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MINERALOGICAL MAPPING IN THE CUPRITE MINING DISTRICT, NEVADA

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INTRODUCTION

The Airborne Imaging Spectrometer (AIS) has provided for the first time, the possibility to map mineralogical constituents in the earth's surface and thus has enormously increased the value of remote-sensing data as a tool in the solution of geologic problems.

The question addressed with AIS at Cuprite was how well could the mineral components at the surface of a hydrothermal alteration zone be detected, identified and mapped? The question has been answered positively as discussed below, and perhaps more importantly a relatively rare mineral, buddingtonite, that could not have been detected by conventional means, was discovered and mapped by the use of AIS.

SETTING

The Cuprite mining district straddles U.S. Hwy. 95 approximately 17 km south of Goldfield in southwestern Nevada. The eastern half of the district studied with AIS is an area of extensive hydrothermal alteration within a sequence of rhyolitic welded ash flow and air fall tuffs. The major unit is the 7 my-old Thirsty Canyon Tuff whose source is the Black Mountain Caldera, 50 km to the southwest (Ashley and Silbermann, 1976). The altered units consist of a central core of almost pure silica, a ring of opalized rocks containing alunite and kaolinite, and an outer argillized zone containing mainly kaolinite and montmorillonite as well as opal and some limonite (Abrams, et al., 1977).

PREVIOUS STUDIES

The Cuprite area has been the focus of remote-sensing studies for the last decade. Because of its varied mineralogy and relatively sparse vegetation cover, a number of spectral remote-sensing studies have been carried out there (Abrams, et al., 1977; Kahle and Goetz, 1983; Goetz, et al., 1985). Abrams, et al. (1977) showed that broad-band multispectral imaging, including bands centered at 1.6 and 2.2 μ m, was far superior in mapping hydroxyl-bearing minerals than those restricted to the region short of 1.0 μ m, and provided the conclusive evidence that aided in the decision to include the seventh band (2.08-2.36 μ m) on the Landsat Thematic Mapper.

Abrams, et al. (1977) found that color ratio composites utilizing the 1.6 and 2.2 μ m bands, in combination with bands at shorter wavelengths, could be used to delineate the major boundaries in surface mineralogy very accurately. The mapping was verified by laboratory analysis of field samples. Although boundaries between units could be mapped accurately, it was not possible to identify the surface mineralogy without resort to in-situ measurements. Laboratory-like spectral reflectance measurements are required to identify mineral constituents in the surface directly. The AIS provides image data at 9.3-nm intervals throughout the

1.2-2.4 μ m spectral region and has sufficient spectral resolution to make direct mineral identification possible.

AIS DATA ACQUISITION

AIS data over Cuprite, Nevada were first acquired in August 1983. Two subsequent flights in 1984 covered the areas shown in Fig. 1. The 1983 flight covered a small area extending from south to north across the southern boundary of the alteration zone. Prominent features are a bright hill in the center of the coverage shown in Fig. 2a and a bulldozed area which shows up very brightly in the northern end of the coverage. During 1984 the area was reflown, but in order to cover the same area exactly it was necessary to roll the aircraft approximately 5°. After overflying the bulldozed area, the horizontal attitude was resumed causing the dogleg seen in Fig. 1.

DATA REDUCTION

On-board data reduction consists of an automatic dark current subtraction before the data were recorded. On the ground the light transfer curve derived from laboratory calibration for each of the 1024 detector elements is applied to produce the so-called "raw" data. The resulting spectrum for each pixel has the general shape seen in Fig. 2b. The major features are a fall-off in signal toward longer wavelengths, a function of irradiance, and the two major atmospheric water absorption features centered at 1.4 and 1.9 μ m. The reduced curve shown in Fig. 2 was obtained by removing the solar spectrum and normalizing the data to an area overflown outside the Cuprite region, but during the same pass. The area was assumed to be spatially uniform and spectrally flat, or at least smoothly varying. All the data in one pass are normalized to this region. The normalization is important to remove residual stripping in the images caused by minor inaccuracies in the laboratory calibration data.

The resulting reduced curve is shown in Fig. 2b. The regions within the atmospheric water bands are very noisy because of the lack of energy reaching the surface at these wavelengths. Mineral spectral features can be seen beyond 2.0 μ m.

RESULTS

The results of the 1983 overflight can be seen in Fig. 2c and Fig. 3. Figure 2c shows images in 32 contiguous channels from 2.03-2.32 μ m to which an equal area normalization has been applied (Goetz, et al., 1985). The result is an enhancement of spectral differences and suppression of brightness differences associated with topography.

Figure 3 shows the result of extraction of spectra from individual 3-by-3 pixel areas. The bright hill exhibits an absorption doublet at 2.17 and 2.20 μ m that is diagnostic of the clay kaolinite while the bulldozed area exhibits a single, broad absorption minimum at 2.16 μ m, diagnostic of alunite. Laboratory spectra for samples collected in these areas are shown as dashed lines.

A ground traverse was carried out to identify the exact boundary of opalized and secondary quartz zones. Figure 1 shows the location of the traverse while Fig. 4 shows laboratory spectra of individual samples

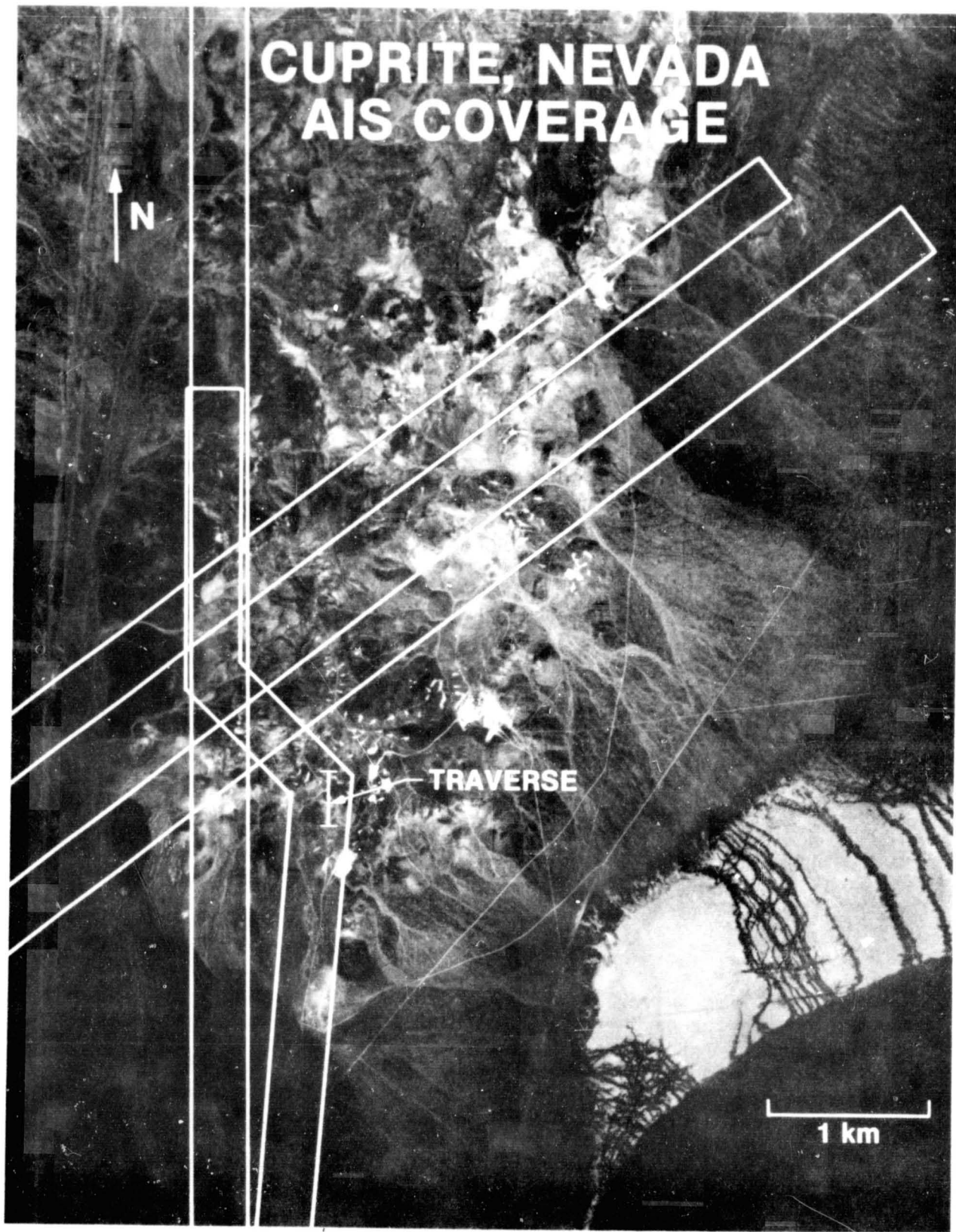


Figure 1. Airphoto of the Cuprite mining district showing the approximate AIS ground coverage.

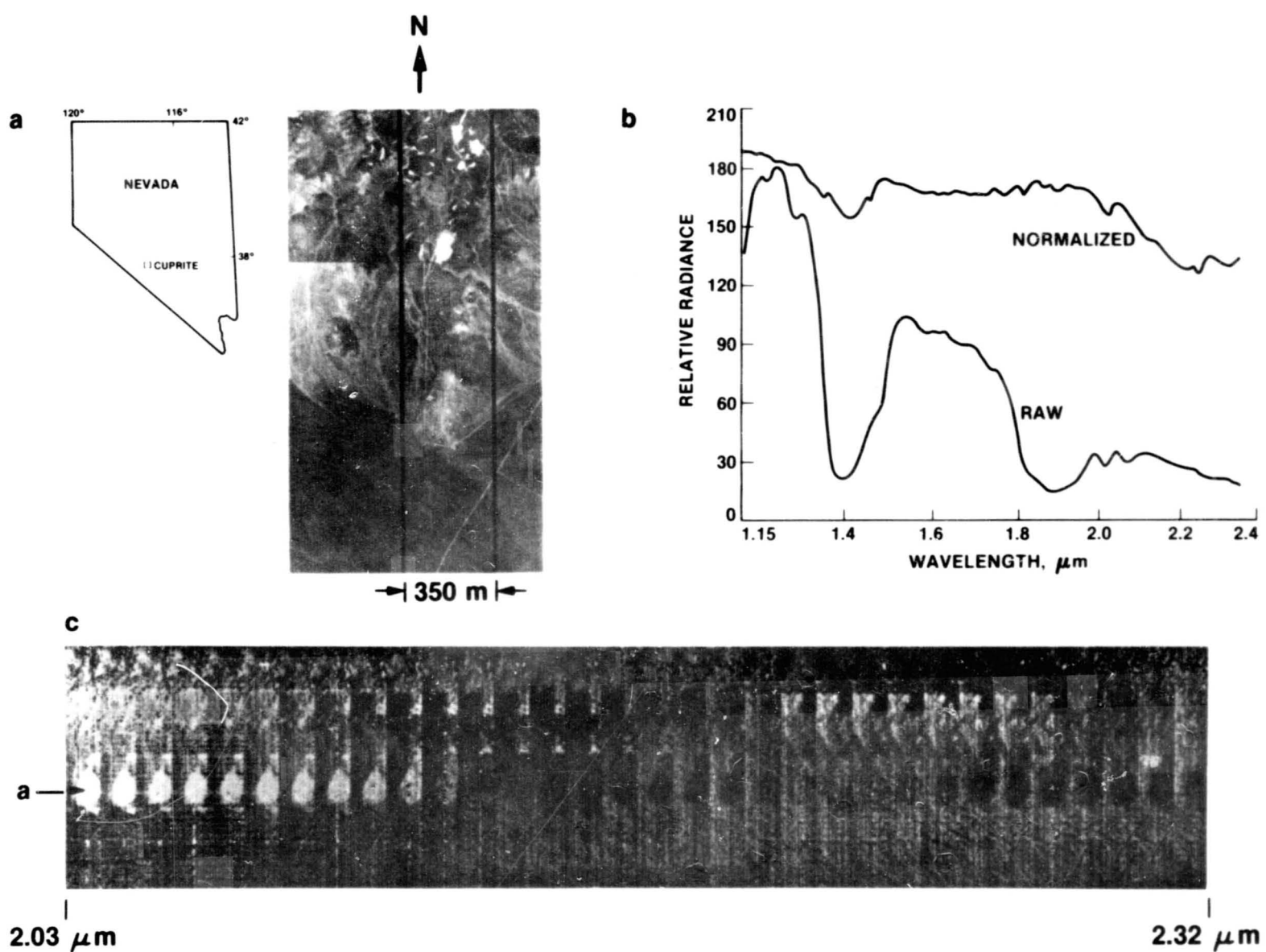


Figure 2. (a) Segment of an AIS ground track covering the southern portion of the Cuprite district. (b) Raw and normalized spectrum from a 3-by-3 pixel area. (c) Thirty-two AIS images covering the wavelength range 2.03-2.32 μm normalized by the equal energy technique so that each pixel spectrum contains the same area under the curve.

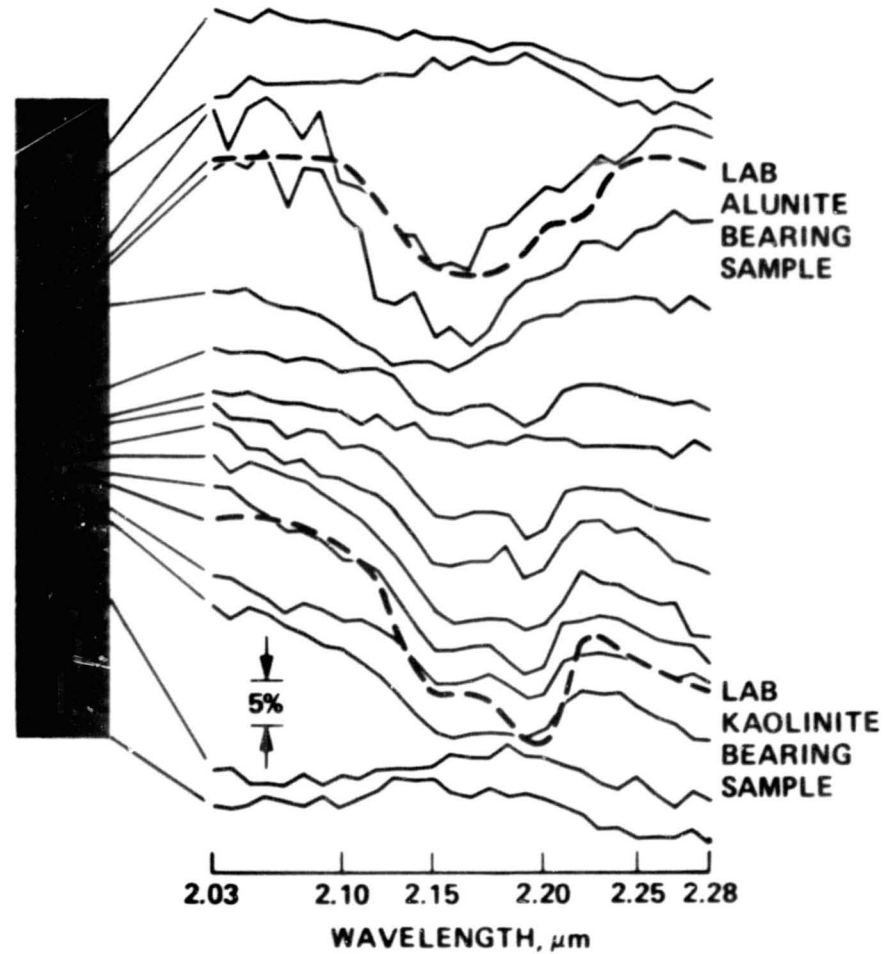


Figure 3. An AIS image at 2.03 μm of the same area as shown in Figure 2(a). Shown here are 3-by-3 pixel spectra taken from the image and in two areas laboratory spectra from samples collected from the locations indicated. The laboratory spectra required 10 minutes to acquire, the AIS spectra 10 ms.

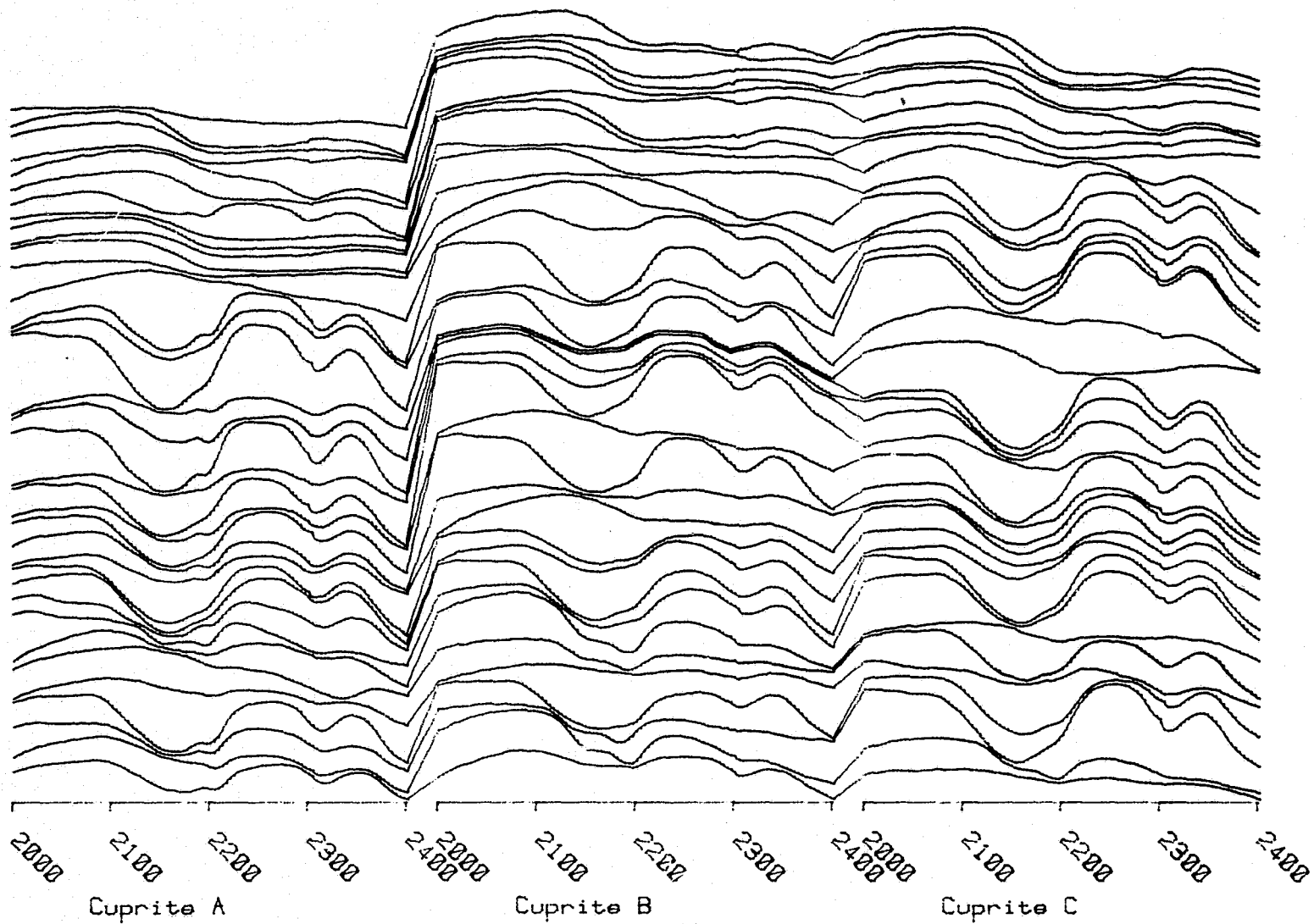


Figure 4. Laboratory spectra from 36 samples taken at 10 m intervals in each of three traverses spaced 10 m apart at the location shown in Fig. 1. The predominant mineral is alunite with absorption at 2.16 and 2.32 μm . At the top of the traverse the flat curves indicate almost pure secondary quartz.

collected at 10-m intervals along the traverse. The traverses A, B and C were spaced 10 m apart in an east-west direction. The dominant features are the 2.16 and 2.32 μ m absorption features of alunite. Several samples contain kaolinite and a mixture of the two minerals is also seen. The secondary quartz spectra seen at the top of Fig. 4 are almost featureless as expected for quartz. However, a 2.25 μ m feature is seen and can be attributed to an Si-OH overtone (Podwysoki, personal communication). The boundaries seen in the traverse spectra are also identified in the AIS images.

The results of the July 1984 flight are seen in Fig. 5. The SPAM program (AIS User's Guide, 1985) was used to map mineral constituents that are plotted in red. In each case the upper spectrum is taken from the image and the lower is a laboratory spectrum of a sample collected in the mapped area.

The mineral buddingtonite, an ammonium feldspar, although not at first identified, was detected through a 2.12 μ m absorption feature in the image spectra and subsequently sampled in the field in the area shown in red. The field sampling was blind because buddingtonite is not identifiable in the field, and at the time the cause of the 2.12 μ m absorption feature was not known. The identification of the mineral was made by L. Rowan (personal communication) after samples were collected. Cuprite is now the fifth known location of buddingtonite in hydrothermal areas (D. Krohn, personal communication).

The AIS is the first modern, albeit modest, imaging spectrometer to be flown over earthly targets. As the results in Cuprite have shown, direct identification of surface mineralogy, and mapping thereof, is feasible. Proper calibration and normalization of the data are required to detect diagnostic absorption features and facilitate mineralogical mapping.

ACKNOWLEDGMENTS

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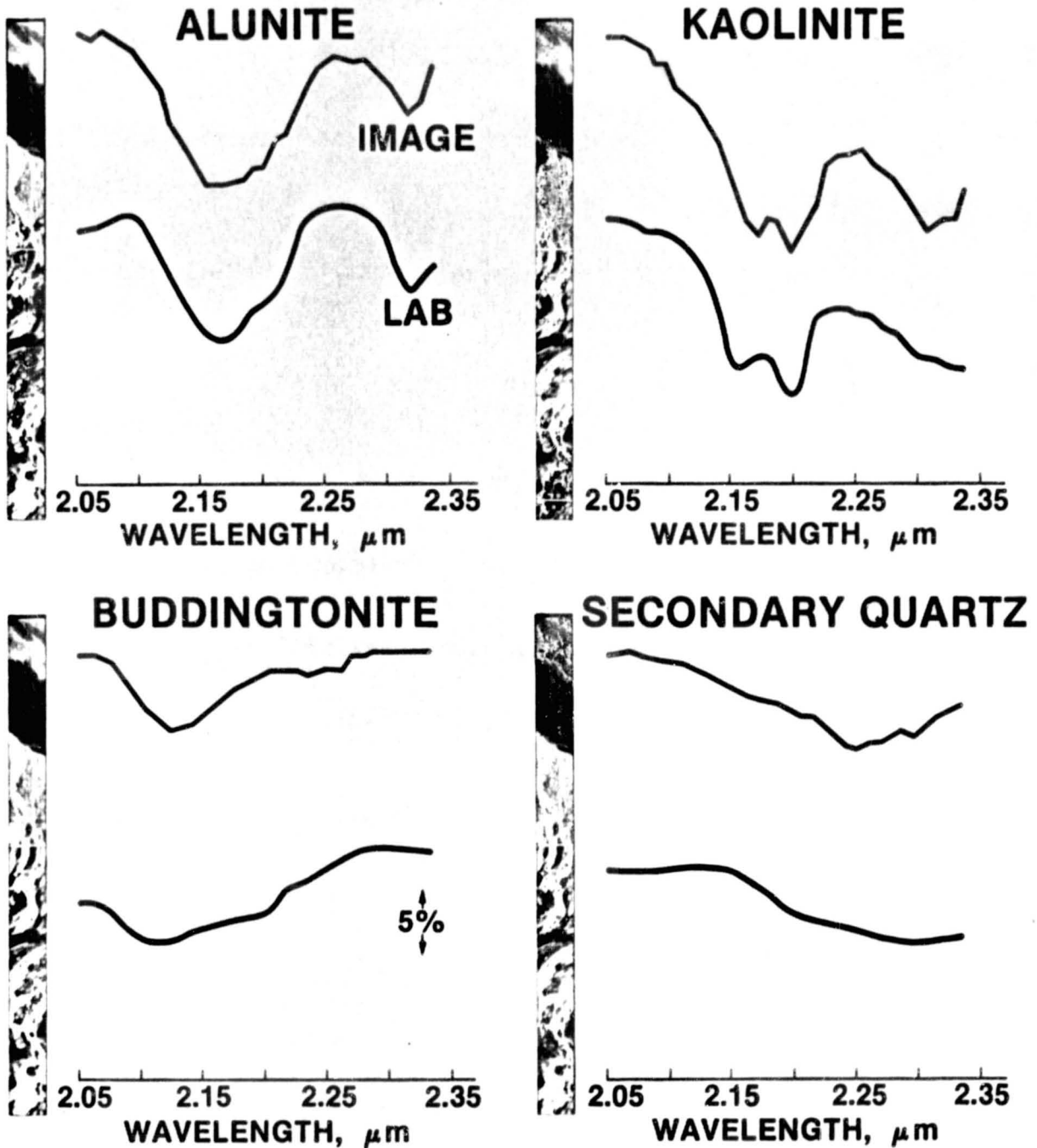


Figure 5. AIS coverage of Cuprite, with south at the top, covering the track with a "dogleg" shown in Fig. 1. The upper curves are the 3-by-3 pixel spectra of the red area in the respective images. The lower curves are laboratory spectra of samples collected in the red areas. The individual mineral maps were made using the SPAM program by selecting representative regions for the four spectral types shown and searching the images for similar spectral types. In each image, the regions of similar spectral types are shown in red.

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