STRATEGY FOR THE GEOLOGIC EXPLORATION OF THE MOON. G. Jeffrey Taylor[1] and Paul D. Spudis[2]. [1]Planetary Geosciences Division, Dept. of Geology and Geophysics, SOEST, Univ. of Hawaii, Honolulu, HI. [2]Lunar and Planetary Institute, Houston, TX.

The Moon is alluring to anyone who wishes to know how the planets formed and evolved. This conveniently-located little planet contains key information, not yet extracted, about how the Earth formed. It contains the elaborate record of its primary differentiation into crust, mantle, and core. The Moon's spectacular variety of igneous rocks records the magmatic and thermal evolution of a planet smaller than the inner planets, but larger than the asteroids. It can tell the story of early planetary bombardment. The thousands of craters that decorate its surface chronicle the impact record of the Earth. In its dark-gray, powdery soil the solar wind has written the history of the Sun. Though it has but a tenuous atmosphere, it is an intriguing one that is informative about other bodies, from Mercury to comets. Though it contains fewer volatiles such as water than other places, the Moon tells a subtle story about volatile materials in the Solar System: some of its deposits, such as the orange glass discovered at the Apollo 17 site, contain substantial amounts of volatile substances. Nobody knows how these volatiles were incorporated into the Moon. In spite of the great vitality of lunar science, the Moon has not yet given up its secrets. This is not surprising: the Moon has barely been explored. We need to know more about it. This will require several types of missions, as explained in detail in Taylor and Spudis (1). We review them here, with emphasis on geologic field work.

Global surveys

Two major types of global studies of the Moon must be done. One is a polar-orbiting spacecraft that would map the Moon geochemically, mineralogically, and geophysically, such as Lunar Observer. This mission, if ever funded, would shed light on numerous unsolved problems in lunar science, including constraints on lunar origin and the Moon's magmatic history. The other type of global study involves surface deployment of a network of geophysical instruments that would probe the lunar interior and monitor the Moon's atmosphere. These could be deployed by automated landers or roving vehicles, penetrators, or humans.

Reconnaissance missions

Automated landers could be sent to numerous sites on the Moon to collect and return samples for analysis on Earth (2). Each such mission would be designed to address a small number of specific questions (e.g., what is the age of the youngest volcanic rocks on the Moon?), so sampling strategies would be simple and relatively easy to automate. The spacecraft could be similar to Soviet Luna spacecraft, but with greater return payloads. Ideal samples would be 1 kg of 1 - 4 cm rock fragments obtained by a rake, 200 g of bulk soil, and a core 1.5 m deep (about 900 g if the core is 2 cm in diameter). A list of 31 candidate sites is given by Ryder et al. (2). Although such missions are extremely valuable, *reconnaissance sampling does not replace field work.* In fact, a savvy geologist would not propose landing an automatic sampler at a complex site. Such an acerebral decision would produce far more confusion than enlightenment.

Geologic field work

Field work is the soul of geology. We have wonderous analytical devices such as mass spectrometers, electron microprobes, transmission electron microscopes, and inductively-coupled plasma mass spectrometers, but the information they contain cannot be understood without knowing the geological context, which is obtained in the field. As Pettijohn (3) noted, "These sophisticated tools are, in the last analysis, just expensive hand lenses to look at a rock and tell us what's there." The science of geology is done in the field, supported by laboratory and mathematical analysis.

Geologic field work involves the study of rocks and rock formations in their natural environment. It entails making observations, finding the contacts between lithologies and then mapping the distribution of rock types relative to each other, measurement of parameters that can only be made in the field (e.g., the angle a layer makes with the horizontal), and collection of samples from a known geologic context. *These tasks must be done by a human geologist.* The complex yet subtle nature of geological materials requires powers of observation, pattern recognition, and synthesis not possessed by automated devices. Such preprogrammed machines are also not capable of taking advantage of surprises. Because field study is fundamental research, the field geologist must be alert for the unexpected discovery, as Eugene Cernan and Harrison Schmitt were when they discovered the orange soil at the Apollo 17 landing site. The goal of field work is to understand planetary processes, the nature of geologic formations, and planetary geological history at all levels of detail. Besides absolutely requiring a human brain to do it, field work also requires a lot of time to make the observations and to think about them while in the field. It is also an iterative process and so requires return visits to the same site.

The roles of humans and teleoperated robots in field work

Human powers of observation and thought are essential for field work. However, because of the hazards that the space environment poses to humans, it is desirable to protect people from this environment by sending robots in their place. We have proposed a robotic field geologist (4,5) that would be teleoperated from a base on the Moon, or possibly from Earth. The design incorporates telepresence, so the operator-geologist ahs the sensation of being inside the body of the robot, though actually located thousands of kilometers away from the telerobot (possibly even located on Earth). The system could be equipped with super-human sensory capabilities, such as multi-spectral eyes. This concept combines human intelligence with robotic capabilities, without risk to a human operator, yet still provides the operator with the important sense of personal involvement in the field work. The use of teleoperators converts a single lunar base into a global base. The feasibility of this concept needs to be determined; many issues are discussed in (5). The most important technical issue is whether geologists-operators could be located on Earth. The question focuses on the maximum time delay that can be tolerated *without degrading the quality of the field work.* There might be more flexibility for field work than for complex mechanical tasks such as construction or repair.

If experiments show that high quality field work can be done on the Moon by operators located on Earth, many interesting possibilities spring to mind. Most important is the active involvement of many more geologists than will be on the Moon during the first few decades of base operations. More areas could be studied, more samples could be returned, and more intellectual energy could be expended on solving problems in lunar and planetary science. Graduate students, some of whom might someday do field work in person on the Moon or Mars, could be trained in extraterrestrial field work. A major advantage of this is that many important geological discoveries have been made by students doing field work for their master's or doctoral theses. We could expect the same on the Moon. It might turn out that for the first couple of decades after we finally return to the Moon that the only permanent inhabitants are teleoperators.

When do human geologists do lunar field work? There are three likely cases. First, humans ought to study the geology near the lunar base; a geologist at the base will certainly want to. Second, and most important, the human needs to go in person when a problem is too complex for the teleoperator-human operator team to figure out. Third, possibly when the terrain calls for more agility than a vehicle can provide. Fourth, whenever an astronaut-geologist wants to.

References: 1) Taylor, G. J. and Spudis, P. D. (Editors) (1990) *Geoscience and a Lunar Base: A comprehensive plan for lunar exploration*, NASA CP 3070. 2) Ryder, G., Spudis, P. D., and Taylor, G. J. (1990) The case for planetary sample return missions. *EOS* **70**, 1495, 1505-9. 3) Pettijohn, F. J. (1984) *Memoirs of an Unrepentant Field Geologist*, University of Chicago Press. 4) Spudis, P. D. and Taylor, G. J. (1991) The roles of humans and robots as field geologists on the Moon. *Proc. Second Lunar Bases Symp.*, in press. 5) Taylor, G. J. and Spudis, P. D. (1990) A teleoperated robotic field geologist. *Proc. Space '90*, 246-255.