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MINERALOGY AND COMPOSITION OF ARCHEAN CRUST, GREENLAND: A PILOT STUDY

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Summary

The Portable Instant Display and Analysis Spectrometer (PIDAS) (Goetz *et al.*, 1987) was taken to southwestern Greenland to investigate *in situ* the potential application of AVIRIS to estimate the mineralogy and composition of rocks exposed in Archean terranes. The goal was to determine the feasibility of using a high spectral resolution scanner to find and study pristine rocks, those that have not been altered by subsequent deformation and metamorphism. The application of AVIRIS data to the problems in Greenland is logical. However, before a costly deployment of the U-2 aircraft to Greenland is proposed, this study was undertaken to acquire the spectral data necessary to verify that mineralogical mapping in the environmental conditions found there is possible.

Although field conditions were far from favorable, all of the major objectives of the study were addressed. One of the major concerns was that lichens would obscure the rock surfaces. While lichens do cover a high percentage of many of the rock outcrops, it was found that the spectral signature of the lichens was distinct from the underlying rocks. Thus, a spectrum of a rock outcrop, with its partial cover of lichens, can be un-mixed into rock and lichen components. The data acquired during the course of this study supports the conclusion that areas of pristine Archean crust can be differentiated from that which has experienced low grade alteration associated with Proterizoic faulting. It was initially thought that high soil moisture would hinder the usage of remote sensing. In almost all cases it was found that wet areas occurred in areas covered by ice rafted material. Because the mineralogical composition of this material gives no insight into the geology of the bedrock, the increased soil moisture in these areas is of little concern. Because these materials have no relationship to the underlying bedrock, the differentiation of this

glacial float from the bedrock is one of the major problems that must be addressed prior to the deployment of AVIRIS in Greenland.

Introduction

Areas of preserved Archean crust provide windows into the Earth's earliest recorded geologic history. On the other hand, Archean terranes are complex, and the original disposition and composition of their rock units have commonly been modified by deformation and metamorphism. Therefore, a detailed inventory of the mineral assemblages and chemistry present in these rocks is an initial constraint essential to unraveling crustal history. The terrane is extensive and difficult to traverse. The Airborne Visible Infrared Radiometer Imaging Spectrometer (AVIRIS) and The Thermal Infrared Multispectral Scanner (TIMS) are instruments that provide high enough spectral and spatial resolution to make possible the direct identification of minerals present in exposed rocks, under favorable conditions, allowing rapid estimation of rock mineralogy from which compositions can be inferred over broad areas. This study was undertaken to determine if adequate information can be acquired from reflectance spectra of outcrops which, in some cases, are lichen covered and/or water saturated.

The Portable Instant Display and Analysis Spectrometer (PIDAS) (Goetz *et al.*, 1987) was used to investigate *in situ* the potential application of AVIRIS to estimate the mineralogy and composition of rocks exposed in Archean terranes. Greenland is an unique area because the 3600-3700 Ma white and grey Amitsoq gneisses and the 3800 Ma Isua supracrustral belt are the most extensive exposures known of earliest Archean rocks (Baadsgaard *et al.*, 1986). In addition, although deformation is responsible for the predominance of strongly banded Amitsoq gneisses, the least deformed Amitsoq gneisses are reported to be among the best preserved of early

Archean plutonic rocks (Nutman and Bridgwater, 1986). The special characteristics of this terrane which make it particularly suitable for eventual AVIRIS/TIMS coverage include the presence of extensive outcrop, a broad spectrum of rock compositions, the low surface coverage of lichens, and the absence of rock coatings and extensive oxidation of the rocks' surfaces. The study was carried out in cooperation with Dr. Robert F. Dymek, Washington University, who has accomplished pioneer metamorphic studies in the area of Isua (Dymek, 1978; Boak *et al.*, 1983; Dymek *et al.*, 1983; Dymek, 1984). Dr. Dymek has spent three field seasons in Greenland and gathered an impressive rock sample collection and chemical data base to which we will have access.

Nutman and Rosing (1985) have stressed the importance of distinguishing primary geochemical characteristics of Archean crust from perturbations due to tectonometamorphic and metasomatic events. For example, some metasomatic changes in the grey Amitsoq gneisses can be shown to be due to the intrusion of younger white Amitsoq gneisses. In fact, the disturbance of the major and trace element chemistry and isotopic systematics of the grey gneisses caused by this metasomatic event have been the subject of in-depth studies by Baadsgaard *et al.* (1986) and Nutman and Bridgwater (1986). Thus, finding pristine rocks is essential to characterize the protolith of the grey gneisses. Our efforts were focused in an area of Isukasia where the grey gneisses are reported to be least deformed (McGregor *et al.*, 1985, Nutman *et al.*, 1983). The metasomatic alteration imposed on the grey gneisses by the intrusion of the white gneisses is reported to have modified the primary petrography of the grey gneisses (Baadsgaard *et al.*, 1986). The first signs of alteration result in the alteration of plagioclase to zoisite and muscovite, with a concurrent increase in water content of the rocks. Where more intense alteration has occurred in association with deformation along faults, the mafic minerals biotite and hornblende are altered to phengite and chlorite, while plagioclase is converted to zoisite, phengite, quartz and carbonate. If it can be demonstrated that these mineralogical changes are detectable spectrally, it may be possible to guide the field geologist to areas where more adequate sampling can be accomplished. In other words, AVIRIS/TIMS data might be used to "forage for pristine Archean crust," i.e., the data would be used to pick out candidate pristine zones for further detailed field and laboratory work.

Fieldwork

The primary objective of the fieldwork in the Isua area was to evaluate the feasibility of using remote sensing data to solve a broad range of geologic problems. This was accomplished by observing the amount of bedrock exposure, the extent to which lichen obscured the various rock units, the amount of vegetation cover and the spectral contrast between units. Our group (B. Curtiss (CU), B. Rivard (WU)) joined Dr. Dymek's expedition and spent seven days in the eastern part of the Isua supracrustal belt followed by eight days in the south-west extremity of the belt.

Initial work in the eastern part of the belt consisted of elaborating a rock and vegetation classification scheme which was then used for the description of surfaces on which spectral measurements were acquired. Reflectance measurements in the 450 nm to 2500 nm region of the spectrum were measured using the Portable Instantaneous Display and Analysis Spectrometer, (PIDAS). Because of poor weather conditions during these seven days, spectral data was acquired on only two days.

Reflectance spectra and samples were obtained for the two upper members of sequence B supracrustals, the felsic gneiss and garnet-biotite schists. Three transects approximately 100 meters in length, and 30 meters apart, were laid out perpendicular to the strike of these units. Reflectance spectra were measured at approximately 5 meter intervals along each transect. A wide variety of surfaces, including unvegetated weathered rock surfaces, weathered rock surfaces with variable lichen covers, and wet rock surfaces were included. Additionally, field reflectance spectra and samples were obtained for a wide range of boulder lithologies and lichen types. While the weather did not permit the use of PIDAS to make additional field spectral measurements, samples of the various lithologic units, including the garbenschiefer and carbonate units, were collected.

The second camp site was located in the western segment of the Isukasia belt in the vicinity of the sequence A type section. Once again, poor weather conditions limited the days during which PIDAS data could be acquired. Because the poor weather conditions did not allow the measurement of the reflectance spectra in the field, samples were collected along the sequence A type section of the supracrustal rocks (Nutman 1984). PIDAS reflectance measurements were made at a series of sites located in the vicinity of the proterizoic Ataneq fault. These data were used to examine the spectral changes associated with alteration along the fault.

Sky conditions and performance of the field spectrometer during the course of the fieldwork were far worse than anticipated. There was one day of clear blue skies, and three half days with some clouds. Additionally, many problems were encountered in the operation of PIDAS under the environmental conditions found in Greenland. These problems include IR spectrometer gains that were optimized for mid-latitude summers, IR spectrometer grating drives that did not properly step the gratings when the instrument was cold, and drift in the visible spectrometer dark current. One of the major problems was associated with the thermoelectric "coolers" mounted on each of the detector arrays. These coolers are intended to provide temperature stabilization for the detectors. To maximize battery life and because warm climates were assumed, the thermostats on the T.E.C.s were set to about 23°C. Thus, when the ambient temperature is less than 23°C (as it was the majority of the time in Greenland), the T.E. coolers are actually heating the detector arrays. Because of the erratic nature of the T.E.C.s in heating mode, the signal / noise under these conditions is about half of normal.

While the overall quality of the reflectance data acquired in the field was low, it was sufficient to accomplish several of the objectives of the study. In many cases, samples were collected in the field to assure that adequate reflectance measurements could later be made in the laboratory. Additional reflectance measurements of rock surfaces, both lichen covered and lichen free, were made in the laboratory using PIDAS on return from Greenland.

Results

The presence of extensive lichen cover is one of the major problems that must be addressed prior to the application of remote sensing to geological mapping in Greenland. While lichen cover is pervasive in the coastal regions, the areas closer to the ice sheet typically have only ten to fifty percent of the surface covered by lichen. Laboratory reflectance measurements of lichen free (Figure 1a and b) and lichen covered regions (Figure 2a and b) of the same sample confirm that the various forms of lichens all have a similar spectral shape in the short wave infrared portion of the spectrum. While the rock substrate cannot be seen through the lichen cover, the spectrum of the lichens is sufficiently distinct from any of the rock spectra. Thus, the mixed signature of a partially lichen covered outcrop could be unmixed into "rock" and "lichen" components.

The presence of moisture in surface soils regolith was determined to be of minor consequence. All of the observed rock outcroppings were found to have very

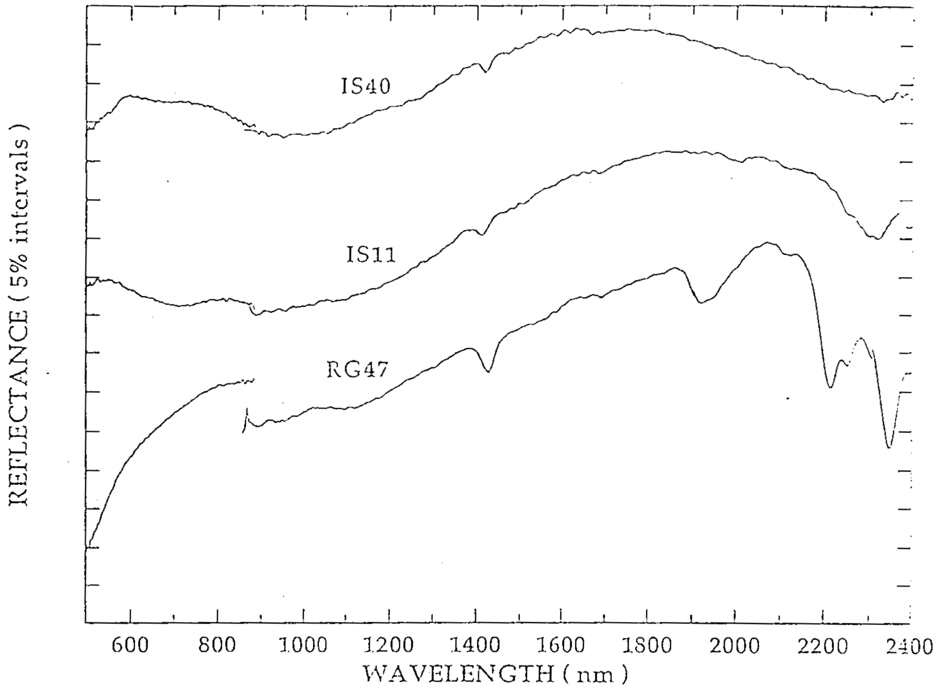

Figure 1a. Reflectance spectra of lichen free surfaces of the same samples shown in Figure 1. Samples IS40 and IS11 are both from the Garbenschiefer unit of the Isua supracrustal belt; sample RG47, a pegmatite, is an example of ice rafted material. As can be seem from a comparison to Figure 2, the presence of the lichen totally obscures the absorption features seen in these reflectance spectra. The spectra have been offset vertically for better viewing.

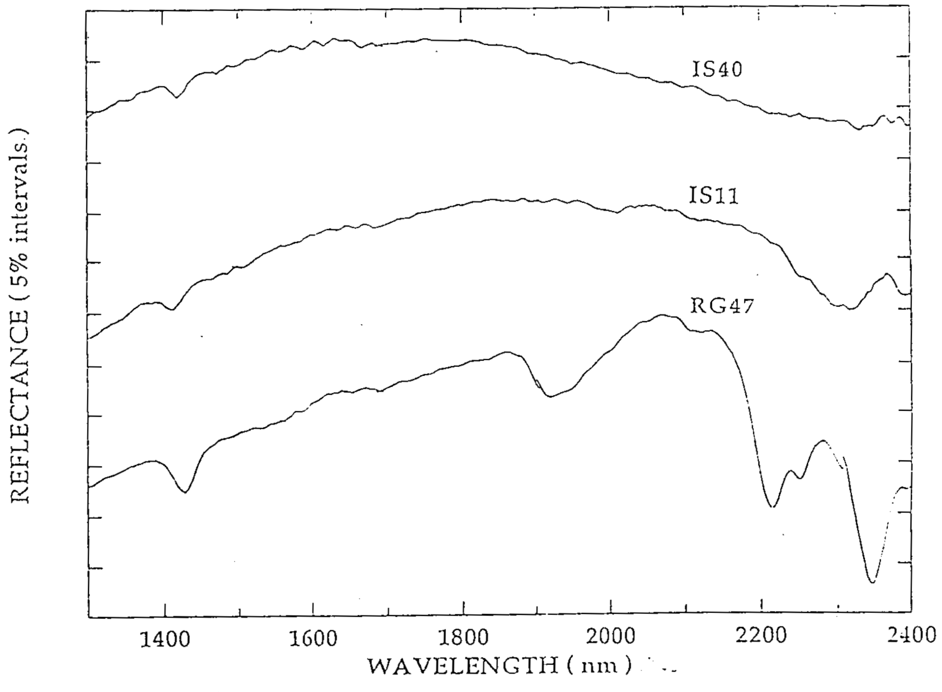

Figure 1b. This figure shows the detail in the short wave infrared of the spectra show in Figure 1a. The spectra have been offset vertically for better viewing.

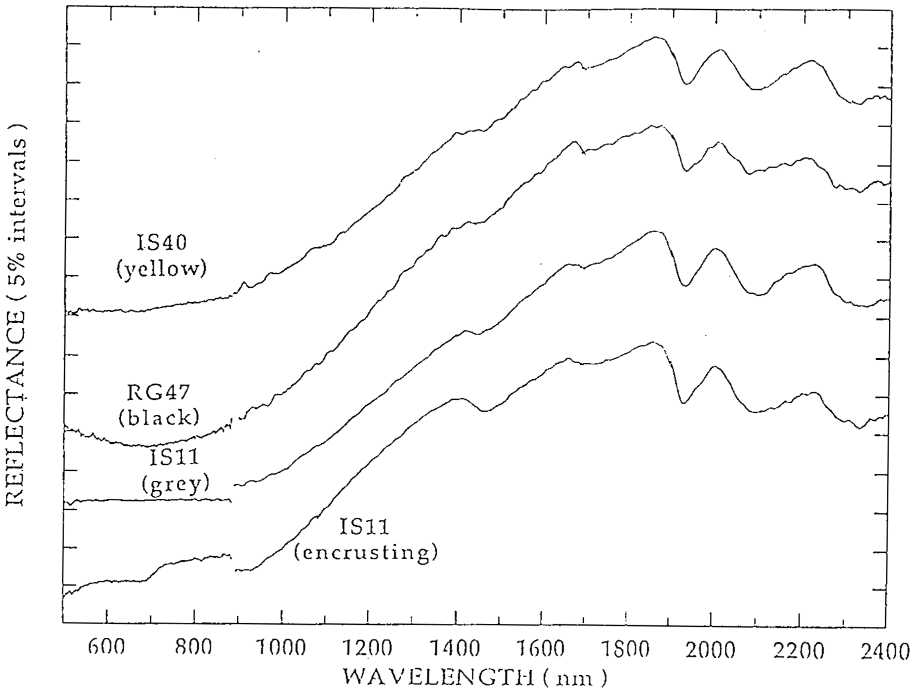

Figure 2a. Reflectance spectra of five lichen covered surfaces, sample numbers are noted on each spectrum. These spectra are representative of the four dominant type of lichen found in the Isua area: yellow, black, grey, and encrusting black. While there are slight differences in the visible region of the spectrum, the spectra are almost identical in the short wave infrared region.

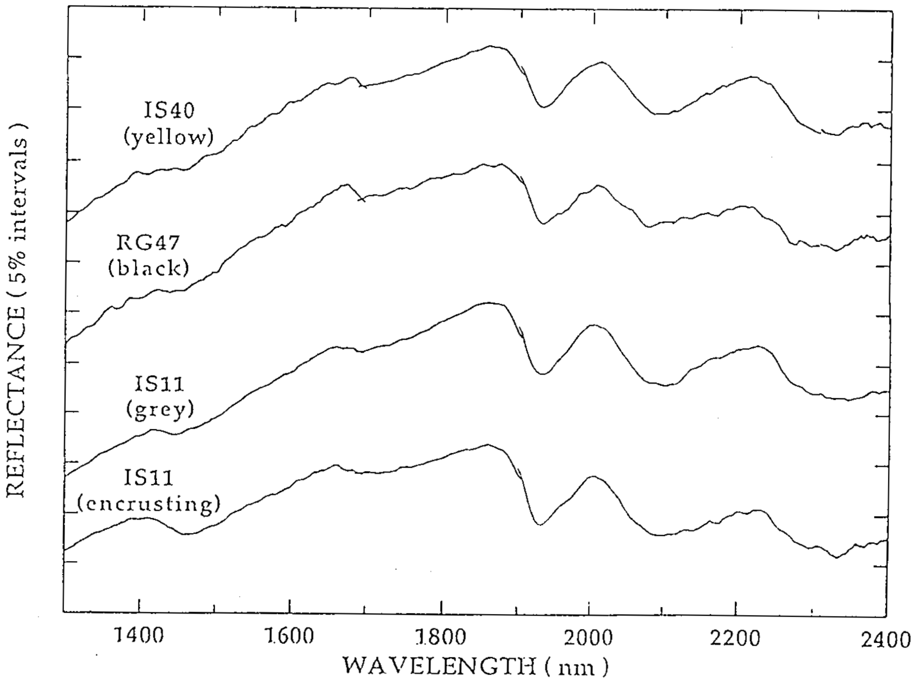

Figure 2b. This figure shows the detail in the short wave infrared of the spectra show in Figure 2a. The three absorption features in the 2100 - 2300 nm region are probably due to the presence of cellulose in the lichens. The spectra have been offset vertically for better viewing.

low porosity, and thus do not hold moisture for an appreciable period of time. Those surfaces which were found to be wet were most often comprised of glacially deposited material. While the reduction in the spectral contrast of these materials resulting from surface moisture will hinder the spectral determination of their mineralogy, these materials are totally unrelated to the underlying bedrock.

The ability to differentiate glacially deposited materials from bedrock outcrops will be essential to the interpretation of any remotely sensed dataset. The surface textures of these glacially deposited units is quite distinct from the bedrock outcroppings. The outcroppings are topographically higher and tend to form broad smooth surfaces without much small scale shadowing, while the glacial units consist of close packed rounded boulders (0.5 - 2 meters in diameter) and have considerably more small scale shadowing. The use of mixing models that utilize shade as a component and a classification scheme that uses the spatial variation in shading should provide a means to differentiate these two types of surfaces.

Reflectance spectra of outcroppings of the grey Amitsoq gneisses were measured along a transect perpendicular to the Proterizoic Ataneq fault zone to determine the spectral changes associated with low grade alteration which occurs along the Ataneq and similar Proterizoic faults throughout Greenland. While the quality of the reflectance spectra was low, the relative intensities of the absorption features in the 2000 - 25000 nanometer region of the spectrum change as a function of the distance form the fault (see Figures 3 and 4). The absorption feature at 2220 nm is indicative of muscovite and the feature at 2350 nm is consistant with the presence of chlorite. The presence of muscovite in these rocks is indicative of the first stages of alteration. The formation of chlorite is a result of more intense alteration, commomly found in association with deformation along faults.

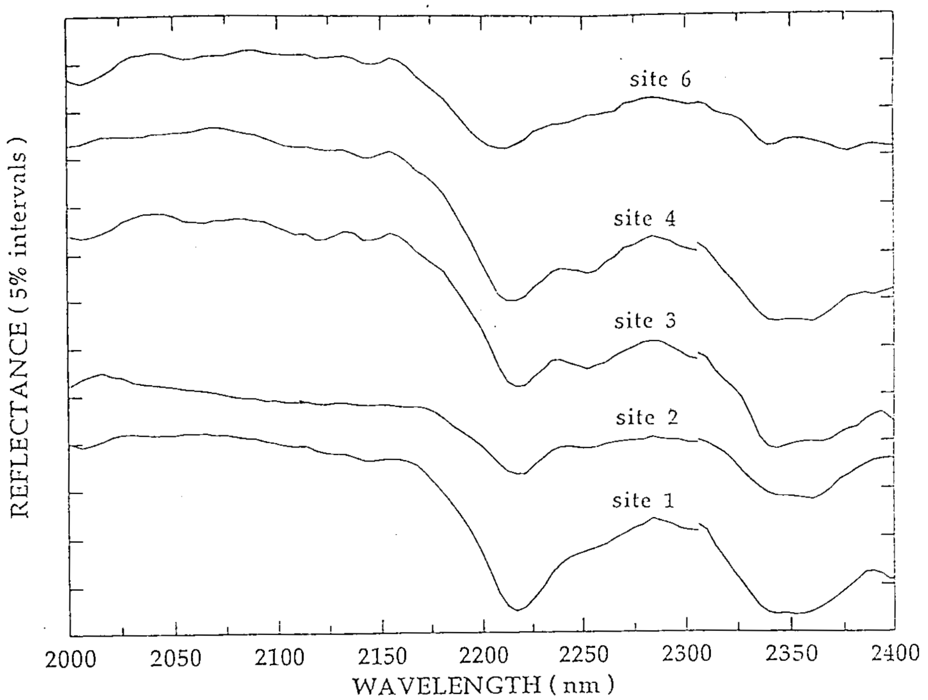

Figure 3. Short wave infrared reflectance spectra of grey Amitsoq gneisses along a transect perpendicular to the Ataneq fault zone. Site 6 is the furthest from the fault, approximately 1.5 kilometers. The absorption feature located at 2220 nm is associated with muscovite, a product of regional low grade alteration in the grey gneiss, and the feature located at 2350 nm is associated with chlorite, a mineral produced as a result of the more intense alteration associated with the faulting.

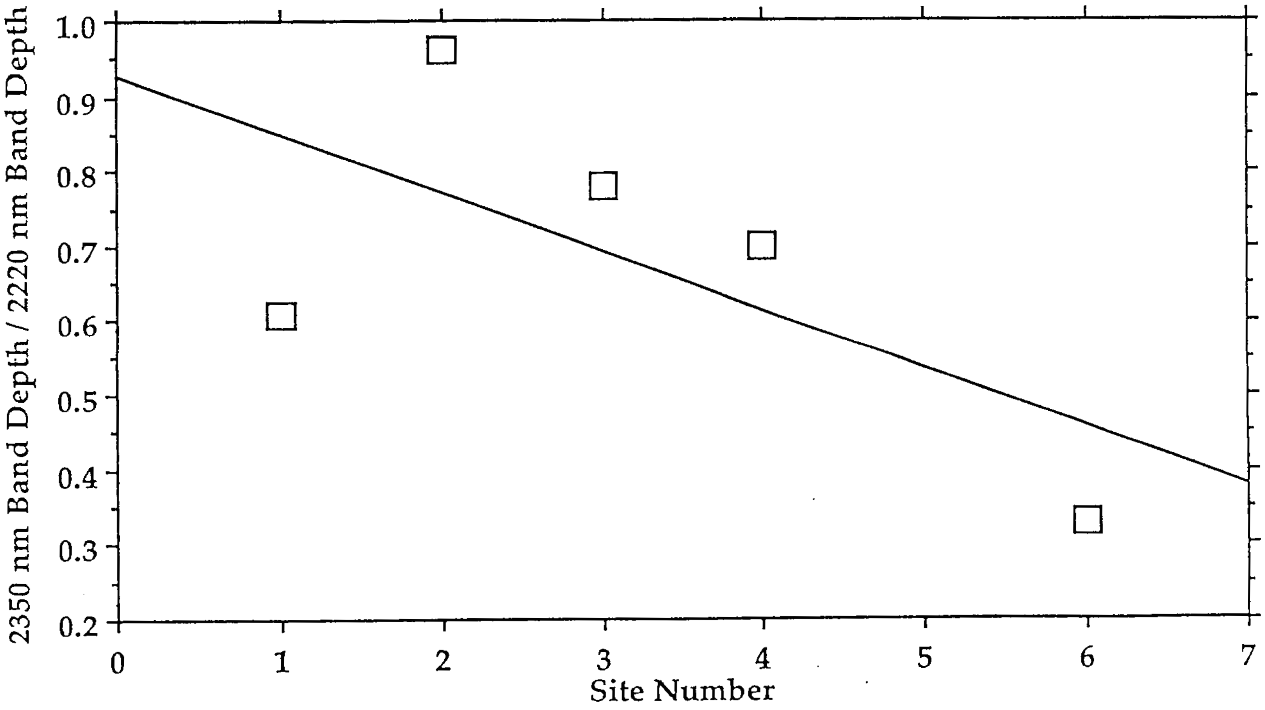

Figure 4. The ratio of the band depths of the 2220 nm (biotite) and the 2350 nm (chlorite) features shows a decreases with distance from the Ataneq fault zone. This demonstrates that the low grade metamorphism associated with Proterizoic faulting can be identified using high spectral resolution remote sensing.

Recommendations

Reflectance spectra acquired in both the field and in the laboratory support the conclusion that a high spectral resolution scanner, such as AVIRIS, would provide a useful tool in the mapping of bedrock lithologies in southwest Greenland. The problems introduced by extensive lichen cover and by the presence of large regions of glacially deposited material can be overcome through the use of sophisticated image processing techniques such as mixed signature modeling and texture analysis. While lichen cover in the Isua region is relatively low, other areas in Greenland, in particular the coastal regions, have much higher coverage. Traditional sensors, such as Thematic Mapper, should be used to asses the degree of lichen cover prior to the planning stage of a full scale deployment of AVIRIS.

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