THE IN SITU ROCK THIN SECTION INSTRUMENT FOR SPACE EXPLORATION. C. B. Dreyer[1], K. Zacny[2], R. C. Anderson[3], J. Skok[1], J. Steele[1], G. Paulsen[2], M. Szczesiak[2], J. Schwendeman[1], [1]Colorado School of Mines (cdreyer@mines.edu), [2]Honeybee Robotics Spacecraft Mechanisms Corporation, New York, NY, (zacny@honeybeerobotics.com), [3]Jet Propulsion Laboratory, Pasadena, CA.

Introduction: Thin section analysis provides a perspective to understanding planetary surface material that will be uniquely different from the viewpoint obtainable from any previous orbital or surface missions. Thin sections of rock or regolith samples produced *in situ*, i.e. on a planetary body, can improve the understanding of local mineralogical content and geologic history.

We have developed a design for an integrated In Situ Rock Thin Section Instrument (IS-ARTS) for Space Exploration. The limiting steps toward the development of such a device have been studied. We have developed methods for rough cutting, epoxy/slide application and grinding/polishing to finished thin section quality. The petrographic instrument, along with mobility, would result in the collection of a diversity of samples required to answer a very large number of scientific questions about many of the planetary bodies of current and future scientific interest.

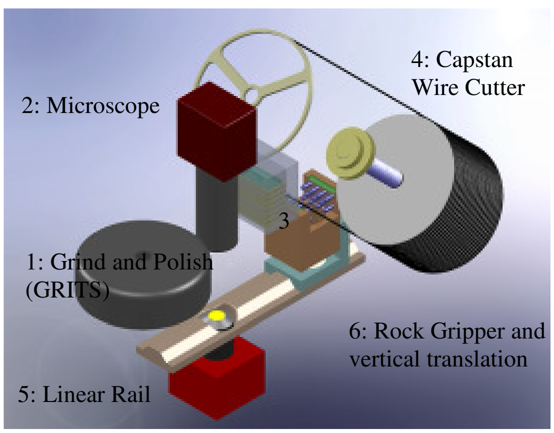

Figure 1: Schematic design concept of an integrated system. Six major subsystems as annotated. 3: Slide/Epoxy Application. Three independent motorized degrees of freedom: Linear Rail, Rock Gripper Vertical Translation, and a shared drive motor for GRITS and the Wire Cutter. Gripper open/close and slide/epoxy application will be engaged by passive mechanisms via Linear Rail and Vertical Translation. Rock receiving at the Right end of Linear Rail. A set of cameras will be installed at critical points to aid the 'remote' operation. The thin sections, after analysis, could be placed in a receptacle for transfer to analytical instruments.

Integrated Design Concept: In Fig. 1 a schematic of the design concept is shown, composed of a diamond wire saw, a combined coarse grinder and polisher, an epoxy application unit, sample manipulation unit, and petrographic microscope. The Rock Gripper (item 6) moves along the Linear Rail (item 5). The Linear Rail provides a long axis of translation (~17cm) so that the sample can be presented to several stations to perform the processing steps needed to make a thin section. The Linear Rail delivers the sample to the grinding and polishing stage, GRITS, (item 1), a petrographic microscope (item 2), slide and epoxy application (item 3), Rough Cutting (item 4), and receiving station (not labeled). Contact switches, motor current sensing, and encoders are used to verify operational status.

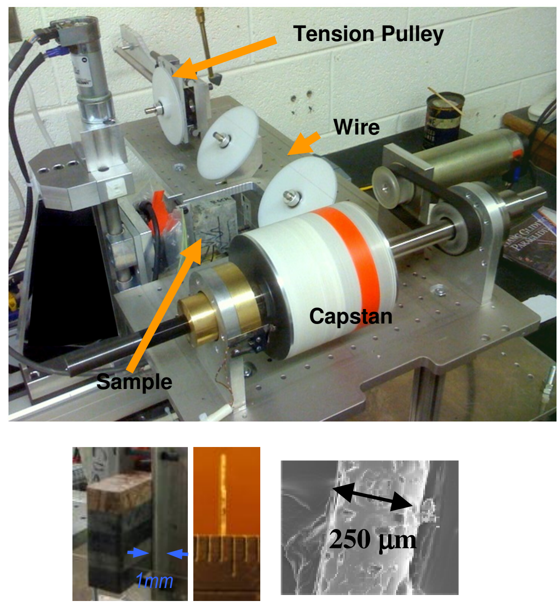

Figure 2: Top Rough Cutting Testing prototype. Bottom: Multi-rock sample for lifetime and cutting rate tests (left). The wire is visible. Ultra-thin cut sample of anorthosite (center); <0.5mm thick. Right: SEM image of the wire.

Rough Cutter: The process of preparing a thin section begins with the downsizing of a selected rock specimen from its original size and shape to a tablet of roughly 20 x 20 x 5 mm or smaller. We have developed a miniature diamond embedded wire saw for rough cutting at the Colorado School of Mines (Fig. 2). The diamond saw requires less energy, reduces overcutting waste (kerf), produces less dust, has the capability to cut in multiple directions, and reduces system weight and volume relative to other cutting devices. We use a capstan design with the wire wound onto the capstan for storage, and the wire is spooled off the capstan through guide pulleys and past the rock before being rewound onto the other end of the capstan. This approach requires an oscillatory motion profile and good control of the kinematic behavior of the wire motion. Testing of wire performance, wear rate, specific energy used, and viability of different configurations have been conducted in a prototype system.

GRITS: Grinding Rocks Into Thin Sections (GRITS) is a grinding/polishing system developed by Honeybee Robotics. The prototype system is designed so that the grind station can be oriented to grind with either a cup or straight type grinding wheel. The sample holder is mounted to a load cell to provide information on the force with which the wheel is pressing against the rock and in turn the grind pressure. The load cell is mounted to a precision linear lift stage with a resolution of 0.2 microns. Finally, this stage is mounted to a stage for tablet transfer between stations to enable oscillatory motion (back and forth) during the grinding process. The configuration described is similar to the conceptual design shown in Fig. 1.

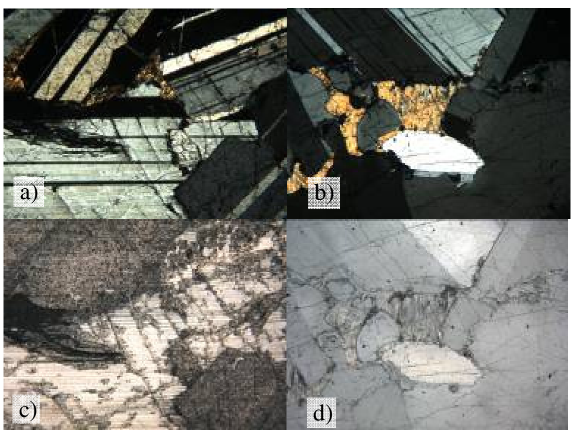

Figure 3: A thin section of an Anorthrosite sample under cross polarizers (top: a and b) and reflected light (bottom: c and d) as produced by the GRITS system (left: a and c) and by traditional preparation (right: b and d).

Using autonomous grinding the GRITS system has successfully completed grinding a tablet to a thickness of ~33 microns and to a surface finish that is adequate for petrographic analysis using a polarizing microscope. In Fig. 3 micrographs of an Anorthrosite sample are shown. The images on the left, Fig. 3a and 3c, were produced by the GRITS system under automated grinding. The images on the right, Fig. 3b and 3d, were produced using traditional preparation by a skilled petrographer. The GRITS prepared thin section has increased pitting on some minerals and grinding marks can also be seen. While the traditionally prepared thin section is clearly superior to the GRITS prepared thin section, the GRITS prepared thin section was deemed adequate for petrographic analysis by a petrographic expert.

Rock Gripper: The rock gripper is used to hold the rock during cutting, grinding and polishing. A precision vertical translation stage integrated into the Rock Gripper provides the motive force to drive the sample into the GRITS grind/polish wheel, position the sample in focus for the microscope, receive a slide and epoxy, and create vertical cuts with the wire. Passive mechanisms activated by the Linear Rail and vertical translation will be used for several functions such as: open/close gripper, and flip the sample or slide. The rock gripper will also serve as the sample platform for petrographic analysis with a cross polarizer microscope. The gripper will position the sample in the focal plane of the microscope. A hole through the gripper will allow for light transmission.

Epoxy: Epoxy application refers to the application of glue to bind to a cut sample surface and microscope glass slide. The team of authors has investigated several approaches including UV cure epoxies, thermoset epoxies, combined slide and epoxy approaches, and slide-free approaches. Epoxy requirements include compatibility with the space environment, that it is opaque, has a high refractive index, that it does not alter the sample, and that it does not obscure significant chemical signatures measured by analytical instruments.

Microscope: The microscope shown in Fig. 1 would include a color camera and optics to operate at fixed moderate magnification. A filter wheel is included to insert or remove the analyzing polarization filter. A white light source below contains a linear polarization filter.

Conclusions: The development of an automated rock thin section device for space exploration is a challenging endeavor. The conceptual design we have presented for an automated rock thin section device is the result of research focused on major subsystems.

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