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MAPPING ALLUVIAL FANS IN DEATH VALLEY, CALIFORNIA, USING MULTICHANNEL THERMAL INFRARED IMAGES

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Abstract. We have mapped alluvial fans in Death Valley, California using NASA's 8-12 µm six-channel airborne Thermal Infrared Multispectral Scanner (TIMS). We are able to recognize both composition and relative age differences. Age unit boundaries are generally consistent with those obtained by conventional mapping. Composition was verified by field investigation and comparison with existing geologic maps. Bedrock and its young derived fan gravels have similar emissivities. The original composition of the fans is modified by differential erosion and weathering, permitting relative age mapping with TIMS.

Introduction

Recently Kahle and Goetz [1983], describing the first results from NASA's airborne Thermal Infrared Multispectral Scanner (TIMS), showed they could readily distinguish the mapped quartzites, carbonates, volcanic rocks and saline deposits in Death Valley. They used color images constructed from data acquired in the spectral region 8-12 µm. Differences among the colors representing alluvial fans appeared to be related to source materials for the gravel, the ages of the surfaces, and the development of desert varnish. We have now studied the TIMS images of these fans in greater detail, and present here an interpretation based upon examination of the images and of the fan gravels in the field, previous laboratory spectroscopic studies, and the geologic mapping of Hunt and Mabey [1966].

Geologic Setting

Death Valley is a deep, narrow north-south graben in the Basin and Range province. The graben is partly filled by saline lake sediments, and is flanked by alluvial fans and by remnants of Tertiary volcanic rocks. The climate is hot and arid, and vegetation is sparse. A lithologic map of the study area, generalized from Hunt and Mabey [1966] is given in Figure 1. The study area covers part of the western margin of Death Valley and the adjacent Panamint Mountains.

Bedrock Geology. In the study area the Panamint Mountains consist of a sequence of lightly metamorphosed Precambrian-Paleozoic sedimentary rocks underlying Miocene volcanic rocks. In Figure 1 these are grouped by composition into units that could be readily distinguished in the TIMS data (Figure 2). The most widespread sedimentary rocks are dolomite and limestone, which resist erosion here. Argillaceous rocks such as shale of the Johnnie Formation are common between Blackwater Wash and Tucki Wash. They are fissile and readily eroded. Quartzites, found throughout the stratigraphic section, are most evident near Blackwater Wash. The steeply dipping sedimentary rocks are highly faulted and the section is commonly repeated. The volcanic lavas and tuffs range in composition from basalt to rhyolite. The Amargosa thrust complex in the southern part of the study area, contains a breccia of the sedimentary rocks, older metamorphic rocks, and felsite dikes and granite.

Quaternary Sediments. Most of the Quaternary deposits are lake sediments (evaporites, saline silts and sand) and alluvial fans. Hunt and Mabey [1966] mapped four Quaternary alluvial fan units, based upon relative weathering and geomorphic characteristics but not upon lithologic composition. The three younger fan units occur within the study area. Of these, the youngest unit (Q_4) comprises active channels containing silt, sand and gravels reworked from the older fan deposits. The intermediate unit (Q_3) consists of similar gravels in inactive channels. These are moderately coated by desert varnish [Hooke, 1972]. The oldest unit (Q_2) is typified by heavily varnished pebbles forming desert pavement. Hooke [1972] subdivided Q_2 into three units of different age. In the older units the pavement had been partly eroded, reducing the amount of varnish and locally exposing caliche. The fan gravels reflect the lithologies found in the drainages of the Panamints.

TIMS Data Acquisition and Processing

Six channels of calibrated TIMS digital radiance images with an 18-m nadir pixel size were acquired over Death Valley near noon on August 27, 1982. TIMS acquires data at wavelengths near 8.3, 8.7, 9.1, 9.8, 10.4 and 11.3 µm. This spectral region contains diagnostic emissivity minima for silicate minerals [Lyon, 1965; Hunt, 1980]. The depth and position of the minima vary with the crystal structure. To display these spectral differences, we used a decorrelation technique [Soha and Schwartz, 1978; Kahle et al., 1980] that suppressed temperature information while exaggerating emissivity features. Following Kahle and Rowan [1980] and Kahle and Goetz [1983], we created a color composite image from the enhanced channels 1, 3 and 5 displayed as blue, green and red, respectively (Figure 2). Colors referred to in this article are those of this enhanced image, and not "natural" colors.

Figure 2 clearly shows several units that are differentiable by texture and color. Textural differences related to topography allow us to distinguish bedrock from alluvial fans and lake deposits. Comparison with the lithologic map (Figure 1) shows that image color is related to composition [Kahle and Goetz, 1983]. Carbonate rocks appear green and quartzites are deep red. Other clastic sedimentary rocks such as the shale of the Johnnie Formation appear purple, as do most volcanic rocks. Basalts appear blue. Rocks

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of the Amargosa thrust complex are orange or brown. Lake deposits, to be discussed in a later paper, are yellow, green and blue in Figure 2, which may be due to different saline facies.

The alluvial fans are represented by the same wide range of colors as the bedrock of the Panamints. The larger fans are red (Blackwater Wash or Trail Canyon) or purple (Tucki Wash). Smaller fans are green, purple, yellow, or brown. The range of colors within a given fan is limited, but distinct variations are present. In general, contacts appear sharp, not gradational.

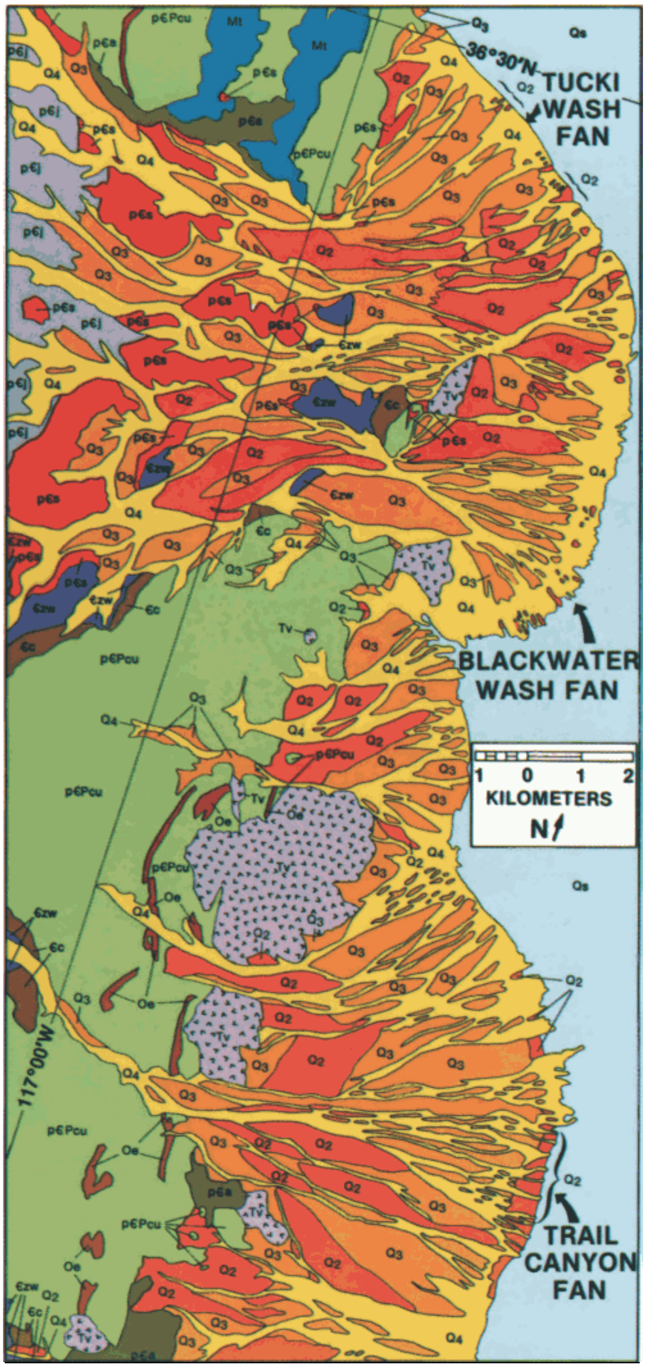

Fig. 1. Simplified lithologic map of the study area, after Hunt and Mabey [1966]. Units are those that can be distinguished in Fig. 2. Explanation on the next page.

Interpretive Map

Figure 3 is an interpretive map based on the TIMS image (Figure 2). Identification of the mapped bedrock and alluvial units was based upon our field inspection and Hunt and Mabey [1966]. The old gravels (Q_2) of Hunt and Mabey were consistently recognizable in the TIMS image as deep red or pink areas in the reddish purple fans. The Q_2 of some, but not all, of the green fans are depicted as light orange. However, distinction between the younger Q_3 and Q_4 gravels was not always possible in the TIMS image.

Hunt and Mabey [1966] mapped alluvial gravels based on relative age only. We further subdivided the gravels according to composition and provenance. We recognized six suites of fan gravels, distinguished by their assemblages of lithologies. Fans below the major canyons contained a wide mixture of rock types, dominated by the shales and quartzites found near the crest of the mountains. The fan gravels of Tucki Wash were largely shales of the Johnnie Formation, with lesser amounts of the resistant dolomite member. Fans below Trail Canyon and Blackwater Wash had more Stirling Quartzite and less shale. The fan gravels between Tucki Wash and Blackwater Wash contained quartzite and shale, but little dolomite. Lithologically, these fans were intermediate between those of Tucki Wash and Blackwater Wash. Fans of the fourth type were composed dominantly of carbonate clasts. These fans were found below smaller drainages that did not penetrate deep into the mountains, but were cut into only the resistant carbonate rocks at the range front. Fans beneath large exposures of the Tertiary volcanic rocks consisted largely of the volcanic rocks. Finally, some fans contained a mixture of volcanic, carbonate, argillaceous and other rock types. We mapped these compositionally complex fans as undifferentiated mixtures.

Discussion

The colors depicting the alluvial gravels appear to be controlled primarily by the prove-

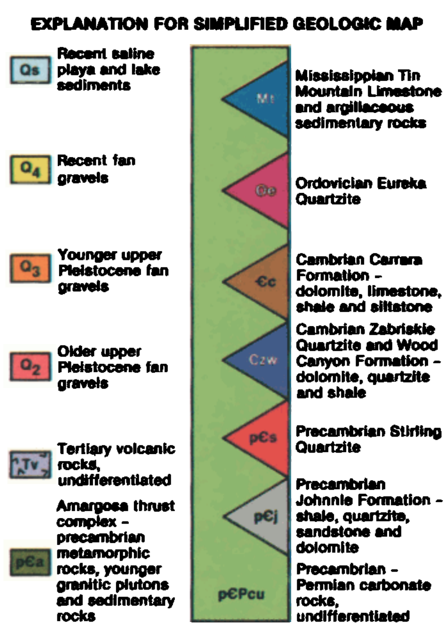

Fig. 2. Enhanced TIMS radiance image. Scales and orientation are shown in Fig. 3.

nance. Debris from slopes consisting of a single rock type is the same color as the bedrock, and in some cases the contact between debris and bedrock cannot be distinguished. This is especially evident in Blackwater Wash, for source regions of Stirling Quartzite (red) and carbonate rocks (green). The color of fan gravels of mixed lithologies can be predicted from the colors of the source rocks. Thus, in Blackwater Wash and Trail Canyon, the magenta of the younger gravels (Q_3 and Q_4) arises from mixing red Stirling Quartzite and purple shale of the Johnnie Formation.

Differential erosion of bedrock plays a major role in determining the lithologies present in the fan gravels. In Trail Canyon, gravels of easily eroded quartzite and shale, which crop out west of the study area, are transported through 4.5 km of resistant dolomite bedrock before deposition on the alluvial fan. The color of these

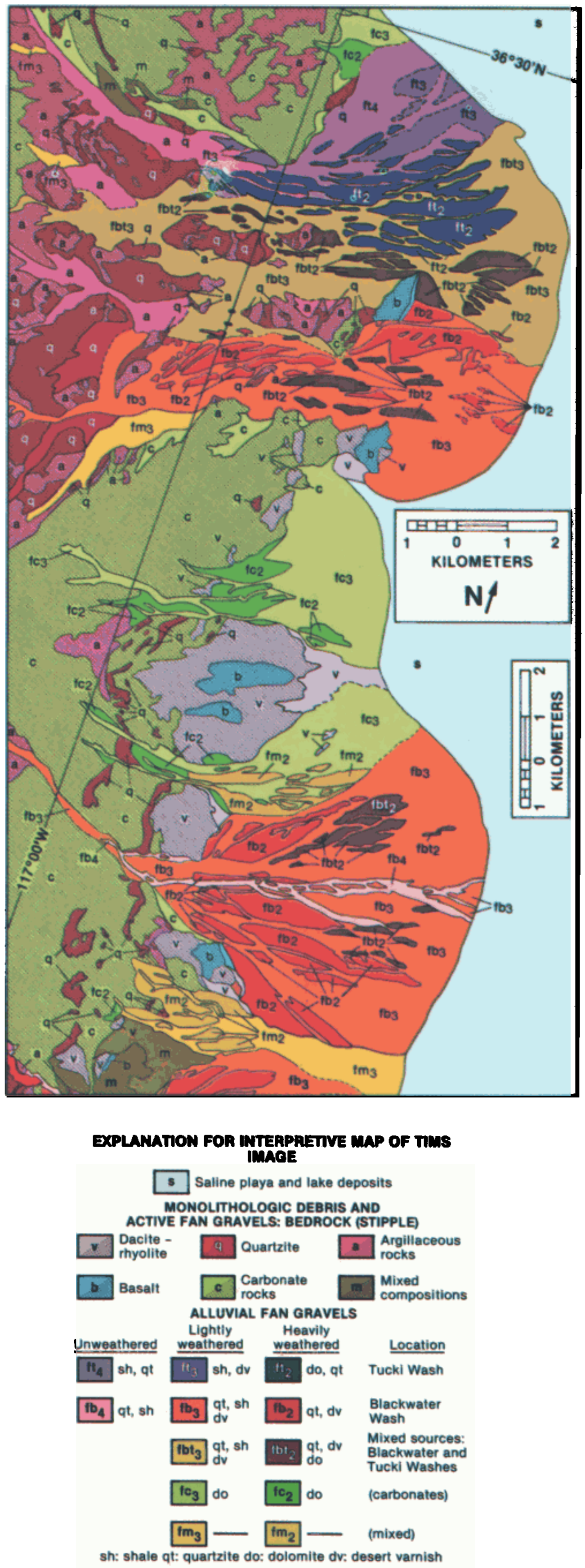

Fig. 3. Interpretation of the TIMS image. Vertical and horizontal scales differ.

gravels above and below the dolomite are virtually the same, showing that the admixture of dolomite is minor.

Differential erosion of gravels within a fan contributes to compositional change over time. This controls the color in the TIMS image and forms the basis for the relative age discrimination. For example, the gravels in the active channels of Tucki Wash are dominately fragments of fissile shale. Surfaces of the older alluvial deposits (Q_2) are a desert pavement of dolomite and quartzite; exposed shale has been reduced to fine grains and removed. This would have the effect of removing purple, and could account for the pink color of this Q_2. Compositional changes also occur in some carbonate fans as they weather. We attribute the yellow color of Q_2 gravels north of Trail Canyon to the dissolving of carbonate from gritty dolomite, concentrating quartzite and other clastic sediments. Dissolved carbonate may be precipitated as caliche near inactive surfaces of fans. Such caliche has been widely exposed by erosion and deflation of some Q_2 surfaces [Hooke, 1972]. Mixing of the green of the carbonate caliche with the deep reddish purple of the uneroded gravels could result in pink. We observed exposed caliche on the pink Q_2 units north of the active channel of the Trail Canyon fan and in Tucki Wash.

Many of the gravels found throughout the area, especially the quartzite and other clastic sedimentary rocks, are heavily coated with desert varnish. Thermal IR reflectance spectra of varnished quartzite (M. J. Bartholomew, pers. comm., 1984) indicate that the emissivity minimum will be smaller and will occur at a longer wavelength than that for unvarnished quartzite. Varnish should decrease the intensity of the red color of the quartzite and perhaps shift the color towards blue or purple. This may occur on the varnished Q_2 gravels on the northern half of the Trail Canyon fan. However, the equally heavily varnished gravels of the Q_2 desert pavement south of Trail Canyon appear to be the same shade of red as the bedrock quartzite. We think this similarity is an artifact of the enhancement process, but it will be the subject of further study.

Conclusion

Alluvial fan units of different lithologic compositions and weathering have been mapped according to provenance and relative age with the aid of multichannel thermal infrared images. The lithologic data included here are usually not given for fan gravels in conventional geologic maps. Boundaries of the age units determined from the thermal images are generally consistent with those of Hunt and Mabey [1966]. The ability to map lithologic composition and relative age of gravels is a significant advance in remote sensing. Compositional mapping with multichannel thermal infrared images is widely applicable, as long as vegetative cover is incomplete.

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