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APPLICATION OF IMAGING SPECTROMETER DATA TO THE KINGS-KAWEAH OPHIOLITE MELANGE

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Abstract

The Kings-Kaweah ophiolite melange in east-central California is thought to be an obducted oceanic fracture zone and provides the rare opportunity to examine in detail the complex nature of this type of terrain. It is anticipated that the distribution and abundance of components in the melange can be used to determine the relative importance of geologic processes responsible for the formation of fracture zone crust. Laboratory reflectance spectra of field samples indicate that the melange components have distinct, diagnostic absorptions at visible to near-infrared wavelengths. The spatial and spectral resolution of AVIRIS is ideally suited for addressing important scientific questions concerning the Kings-Kaweah ophiolite melange and fracture zones in general.

Introduction

The development of imaging spectrometers as accurate and reliable tools for the examination of geologic terrain (Goetz et al, 1986) has opened up a whole new range of scientific problems that can be addressed. The application of imaging spectrometer data is advanced even further by the development of powerful analytical tools which can reduce the enormous volume of data obtained by such instruments to basic information about the surface (i.e Kruse, 1988; Mustard and Pieters, 1987; Adams et al, 1986). However, not all geologic problems are amenable to this type of analysis and careful merging of scientific goals, the specific geology and nature of the terrain, and capabilitites of the instrument are necessary in order to exploit the unique perspectives provided by imaging spectrometer data.

The Kings-Kaweah ophiolite melange poses scientific questions which are best addressed with imaging spectrometer data. The overall composition and nature of deformation in this ophiolitic terrain led Saleeby (1978, 1979) to conclude that it is an obducted oceanic fracture zone. There are few well documented fracture zone assemblages exposed sub-aerially and the Kings-Kaweah ophiolite melange is particularly interesting because of the range of fracture zone processes exposed. It provides a rare opportunity to examine the net result of the deformation of oceanic crust to form fracture zone crust. Fundamental questions remain regarding the development of the melange matrix and the relative importance of various processes thought to be active in fracture zones. We propose to map the distribution and abundance of important mineral components in the matrix of the melange with imaging spectrometer data and relate regional geochemical variations to the tectonic development of fracture zone crust.

Background

Fracture zones, which are common and well recognized features in oceanic crust, are typically hundreds to thousands of kilometers long and 5–50 kilometers in width. The crust within the boundaries of a fracture zone is commonly refered to as fracture zone crust. In regions where oceanic crust is being formed at a rapid rate (i.e the East Pacific Rise) fracture zone crust comprises about 10–15% of the ocean floor while in areas of extremely slow spreading (i.e. Southwest Indian Ridge) fracture zone crust may reach 50% of the ocean floor (Abott, 1987). Although some basic characteristics of fracture zone crust have been deduced from geophysical investigations and examination of material dredged from fracture zones (Fox and Gallo, 1984; Forsythe and Wilson, 1984) the exact nature of the processes responsible for its formation as well as the details of the interactions between active processes in fracture zones are still not well understood.

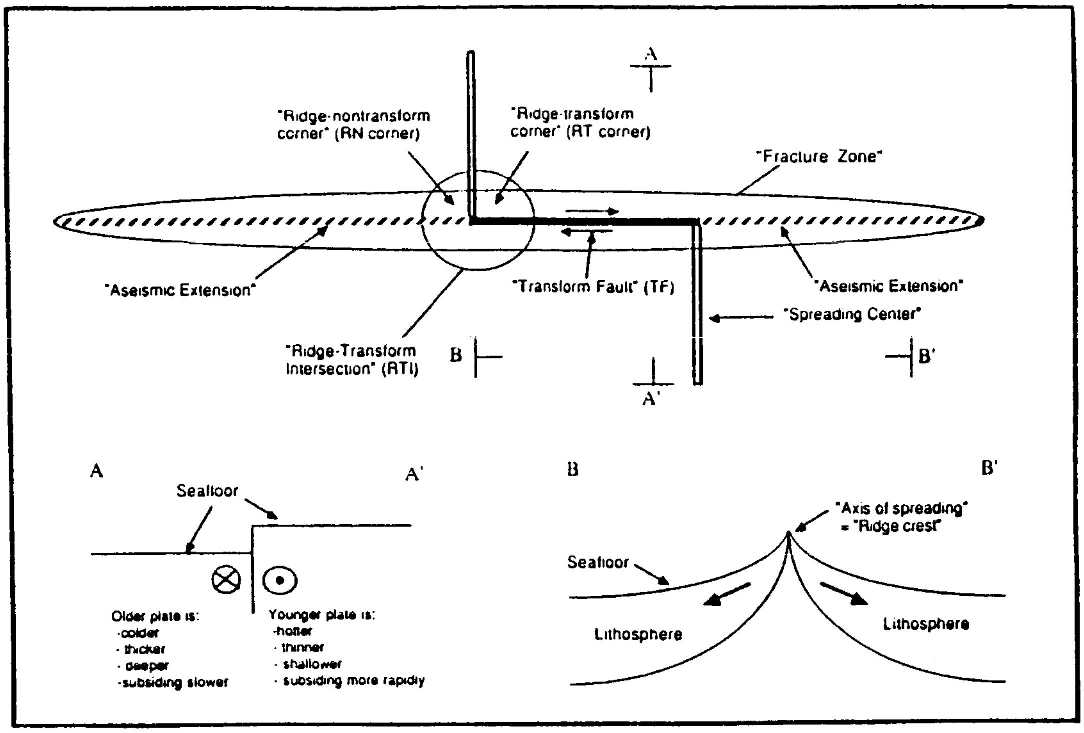

Figure 1. General terminology and spatial relationships of components associated with fracture zones (from Kastens, 1987).

In general a fracture zone consists of two primary segments (Fig. 1); the transform domain which occurs in the region between offset spreading centers and the non–transform or aseismic extension which can extend for many hundreds of kilometers beyond the ridge–transform intersections. Deformation processes within these domains are variable, complex, and polyphase. The active processes can be summarized as consisting of strike–slip and dip–slip faulting, hydrothermal alteration and metamorphism, ridge crest magmatism, diapiric intrusion of serpentinized ultramafics, and sedimentation. These processes are active with variable intensity throughout both segments of a fracture zone, but generally have localized zones of maximum intensity (i.e. the principal region of strike–slip deformation occurs in the transform domain while ridge crest magmatism is localized at the ridge–transform intersection (Karson and Dewey, 1978). The principal driving forces are spreading at the ridge crests and the offset thermal decay histories of the oceanic segments on either side of the fracture zone.

Serpentinization and protrusion of ultramafic mantle material is thought to be a common, and perhaps dominant process in fracture zones (MacDonald and Fyfe, 1985). The serpentinization of mantle rocks is facilitated by the highly fractured crust in fracture zones, availability of abundant water, and the discontinuity of thermal profiles across the fracture zone which can drive vigorous hydrothermal cells. Under these conditions serpentinite bodies are very mobile. Diapiric emplacement of serpentine is facilitated by the density contrast between the serpentine bodies and the surrounding country rock as well as the weak shear strength of serpentine. A consequence of these processes is that abundant fine–grained sheared serpentined is created which is then available to form the matrix. In addition, vertical mixing of ophiolitic components is enhanced by diapiric activity (Saleeby, 1984).

The net result of these processes is that the standard three layer stratigraphy of oceanic crust is disrupted and blocks and fragments of typical ophiolite crust are distributed in a fine–grained mobile matrix creating fracture zone crust. Although the matrix is predominantly serpentine, contributions from the mafic components and the effects of the mechanical and geochemical processes operating in fracture zones can alter the overal bulk chemistry. Therefore, the distribution and abundance of mineral components within the melange matrix contains important information for understanding these complex geologic zones. Most of the previous work on sub-aerially exposed fracture zones have focused on the structural relationships between components and chemical analysis of the protoliths (Saleeby, 1977; Karson and Dewey, 1978). Analysis of regional geochemical variations in the matrix has not been pursued becaused of the diffuculty in obtaining unbiased samples for analysis (due to the extreme, small-scale heterogeneity of the matrix components). However a tool such as AVIRIS is ideally suited for examining the nature of regional geochemical variations in this type of terrain. The pixel size (20 m) averages the small scale heterogeneity and allows large scale processes to be recognized. Also, characteristic minerals in the melange have diagnostic features throughout the AVIRIS wavelength range.

General Geology and Spectroscopic Character

The Kings-Kaweah ophiolite melange is located in the eastern foothills of the Sierra Nevada near Fresno, California (Fig. 1). In constrast to the classical interpretation that ophiolite-melange associations are indicative of a convergent margin emplacement (i.e. Coleman, 1971), the primary tectonic mixing and melange development for the Kings–

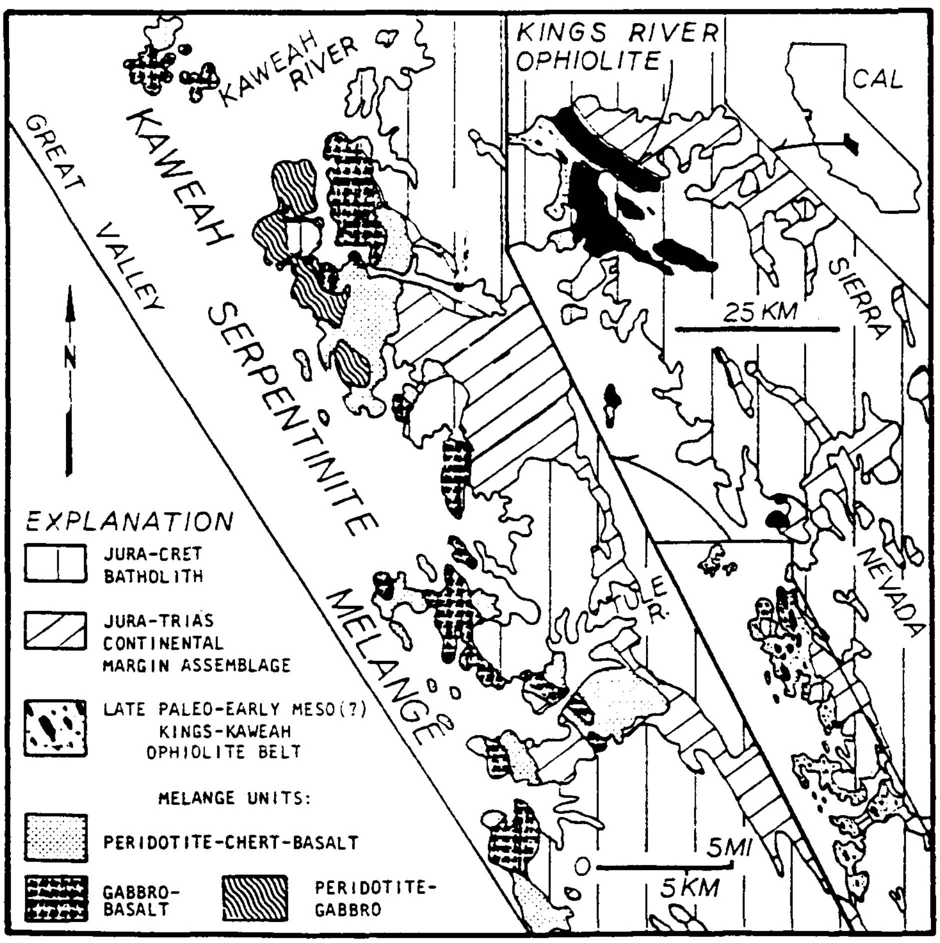

Figure 2. Location map for the Kings-Kaweah ophiolite melange showing the distribution of tectonic slabs and blocks. Also shown is the melange unit map of the Kaweah serpentinite melange (from Saleeby, 1979).

Kaweah ophiolite melange occured on the ocean floor in a fracture zone environment (Saleeby, 1977). This interpretation is based on the observations that no continental or arc rocks and sediments are found in the melange, no minerals typical of subduction emplacement are found, continental margin rocks are deposited unconformably over the melange, and the range and nature of the polyphase deformation is most consistent with an oceanic fracture zone. The Kings-Kaweah ophiolite belt was emplaced against the truncated margin of North America in Triassic to Middle Jurassic time and was contact metamorphosed to the hornblende-hornfels facies during the intrusion of the Sierra Nevada plutons between 125 and 102 my ago (Saleeby, 1977).

The Kings-Kaweah ophiolite melange is composed of two primary segments (Fig. 1): the Kings River ophiolite in the northern part of the belt and the Kaweah serpentinite melange in the southern part of the belt. The Kings River ophiolite contains large slabs of basalt, peridotite, and gabbro seperated by thin zones of serpentine melange. In contrast the Kaweah serpentinite melange contains no tectonic slabs and the serpentine matrix is very well developed (Saleeby, 1978; 1979). We have chosen to focus on the Kaweah serpentinite melange because the fracture zone assemblage is more highly developed and therefore the complex interactions between the processes responsible for the overall character of fracture zone crust should be better represented.

The Kaweah serpentinite melange consists of coherent to semi-coherent blocks distributed in a pervasively deformed matrix. The blocks range in size from millimeter sized particles to fragments tens to hundreds of meters in length. The blocks consist of harzburgite, peridotite, serpentinized ultramafics, gabbro, basalt, silica-carbonate rocks, and chert. They commonly show a tectonic fabric which parallels the schistosity of the matrix and the general southeast-northwest trend of the belt (Saleeby, 1979). Bidirectional reflectance spectra of a few representative handsamples collected from the field are shown in Fig. 3a. All spectra were measured from naturally weathered surfaces. Fe^{2+} and Fe^{3+} absorptions dominate in the visible and near-infrared portions of the spectra while overtones and combination overtones of fundamental OH^- absorptions are primarily responsible for the narrow features in the infrared portions of the spectra.

The matrix primarily consists of schistose serpentine, ophicalcite, and silica-carbonate rocks, although talc and tremolite are locally abundant. Variations in matrix composition reflect shifts in the bulk chemistry (i.e. the presence of talc over serpentine represents a siliceous shift in the bulk chemistry) (Saleeby, 1979). This variation is of fundamental importance for addressing questions related to the character and developement of fracture zone crust. Some examples of reflectance spectra from exposed matrix surfaces are shown in Fig. 3b. Like the spectra shown for the block lithologies, the visible to near-infrared portion of the spectra are dominated by Fe^{2+} and Fe^{3+} absorptions while the infrared portions of the spectra are dominated by absorptions related to OH^-.

Much of the field area has a variable cover of soils and grass. It will be necessary to remove the spectral signatures of the grasses using an appropriate mixing model (Mustard and Pieters, 1987; Adams et al, 1986) while the soils may provide clues as to the nature of geochemical variation within the subsurface. We have collected an extensive series of grass and soil samples and some examples of reflectance spectra from these are shown in Fig. 3c. Field spectra of rocks, soils, and grasses have also been acquired with PIDAS (Goetz, 1987) to characterize the actual ground reflectance of these surface types as well as potential calibration targets. A PIDAS spectrum of typical grass cover is shown in Fig 3d. This type of data is an essential link between laboratory and remotely acquired reflectance data.

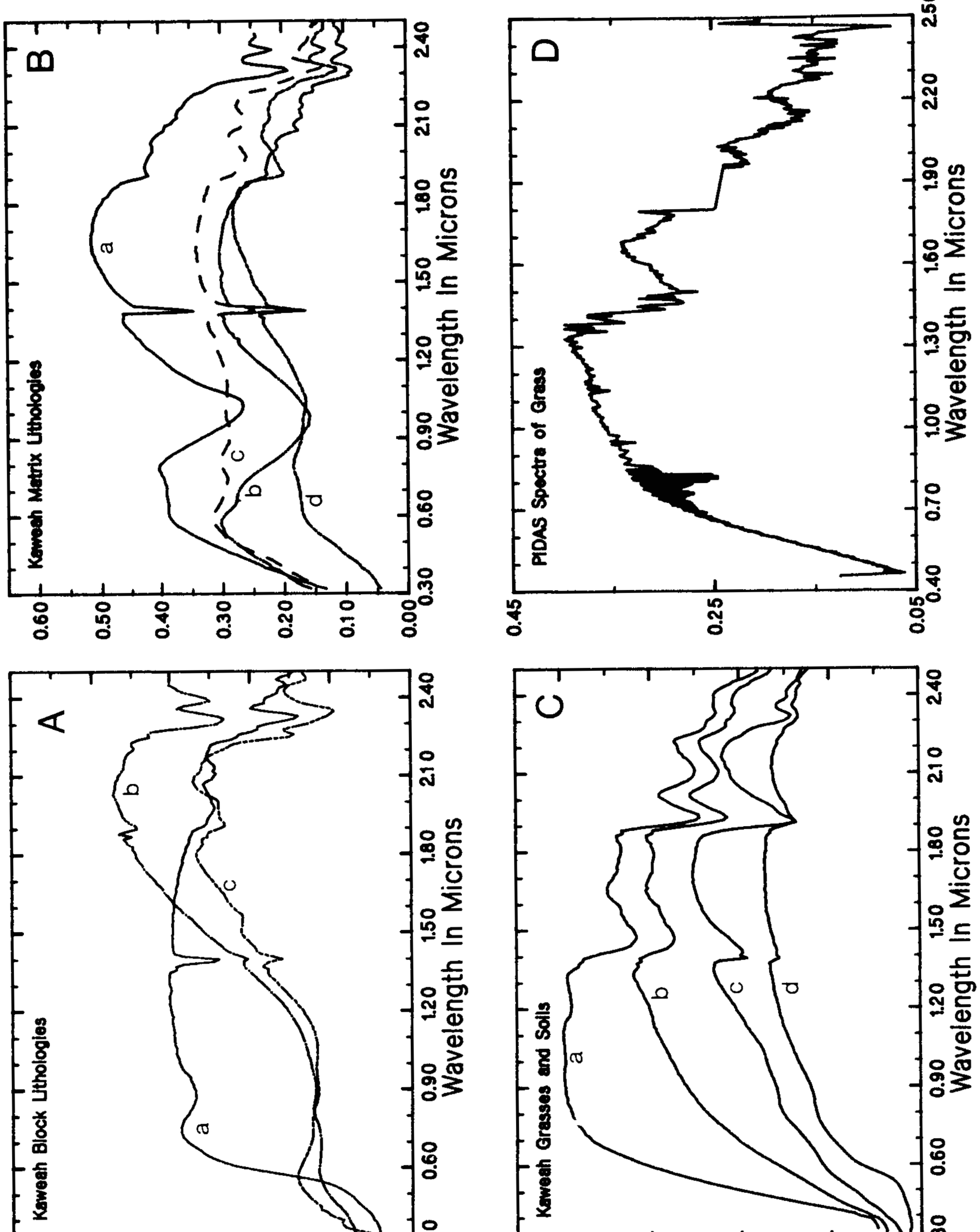

Figure 3. RELAB reflectance spectra of some components in the Kaweah serpentinite melange. A) Some typical block lithology spectra where (a) is a serpentinized peridotite, (b) is a gabbro, and (c) is a pillow basalt. B) Examples of matrix lithology spectra where (a) is predominantly talc bearing, (b) has both talc and tremolite, (c) is from a serpentine rich region, and (d) is an ophicalcite. C) Examples of grass and soil spectra where (a) is dry, brown grass, (b) is partially decayed grass, (c) is a talc rich soil, and (d) is a soil containing Fe–oxide. D) Field spectrum of a grassy area. The spectra of the components grass, decayed grass, soil, and shade are all contribute to this average spectrum.

Imaging Spectrometer Analysis

Imaging spectrometer data were acquired over the field site on September 14, 1987 with AVIRIS. Although the principal science target was not covered by the AVIRIS overflight, some secondary targets were imaged as well as a calibration target. Examination of these data indicate that the spatial resolution of the instrument is very good for addressing the scientific goals outlined above. However, the complexity of the field site and nature of the extraneous ground cover (grasses) requires that the instrument perform at optimum precision and accuracy. Due to the low signal to noise during this flight, and other problems outlined by others in this volume, it is not possible to address our scientific goals with these data.

In summary, the Kaweah serpentinite melange provides the opportunity to address fundamental scientific questions concerning the formation and development of oceanic fracture zones and the general behavior of oceanic crust during intense disruption. An imaging spectrometer such as AVIRIS permitts the mapping of the distribution and abundance of diagnostic minerals in the highly deformed and complex matrix, and this information, which is not readily obtained by other methods and techniques, allows one to begin to unravel the complexity of such terrain. We look forward to analyzing high quality AVIRIS data over the principal science target in the near future.

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