Integrated analyses of mineral zoning and surface geochemistry of Miocene hydrothermal systems and associated mine sites in the Antelope Range, Marysvale Volcanic Field, Utah

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1. Introduction

New analytical remote sensing and laboratory techniques are being employed to study patterns of mineral zoning and hydrogeochemistry associated with Tertiary acid-sulfate hydrothermal systems formed at 21.3 Ma in the Marysvale Volcanic Field of southern Utah, USA. Imaging spectroscopy, a powerful tool for mapping subtle variations in surface mineralogy, was applied to this study in the hope of refining the existing genetic model for this type of relict epithermal hot springs system, and to more fully understand the relations between mineralization and possible environmental effects due to acid leaching and trace metal dispersion. Data from the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) sensor were analyzed using the USGS Tetracorder expert system to generate maps of surface materials. ICP-MS, X-ray diffraction, and field studies were used to verify the results of the AVIRIS-based mineral mapping. Studies of stable isotopes and $^{40}Ar/^{39}Ar$ dating were integrated to trace the hypogene origin and supergene destruction of the replacement alunite deposits in the area.

2. Genetic Model for Miocene Replacement Alunite Deposits

The relict hydrothermal systems exposed in the Antelope Range near Marysvale, Utah, are associated with small deposits of replacement alunite, Au, Ag, and Cu, and were formed during and immediately after the intrusion of a series of quartz monzonite stocks at ~23 Ma. The intrusion of these stocks set into motion a series of convective hydrothermal cells spaced at roughly even intervals around the periphery of the stocks. Several of these cells are characterized by a well-defined "bulls-eye" zonation pattern of acid-sulfate alteration minerals that grades outwards from a core of K-rich alunite to concentric halos of alunite-kaolinite, kaolinite and quartz-dickite-kaolinite. This transition of minerals represents an outwards gradation from replacement-dominated processes present at the center of the systems to fracture-dominated processes around the peripheries. The alunite in the core of the deposit was formed just below the paleo groundwater table and grades upward to hypogene jarosite from the paleo vadose zone, to hematite, and finally to massive replacement, sub-sinter silica that is cut by hydrothermal breccia pipes. Veins of hypogene gypsum have also been identified within and near the alunitic rocks. The argillic and advanced argillic alteration zones at the core are surrounded by propylitically-altered lava flows. Immediately adjacent to and beneath the core of argillically-altered rocks, a "proximal" propylitic mineral assemblage occurs that formed within the rising plume of H_2S in reducing environments beneath the paleo groundwater table. This assemblage consists of the minerals pyrite, illite, kaolinite, local barite, and relict feldspars such as albite and sanidine. Farther away from this core, montmorillonite, chlorite, epidote and calcite become more prevalent as a "distal" propylitic mineral assemblage. The inner, proximal propylitic rocks have been exposed on the face of Big Rock Candy Mountain (BRCM) by the downcutting of the Sevier River. Similar rocks exposed 1.5 km NE of BRCM on the east bank of the river are part of the Big Star hydrothermal cell.

3. Mineralogy, Geochemistry, and Acid Drainage Potential

The acid generation potential of natural, in-situ, pyritic rocks exposed on the face of BRCM is much greater than that of waste rock at nearby abandoned mine sites. Significant amounts of acidic runoff and sulfate-rich alluvial sediments are being generated from these rocks. The propylitically altered, pyritic lava flows represent the feeder zone of the Big Rock Candy hydrothermal cell, and are undergoing active subaerial supergene alteration to fine-grained crusts of the sulfate minerals copiapite, alunogen, and epsomite. These crusts precipitate from surface runoff draining the pyritic rocks after rain events, and eventually break down to yellowish, fine-grained coatings of natrojarosite and smectite clays. Most of the natrojarosite accumulates along ridges near the base of the mountain rather than in drainage channels, where the mineral can be readily dissolved and removed by surface runoff. ICP-MS analyses of the natrojarosite from BRCM indicate the presence of appreciable amounts of Mo (325 ppm), and the base metals Zn (115 ppm) and Cu (110 ppm). Surface runoff from BRCM was measured to have a pH of 2.6 and contains Ca, Mg, Si, Al, Fe, Mn, Cl, and SO_4. Coarse crystals of gypsum (as selenite) occur in cross-cutting fractures and in weathering crusts throughout the pyritic, proximal propylite. The sulfur and oxygen stable isotope data indicate that the aqueous sulfate for the gypsum at BRCM is a mixture derived from the dissolution of primary hypogene gypsum as well as alunite and from the oxidation of pyrite. Sediments bearing abundant jarosite and gypsum are actively being deposited in drainages running northwards, northeastwards, and eastwards from the mountain. It can be assumed that some natural acidic runoff is reaching the northwards-flowing Sevier River. Intrusive rocks characterized by the pyrite-poor, distal propylitic assemblage located east of the Sevier River in the vicinity of BRCM are characterized by abundant epidote, calcite and chlorite. These minerals have moderate to high acid neutralizing potential, and thus may serve to buffer some of the locally-generated acidic solutions.

4. Varieties of Jarosite as Indicators of Acid Drainage Potential

Jarosite is an important indicator mineral for the presence of pyritic rocks that are the source of acidic solutions that may leach toxic metals into the environment. Several varieties of jarosite were mapped in the vicinity of BRCM that were formed by different processes and have different levels of acid generation potential. Small exposures of coarse-grained jarosite mapped on the top of BRCM within alunite-bearing rocks may represent hypogene jarosites formed by ascending, steam-heated hydrothermal solutions. These hypogene jarosites are not associated with abundant pyrite, and therefore have acid generation potential less than that of the pyritic rocks from the underlying propylitically altered feeder zone that are in the process of oxidizing to natrojarosite. Other jarosites were discovered by the AVIRIS mapping on top of BRCM above the alunite zone that may be formed by pyrite oxidation. These jarosites occur as float near resistant ridges of quartz-dickite-kaolinite. These jarosites are K rich, similar to other hypogene jarosites in the Antelope Range, but isotopic studies have indicated that the $d^{34}S$ values are lower than any observed for pyrite in the area, and $d^{18}O_{SO_4}$ values are high, indicating a significant component of atmospheric oxygen in the parent aqueous sulfate. The textural appearance of these jarositic rocks are that of dried, silicified mud in contrast to the microcrystalline texture of the replacement alunite. These characteristics suggest that this K jarosite may be related to the supergene oxidation of pyrite associated with the feeder zone of a small hydrothermal cell located 0.8 km to the SSW that is probably slightly older than the one at BRCM.

Jarosite associated with both mine waste and naturally occurring rock alteration was mapped with the AVIRIS data at the Antelope Mine. These rocks are a source for the generation of acidic solutions. Metals associated with the Antelope Au/Ag deposit may be available for mobilization by the acidic solutions into the ground and surface water system. A stream channel, which is dry most of the year, runs southwards and then westwards from the Antelope Mine, eventually reaching the Sevier River. Along this stream channel between the mine and the Sevier River, about a kilometer west of the Big Star natroalunite mine, propylitically altered Bullion Canyon volcanic rocks contain abundant epidote, calcite and chlorite. Like the BRCM site, the presence of these minerals may serve to buffer acidic solutions that are generated by pyrite oxidation at the Antelope mine site. Metals derived from mineralized rocks in and around the mine site may have precipitated in the vicinity of this propylite due to local increases in solution pH. The capability of remotely sensed spectroscopic mapping to discriminate abrupt changes in bedrock mineralogy is useful for identifying discrete areas where geochemical changes in surface and ground waters can lead to the deposition of potentially toxic metals.

Replacement alunite deposits, Marysvale Volcanic Field, Utah:

Big Rock Candy Mountain, Big Star, and Winkleman hydrothermal cells

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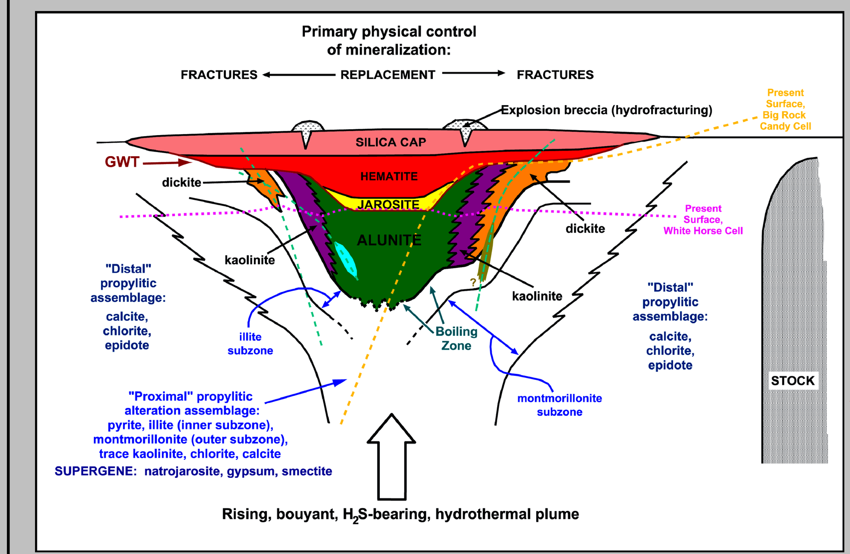


GENETIC MODEL

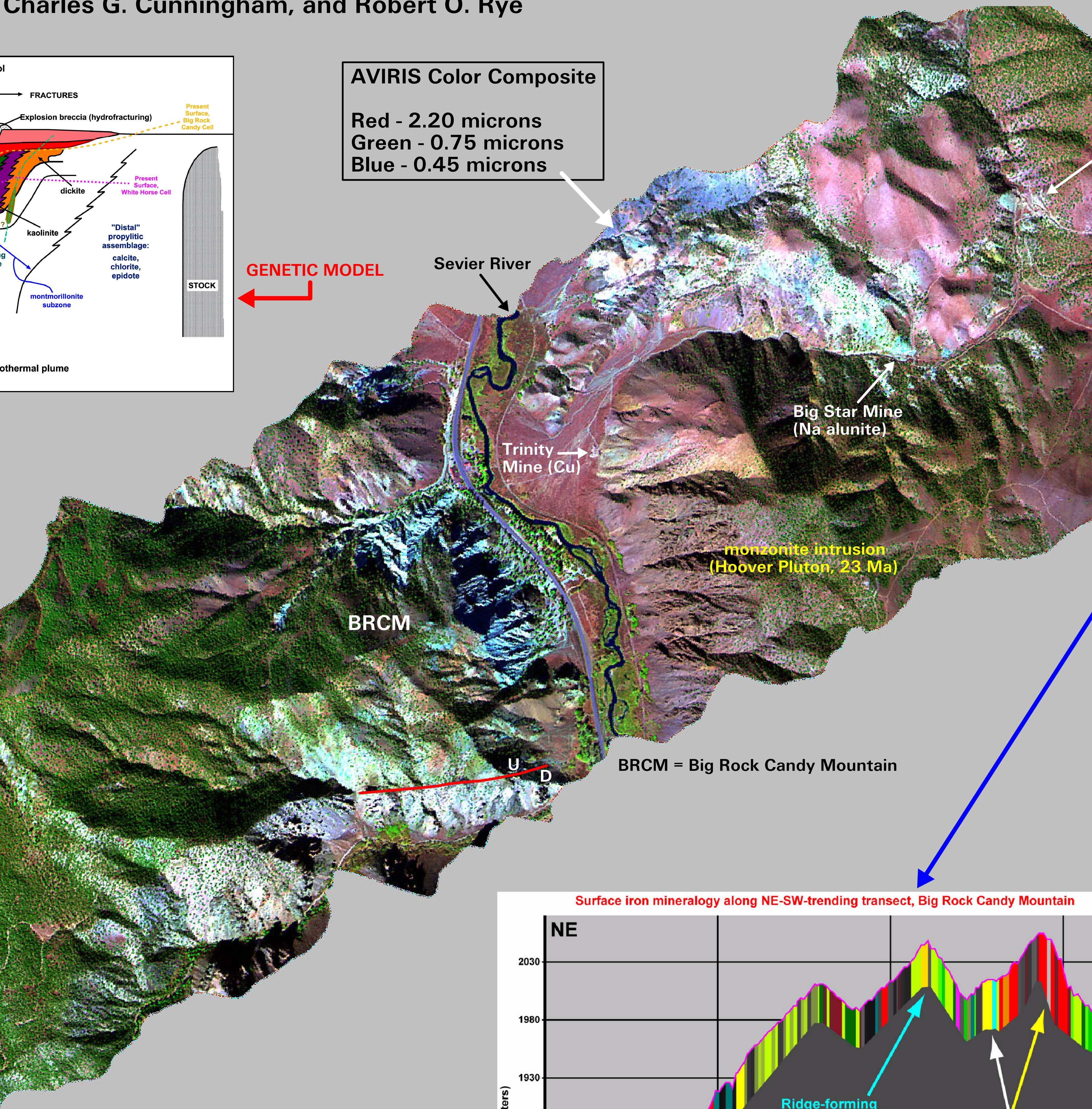
LEGEND:

- silica-bearing fracture zones
- pyrophyllite in fracture zones
- dickite +/- natroalunite in fractures or veinlets

GWT - paleo Ground Water Table

AVIRIS Color Composite

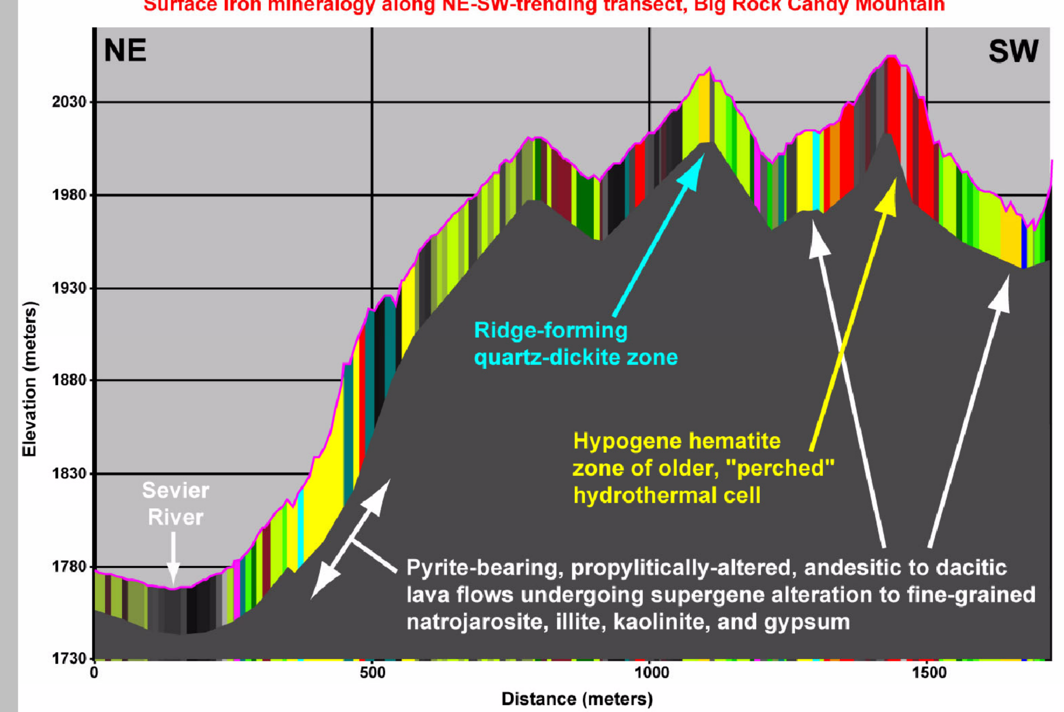
Red - 2.20 microns
Green - 0.75 microns
Blue - 0.45 microns



BRCM = Big Rock Candy Mountain

View of Big Rock Candy Mountain along Marysvale Canyon, looking south. The yellowish color of the rocks on the exposed flanks of the mountain is due to thin coatings of jarosite formed by supergene weathering of pyrite-bearing rocks from the propylitically-altered feeder zone of an acid sulfate hydrothermal system that formed at 23 Ma. Residual K alunite formed within the vadose zone of the hot springs system is visible at the very top of the mountain as subhorizontal, white cliffs.

Surface iron mineralogy along NE-SW-trending transect, Big Rock Candy Mountain



View of the southern flanks of Big Rock Candy Mountain, looking northwest. The reddish rocks in the center of the photo represent the distal edges of the alteration formed by vadose zone processes, and contain hematite, goethite, Na alunite, kaolinite, and dickite. This alteration was primarily fracture controlled and was formed by high-temperature (150° - 290° C) fluids. On the left, a prominent E-W-trending normal fault related to Basin and Range tectonism has placed altered Bullion Canyon volcanic rocks (to right of fault) in contact with unaltered Mt. Belknap volcanic rocks (to left of fault). The Bullion Canyon rocks were formed at 35 Ma and were altered at 23 Ma. The Mt. Belknap rocks were formed at 19 Ma.

N

UTM Projection
Zone 12
Clarke 1866 Spheroid
NAD27 Horizontal Datum

Scale 1:10,000

Kilometers: 0.2 0 0.2 0.4 0.6 0.8 1 1.2
Miles: 0.2 0 0.2 0.4 0.6
Meters: 200 0 200 400 600 800 1000 1200

Legend for low altitude AVIRIS mapping: Fe-bearing minerals

Iron Sulfate Minerals
- jarosite: fine-grained
- jarosite: coarse-grained
- goethite + jarosite

Iron Hydroxide Minerals
- goethite: coarse-grained with trace jarosite
- goethite: coarse-grained
- goethite: medium-grained
- goethite: fine-grained
- goethite: thin coating

other iron oxides/hydroxides

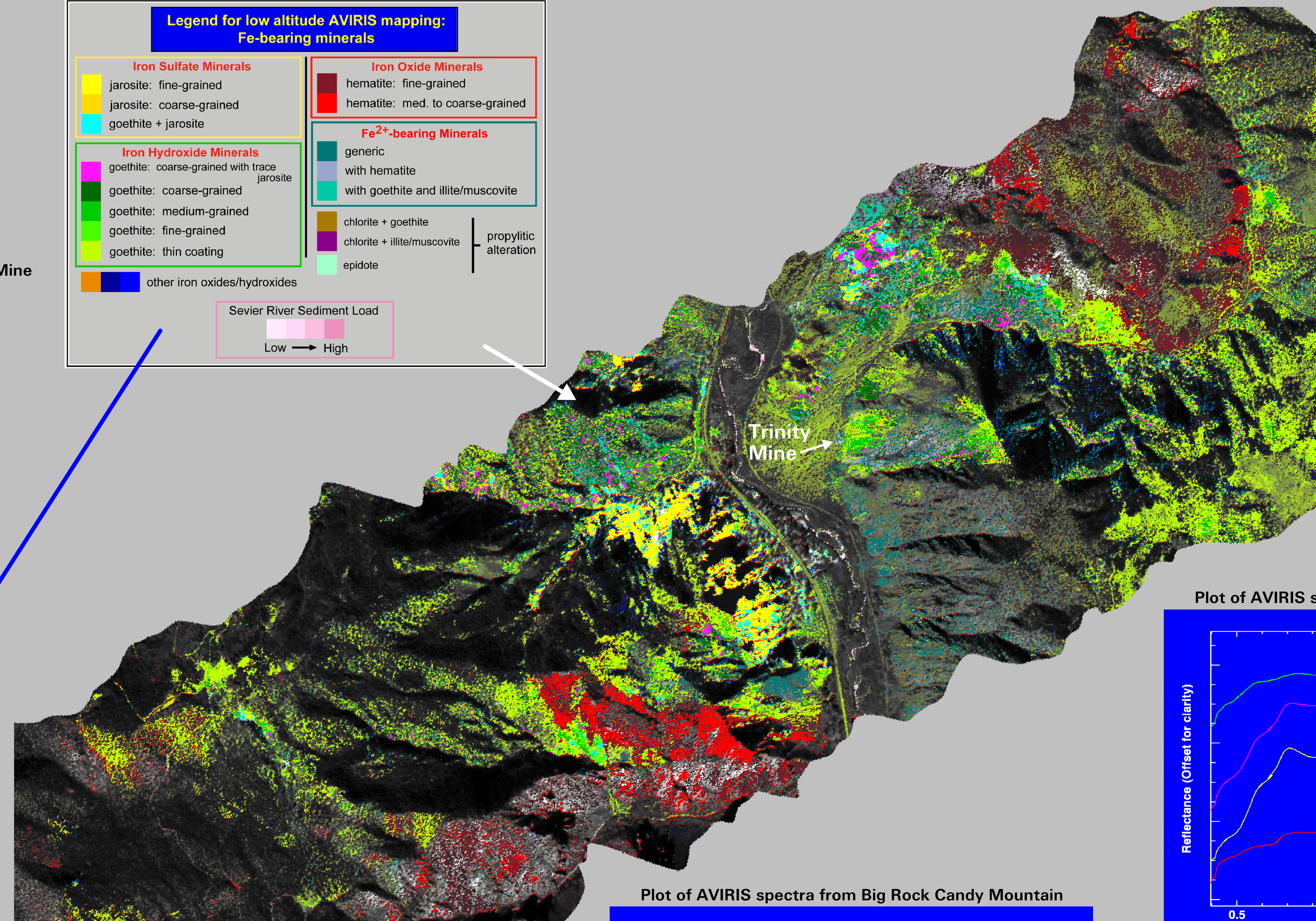
Iron Oxide Minerals
- hematite: fine-grained
- hematite: med. to coarse-grained

Fe^{2+}-bearing Minerals
- generic
- with hematite
- with goethite and illite/muscovite

- chlorite + goethite
- chlorite + illite/muscovite
- epidote

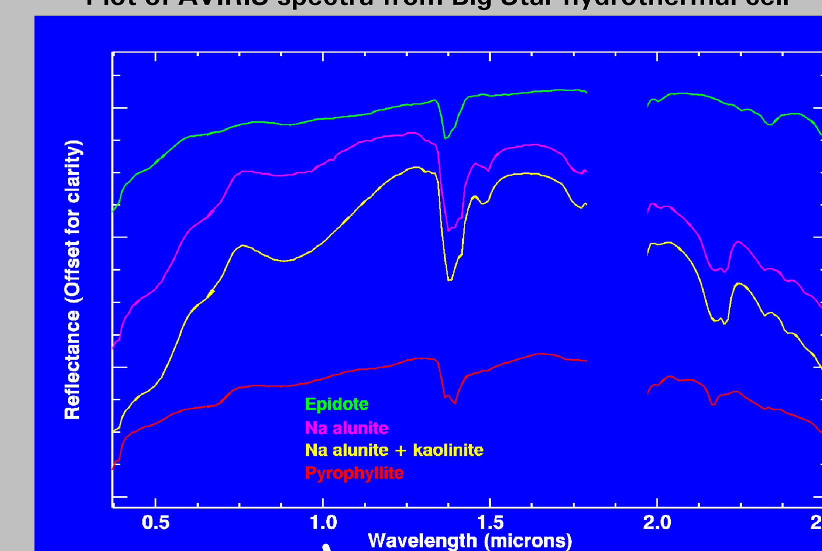
(chlorite + goethite, chlorite + illite/muscovite, epidote: propylitic alteration)

Sevier River Sediment Load
Low → High

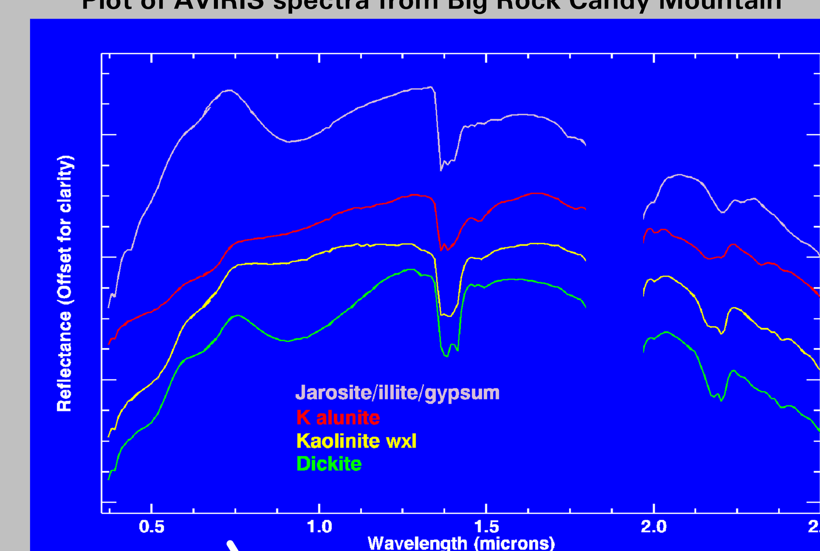


- Low altitude AVIRIS data acquired October 17, 1999
- Twin Otter altitude: 17,500 feet (~11,000 feet AGL)
- Flightline designation: f991017t01p02_r11
- Ground speed: 82.1 knots
- Geocorrected pixel size: 2.9 meters

Plot of AVIRIS spectra from Big Star hydrothermal cell



Plot of AVIRIS spectra from Big Rock Candy Mountain



Legend for low altitude AVIRIS mapping: clays, carbonates, sulfates and micas

Kaolinite Group Minerals
- kaolinite (well crystalline)
- kaolinite (poorly crystalline)
- kaolinite + illite/muscovite
- kaolinite + montmorillonite
- dickite
- pyrophyllite
- pyrophyllite + kaolinite
- pyrophyllite + illite/muscovite

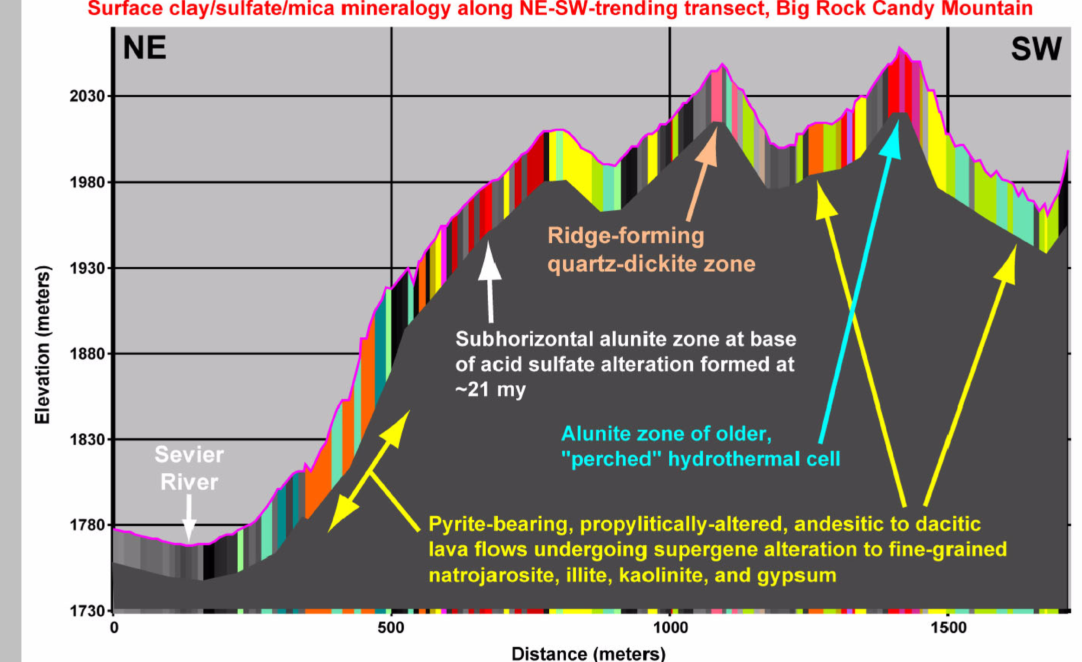
Propylitic Alteration
- calcite
- epidote
- calcite + muscovite
- undifferentiated propylite: calcite, chlorite, epidote +/- muscovite, montmorillonite (talc/tremolite may occur locally, e.g. Trinity mine dumps).

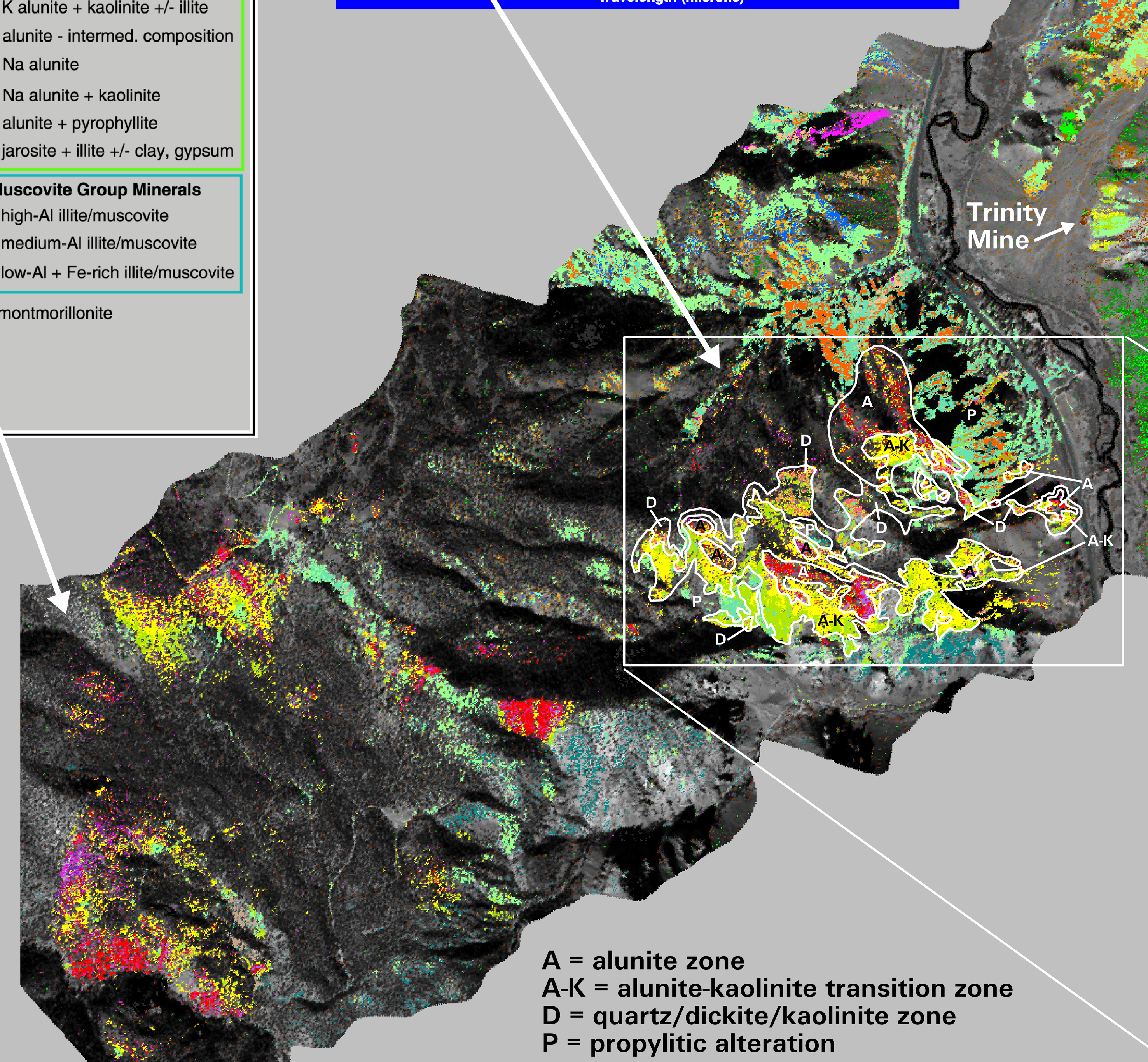
Sulfate Minerals
- K alunite
- K alunite + kaolinite +/- illite
- alunite - intermed. composition
- Na alunite
- Na alunite + kaolinite
- alunite + pyrophyllite
- jarosite + illite +/- clay, gypsum

Muscovite Group Minerals
- high-Al illite/muscovite
- medium-Al illite/muscovite
- low-Al + Fe-rich illite/muscovite

- montmorillonite

Surface clay/sulfate/mica mineralogy along NE-SW-trending transect, Big Rock Candy Mountain





A = alunite zone
A-K = alunite-kaolinite transition zone
D = quartz/dickite/kaolinite zone
P = propylitic alteration

Map of Alteration Zones