PLANETOLOGY—COMPARATIVE PLANETOLOGY OF EARTH-LIKE PLANETS AND ASTROBIOLOGY

Bernard H. Foing
ESA Chief Scientist, ESTEC/SCI-SR, Noordwijk, The Netherlands

Keywords: Earth, planets, moons, solar system, organics, water, origin and evolution of life, astrobiology, space exploration and technologies

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Summary

Planetology treats planetary bodies, their atmospheres and smaller bodies in the planetary system. With comparative planetology research, we aim at better understanding of the evolution of planetary environments over geological time. It builds on recent findings from lunar missions (Clementine, Lunar Prospector) and opportunities from the near future (SMART-1, Lunar-A, Selene, Chandrayaan-1, Change 1, US Lunar reconnaissance orbiters, and landers). This research exploits the scientific framework opened by recent Mars missions (Mars Global Surveyor, Mars Odyssey) and ones launched in 2003 (Mars Express, US Mars Exploration Rovers) and future Mars landers (MSL or ExoMars) or sample return missions. With the many discoveries of life existing in extreme environments on Earth, the chances of primitive life also existing in other parts of our Solar System are increasing. Within astrobiology research, there is a need to develop methods to search and characterize complex organics and living organisms, and to study their survival in these extreme space environments. Given the flight opportunities (e.g. planetary missions and surface

landers) and advances in technology, it ought to be of high priority to pursue this exciting research which will provide new discoveries and deeper understanding on how Earth-like planets and Moons work and can be habitable to life. This research is needed to support the next steps of robotic and human exploration of the solar system

1. Introduction

Planetology is a branch of science, which deals with other planets (essentially in the solar system) including their atmospheres, and with smaller solid bodies in the solar system. The following four articles describe in more detail various branches of planetology:

W.-H. Ip: *The Solar System*.
T. Spohn, D. Breuer and P. Lognonne: *Comparative Planetology*.
D. Steel: *Planetary Satellites, Asteroids, Comets and Meteors*.
R. Schwenn: Solar Wind and Interplanetary Magnetic Field.

The first article deals with the solar system and its planets as a whole, particularly with its history and development. The second article explains in more detail the comparative planetology. The third article treats smaller bodies in the solar system, namely planetary satellites, asteroids, comets and meteors, knowledge of which provides us with information about the state and development of the solar system in the early phases of its history. The fourth article describes the solar wind, which is not part of 'classical' planetology but which fills in the interplanetary space and, therefore, is added to planetology for the sake of the Encyclopedia.

Here we deal with those parts of planetology, which are most important for life support systems, i.e. with comparative planetology and astrobiology. Comparative planetology allows us to utilize knowledge of other planets for better understanding of the Earth and its development. Astrobiology is of crucial importance for understanding the origin of life on Earth and development of its primitive forms. While the four specialized articles focus on the-state-of-the-art and a bit on history, the focus of this contribution is to a significant extent the future, including space missions under preparation.

2. Comparative Planetology

Comparative planetology is a core study area, and is a necessary part of the preparations for upcoming planetary missions, as well as being highly desirable for successful use of the data obtained and maximizing its scientific potential. More fundamentally, comparative studies are key to the continuing advance of our scientific knowledge of the Earth and the Solar System. Studies of the Moon, Mars, Venus and Mercury provide us with unique opportunities to further understand the processes and factors that have shaped our own planet.

2.1. Lunar research and exploitation.

2.1.1 A new fleet of lunar robotic missions

For example, the Moon, our closest planetary neighbor, bears the scars of countless impact craters, and holds the only accessible record of the conditions present in the Earth-Moon system over the past 4.5 billion years. The active geology and climate have long since destroyed the early record of these events on the Earth, so the Moon is critical to our understanding of the early history of our planet. The recent Clementine and Lunar Prospector missions to the Moon provided our first views of global geochemistry. The SMART-1 mission, and later SELENE will add to this our first global infrared data-set, and the first global measurements in X-ray Fluorescence, which will allow for the mapping of elemental Mg, and the minerals olivine and pyroxenes across the surface. These are critical to our understanding of the Moon's crustal evolution and origin, which is intrinsically linked to the early evolution of the Earth.

The Clementine and Lunar Prospector geochemical data-sets allowed stand-alone research into crustal evolution, thermal and volcanic evolution, and stratigraphic sequencing of the units on the Moon, as well as looking at potential sites of special interest for future investigations. These studies provide the base from which the data returned using SMART-1, Lunar-A, SELENE, Chandrayaan-1 and future lunar missions, will be analyzed. The lunar investigations will also prepare for the geochemical investigation of Mercury by the NASA Messenger and ESA's Bepi-Colombo Cornerstone mission.

2.1.2 What does the Moon tells us about our origin?

Lunar data can teach us about the formation and evolution of rocky planets and moons.

How was the Moon formed? The current consensus is that a Mars-size planet embryo impacted the proto-Earth, and that the Moon resulted from the re-accretion of material ejected during the impact, coming mostly from the impactor. The global composition of the Moon can constrain our understanding of the proto-Earth and of the physico-chemical processes that followed the impact. The compositional similarities between Earth and Moon are still a puzzle.

How do rocky planets form and grow? Models assume accretion from planetesimals originating from different parts of the Solar System. The Moon carries a record of the bombardment history in the inner Solar System, which was erased on Earth. Also the gravity, physical and chemical signature of giant impact basins is still imprinted on the lunar surface. The physics of impact processes can be investigated on different scales, making use of remote sensing, in-situ and sample data.

How do planets work and evolve? As a small planetary body, the Moon is a cornerstone for comparative planetology, allowing us to study processes of planetary differentiation, magmatic activity, volcanism, crust formation, and single-plate tectonics. The Moon appears to have significantly melted after its formation. To constrain theories on a possible magma ocean and on lunar crust origin, the magnesium abundance should be determined, a key goal for future X-ray measurements.

What is new about the Moon? Apollo and Luna samples have been put into a more global context with the Clementine and Lunar Prospector data. It was shown that the distribution of elements from orbit differs from that derived from lunar samples, which are limited in geographical coverage. The South-Pole Aitken basin was found to be the largest impact basin in the Solar System; it differs significantly in composition from highlands or marina and may provide a window to mantle material.

Is the Moon an attic of Early Earth and Solar System? The lunar surface is also a huge collector for samples from comets, asteroids, or even the early Earth, from the era of giant bombardment or emergence of life. It has been proposed that water ice could be trapped and survives in permanently shadowed craters at the poles. Lunar Prospector recently detected enhanced hydrogen concentration in these areas. There is still debate, as to whether this results from enhanced solar wind H trapping or from successive impacts of recent comets or water-rich asteroids. Clearly more data will be obtained from orbit on these polar volatiles, but we shall need in-situ measurements, and possibly deep samples to elucidate the buried record of water-rich impactors in the inner Solar System. This water ice issue has strong consequences for sustained scenarios of future human lunar exploration.

Biospheres on the Moon? The moon is an ideal test-bed to learn how life can adapt to an extraterrestrial environment. First we can study extraterrestrial organics without contamination, and validate procedures for planetary protection. We can also see how microbial populations can be maintained and evolve in another planetary surface. Using resources from the Moon, we can progressively settle living bacteria, vegetal, and animal communities. The Moon can be used as a laboratory for sustained development of biospheres, using in-situ resources and closed ecological life support systems. Finally, the Moon has potential to host permanent human bases and villages, or even to serve as a refuge for Earth-life and a springboard for human exploration of the solar system.

2.2. Mars research

2.2.1 Mars and the Earth

Like the other planets in the Solar System, the Earth and Mars are thought to have condensed about 4.6 billion years ago from the solar nebula, a giant cloud of hot gas swirling around the young Sun. The evolution of the two planetary neighbors has been driven ever since by the loss of heat produced by radioactive decay within their interiors.

The two planets share many similarities—both have hard crusts and dense cores, and are made from the same materials, though in different proportions—but they are also very different. Today, Earth is a dynamic place, teeming with life. Mars is relatively static and lifeless—although it's just possible that primitive life exists below the surface.

It is not surprising that the evolution of the two planets has resulted in these very different outcomes. Mars is one and a half times as far away from the Sun as Earth, and it is also much smaller. Because of its smaller size, Mars has also cooled more rapidly than Earth, and this accounts for its present relatively static state.

The Earth's surface is still continually changing. Plate tectonics is one of the major forces that sees to that. New crust forms at seafloor spreading vents and old crust is swallowed up into the Earth's interior at subduction zones. Plate tectonics may have played a role in shaping the Martian surface during the planet's first 500 million years, but large parts of the Martian crust have been undisturbed by such major transforming forces.

Most of the southern hemisphere of Mars consists of such ancient crust. (Only small isolated pockets of 4 billion-year-old rocks still exist on Earth.) Planetologists date the surface of rocky planets from the number, size and degradation of impact craters: the higher the density of craters the older the crust. The southern crust of Mars is scarred by many impacts, indicating that it has not been reformed since the impacts were made. On the edges of this ancient crust are the largest volcanoes in the Solar System. Their great size suggests that they have been allowed to grow for billions of years undisturbed by major crustal recycling. The northern crust of Mars is far less scarred than in the south, suggesting a younger age. The processes that formed this young, lowland region, but left the south undisturbed, remain a major unknown about Mars.

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Biographical Sketch

Prof. Bernard H. FOING, is Chief Scientist for the ESA Science Programme. Born in Carcassonne, France, he was admitted in 1977 at ENSET "Ecole Normale Supérieure of Education & Technology". He became Professor Agrégé of Physical sciences in 1982. He obtained a PhD on "Astrophysics and Space Techniques" using a sounding rocket ultraviolet camera experiment with Prof R.M. Bonnet, at CNRS/LPSP and research stays in the US (Lockheed Palo Alto, Sacramento Peak NM, HAO Boulder CO , Harvard Observatory). On 1983-1986, he worked in Chile as astronomer for ESO European Southern Observatory, Cooperant with French embassy, and as Professor of Astrophysics. A permanent researcher at CNRS Institut d'Astrophysique Spatiale (1986), he obtained responsibility for direction of research in 1990. Since 1989, he has worked at ESA Space Science Department/ESTEC, as visiting scientist, staff scientist, study scientist (SIMURIS interferometer, MORO lunar orbiter, EuroMoon polar lander), Research Unit Coordinator, Project scientist of SMART-1 (first European mission with solar electric propulsion to the Moon, launched in 2003), Head of the Research Division, and Chief scientist. He has been active at ILEWG (International Lunar Exploration Working Group, sci.esa.int/ilewg) as president (1998-2000), and now as Executive Director. He has published over 300 articles, including 120 refereed papers, in solar/stellar physics, fullerenes and complex organics in space, astrobiology, instruments, lunar and planetary exploration, and was Co-I of space projects such as TRC, SOHO, XMM, BIOPAN, SMART-1, Mars Express, COROT, ISS/Expose, as well as PI /co-I on more than 100 investigations/campaigns using ground/space facilities. He has edited 15 books and organized over 35 international conferences and symposia. He shares with students and the public his passion for space and Europe, and has realized numerous material, exhibitions and media events. He has been hiking up to 5500 m in the Andes during an eclipse expedition. An amateur of arts, he plays viola (superior studies), guitar and accompaniment piano.