Mapped Minerals at Questa, New Mexico, using Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) Data – Preliminary Report for:

First Quarterly Report of the U.S. Geological Survey Investigation of Baseline and Pre-Mining Ground-Water Quality in the Red River Valley Basin, New Mexico, November 13, 2001

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Cover: Hansen Creek landslide "scar" surface, Red River drainage.

Abstract

This preliminary study for the First Quarterly Report has spectrally mapped hydrothermally altered minerals useful in assisting in assessment of water quality of the Red River. Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) data was analyzed to characterize mined and unmined ground at Questa, New Mexico. AVIRIS data covers the Red River drainage north of the river, from between the town of Questa on the west, to east of the town of Red River.

The data was calibrated and analyzed using U.S. Geological Survey custom software and spectral mineral library. AVIRIS data was tested for spectral features that matched similar features in the spectral mineral library. Goodness-of-fit and band-depth were calculated for each comparison of spectral features and used to identify surface mineralogy. Mineral distribution, mineral associations, and AVIRIS pixel spectra were examined.

Mineral maps show the distribution of iron hydroxides, iron sulfates, clays, micas, carbonates, and other minerals. Initial results show a system of alteration suites that overprint each other. Quartz-sericite-pyrite (QSP) alteration grading out to propylitic alteration (epidote and calcite) was identified at the Questa Mine (molybdenum porphyry) and a similar alteration pattern was mapped at the landslide ("scar") areas. Supergene weathering overprints the altered rock, as shown by jarosite, kaolinite, and gypsum. In the spectral analysis, hydrothermally altered ground appears to be more extensive at the unmined Goat Hill Gulch and the mined ground, than the "scars" to the east. Though the "scars" have similar overall altered mineral suites, there are differences between the "scars" in sericite, kaolinite, jarosite, gypsum, and calcite abundance. Fieldwork has verified the results at the central unmined "scar" areas.

Introduction

A baseline and pre-mining ground-water quality study of the Red River Valley Basin, New Mexico is being undertaken by the U.S. Geological Survey. As part of this study, Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) Data is being analyzed to characterize mined and unmined ground along the Red River between the towns of Questa and Red River, New Mexico. Preliminary analysis of these reflectance data has identified mineral assemblages and other surface materials of interest that can influence water quality.

Data

The AVIRIS data was acquired by a single west to east NASA/JPL overflight on June 30, 1999. The flightline trends parallel to the Red River, starting at the town of Questa and ending east of the town of Red River. All ground on the north side of Red River was imaged. AVIRIS data is measured in units of radiance from the ultraviolet (0.4µm), through the visible, and into the infrared (2.5µm). It is acquired as 224 discrete band images, with each band (channel) containing a narrow wavelength interval of light. Picture elements (pixels) in the image locate positions of the ground surface with a resolution of 20 meters. Each pixel within the image comprises a 224 channel spectrum for a point of ground.

Methods

NASA/JPL AVIRIS data were acquired, calibrated to ground reflectance, and analyzed using custom U.S. Geological Survey software and spectral mineral library (Clark and others, 1993a, 1993b, 1993c). Field examination was used to verify these preliminary results in unmined areas. This analysis system has been developed and used over the past 15 years to map a range of geologic terrain, including several porphyry systems and other hydrothermally altered ground. Identifiable minerals include a variety of iron hydroxides, iron sulfates, clays, micas, carbonates, and other sulfate minerals. Iron sulfates are identifiable and can be useful in identifying potential sources of acid-water. Carbonates and certain silicates can be useful in identifying potential pH buffering areas.

Data calibration converts radiance data measured by the AVIRIS instrument at altitude to light reflectance at the ground surface. A three-stage process is performed to do this. The data is converted to an estimated ground reflectance using an atmospheric model in the Atmosphere REMoval (ATREM) Program (Gao and others, 1997). This estimated reflectance data is then calibrated to ground reflectance using a ground calibration site. Soil from this site was measured using a field spectrometer. Spectra from the calibrated data set are visually inspected for processing artifacts. The artifacts are removed through recalibration using new multiplier and offset constants.

During analysis of AVIRIS data, the U.S. Geological Survey's Tetracorder program was used to test the data against the U.S. Geological Survey's spectral mineral library. Pixel spectra were tested against several hundred mineral and mineral mixture library spectra. A statistical goodness-of-fit between absorption features in each mineral library spectrum and the pixel spectrum was used to indicate the likelihood of mineral identification. Further tests by the Tetracorder program used absorption band depth, continuum slope, and mineral exclusion rules to refine mineral identification. Goodness-of-fit, band depth, and continuum slope thresholds, and the absorption band interval were redefined between Tetracorder program runs. During the program runs, the data was normalized by continuum removal of the pixel spectrum to remove illumination effects. Band 20 (red wavelength) image pixels were substituted for vegetated and non-identified pixels to enhance topographic and spatial detail of the final mineral maps.

Mineral maps made of the Questa area show the identified mineral and mineral mixtures. Mineral maps were created after Tetracorder results of statistic fit and fit-times-depth values, mineral distribution, and mineral associations were visually judged and pixel spectra were plotted and examined. Identified minerals have the strongest spectral signature of the minerals tested, however, they are not necessarily the most abundant on the ground. Very common rock forming minerals such as quartz and most feldspar are not discernable using AVIRIS wavelengths.

Field examination verified the mapped minerals at the unmined scar areas. This examination involved collection of representative surface samples within spectrally mapped areas. The samples were field identified, their corresponding lithologies were examined, and their field relationships were interpreted. Laboratory studies of field samples will be used to further identify and confirm surficial mineralogy.

Molybdenum Porphyry Deposit Model

The Questa molybdenum porphyry deposit is a system of molybdenum bearing veinlets, fractures, and disseminations in a silica rich granite-rhyolite stock. Figure 1 (Mutschler and others, 1981) shows a cross section of a Climax molybdenum type deposit, such as found at Questa. In this model, the intrusive porphyry supplied the heat source to drive the hydrothermal system. A series of mineral alteration suites grade away from this thermal cell. As seen in figure 1, a silicic cap with potassic alteration overlies the idealized porphyry, followed upward and outward by halos of quartz-sericite, argillic, and propylitic alteration.

Preliminary Results

Three mineral maps have been created that show the mineral distribution of a variety of iron hydroxides (goethite) and iron sulfates (jarosite) (fig. 2), clays, micas, and other sulfates (fig. 3), and carbonates, alunite, and epidote (fig. 4), all identified using AVIRIS data. Mapped minerals were identified as being the spectrally most abundant surface material; highly vegetated areas are not mapped. The minerals and mineral mixtures were detectable with a lower threshold of a few percent, though most rock forming minerals are not detectable using AVIRIS and appear spectrally flat. These results are preliminary and have been partially field verified.

Initial results show a system of alteration suites that overprint each other within three sub-districts: 1) the Questa mine site, 2) the scars (Little Hansen, Hansen, Straight, and Hottentot

Creek landslide areas) 2 to 4 miles east of the mine, and 3) the Bitter Creek scar, 2 miles northeast of the town of Red River. The Questa molybdenum mine contains a mixture of sulfides and sulfates within a wide zone of quartz-sericite-pyrite (QSP) alteration that grades outward into a propylitic zone with the minerals calcite and epidote spectrally identified. Two to four miles eastward from the mine, a second unmined stock has hydrothermally altered overlying rock that is similarly characterized; with landslide scar areas (fig. 5) uncovering QSP and clay altered rock (the "scars"). The "scars" have jarosite - goethite gossan that indicates an active erosional environment exposing sulfides for weathering along fresh rock surfaces. The third mineralized district is northeast of the town of Red River. This small area also contains sulfides, sulfates, sericite micas, and clay minerals. Field-work has verified the results at the central scar areas of Little Hansen, Hansen, Straight, and Hottentot Creeks. Goat Hill Gulch and the area west of the Questa mine have been briefly examined.

Known mineral occurrence descriptions based on spectral analysis and field reconnaissance from west to east are:

West of Questa Mine

A small mineralized area north of the Red River ranger station contains kaolinite and alunite in a north-south trend, with epidote, calcite, and goethite on the east and west. Small areas containing gypsum and jarosite occur towards the mine. Field examination showed the kaolinite and alunite may be in hydrothermally brecciated rock.

Goat Hill Gulch

Moderate to strong sericite-pyrite alteration trends along Goat Hill Gulch and in the surrounding hills. The sericite was spectrally identified while the pyrite was inferred from the presence of spectrally identified jarosite. Kaolinite and goethite surround the sericite-pyrite occurrences. Supergene jarosite (after pyrite) along with scattered gypsum occurs in altered rock.

Questa Molybdenum Mine

Moderate to strong sericite-pyrite alteration, with kaolinite and goethite, is on the top surface of certain dumps and in the scar zones above the pit. Moderate to strong sericite-kaolinite, barren of iron oxides and iron sulfates, encompasses the open-pit and most of the dump side surfaces. The absence of jarosite over much of the ground suggests that during mining, the near-surface waste rock, now forming the top bench waste-pile surfaces, and natural scar surfaces, contained pyrite, while rock mined deeper in the open-pit, now distributed on the waste pile side-slopes had a lower pyrite content. Small pockets of potentially acid buffering epidote and calcite (indicating propylitic alteration) are present surrounding the mined ground. A small area of alunite has been spectrally identified. These results have not been field checked yet (Dec. 2001).

The altered areas appear to be overprinted by supergene weathering as shown by jarosite and kaolinite, but lack the strong gypsum exposures seen in the scars to the east. Based on mapped mineral assemblages, hydrothermally altered ground appears to be more extensive at both the unmined Goat Hill Gulch area and the mined ground, than the scars to the east.

Scar-zones east of the Questa Mine

Moderate to strong sericite-pyrite alteration is in the scar-zones of Little Hansen, Straight, and Hottentot Creeks. Strong argillic (kaolinite) -sulfide-rich alteration with some sericitic mica occurs in the southern part of Hanson Creek scar and strong argillic-sulfide-poor alteration is in the northern part.

The scar-zones appear to be overprinted by supergene weathering as shown by the minerals jarosite, kaolinite, and gypsum. Gypsum is most abundant in the Little Hansen Creek scar and (spectrally) least abundant in the Hansen Creek scar.

The scars have similar overall altered mineral suites, but there are unique differences. The Hansen Creek scar and the top (northern most part) of the Straight Creek scar have abundant kaolinite and lesser amounts of sericite. The Little Hansen Creek scar contains more gypsum and an increased amount of sericite, and the Hottentot Creek scar has the strongest sericite altered center and a small region of spectrally identified alunite. Goethite is usually located as an outer halo, surrounding a goethite-jarosite core. Calcite is spectrally identified scattered on the hillsides between Red River and the scars.

Bitter Creek Scar

Moderate to strong sericite-pyrite alteration occurs in the Bitter Creek scar, 2 miles northeast of the town of Red River on the northwest slope of Bitter Creek. Jarosite and gypsum occur in the center of the scar, surrounded by goethite.

Conclusion

For this preliminary report, the distribution of hydrothermally altered minerals that are useful in assisting in the assessment of water quality of the Red River were spectrally mapped. Mineral distribution, mineral associations, and mineral assemblages used to characterize altered rock in the Red River drainage suggest areas of acid generation and acid buffering potential. Based on spectral analysis and the resulting characterization of mineral alteration, there are regions within the study area that differ in water chemistry, erosional stability, and underlying mineralogy.

Future Direction

Field verification of the Questa Mine site will increase the confidence of results of the mapped minerals. Laboratory characterization of field samples will independently confirm clay mineral identification. Additional field occurrences of minerals unmapped using the AVIRIS data can be sampled and spectrally characterized. The minerals may then be mapped by comparing the minerals' spectral features with similar features found within the AVIRIS data.

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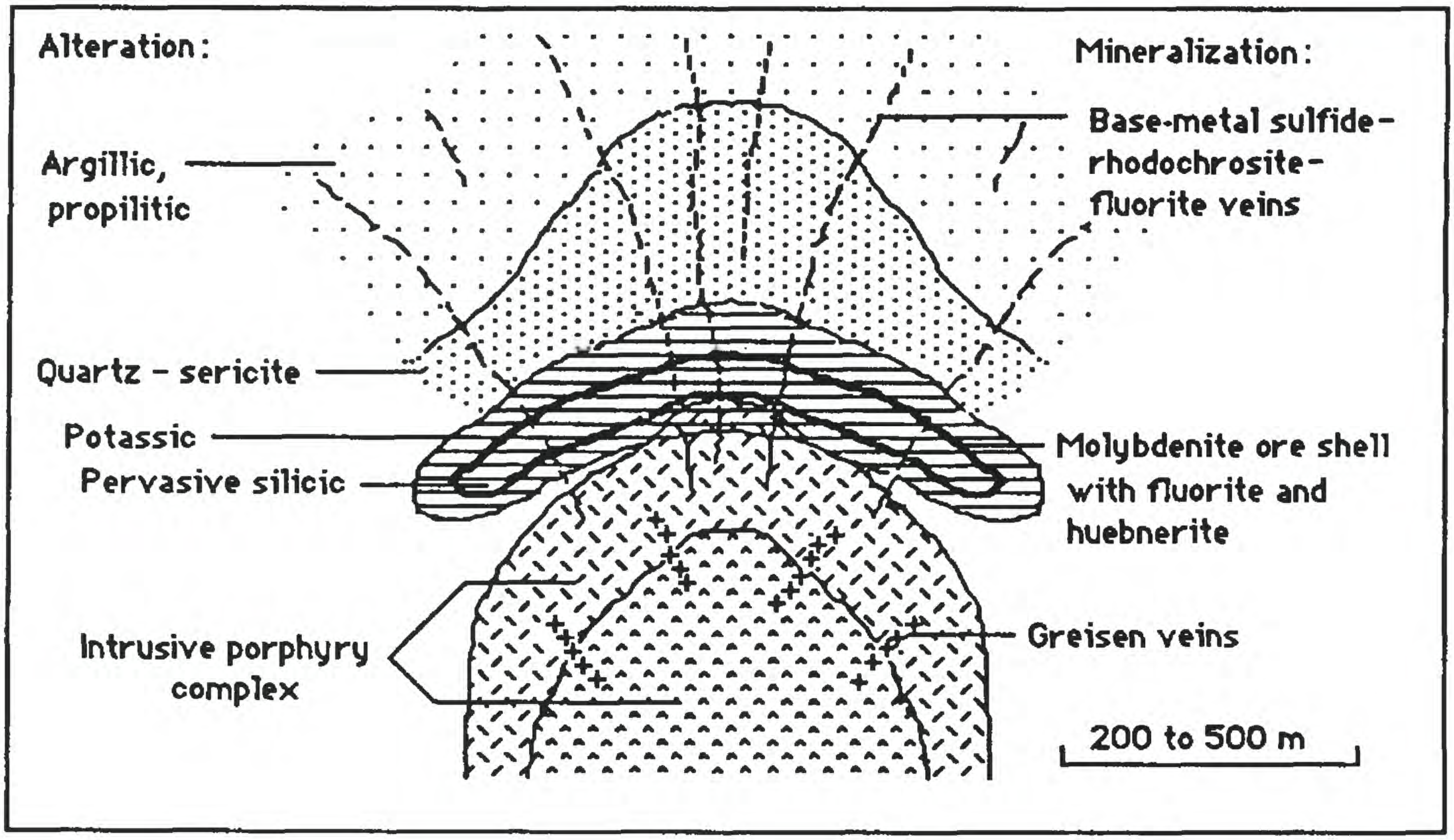

figure 1. Cartoon cross section of Climax Molybdenum Deposit showing relationship of ore and alteration zoning to porphyry intrusions from Mutschler and others (1981).

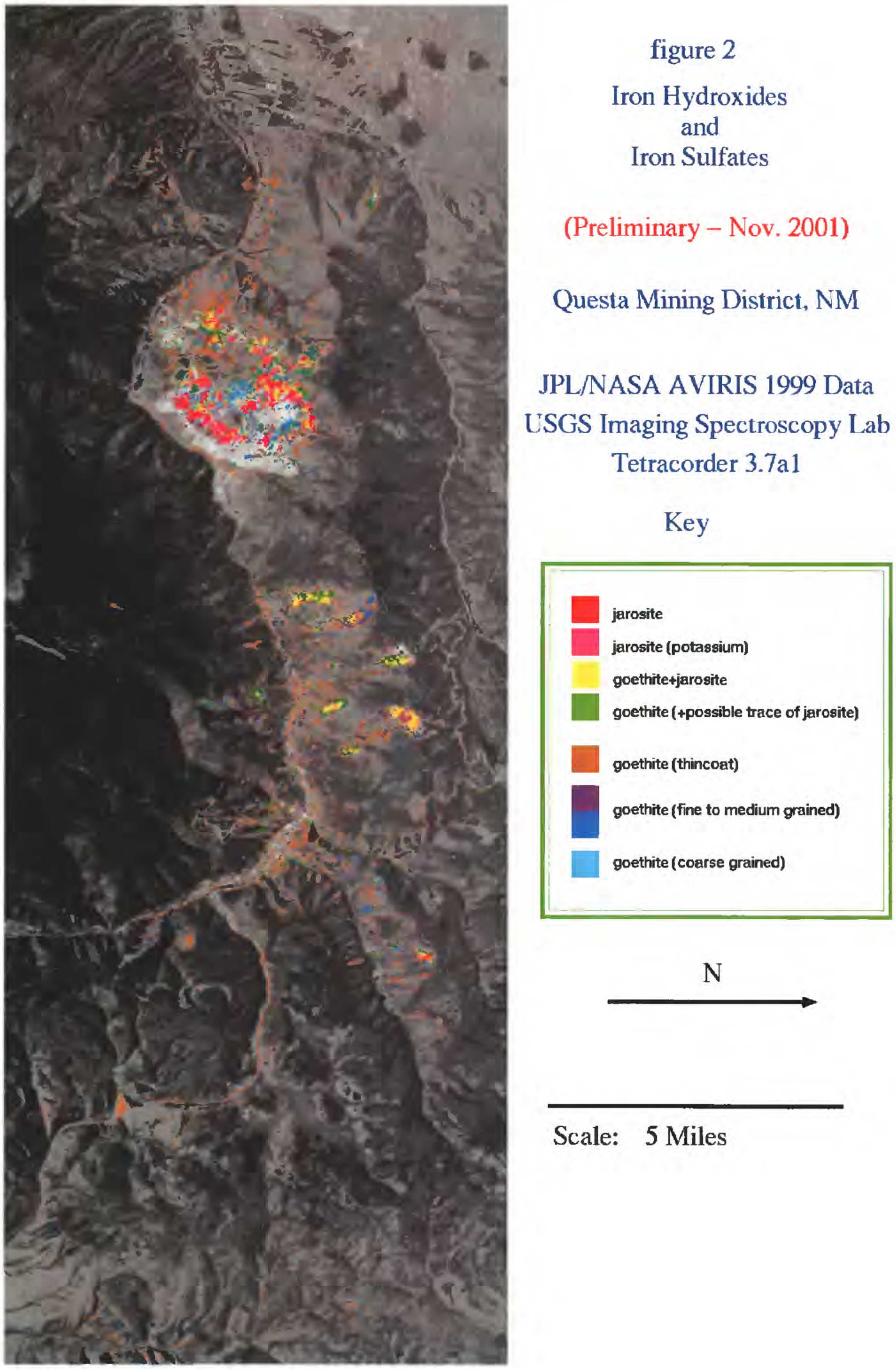

figure 2. Mineral map showing jarosite and goethite.

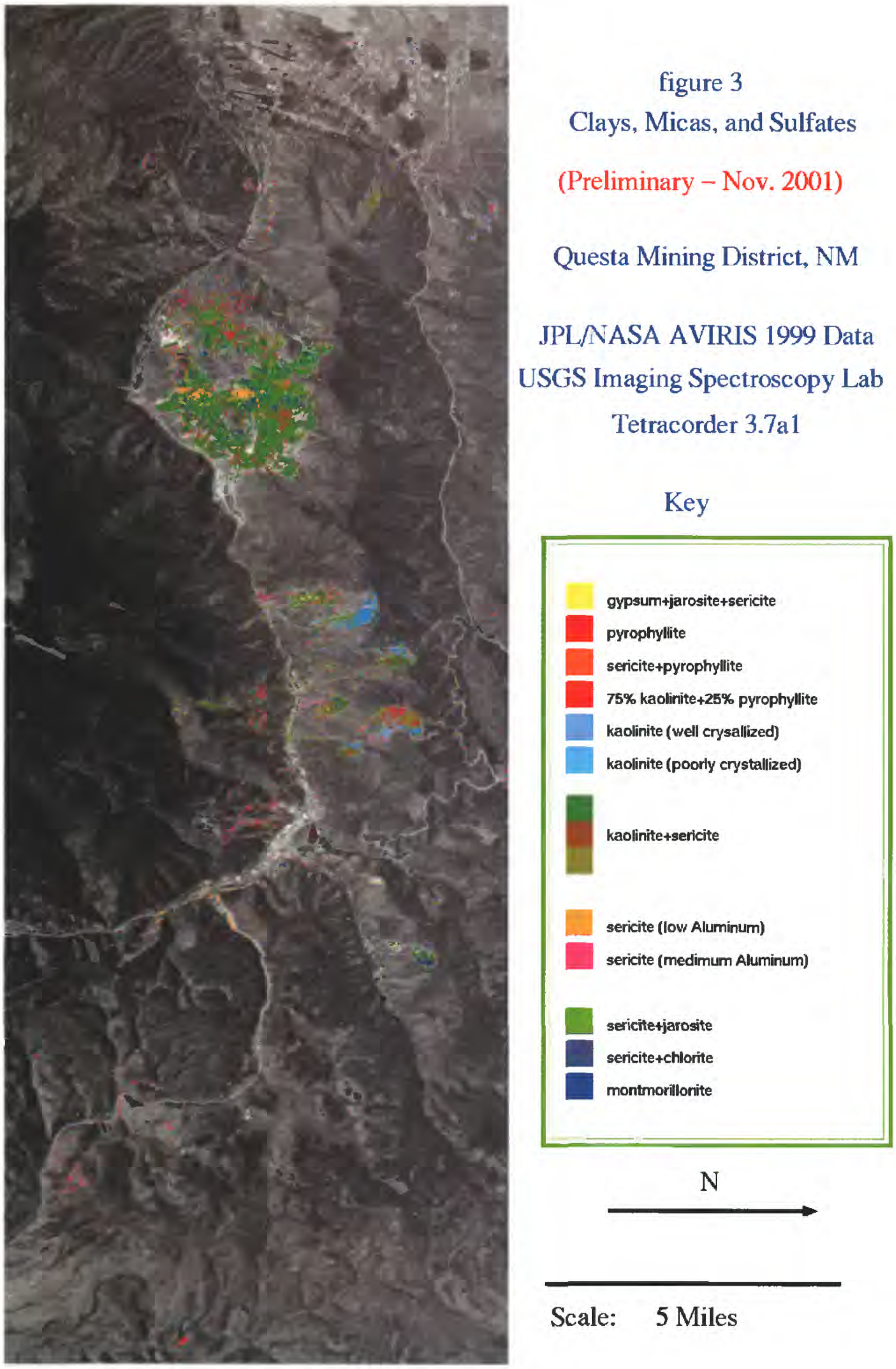

figure 3. Mineral map showing clay minerals, micas, and other sulfates.

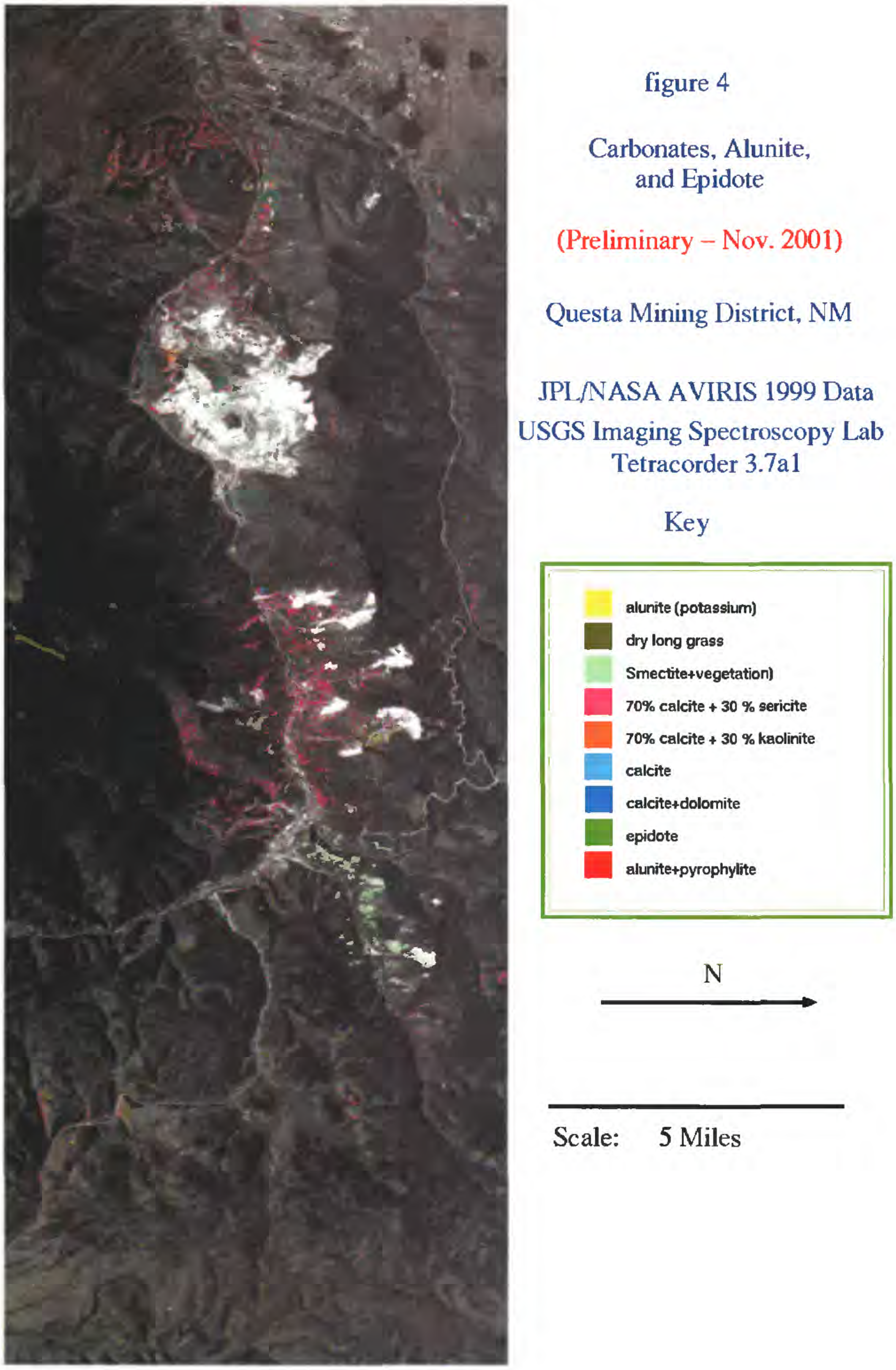

figure 4. Mineral map showing carbonates, alunite, and epidote.

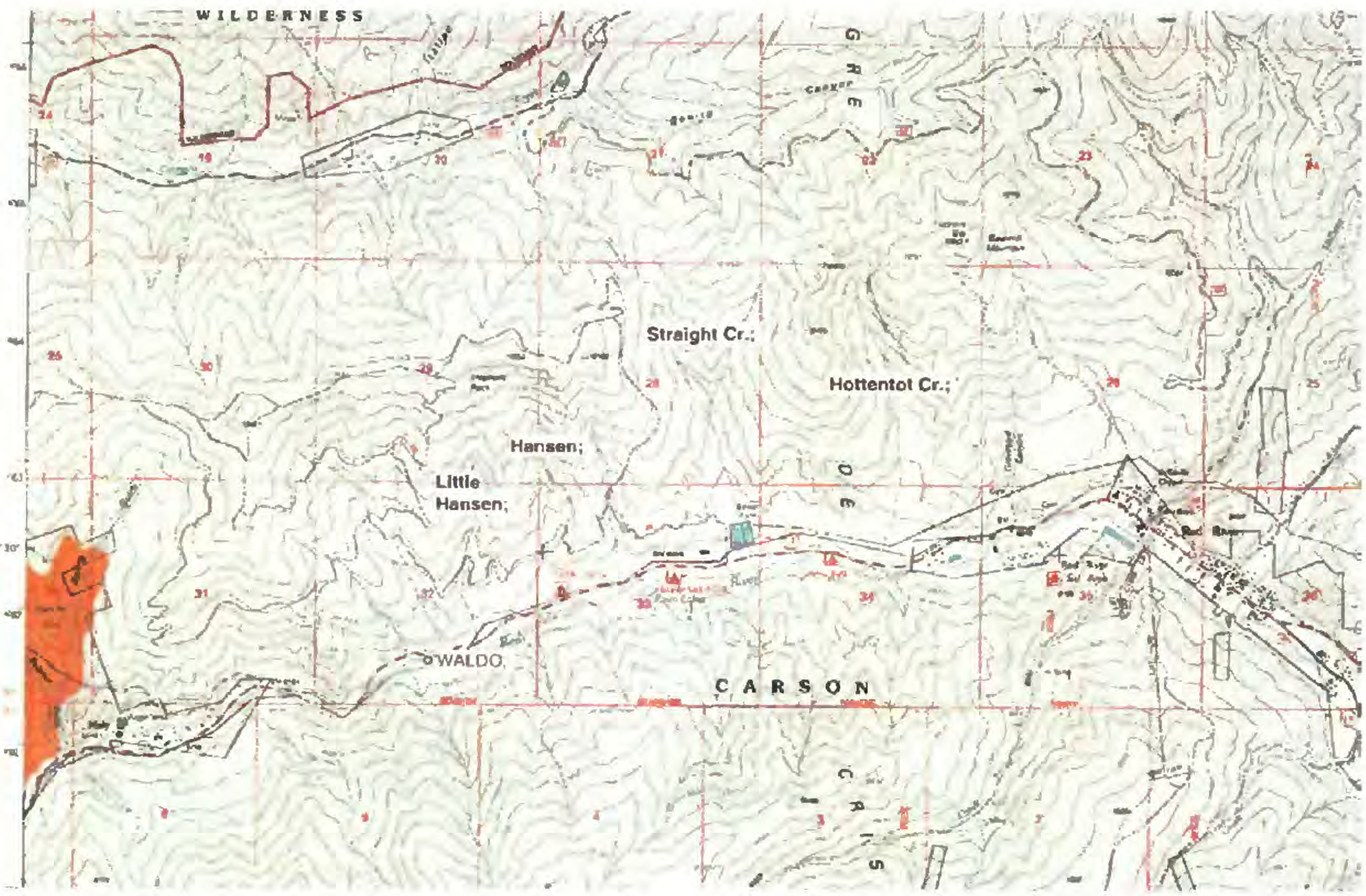

figure 5. Location map for landslide "scar" drainages.