THE MOON AS A TOUCHSTONE FOR SOLAR SYSTEM SCIENCE. James W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912 (james_head@brown.edu).

Lessons From Lunar Exploration: Ten things we have learned about the Moon have set the stage for our thinking about the early evolution of the Earth and other planetary bodies: 1) The Moon formed from the impact of a Mars-sized object into early Earth: How does this process, and its immediate aftermath, set the Moon on an evolutionary path that is the same as, or different than, other planetary bodies? 2) The early Moon was characterized by a global-scale magma ocean: Near-global melting caused by accretional energy produced an anorthositic highland crust, a "primary crust". Is the evolution of the lunar "primary crust" unique? How do primary crusts on planets with different compositions and interior structures form and evolve? 3) The Moon initially differentiated into chemical layers, including a crust and mantle, which set the stage for further evolution. What is the nature of late-stage crustal differentiation processes and how do they contribute to the character of lower planetary crusts? 4) The chemical and thermal nature of these stratified layers may have led to net negative buoyancy, large-scale overturn, and significant vertical mixing. Is this predicted early overturn unique to the Moon or applicable to other planets? 5) The Moon is stratified into mechanical layers; the lithosphere, the outer thermal boundary layer, thickened and became less heterogeneous with time. What controlled the initial thickness, variability and rates of thickening on the Moon and other planets? 6) Tectonically, the Moon is a one-plate planet, characterized by a globally continuous lithosphere; how does the evolution of the global state of stress in the lithosphere, recorded in the sequence of tectonic features, and the thickness of the lithosphere with time, as recorded in its flexural response to loads and in the gravity field, vary from body to body? 7) Lunar volcanism records processes of mantle melting in space and time, and the volcanic record reflects the general thermal evolution of the Moon, including the state and magnitude of stress in the lithosphere. The unique ability to link lunar samples to specific deposits significantly enhances our understanding of these processes: for example, recent results implicate water in the formation of volatile-rich pyroclastic eruptions. How does the volcanic record of the planets differ? 8) The Moon is a fundamental laboratory for the study of impact cratering processes, particularly at the complex crater to multi-ring basin scale. The ability to combine studies of lunar impact breccias and melts with crater and basin deposits considerably enhances this understanding. How can this understanding be applied to other planets? 9) The Moon is a template for the record of the distribution and history of impactors in the inner solar system. The lunar cratering record, in conjunction with the unique chronology afforded by returned and dated samples, can inform us about a) the reality of a Late Heavy Bombardment, b) the changing size-frequency distribution of impactor populations with time, and c) the potential non-linear nature of the bombardment record in the last half of solar system history. 10) Volatiles play a more important role in lunar evolution than previously thought: Recent reports of detection of water and water-related species: a) as coatings on surface minerals, b) in buried near-polar deposits, and c) in mantle derived melts, all provide exciting insight into a range of water-related processes during different time in lunar history, including accretion, differentiation, cometary impact, and interaction with the solar wind.

Role of the Moon in Future Planetary Exploration: In what context does this integrated comparative planetology perspective place the Moon? Some see the Moon as a *cornerstone*: this metaphor implies that the Moon is of extreme importance because all other stones will be set in reference to it, thus determining the position of the entire structure. The Moon as a *keystone* implies a central cohesive source of support and stability for ideas about the formation and evolution of planets. Still others see the Moon as a *Blarney stone*: those who have "kissed the stone" have been imparted with an excessive skill in flattery about the Moon. It can be argued that the lessons from comparative planetology place the Moon where it belongs, as one member of a family of Solar System objects, each of which provides insight into fundamental lessons of planetary evolution. As such, an appropriate metaphor for the Moon might be a *touchstone*, which refers to any physical or intellectual measure by which the validity or merit of a concept can be tested.

The Renaissance of Lunar Exploration and What it Means for the Future: At the advent of the atomic age, Albert Einstein is reported to have said: "Everything has changed but our way of thinking", a thought that might be applied to our current understanding of the Moon and its role in solar system exploration. ESA, Japan, China, India and the United States have launched comprehensive missions to the Moon, and each has plans for continuing lunar exploration. The onslaught of new data is monumental, and the data are just barely starting to be ingested, digested and analyzed. Nonetheless, the future is clear. We are on the verge of a renaissance in our study and understanding of the Moon. We are acquiring extremely high spatial and spectral resolution data across a wide wavelength range. This has changed everything, and fundamental changes in our way of thinking will surely follow: The distribution of rocks from the lunar sample collection can now be mapped globally. New minerals and rock types are being discovered. The provenance of recognized rock types can be studied and established using new very high spatial and spectral resolution data. The mineralogy and context of individual large boulders and clusters of boulders can be mapped, and then placed in their geological contexts. Models of crustal stratigraphy can be tested and depth of sampling of craters can be assessed. Refined models of crustal stratigraphy and evolution can be constructed. New avenues of communication are being opened between planetary scientists utilizing approaches such as mineralogy, petrology, geochemistry, geology, spectroscopy, geophysics, etc. The lunar renaissance is propelled not just by the new data, but also by the fundamental foundation and interpretative context provided by information collected by dozens of previous missions, and analyzed in sophisticated laboratories on Earth. These data have provided a basic framework that is unequalled on any planetary body other than the Earth.

Lessons for Future Lunar Exploration: The basic framework of the lunar renaissance will crisply define the questions to be addressed by a range of new lunar robotic missions including geophysical networks, sample return, and integrative rover missions. When humans inevitably return to explore the Moon in the coming decades, the lunar renaissance will have provided both compelling reasons for human exploration and detailed locations at which humans can optimize their exploration skills.