Exploration Timeline

The Apollo missions returned many valuable rock samples, but the astronauts visited only a few locations — less than 1% of our Moon's surface has been explored. To extend our knowledge of the entire lunar surface, scientists gather spectral and other data using instruments onboard spacecraft orbiting the Moon. Researchers use this information to unravel the geologic history of the Moon and identify where concentrations of resources occur to support human habitation. Several missions have looked at our Moon in a "new light." Each brought increasingly sophisticated instrumentation to the Moon, and each provided new scientific information . . . and raised new questions!

NASA's **Galileo** spacecraft flew by the Moon en route to Jupiter. The spacecraft carried a camera that captured information in specific visible and near-infrared wavelengths and provided the first multispectral images of the Moon. These data helped scientists coarsely map abundances of minerals, and provided new information about the composition of the lunar farside and polar regions.

The **Clementine Mission** (Department of Defense and NASA) spectrometers measured reflected light in eleven wavelength bands from ultraviolet to the near-infrared (415 to 2800 nanometers). The spectral signatures allowed scientists to map the broad distribution of lunar rock types and soils, resolving the surface at a scale as small as 325 feet (100 meters). They mapped the compositional differences in the largest impact basin on the Moon — and the biggest hole in our solar system — South Pole Aitken Basin. They also identified regions near the lunar south pole that may be in permanent shadow; these permanently cold regions are ideal environments for water ice to collect.

Lunar Prospector followed Clementine, collecting spectral data to identify potential resources in the lunar crust, including minerals, water ice, and certain gases. It carried a gamma ray spectrometer. Gamma radiation is not reflected radiation; it is emitted from the decay of radioactive elements or from elements bombarded by high-energy solar radiation. Each element emits gamma rays at a characteristic energy or wavelength. The gamma ray spectrometer mapped the abundances of ten elements on the lunar surface. Some of these, such as iron, oxygen, aluminum, silicon, and titanium, are important resources for future habitation. Data collected by other spectrometers onboard suggested the presence of hydrogen, possibly related to water ice, in the permanently shadowed polar regions.

The European Space Agency's Small Missions for Advanced Research in Technology (**SMART-1**) spacecraft included several spectrometers to characterize the chemical composition and help identify water ice on the Moon. The mission identified compositional changes associated with impact craters and analyzed the lunar interior excavated by the impactors. The Japan Aerospace Exploration Agency's **Kaguya** carries X-ray and gamma-ray spectrometers that will provide information about the major elements in the lunar crust to help scientists understand how the crust formed. **Chang'e-1**, part of the China National Space Administration's lunar program, carries an imaging spectrometer, as well as X-ray and gamma-ray spectrometers, to help determine the composition of the lunar surface.

The Moon Mineralogy Mapper, a NASA instrument onboard the **Chandrayaan-1** spacecraft, will allow scientists to create the first highly detailed maps showing the surface distribution of minerals across the entire Moon. Data from another Chandrayaan-1 instrument, the Mini-SAR, will help to characterize the roughness of the lunar surface and search for ice in the permanently shadowed polar regions.

NASA's **Lunar Reconnaissance Orbiter** mission instruments will characterize the radiation levels and temperatures of the lunar environment, and will collect high-resolution images to determine future landing sites. Its instruments include the Lunar Exploration Neutron Detector, designed to characterize possible near-surface water ice deposits in the permanently shadowed regions, the Lunar Reconnaissance Orbiter Camera, which will provide multispectral data to map mineral resources, and the Lyman-Alpha Mapping Project, which will detect ultraviolet radiation reflected from permanently dark regions to identify water ice and map surface features. NASA's **Lunar Crater Observation and Sensing Satellite** will use visible light and infrared spectrometers to search for signs of water ice in a permanently shadowed crater near the Moon's pole.

These missions provide scientists and engineers with detailed maps of the lunar surface features, materials, and environment and will be used to determine the locations of future lunar outposts. This new information, enhanced by future exploration, will help scientists decipher the history of the Moon and early Earth — and lead to new questions!