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DIFFERENTIAL SCANNING CALORIMETRY (DSC) FOR PLANETARY SURFACE EXPLORATION

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Principles of DSC. DSC is the quantitative measurement of the enthalpic response of a material to a systematic change in temperature [1]. In practice, the heat flow into or outward from a sample is measured as the sample is heated or cooled at a carefully controlled rate. DSC superficially resembles, but is not the same as, differential thermal analysis (DTA), which is the measurement of temperature differences between a sample and reference material as the pair is heated or cooled. The fundamental properties measured by DSC are enthalpies and temperatures of phase transitions and constant-pressure heat capacities. Depending on instrument design and the nature of the sample, high-quality DSC analyses can be obtained on only a few milligrams of solid materials. DSC requires direct contact with the sample and generally degrades, if not destroys, the sample as a consequence of heating. In laboratory applications, it is common to subject the gaseous effluent from the DSC to analysis by a separate evolved-gas analyzer (EGA).

Planetary Applications. In the planetary context, DSC can be used to identify minerals according to their heat-flow "fingerprints," using pattern-recognition strategies that are generally similar to those employed in spectrophotometry. The principal strength of DSC in the planetary context is identification of ices and volatile-bearing minerals, including clays, hydrous salts and oxides, and carbonates. Given the mineral identities, characteristic enthalpic peaks can be integrated to yield relative proportions of the minerals present. Unlike spectrophotometry, DSC results are relatively insensitive to particle coatings or other matrix effects. Although the appearance of a given heat-flow curve can depend on the physical characteristics of the sample, integrated ratios of enthalpic peaks change less severely with physical properties than do peaks in reflectance spectra.

Instrument Development History. DSC-based experiments have been previously designed but never flown on spacecraft. The Planetary Soil Water Analyzer (PSWA) experiment [2], which included a DSC backed by an electrolytic-cell detector for evolved water vapor, was developed in the early 1980s as a post-Viking follow-on experiment for Mars. However, no further Mars landing missions were flown and the PSWA project was discontinued. A preliminary design for a DSC experiment was included during the middle 1980s in plans for the Comet Rendezvous and Asteroid Flyby (CRAF) Penetrator-Lander but the instrument was never built and the CRAF mission has since been cancelled. Therefore, absence of planetary flight opportunities and the lack of sustained funding has seriously hindered development of flight-qualified DSC instruments.

In 1989, concepts for DSC-based planetary experiments were renewed as the Thermal Analyzer for Planetary Soils (TAPS) project at JSC (Fig. 1) [3,4]. Support for Phase A development of TAPS, with emphasis on applications to small Mars landers, was begun in mid-1992 through funding from the Planetary Instrument Definition and Development Program (PIDDP) at NASA Headquarters. The sample-acquisition function is being developed as an integral part of a self-contained experiment. Using 1980s technology, a version of TAPS packaged for

Mars applications is estimated to have the following characteristics: 1.2 kg mass, 850 cm^3 volume, 5 W peak power, and 1.5-W hr per analysis.

Design Issues. The most important technological needs include small, reliable sample-delivery mechanisms and lightweight, energy-efficient electrical furnaces for the DSC. Miniaturization of electronic components is highly desirable but miniaturization of mechanical and sensor components faces natural limits set by the fundamental scale of the scientific problem. First, based on experience with lunar samples and with Viking results from Mars, the *minimum* size of a representative planetary soil sample (of about 2 g/cm^3) is on the order of 10-100 mm^3 (equivalent to a few tens of milligrams). Therefore, the sample-acquisition mechanisms and calorimetric sensors cannot be reduced below about the centimeter scale without substantial loss of scientific validity. Second, optimum operation of the DSC for analysis of volatile materials requires a continuous gas purge at $\geq$ 10 cm^3 STP/min; the gas-purge system must be scaled for compatibility with the calorimetric sensors.

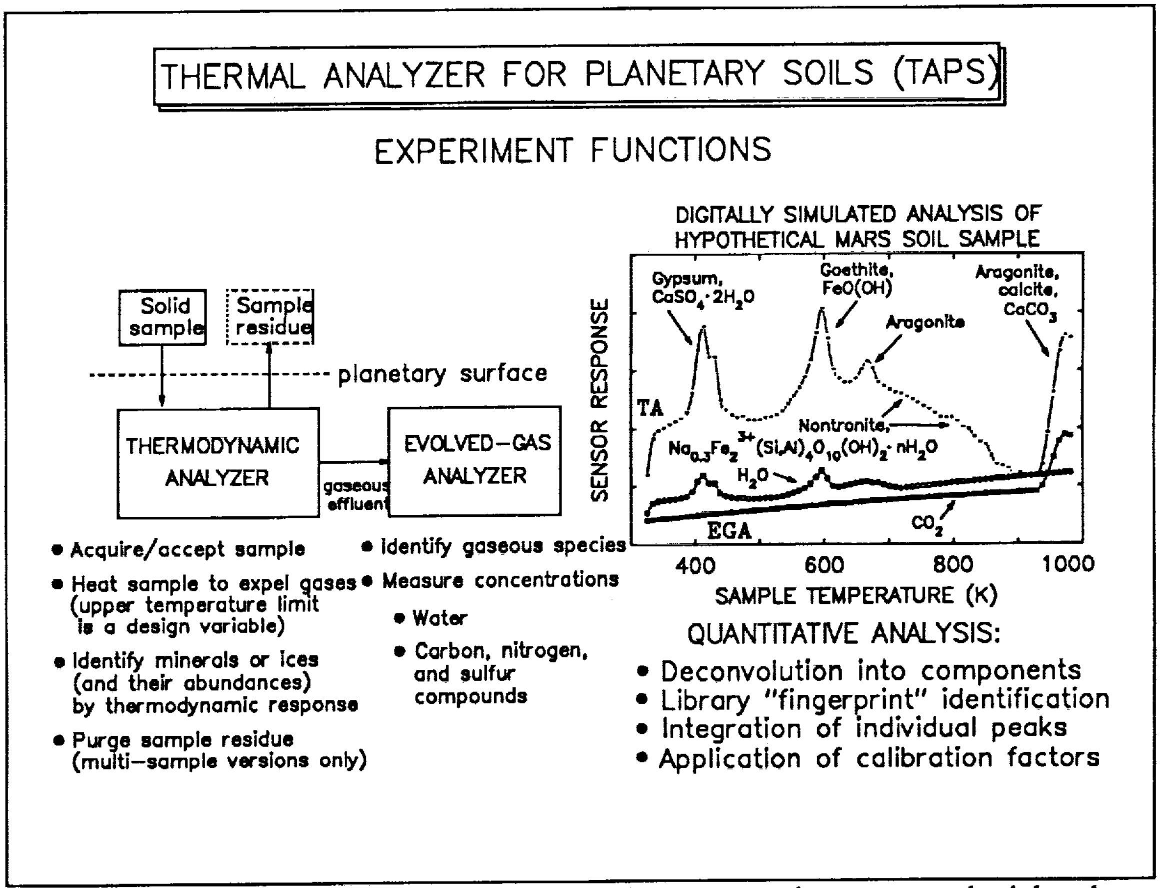

Figure 1. Functional diagram and simulated data for the TAPS experiment concept that is based on a DSC module backed by single-function gas sensors.

References: [1] Wendlandt, W. W. (1986) *Thermal Analysis* (third ed.), John Wiley and Sons, New York, 814 p. [2] Ball Aerospace Systems Division (1982) *Planetary Soil Water Analyzer Final Report,* Huntington Beach, CA, 54 p. [3] Gooding J. L. (1991) *Lunar Planet. Sci. XXII,* Lunar and Planetary Institute, Houston, TX, 457-458. [4] Gooding J. L. et al. (1992) *Lunar Planet. Sci. XXIII,* Lunar and Planetary Institute, Houston, TX, 427-428.