Robotic sample acquisition

The primary purpose of the robotic planetary rover is to deploy scientific instruments to targets of interest and acquire physical samples for in situ analysis by scientific instruments or for subsequent return to Earth. The first step in scientific analysis of soil and rock from planetary surfaces and subsurfaces in particular is sample acquisition. Sample acquisition is typically performed by robotic manipulator, abrasion, drilling, and burrowing. Each is considered in turn. The first step toward such acquisition is to understand the nature of the environment from which the sample is to be extracted. There are two types of regolith environments that are likely to be encountered (excluding ice): (i) regoliths from planets with atmospheres such as Mars which have been subjected to weathering influences but which have been spared microtektite bombardment; (ii) regoliths from planets or other small bodies which have not been exposed to weathering but have been subjected to eons of microtektite bombardment (e.g., the Moon). For the Moon, hollow drive-coring tubes were hammered vertically into the regolith by the Apollo astronauts to depths of 1 m—it took 50 hammer blows to penetrate to 70 cm. Rotary drill core tubes were able to penetrate to depths of up to 3 m at which point the soil became highly compacted due to eons of micrometeoroid bombardment [1099]. The regolith layer is estimated to be 10–30 m thick. This characteristic of a thin layer of loose regolith overlying a highly compacted layer is expected to occur for all atmosphereless bodies such as asteroids.

The Martian surface and near-surface regolith is believed to be saturated in oxidants such as hydrogen peroxide, metal oxides, peroxides, and superoxides. This region will thus be devoid of organic material—the Viking lander gas chromatograph/mass spectrometer detected no organics at the parts per billion level for heavy organics and the parts per million level for light organics. This upper limit is far lower than that expected from meteoritic influx of carbonaceous chondrites over the eons. It is believed that solar UV flux acting on the small
amount of water vapor in the lower atmosphere generates hydrogen peroxide and other peroxides in the soil. In addition, the UV-induced Fenton’s reaction may occur forming hydroxyl radicals in the soil which rapidly oxidize organic compounds. UV flux at the Martian surface is 2.6 mW/cm² (around four times that on Earth). Furthermore, the loss of atmospheric water constituents such as hydrogen from Mars was due to the higher UV flux during the Sun’s early main sequence phase which led directly to the incorporation of oxidants into the soil [1100]. The distribution of this oxidant layer is controlled through both molecular diffusion and meteoritic impact gardening which suggests a depth of several meters, nominally an average oxidant extinction depth is ~3 m based on crater population, onset of oxidizing conditions, and absorption of water [1101–1104]. Oxidants comprise H₂O₂, O₃, and H₂O in the Martian atmosphere at ~10¹⁰/cm³ which diffuse into the Martian soil. The diffusion may be modeled by Fick’s law of linear diffusion:

$$\phi = \frac{dC}{dt} = -D \frac{\partial^2 C}{\partial z^2} = -D \frac{f}{q} \frac{dy}{dz}$$

where C = peroxide density (concentration) in regolith, Φ = UV flux, D = diffusion coefficient, f = porosity, q = tortuosity, γ = mass density of pore vapor, and z = vertical depth. The extinction coefficient is defined to be the point at which peroxide density drops to 10⁻⁶ of its surface value. The regolith is fully oxidized to a depth of 30 cm by diffusion. The onset of oxidizing conditions occurred after the end of the heavy bombardment phase ~3.8 Gyr ago when the cratering rate was 10⁴ that subsequently. Oxidants cannot survive excess water conditions. Hence, the mixing conditions for oxidant stirring by impact gardening would have been reduced suggesting a 1/e oxidant depth of 0.5–0.85 m (i.e., absence of oxidant below a depth of 2–3 m). Hence, astrobiological prospecting will require accessing samples from subsurface depths below this [1105, 1106].

Although Kapvik did not incorporate any subsurface drilling capability, the Vanguard Mars rover concept did. The mode of subsurface penetration selected for Vanguard was the ground-penetrating mole. In situ sensor heads may be accommodated within the mole while the instruments themselves reside on the rover. Such a device can penetrate to a nominal depth of ~3 m. By employing three such devices, there is no requirement to return the moles back to the surface once they have been deployed—they can emplace sensor heads of rover-mounted instruments into the borehole. This significantly reduces the robotic complexity involved in extracting the moles. The microrover can deploy each mole in turn to provide a triplicate depth profile. This requires the use of remote-sensing instrumentation that can exploit separation of the sensor head from the main instrument to eliminate the need for taking soil samples—the primary instruments would be a Raman spectrometer, an infrared spectrometer, and a laser plasma spectrometer. Augmentation with thermal probes and/or magnetometers within the moles would provide valuable in situ geophysical data. The use of a ground-penetrating radar for drill site selection would ensure that submerged boulder obstacles within the regolith could be avoided. Given that the Martian regolith