

Development of a thin section device for space exploration: Overview and system performance estimates

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Received 22 May 2012; received in revised form 13 December 2012; accepted 17 December 2012

Available online 23 December 2012

Abstract

In this paper we present a conceptual design of a spaceborne instrument for the *in situ* production of rock thin sections on planetary surfaces. The *in situ* Automated Rock Thin Section Instrument (IS-ARTS) conceptual design demonstrates that the *in situ* production of thin sections on a planetary body is a plausible new instrument capability for future planetary exploration. Thin section analysis would reduce much ambiguity in the geological history of a sampled site that is present with instruments currently flown. The technical challenge of producing a thin section device compatible with the spacecraft environment is formidable and has been thought too technically difficult to be practical. Terrestrial thin section preparation requires a skilled petrographist, several preparation instruments that individually exceed typical spacecraft mass and power limits, and consumable materials that are not easily compatible with spaceflight. In two companion papers we present research and development work used to constrain the capabilities of IS-ARTS in the technical space compatible with the spacecraft environment. For the design configuration shown we conclude that a device can be constructed that is capable of 50 sample preparations over a 2 year lifespan with mass, power, and volume constraints compatible with current landed Mars mission configurations. The technical requirements of IS-ARTS (mass, power and number of samples produced) depend strongly on the sample mechanical properties, sample processing rate, the sample size and number of samples to be produced.

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Keywords: Planetary missions; *In situ* measurement; Sample preparation; Space science instrument

1. Introduction

A number of analytical instruments such as for example alpha particle x-ray spectrometer (Rieder et al., 2003) and the mössbauer spectrometer (Morris et al., 2004) have landed on different planetary surfaces. Although these instruments provided valuable elemental data, they are

not the typical instruments used by a terrestrial geologist. Science data collected from planetary rovers and/or landers is analogous to a geologist's measurements in the field. Elemental composition data does not provide definitive answers regarding the mineralogy of the rocks or possible evidence of life (microfossils). Mineralogical and petrological evidence for the presence or absence of past water, secondary alteration such as weathering and metamorphism (shock and heat), and local habitat identification cannot be determined with a high degree of certainty using data sets currently available for planetary surfaces. On Earth, the main tool used by a geologist to gather this type of information is to identify the optical properties of the minerals by making thin-sections of the rocks/soils and

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examination using a petrographic microscope. In examining thin sections of rocks/soils, not only is the identification of fossils and minerals possible, but relationships between grains can be easily determined (e.g. textural and spatial). Even on loose rock grains, optical properties can be determined to permit mineral identification. Microfossils imaged in thin section are used in studies of terrestrial paleoenvironments (Corsetti et al., 2003). A microfossil imaged in thin section can provide direct evidence of past biological activity and would enable imaging of a diversity of structures (Schopf et al., 2010).

Petrographic thin sections have been in use for more than 150 years on Earth and have been a fundamental tool for geologists (Vernon, 2004). A thin section is composed of a rock or soil sample reduced to a thickness of 30 microns, at which most minerals are transparent and single crystal grains transect the sample thickness. Petrographic analysis is defined as the process of transparent mineral identification in rocks and soils through the use of petrographic thin sections on a specialized polarizing microscope. A petrographic microscope uses linearly polarized white light transmitted through a thin section to produce colored images of minerals in the specimen. The natural birefringence and crystalline lattice of minerals result in the transmission of unique component colors of light through the crossed polarizers.

The most basic method to identify minerals uses the color of mineral grains viewed in cross polarized light. In addition, various analytical devices can be incorporated in the microscope to produce additional information to further enhance the identification of minerals. Petrographic microscopes can include optical elements to measure mineral interference figures and extinction axis. Petrographic analyses of thin sections are used to identify minerals, their structural aspects (cleavage, fractures, mineral zoning) and rock textures that indicate the mode of formation of the rock (igneous, metamorphic, sedimentary). If samples are provided in small fragments, such as sand or dust, a grain mount can be made consisting of the sample dispersed through an epoxy matrix. In recent decades, polished thin sections and grain mounts have been the preferred sample preparation for electron microprobe, SEM and other types of microscopic chemical analysis, as the polished surface allows geometrical factors to be eliminated from the interpretation of spectroscopic data.

An instrument capable of producing petrographic images of rocks in thin section on the Moon, Mars, an asteroid, or other planetary body would serve to remove much ambiguity from interpretation of the geological history of the sampled site. For example, the composition of the lunar mare regolith, the underlying basaltic rock, an impact melt breccia made from the local regolith, or impact glass made by melting the regolith may be quite similar in reflected light, but the materials can all be distinguished using a petrographic thin section (Ryan, 2012). Unpolarized light microscopy can enable some mineral, texture, and structure identification. Opaque minerals can be

identified and characterized in a polished thin section through the use of the reflected light components of a petrographic microscope.

A thin section instrument with petrographic microscope in combination with chemical analytical data obtained using for example X-ray Diffraction (XRD), X-ray fluorescence (XRF), Hyperspectral Reflectance Spectroscopy, or Laser Induced Breakdown Spectroscopy (LIBS), would significantly enhance mission capabilities. If Microprobe or Scanning Electron Microscope (SEM) instruments are included in the spacecraft instrument suite, mineral composition can also be determined and quantified; and the data quality returned by these instruments would be greatly enhanced by a polished surface. Indeed, SEM and Electron Microprobe instruments are already in development for space exploration (Thaisen et al., 2009; Gaskin et al., 2009; Wilcox et al., 2005). Due to the high quality surface finish and sub-sampling capabilities present with thin section production, IS-ARTS would significantly improve the quality of scientific results obtained with visible and infra-Red (IR) micro-imaging (Nuñez et al., 2010), micro-Raman mapping (Fries, Bhartia, Beegle, Gursel, & Mungas, 2010), XRF, or other chemical mapping instruments.

The preparation of thin sections has traditionally been more of an art form than a science, with the most difficult handwork problems being the mounting of the sample and the determination of the thickness of the section. The rock thin section has been standardized to 30-micron thickness because most common minerals (e.g. silicates) are transparent at that thickness, while some minerals (e.g. ilmenite, spinel, sulfides) are opaque. Samples are prepared with various saws, grinding pads and grinding/polishing slurries. Sample thickness is reduced to between 30–50 μm by mechanical means, such as a mechanical stop in a grinding machine. Following this the polarizing microscope allows the birefringence of minerals to be used for mineral identification. A petrologist does not directly measure thin section thickness, but rather uses known interference colors of minerals as viewed through the petrographic microscope to judge sample thickness. As the sample is polished and thickness reduced the interference colors progress through a known pattern. Part of the art of thin section preparation has been the skill of the preparer in judging the thickness of the rock sample by observing the section in the polarizing microscope for interference colors that are related to the thickness of known mineral grains.

Miniature and semi-automated thin section instrument prototypes have been developed for space exploration in the past. During the Apollo program, the United States Geological Survey (USGS) in Flagstaff, AZ, funded the development of an astronaut tended semi-automated thin section device, shown in Fig. 1, for field training of astronauts (USGS, 2012). The Apollo era semi-autonomous thin section device is similar to systems now produced by commercial petrographic suppliers (Logitech, 2012; Buehler, 2012). Miniature all-in-one table top units are produced by the company founded by the developer of the

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