ago during another period of severe glaciation. The sides of the distal fan were formed approximately 50 to 60 thousand years ago and the center portion of the distal fan was formed approximately 10 to 12 thousand years ago. All of the dates are only approximate being inferred from known glacial history and geomorphology.

METHODS

Soil Profile Development Index

Soil pits were excavated in four of the general age classes determined from air photos and geologic knowledge to provide further age control. We analyzed the soil profiles obtained from these pits using a soil profile development index (Harden and Taylor, 1983). The index is a measure of soil development from which relative age can be determined. We assumed a constant rate of soil development since climate effects should have been constant over this relatively small region bounded by mountains on the east and west sides.

Spectral Mixture Analysis

High dimensional data sets from imaging spectrometers are large enough to overwhelm existing computer systems using traditional image processing techniques. We used a spectral mixing model (Adams, et al., 1989) to tremendously reduce the dimensionality of the data set. The model is based on the theory that most pixels are mixed and the whole is equal to the sum of its parts. Each pixel was modeled to contain a mixture of spectrally pure elements ("endmembers"). The digital number (dn) of the pixel as recorded in each spectral band of AVIRIS is equal to the sum of the dn's of each endmember weighted by the fraction of the pixel occupied by that endmember. A premise of the model is that even high dimensional data sets can be reduced to four or five endmembers, thereby simplifying complex data sets such as the 224 channels of AVIRIS data.

Once the endmembers are identified, each pixel can be analyzed to determine the percentage of the pixel covered by each endmember. The

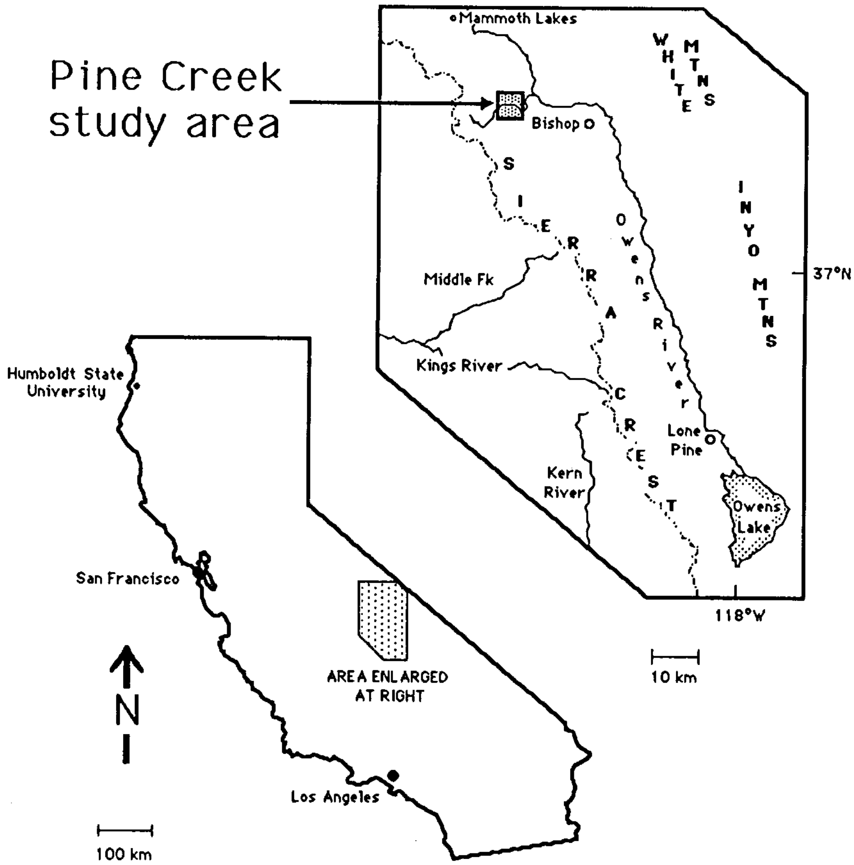

Fig. 1. Location map of the study area

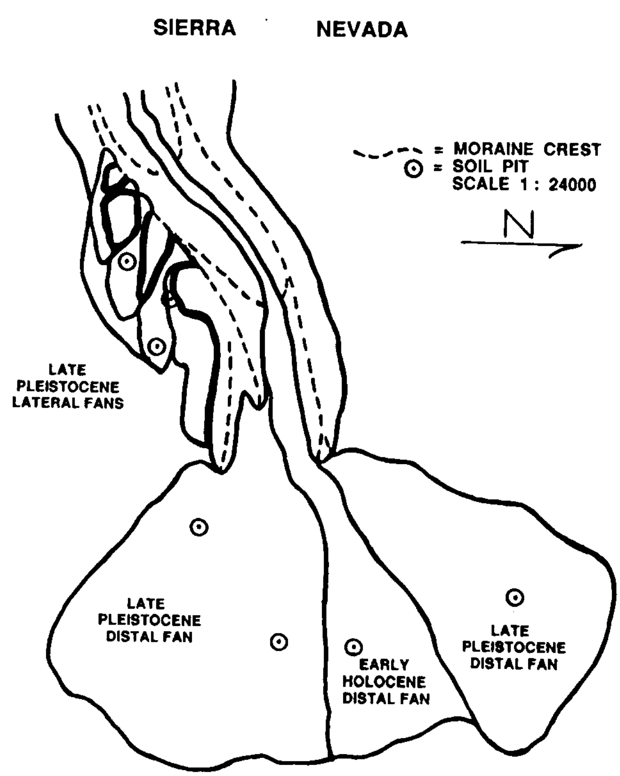

Fig. 2. A sketch map of gross morphology of the moraine made from low-altitude, color aerial photographs

analyst is able to create fraction images that display the fraction (percentage) of each pixel occupied by a given endmember as a digital number and therefore a grey level.

RESULTS

Soil Profile Development Index

We plotted the soil profile development index as a function of soil depth for three of the soil pits excavated (Fig. 3). The top curve was derived from a soil pit in an older lateral fan, approximately 65 to 70 thousand years old. The middle curve was from the side of the distal fan, approximately 65-to 70-thousand years-old and the lower curve was from the youngest part of the distal fan, approximately 10 to 12 thousand years old. A log relationship provided the best fit to the data when compared to linear regression or polynomial regression. Values of r^2 were between 0.92 and 0.95 for each of the three curves. As expected, soil development increased with depth for each soil analyzed.

Of greater interest to this study is the comparison of the three curves plotted in Fig. 3. Statistical comparison was not possible since each curve represents only one soil profile. However the data suggest that the curves are distinct and represent differences in soil age. The lowest curve was least developed and came from the youngest part of the distal fan. The middle curve was from the same age range as the upper curve yet the profile (the middle curve) suggests that the soil is younger.

Spectral Mixture Analysis

Four endmembers were selected to represent the multidimensional data cloud from AVIRIS. A darker, and therefore older, soil was chosen and named "red soil". A very light, and therefore younger soil was selected and named "white soil". These soils were selected after a general inspection of the area and the determination that various ages of soil could be represented by these two soil endmembers. Two vegetation endmembers (green and dry) and a shadow endmember were added to the model to account for the desert shrub vegetation, shadows from vegetation and terrain shadow, present in the imagery of the study area.

Dn's from the "red soil" fraction image and dn's from the white soil fraction image are displayed in Fig. 4. A large red soil dn indicates that a large percentage of the pixel was covered with red soil. From this we infer an older surface. A large white soil dn indicates that a large percentage of the pixel was covered with white soil. From this we infer a younger surface. These dn's are plotted as a function of age in Fig. 4 and we noticed a downward trend in white soil fraction and a general upward trend in red soil dn with increasing age. Linear regressions were significant ($P<0.05$) and r^2 values were 0.92 for the red soil fraction image and 0.80 for the white soil fraction.

PDI vs. DEPTH vs. AGE

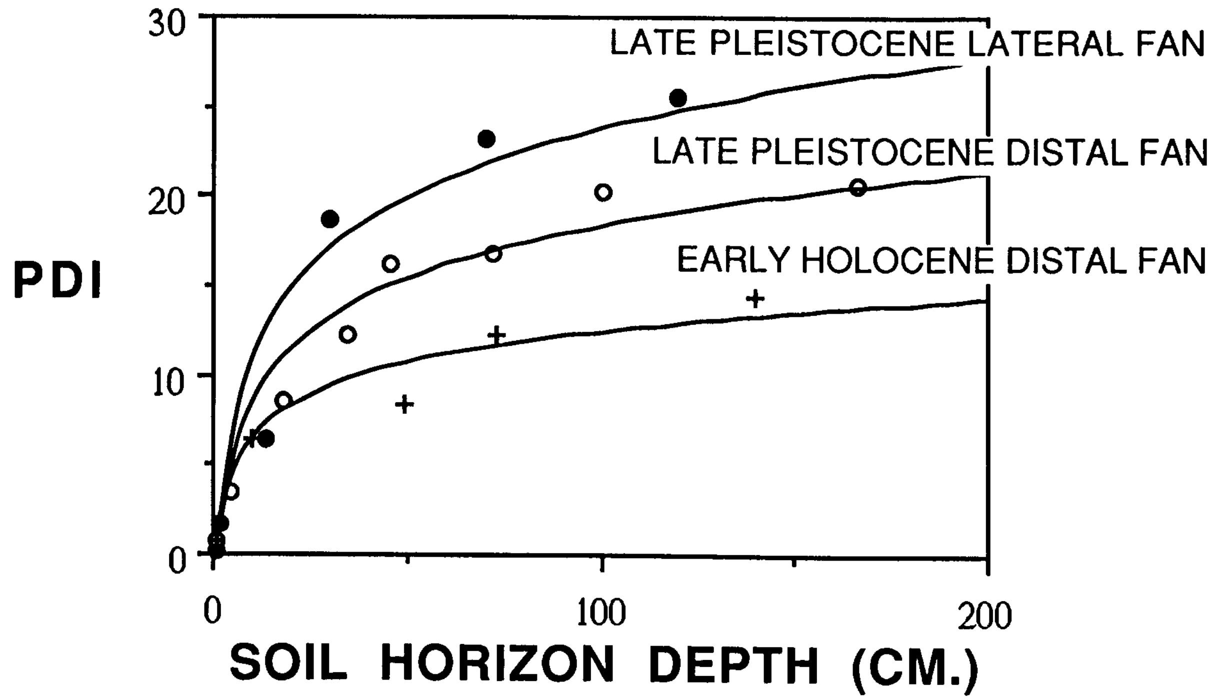

Fig. 3. A plot of the soil profile development index for three soil profiles from different parts of the study area.

RED/WHITE BRIGHTNESS COMPONENTS vs AGE

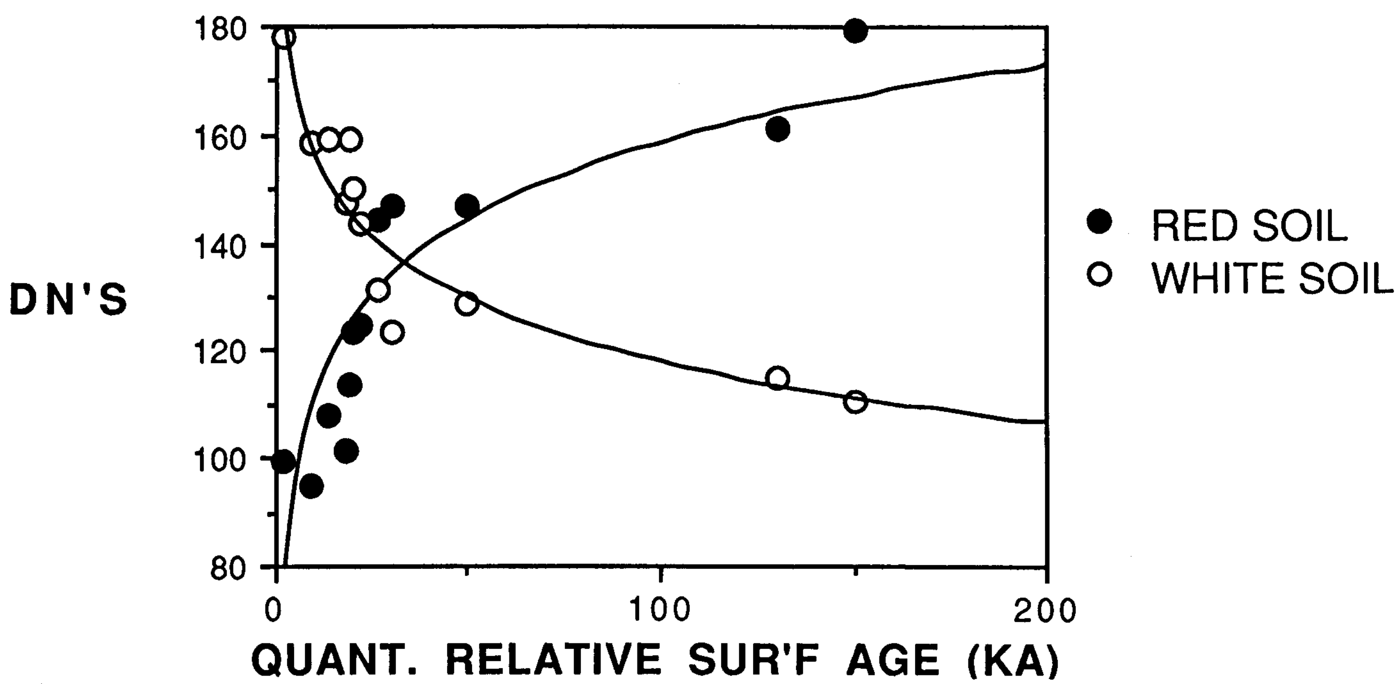

Fig. 4. A plot of the digital numbers of two fraction images for various ages of surfaces in the study area

DISCUSSION

Trends observed so far are encouraging in that surface ages seem to be well-correlated with soil development and fraction images are producing brightness values that are correlated with surface age. However, these results are tentative, due to small sample sizes and the very complex nature of the distal fan at Pine Creek. Over the next year we plan to collect additional soil profile data and further process imagery to concentrate on specific sections of the distal fans and the lateral fans.

REFERENCES CITED

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