ANALYSIS OF AN IGNIMBRITE PLATEAU IN THE CENTRAL ANDES USING LANDSAT THEMATIC MAPPER DATA: IMPLICATIONS FOR THE IDENTIFICATION OF ASH DEPOSITS ON MARS; ***David A. Crown, Ronald Greeley, and Michael F. Sheridan**, Department of Geology, Arizona State University, Tempe, AZ 85287 and **Raul Carrasco**, Servicio Geologica de Bolivia, La Paz, Bolivia*

The existence of large-scale explosive volcanic deposits on Mars is controversial [1]. Various mechanisms for the eruption and emplacement of pyroclastic materials have been considered theoretically for martian environmental conditions [2, 3]. Recently, a number of investigations have considered deposits possibly generated by large, explosive volcanic eruptions [2-7]. An erosional morphology uncharacteristic of effusive shield volcanoes on Mars is the primary evidence cited indicating the presence of ash deposits. While the erosional characteristics suggest a pyroclastic origin, other hypotheses are also consistent with the observed morphologies [1, 8, 9]. The existence, abundance, and distribution of ash deposits on Mars is critical for a comprehensive understanding of the history of the planet, including the volcanic evolution, the relationship between volcanism, tectonism and volatiles, and the general evolution of the surface and near-surface environments. Interpretations of martian volcanic eruption styles and landforms are hindered by the relatively few observations of large, terrestrial explosive eruptions and the poor state of preservation of the resulting ash deposits. A remote sensing and field reconnaissance study of the Frailes Formation in the Central Andes has been initiated to develop morphologic and spectral criteria for the remote identification of ash deposits. A primary objective is the assessment of the utility of LANDSAT Thematic Mapper (TM) data in mapping volcanic materials in order to make interpretations regarding the eruption and emplacement processes leading to their formation.

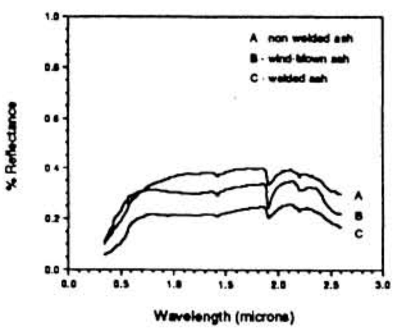
The Frailes Formation is an extensive ignimbrite plateau (>100 km in diameter) located along the western margin of the Eastern Cordillera of the Andes in southern Bolivia. The ash-flow sheets comprising the Frailes Formation, one of the largest ignimbrite deposits in the world, cover ~8,500 km^2 and were erupted in late Miocene time (5 - 8 Ma) [10-12]. These silicic tuffs display various degrees of welding with exposures averaging 100 m in thickness and reaching a maximum of ~1 km. The Frailes Formation overlies a folded sequence of Paleozoic and Cretaceous sediments and earlier Miocene volcanics. Local andesitic and rhyolitic domes and flows occur throughout the plateau.

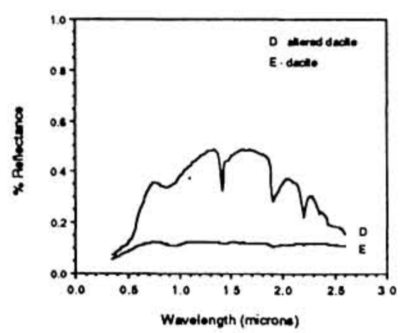
For analysis of the Frailes Formation, a mosaic of three TM quarter frames (Y5052213592 Quad 4, Y5051513531 Quad 3, and Y5086713403 Quad 1) was generated. The spatial resolution (30 m/pixel) and the observed spectral variations as displayed in a Gaussian stretched image of TM bands 1, 4, and 5 (blue, green, and red, respectively) allow mapping of the units and identification of sub-units within the ignimbrite plateau. Determinations made from the TM image are supported by field observations. Using TM data, the volcanic materials of the Frailes Formation are easily distinguished from the surrounding sedimentary rocks in the fold belts of the Eastern Cordillera of the Andes and on the surface of the Altiplano. Extrusive volcanic materials associated with the Frailes Formation can also be differentiated from the ash deposits. The majority of the exposed horizontal rock surfaces of the Frailes Formation are of the partially-welded, columnar-jointed interior of the tuffs (the upper non-welded zone presumably has been stripped off). In areas where the non-welded base of the flows are exposed, they can easily be identified and distinguished from outcrops of partially-welded ash.

Discrimination of probable ignimbrite source areas from other eruptive centers is based upon examination of the TM images and field observations. Four major eruptive centers and their associated flow materials can be identified within the Frailes Formation. To the north in the Frailes Formation are two quasi-circular regions, which appear spectrally different than the main part of the plateau due to the presence of a well-developed glacial deposit. These areas may be the oldest regions of the Frailes Formation but their spectral signature may simply result from weathering processes at higher elevations. These areas, which surround Cerro Livicucho and Cerro Condor Nasa/Cerro Chokkota, are apparently self-contained eruptive centers as extrusive materials form the summits present in the two regions and may represent post-Frailes eruptions at the locations of ignimbrite source vents. This interpretation is supported by the distribution of materials around the high-standing extrusions. The main part of the plateau apparently consists of two overlapping ash shields [13]. Sources appear to be sites of lavas at Cerro Villacollo and Cerro Pascual Canaviri. Cerro Villacollo is a cone of lava with a prominent summit crater, and Cerro Pascual Canaviri appears to be a large, high-standing dome complex centered in the eastern part of the plateau. A fifth and the youngest eruptive center associated with the plateau is the Nuevo Mundo Province, a complex of large rhyolite domes and related ash deposits at the southern margin of the Frailes Formation. Weathered ash from this area has been transported by the wind and blankets much of the southeastern part of the plateau. Identification of the units within the Frailes Formation, including pre- and post-Frailes extrusions, and interpretations of the age relationships on the plateau from analyses of the TM data are generally in agreement with previous remote sensing [13] and geochemical [11, 12] studies, though combined with limited field observations, use of the TM data has provided the most comprehensive synthesis of the Frailes Formation.

Interpretations made from the spectral information of the TM data are supported by laboratory, visible and near-infrared, bidirectional reflectance measurements of samples collected in the field. Samples of Frailes ash are relatively featureless, exhibiting bands due only to H_2O and OH. A progression in brightness from welded to windblown to non-welded ash, as seen in the TM image, is attributed to a decrease in the effective particle size (see below left). Spectra of lavas found in the plateau can be easily distinguished from those of the ash and exhibit a 0.9 μm band due to Fe^{2+} as well as OH and H_2O absorptions (see below right).

From examination of the Frailes Formation, several distinctive morphologic properties of large ignimbrites are evident. The ash-flow sheets of the Frailes Formation form low-relief shields around their eruptive centers which are identified by post-ignimbrite extrusions forming domes and cones [13, 14]. In addition to their steeper slopes, these extrusions are more resistant to erosion than the surrounding ash deposits. On the western margin of the plateau a prominent radial drainage pattern is observed reflecting the topography associated with the Cerro Villacollo eruptive center. From field observations, the partially-welded interiors of the ash flows create cliff-forming exposures, whereas the non-welded bases are slope-forming units. Distinctive erosional outliers of tuff, which are capped by partially-welded ash, are found on the surface of the Altiplano. These attributes may be significant for identifying ignimbrites erupted from central vents on Mars [15].





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