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"A Conflict of Water and Fire": Remote Sensing Imagery of the Uinkaret Volcanic Field, Grand Canyon, Arizona

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1. Introduction

"What a conflict of water and fire there must have been here! Just imagine a river of molten rock running down a river of molten snow."

J.W. Powell
August 25, 1869

The geology of the western Grand Canyon represents perhaps the most spectacular three dimensional displays of volcanological processes in the world. The dramatic sight of frozen basaltic lava falls cascading over the Canyon's inner gorge was first documented during John W. Powell's initial expedition into the region in 1869 (Powell, 1873). Over the past two million years, lavas have erupted from both fissures and central vents, forming the Uinkaret volcanic field. At the southern reach of this tectonically controlled lava field lies the Colorado River and the Grand Canyon. Lavas that erupted close to the edge of the rim flowed down it forming cascades over 900 meters high (Hamblin, 1994). In addition to this activity, multiple vents erupted within the Canyon itself. The products of this activity effectively dammed the river 13 times; the remnants of which are still visible along the Canyon walls today. The largest of the dams formed a 700 meter deep lake which extended up river into present day Utah. Geological investigations of the Uinkaret field, the lava cascades and the remains of the basaltic dams have been relatively few (Koons, 1945; Maxon, 1950; Hamblin, 1994) despite the remarkable nature of the geology. Previous investigations have been hindered by the remoteness of the site and near impossibility of accessing most of the flows.

In addition to the geological interest of this region, the Colorado River, its beaches and riparian habitats are under more intense study in an attempt to document the impact of human damming of the river. As a result of the construction of the Glen Canyon Dam, the average water temperature has dropped over 20 degrees Fahrenheit during the past 30 years. Sediment load, vital for beach replenishment and stabilization has been cut off. The result is a Colorado River that now runs clear and cold where once it ran cloudy and warm. Finally, human use of the Grand Canyon and Colorado River by way of recreational activities like rafting is at an all time high, with tens of thousands of people per year enjoying the Colorado by boat. The need for large scale, relatively inexpensive monitoring of the river and its surrounding environments is evident.

2. Geological Setting

The sedimentary geology of the western Grand Canyon consists of gently northeast dipping sandstones, shales and carbonates. However, due to facies changes within the units, the geomorphology varies from that seen by visitors at the National Park Headquarters. There, the cliff and slope expression of the rocks is replaced in the west by a series of mesas, ridges and horizontal platforms. The largest of these occurs on the Esplanade Sandstone within the Supai Formation. The Esplanade is formed by slope retreat of the overlying units and resistance to erosion by the underlying limestones. It is onto this platform that the lavas of the Uinkaret Plateau were emplaced.

The Uinkaret lava field lies 120 km south of St. George, Utah and is tectonically defined by two major normal faults - the Hurricane to the west and the Toroweap to the east. As the surficial expression of these faults converge to 15 km at the Canyon, the concentration of the volcanic centers increase (Hamblin, 1974). Very few of the actual vents lie directly on the faults, however. The regional stresses associated with fault formation opened north-south trending fissures which accommodated magma rise. The basaltic lava flows were extremely numerous during the height of activity 1.8 m.y. Volumes of most eruptions were rather small and resulted in thin, short flows. The total volume of the lava field was enough to fill the Toroweap and Whitmore valleys to the level of the Esplanade (> 650 m). Eruptions close to the edge of the inner gorge flowed over the rim producing the many lava cascades visible today. Vents that formed within the gorge itself gave rise to the multiple damming events of the river. These dams occurred over a period of 1.4 m.y. and in each case were breached and eroded by the Colorado River in less than 20,000 years (Hamblin, 1994). Prospect, the largest and oldest dam, when overtopped, had a waterfall over 600 meters high with a volume 20 times that of Niagra Falls. The fault system remains active today, but the last eruption of the Uinkaret field occurred over 200,000 years ago.

3. DATA COLLECTION AND ANALYSIS

The purpose of this investigation was to collect visible, near and thermal infrared data at different periods of the day and year. It is expected that these data will provide the ability to retrieve water temperatures; monitor sediment loads; map and examine any changes in the near shore vegetation communities and understand some of the intricacies of the geology. This paper will serve, to some degree, as a progress report on the Grand Canyon study, since only a fraction of the data has been received and processed thus far.

Data from the Thermal Infrared Multispectral Scanner (TIMS) and the Landsat Thematic Mapper Simulator (NS001) were acquired simultaneously on April 4, 1994. The flight line ran along the Colorado in a roughly southeast to northwest direction and covered over 20 river miles. The altitude of 17,000 feet (5.18 km) above ground level produced an image resolution of 13 m/pixel at nadir. The higher altitude was chosen to provide coverage of both the river and shore environments as well as capturing a large portion of the volcanic field and exposed sedimentary units of the Grand Canyon. A second data acquisition occurred on August 27, 1994. The late summer data were acquired at night with the intent of examining seasonal variations as well as to produce a thermal inertia map of the region. At present, only a preliminary examination the spring data has been performed. This data set will provide baseline for monitoring the area and will be used to assess the viability of future data acquisitions at higher spatial resolutions.

Initial analysis of the TIMS data indicates a remarkably noise-free data set with minimal atmospheric attenuation. Standard decorrelation processing (Gillespie, 1986) clearly distinguishes the petrologic variations of the diverse lithology in the scene. Further, significant color variations within the lava fields themselves may indicate subtle differences in lava composition, age and/or surface textures. These variations, if indicative of petrologic or age differences, may improve the understanding and constrain the stratigraphy and timing of the damming events (McKee, et al., 1968). The primary tectonic features, the Hurricane and Toroweap faults, control of the location of the Uinkaret field and are easily discernible in both the TIMS and NS001 images. At river level, the 400 meters of displacement along the Hurricane Fault places the Pennsylvanian Supai Formation in contact with the Cambrian Muav Limestone. Detailed examination of beach and talus along the both sides of the river indicate that little net transport of material occurs from one side of the Colorado to the other. Sand and gravel derived from the Cenozoic volcanics are confined to the northern side, while the south is comprised primarily of carbonate and sandstone detritus.

Figure 1. Western Grand Canyon TIMS imagery acquired on April 4, 1994. The image size is approximately 24 km long by 9.5 km wide with N oriented to the lower right. Both images are the product of the separation of radiant flux into emissivity and temperature. **A.** Band 3 emissivity image (dark grey to black indicate rock outcrops with strong absorptions at 9.2 μm such as the Coconino Sandstone). **B.** Kinetic temperature image. Derived temperatures range from 57 °F (14 °C) on portions of the river to 167° F (75°C) on a sun-facing slope of one of the basalt flows.

The data were also separated into normalized emissivity (Realmuto, 1990; Kannari, et al., 1991) and kinetic temperature images (Fig. 1). Distinct spectral absorption features of the major rock forming units are indicative of the petrologic variability of the scene, the near 100% exposure of the rocks, and the high signal to noise of the data. These spectra will be used as input endmembers into a linear, spectral retrieval model in order to determine subpixel abundances (Ramsey, et. al., 1994) and track sediment addition and transport by the Colorado River. The moderate spatial resolution of the data may prove to be a hindrance when mapping temperature fluctuations along the length of the river. Detectable drops in temperature of several degrees occur over the major rapids such as Lava Falls. However, because the river is only several pixels wide in the image, variations along its length may be due to pixel overlap with the shoreline.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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CAPTION FOR TIMS WORKSHOP SLIDE 1

Thermal Infrared Multispectral Scanner (TIMS) decorrelation stretch image of bands 431 in RGB respectively. The scene covers approximately 9.5 km x 15 km, from river mile 182 to 192, with north to the lower right of the slide. The Esplanade Sandstone of the Supai Fmt. forms the prominent horizontal platform displayed in yellow-orange. The deep green of the inner gorge marks the location of early Paleozoic limestones of the lower Grand Canyon sequence. Several cinder cones in the lower right of the slide lie at the southwest margin of the Uinkaret volcanic field. Basaltic flows (shown in blue) from these and other vents filled the 650 meter deep Whitmore wash (right center of slide) and produced the lava cascades within the inner gorge. Hurricane Fault, the western tectonic boundary of the Uinkaret field, can easily be located striking southward from Whitmore wash towards the upper left corner of the slide.