Solar system

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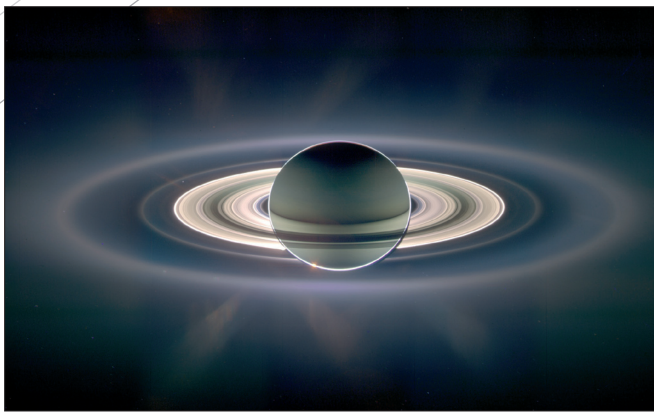
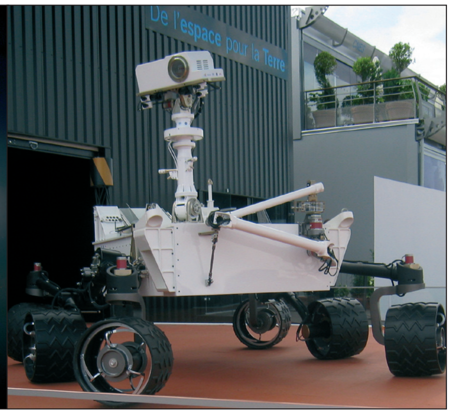


[Fig. 1]



[Fig. 2]

Rosetta: deciphering the Rosetta Stone of our origins

The Rosetta spacecraft of ESA, launched on March 2, 2004, flew by Mars in early 2007 and Earth in November. It passed by the E-type asteroid 2867-Steins on September 5, 2008. On July 10, 2010, Rosetta will fly by the asteroid 21-Lutetia. After a ten-year cruise and four gravity assists (Earth, Mars, Earth, Earth), the satellite will rendezvous with the Churyumov-Gerasimenko comet in 2014 and will then drop off the lander Philae on its surface. These are two world firsts. CNES coordinated all French contributions to the payload and lander: eleven instrumental and two technical contributions (two subsystems for the lander and a part of its ground segment).

Mars Express: flying by Phobos

For more than six years, the European probe Mars Express has been observing the red planet. It represents a great success for Europe, being its first mission dedicated to this planet. Consequently, the mission has been extended until 2012. Between February 16 and March 26, 2010, Mars Express performed a dozen closing approaches of the moon Phobos. On March 3, the closest flyby took place at 67 km above the surface (fig. 3). The objective was to determine the internal structure of the satellite by measuring its gravitational influence on the probe. Most of the instruments were successively used, such as the Omega spectro-imager which should provide interesting information on the mineral composition of Phobos in order to understand the mechanism which led to its formation. Results are currently being analyzed.

Cassini

The Cassini mission has been continuing its observations of Saturn's system since its arrival in July 2004. French scientists, involved in almost every one of the twelve instruments, form the first scientific community after the Americans. Christophe Sotin of the *Laboratoire de Planétologie et Géodynamique de Nantes*, is currently at the Jet Propulsion Laboratory. He is in charge of coordinating the flybys of Titan (more than 70 to this day). An estimate of the depth of Titan's lakes was obtained at the Observatory of Bordeaux by analyzing the data from the Cassini radar. In early February 2010, NASA announced it was extending the mission until 2017. This second extension called "Cassini Solstice Mission" has been granted on the argument that it allows to observe Saturn's system during half a kronian year in order to study the seasonal effects on the planet but also on Titan. This long extension will allow to complete 155 orbits around Saturn, fly by Titan 54 times and Enceladus 11 times. The final stage of the mission foresees the trajectory of Cassini to pass between the rings and Saturn before ending with a controlled entry in its atmosphere.

Mars Science Laboratory: a model of Curiosity

MSL is made of a third generation rover recently named "Curiosity" that will explore the surface of Mars beginning in August 2012. Weighing 750 kg, hence three times heavier than Spirit and Opportunity, it is powered by a radio-isotope generator. This mobile robot will possess analytical capabilities far better than the two Mars exploration rovers currently on Mars.

After a very tight competition, the two French contributions selected by NASA are the following:

- ChemCam (laser-induced remote sensing for chemistry and micro-imaging) is an instrument allowing to realize a first analysis of rocks up to 10 m around the rover. It uses UV spectroscopic analysis coupled with laser ablation. The Los Alamos Laboratory and CESR of the Paul-Sabatier University in Toulouse (CNRS) are participating. CNES is preparing its involvement in the operations of the instrument as part of a cooperation with the Los Alamos laboratory.
- SAM (Sample Analysis at Mars) is an experiment dedicated to the analysis of the atmosphere and the isotopic and molecular composition of organic elements contained in minerals. SAM will be at the heart of the analysis laboratory on board the rover. The Goddard Space Flight Center of NASA and LATMOS of CNRS participate in it.

In fall 2007, the French CESR Co-PI of the ChemCam instrument, supported by CNES and the local representative of the Ministry of Education, launched an educational project aiming at realizing a scale-1 model of the mission rover. The project involved ten technical colleges of the Toulouse area over two school years. The model was shown in front of the CNES stand at Le Bourget the Paris Air Show in June 2009.

Phobos-Grunt: sample return in sight

The CNES-Roscosmos agreement on French contributions to the Phobos-Grunt mission was signed on June 17, 2009 by the presidents of CNES and Roscosmos.

The agreement focuses primarily on instrumental contributions to the scientific payload of the mission. These contributions are currently being delivered in Russia. Moreover, the agreement includes the possibility for CNES to receive ground samples of Phobos brought back to Earth as part of the mission. To be launched in late 2011, Phobos samples are expected in fall 2014.

BepiColombo aims for Mercury in 2020

The BepiColombo mission is made of two probes:

- the MPO (Mercury Planetary Orbiter) dedicated to the study of the planet's surface and interior (under the responsibility of ESA),
- the MMO (Mercury Magnetospheric Orbiter) dedicated to the study of the magnetic field and magnetosphere (under the responsibility of JAXA)

The mission was officially approved by ESA's SPC in November 2009. The two probes will be launched simultaneously from Kourou by a Soyuz II1b rocket. After a common electrically-propelled cruising phase and an injection into orbit by a chemical thrust, they will separate near Mercury to start their respective missions in a coordinated manner. Launch is expected in July 2014 and arrival around Mercury in May 2020.

Since 2005, CNES and the laboratories of CNRS have been pursuing the development of the scientific payloads for the MPO and MMO orbiters.

EJSM: an ambitious mission to Jupiter

After a competition between a mission to Saturn (TSSM, ex Tandem) and Jupiter (EJSM, ex Laplace), both French initiatives, ESA and NASA decided on February 18, 2009 that the L-class mission towards a giant planet would be EJSM.

It is made of a NASA orbiter (JEO: Jupiter Europa Orbiter) to study Europa and Io, and an ESA orbiter (JGO: Jupiter Ganymede Orbiter) to study Ganymede and Callisto. The latter must still be subjected to an assessment phase in 2010. CNES launched a feasibility study in 2010 till mid 2011 on French contributions to the JGO and JEO orbiters' payloads. The call for proposals for the selection of the payloads is expected in late 2010. The final selection of the mission, currently in competition with IXO and LISA, will take place in early 2011. Launches on two separate launchers are envisaged in 2020 in order to arrive in orbit around Jupiter in 2026.

Mars Sample Return

The iMARS commission (International Mars Architecture for the Return of Samples) set up by the IMEWG (International Mars Exploration Working Group) created the scenario of an international reference mission for to return Mars samples around 2020. ESA and CNES co-organized a symposium in Paris to present the results of the group. It was held at the National Library of France on July 9 and July 10, 2008. The public included scientists, engineers, and both industry and agency representatives of many European countries as well as the USA (20), Japan and Russia.

[Fig. 3]

Fig. 1: *A backlit view of Saturn's rings.*
Fig. 2: *Scale 1 model of the rover Curiosity of the Nasa/MSL mission exhibited in front of the CNES pavillon at Le Bourget Paris air show in June 2009.*
Fig. 3: *Phobos in high resolution seen through the HRSC camera of Mars Express during the March 7, 2010 close approach. The resolution reaches 4.4 m.*

Solar system

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French Stardust Consortium: studies of comet grains from 81P/Wild 2.

Consortium français Stardust : étude des échantillons de la comète 81P/Wild 2.

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Abstract

Since the return of the Stardust spacecraft (NASA) in January 2006, six French laboratories have been involved in the study of grains from comet Wild 2. The goal is to understand the chemical evolution which marked the passage of the interstellar matter in the solar nebula. The French consortium studies have focused on mineralogy by electron microscopy and light beams in synchrotrons, geochemistry, isotope analysis and finally NanoSIMS studies of rare gases by laser heating.

Depuis le retour de la sonde Stardust (NASA) en janvier 2006, six laboratoires français sont impliqués dans l'étude des grains de la comète Wild 2. L'objectif est de comprendre l'évolution chimique qui a marqué le passage de la matière interstellaire à la nébuleuse solaire. Les études sont focalisées sur la minéralogie par microscopie électronique et par faisceau synchrotron, et les analyses isotopiques par NanoSIMS et enfin les études de gaz rares par sublimation laser.

Cometary dust particles are believed to be relicts of the primitive material of the early solar system. Their sojourn in a comet nucleus probably allowed the preservation of primordial signatures from thermal, aqueous or irradiation alterations. Cometary material has been available for studies in the laboratories since the Stardust mission (NASA) brought to Earth samples from the comet 81P/Wild 2 in January 2006 [1]. The comet dust was captured in low-density silica aerogel to minimize particle heating and other physical modifications that could occur during hypervelocity impact at 6.1 km/s. Some comet material was also collected using aluminum foils that were positioned between the aerogel cells. Since the return of the Stardust spacecraft, six French laboratories have been involved in the study of the returned grains. The objective of this study is to understand the chemical evolution which marked the passage of the interstellar matter in the solar nebula and constrain models of formation and evolution of planetary systems. The French Stardust Consortium has been supported by CNES and focuses mainly on mineralogy by electron microscopy (LSPES-Lille), synchrotron beams at ESRF and SOLEIL (IAS-Orsay) and geochemistry, noble gas analysis by laser heating, isotope analysis including NanoSIMS studies.

Collected Wild 2 material

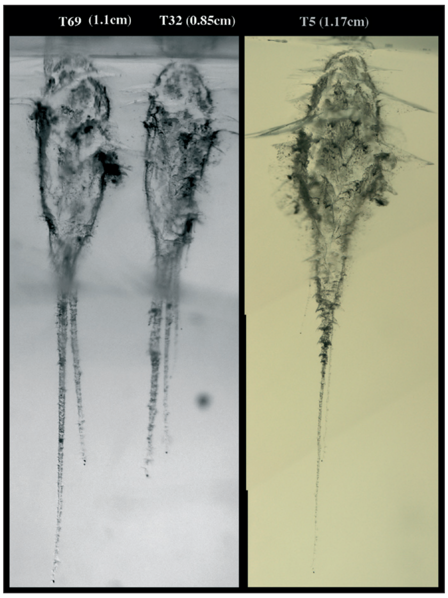
The impact of dust in aerogel generated deceleration tracks (Fig. 1) in which the cometary material itself is unevenly distributed in various proportions [2] [3] [4]. This configuration suggests abrasion and ablation or breaking up of the incident particles during the deceleration in the aerogel. For a number of samples, in particular those extracted from track walls, the Stardust samples display clear evidence of thermal modification in addition to strong intermixing with melted aerogel, showing that the particles suffered thermal alteration during the capture process. This situation significantly complicates the analysis and the understanding of these samples. Our studies showed that these strongly thermally modified samples originate from a fine-grained primitive material, loosely-bound Wild 2 dust aggregates, which were heated and melted more efficiently than the relatively coarse-grained material of the crystalline particles found elsewhere in many of the same Stardust aerogel tracks [5] [6] [7]. Very frequently, the bulk composition of these samples is very close to the CI-chondrite relative abundance, which is the most primitive material of the solar nebula. The detailed nature of this pristine material needs to be studied with more detail in the near future in order to understand the dust history before the accretion of the large parent bodies of our solar system.

The study of noble gases in the Stardust material showed a ubiquitous, primitive organic carrier for neon. Abundance of helium is surprisingly large, suggesting implantation by ion irradiation. This noble gas study points out gas acquisition in a hot, high ion-flux nebular environment close to the young Sun [8].

Particles found at the end of deceleration tracks (called terminal particles) are found well preserved and have not suffered from thermal modification due to the collect process. They correspond to components which penetrated more deeply into the aerogel. They are usually coarse-grained crystalline material, over one micrometer (Fig. 2). They are dominated by silicate grains (olivine and pyroxene) with a wide compositional variation [9], and include CAI-like particles and chondrule-like objects suggesting that some Wild 2 material is comparable to already known chondritic meteorites from the asteroid belt. Some of the particles show clear evidence of igneous processes [10]. These studies also support the view of particle formation in the inner region of the solar nebula followed by a large-scale radial mixing of matter in the protoplanetary disk before accretion in the comet.

Our team is also involved in the study of the interstellar grains which were collected by the Stardust mission. This part of the study is included in an international consortium called the Stardust Interstellar Preliminary Examination (ISPE). It is a three-year program to characterize the collection using non destructive techniques. Our contributions correspond to X-ray absorption on synchrotron beams at ESRF and electron microscopy survey of aluminum foils.

The Stardust samples consist of two main components of different nature. The first component consists of one or more terminal particles found at the end of impact tracks in the aerogel. These particles are crystalline silicates larger than one micrometer, whose composition suggests that they formed close to the Sun and were then redistributed in the cold regions of comet formation. A significant amount of cometary material is also present in track walls in the aerogel. The thermal effects induced by the hypervelocity impacts have partially destroyed the original microstructure. Nevertheless, this material corresponds to aggregates of very fine grains, sub-micrometric, with a composition similar to that of the most primitive meteorites. These aggregates are «cold» components of Wild 2 whose exact nature remains to be elucidated.



[Fig. 1]

[Fig. 2]

Fig. 1*: Deceleration track in the Stardust aerogel.*
Fig. 2*: Terminal particle (here olivine) as seen in the transmission electron microscope (TEM).*

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Solar system

Titan: the only satellite with a dense methane-rich atmosphere.

Titan : le seul satellite avec une atmosphère riche en méthane.

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Abstract

Before the Cassini-Huygens mission, Titan's surface was the largest unknown territory in the solar system. The nominal mission has revealed a variety of surface features including dune fields, lakes, river beds, mountains, few impact craters and some cryovolcanic flows. The surface is the boundary between the interior and the dense methane-rich atmosphere. Any geological feature provides constraints on both the atmospheric processes and the internal processes in the past and at present time.

Avant la mission Cassini-Huygens, la surface de Titan représentait la plus grande étendue inconnue du système solaire. La mission nominale nous a révélé une grande variété de traits géologiques : champs de dunes, lacs, lits de rivières, montagnes, cratères d'impact et coulées cryovolcaniques. A l'interface entre l'intérieur et l'atmosphère dense riche en méthane, la géologie de Titan nous fournit des précisions sur les processus internes et atmosphériques présents et passés.

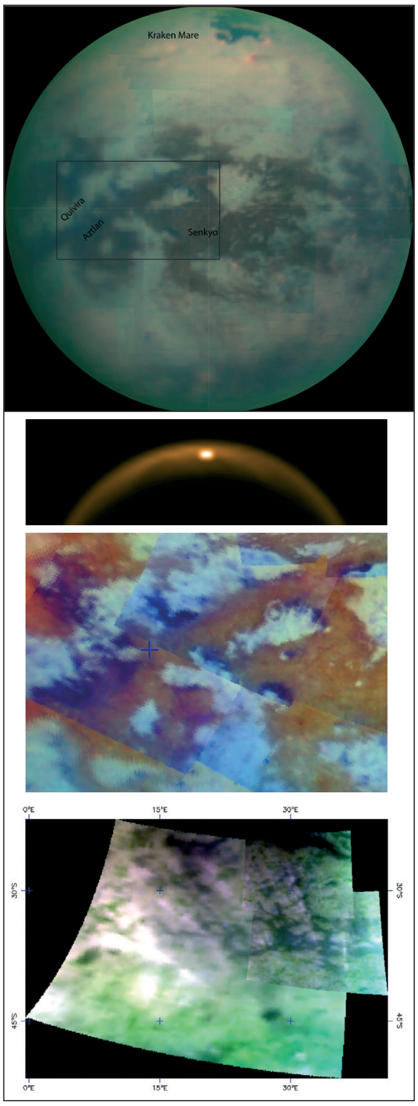
Since July 2004, the Cassini spacecraft has been in orbit around Saturn and has performed more than 60 flybys of Saturn's largest moon Titan. In January 2005, the Huygens probe descended into Titan's atmosphere and recorded its temperature, pressure (1.5 bar at the surface), composition, conductivity and electric field as a function of altitude. Its camera took a series of images revealing the presence of river beds and icy pebbles in the vicinity of the landing site. The remote sensing instruments onboard the Cassini spacecraft (radar, ISS and VIMS) have revealed equatorial dune fields, the mountains of Xanadu, lakes, and a few impact craters [1] [2] [3]. These observations suggest that Titan's surface is shaped by erosion processes involving the carving of bright plateaus by liquids carrying materials in the dark lowlands (Fig. 1). The liquids are likely hydrocarbons such as methane and ethane which rain on Titan. However, Titan is not a cloudy world by terrestrial standards. The cloud monitoring by the optical instruments reveals three different classes of clouds: outbursts at the south Pole, mid-latitude elongated clouds in the southern hemisphere, and a north polar hood likely formed by the downwelling of ethane in the global seasonal circulation.

The atmospheric composition suggests that exchanges between the interior and the atmosphere must have happened in the past. First, methane is the second most abundant atmospheric molecule with values ranging from 5% at the surface to 1.65% at higher altitude as recorded by Huygens. But methane irreversibly transforms into ethane and other higher mass hydrocarbons and should disappear on a timescale of a few tens of millions of years. Replenishment must have happened in a recent geological past as suggested by Tobie *et al.* (2006) [4] who invoked the destabilization of an outer crust made of methane clathrates by convection processes starting late in the history of the satellite. The timing of this event can be anything between a few million years and a few hundreds of million years. Second, the lack of significant amount of ^{36}Ar and the large amount of ^{40}Ar, a product of the decay of ^{40}K, argue for exchange processes between the K-bearing minerals (likely silicates), which are buried in the interior, and the atmosphere. Cryovolcanic features have been tentatively identified by remote sensing instruments [5] [6] [7] [8] [9]. Tui regio is a 5 µm bright area where lobate features have been identified by the radar team. A cryovolcanic construct first identified by the radar team [7] as a volcanic cone was later observed by the infrared spectrometer.

Titan's surface is obviously much younger than that of other Saturnian satellites such as Iapetus or Rhea because the density of impact craters is much lower. An accurate determination depends on the model describing the impact rate as a function of time. It also depends on the density of impact craters which is uncertain because several eroded circular features may turn out to be impact craters. Water ice is not observed at the spatial resolution of the remote sensing instruments. Titan's surface is covered with organics which are manufactured in the atmosphere before they fall and eventually provide the material for the dunes. The intensity of the reflected flux in the infrared windows has been tentatively interpreted as characteristic of a mixture of different molecules including CO_2, H_2O, NH_3, and tholins. The surface temperatures [10] range from 94 K at the equator down to 91.5 K at the North Pole during the winter season. The temperature at the South Pole is 1 K higher. These temperatures are higher than those at the surface of the other Saturnian satellites because methane creates a positive greenhouse effect that exceeds the negative one created by the haze layer.

The determination of both the gravity field and the interior magnetic field is limited by the altitude of the flybys. No induced magnetic field has been observed so far. The values of the gravity coefficients up to degree 3 have been recently published [11]. They suggest that Titan is in hydrostatic equilibrium and that the moment of inertia is intermediate between fully differentiated Ganymede and partly differentiated Callisto. The electric signal observed by the Huygens probe suggests that a conductive layer is present at a 45-km depth [12]. It could represent the thickness of the ice crust overlaying a deep ocean such as those discovered on the icy Galilean satellites.

Titan is a complex world where methane plays a role somehow similar to that of water on Earth. The methane cycle is controlled by several processes including the seasons which are 30 times longer on Titan. The so-called "Cassini Solstice Mission" has been approved for seven years of extension of the Cassini mission. It will witness seasonal changes on another world and answer questions on the formation of tropical clouds, the temperature inversion between the poles, the formation of a south polar hood, and the evaporation of the northern lakes. It will provide more constraints on the gravity field and more territory will be observed. All these observations are necessary to prepare a return to Titan with a new mission which will build upon the discoveries of the Cassini mission.



[Fig. 1]

***Fig. 1**: The four images are color coded images based on the intensity of the reflected signal in the different infrared windows. These images were acquired by the Visual and Infrared Mapping Spectrometer (VIMS) onboard the Cassini spacecraft. The full image of Titan was obtained after the Spring Equinox. The north polar cap becomes illuminated and the polar hood vanishes, unveiling the lakes which were discovered by the radar team. One can observe Kraken Mare whose liquid nature was demonstrated by the specular reflection (2d picture). The equatorial area shows the dark plains of Senkyo filled by dunes flowing around bright plateaus carved by rivers. Two higher resolution images (5 km/pixel) illustrate the complexity of the geological features.*

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COSPAR 2010

Solar system

Mars history: a reappraisal.

Une nouvelle histoire de Mars.

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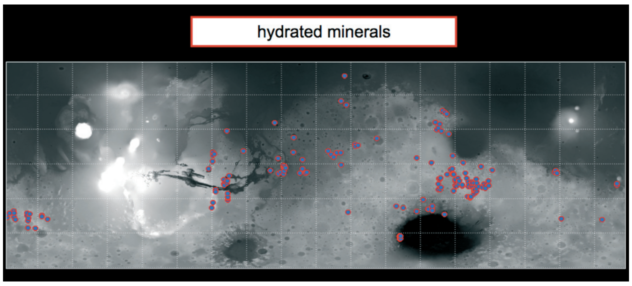
Abstract

The Mars space missions in operation, with Mars Express a major contributor, are acquiring data sets enabling an in-depth revisiting of Mars History at all time scales. They exhibit an ancient era of potential Mars habitability, with surface perennial liquid water, recorded in hydrated phyllosilicates within hundreds of spots across the Martian crust. A few have been identified as favored landing sites for the upcoming MSL and ExoMars missions of astrobiological relevance.

Les missions martiennes actuelles, et notamment Mars Express, éclairent d'un jour nouveau l'évolution de Mars à toutes ses échelles de temps. Elles mettent en évidence une ère, très ancienne, d'habitabilité potentielle de Mars, avec de l'eau liquide en surface. Elle est enregistrée sous la forme de minéraux hydratés spécifiques dans des centaines de sites au travers de la croûte ancienne. Certains sont privilégiés comme sites d'atterrissage pour les futures missions exobiologiques MSL et ExoMars.

The Mars space missions presently operating are acquiring unprecedented data, which give new insights into the Martian evolution from its seasonal changes to its long term climatic and geological variations. In particular, the coupling of imaging and spectrometry, performed by the VIS/NIR hyperspectral imagers OMEGA/Mars Express [1] and CRISM/MRO, has discovered Martian environmental changes, recorded in specific minerals formed and preserved over Mars History. The chronology is derived from the context in which given units, identified and characterized by diagnostic minerals, are observed. Based on these findings, a new mineralogical history is built, distinct from the previous Mars impact history.

The heavy bombardment period, which lasted more than half a billion years, captures a sequence of era of distinct properties. It started with the early accretion, which likely included a giant impact similar to (although of reduced size) the one responsible for the formation of the Earth's Moon: the Martian dichotomy might be a remnant of this event, as well as the moons Phobos and Deimos, possibly re-accreted within the accretion disk resulting from this impact. These



[Fig. 1]

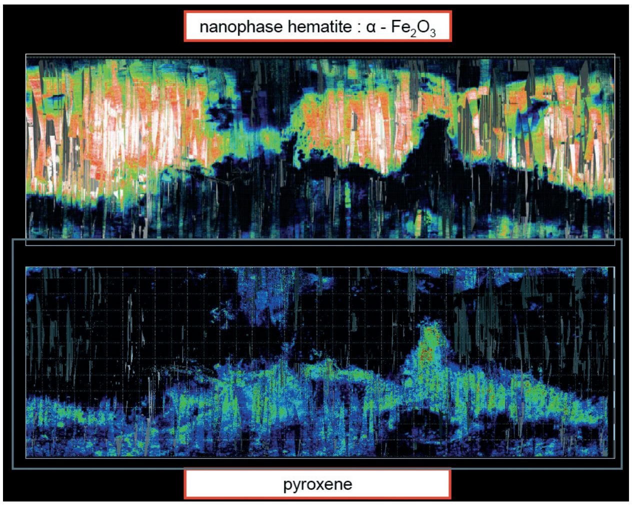
small bodies might thus be, partly, of Martian composition; their analysis, in particular through the upcoming Phobos-Grunt mission, would be of major importance to decipher the early accretion history of inner planets. During the follow-on phases which led to the heavily cratered Martian crust, Mars hosted a warm, aqueous environment, indicated by a key discovery of OMEGA, confirmed by CRISM, of hydrated phyllosilicates within hundreds of kilometer-size spots across the ancient crust. These minerals record a very early era during which liquid water was likely stable at the surface of Mars, as long standing structures, capable of altering minerals down to a few hundreds of meters; such stratification is still preserved in one key site: Mawrth Vallis. This era of potential Martian habitability is named Phyllosian, as recorded by the diagnostic presence of hydrated phyllosilicates.

The formation of phyllosilicates ended rapidly, prior to the drop of the heavy bombardment, the last episodes of which buried most of the surface phyllosilicates with deeper crustal material: most of the crust still exhibits its pristine, unaltered composition. This end of the Phyllosian would then have occurred as Mars suffered a global climatic change, disabling the stability of surface liquid water. One interesting possibility is that this environmental change was triggered by the rapid drop of the planetary dynamo -thus of the magnetic shield against the lethal effects of the still young Sun, which induced a massive atmospheric escape, in particular of the greenhouse gases. The MGS/MAGER magnetic measurements demonstrate that the crust solidified while the Martian dynamo was still active, while the large basins, the Tharsis bulge and the northern plains, crystallized after the dynamo had vanished. The drop of the dynamo might have driven the loss of most of the atmosphere, which in turn triggered the end of the habitable era -the Phyllosilian.

The surface liquid water in part evaporated and escaped, and in part percolated into subsurface ice. The neutral to alkaline aqueous environment, required to account for most phyllosilicates identified, changed into a highly acidic one, recorded by sulfates, discovered in younger terrains. The raise of the geothermal front, as Tharsis formed, brought back to the surface part of the percolated ice as large supplies of liquid water, sufficient to build large deposits of sulfates and to erode the crust in deep outflow channels, without feeding sustained oceans by lack of a dense-enough atmosphere. This era, named Theiikian (after theiikos, sulfates in Greek), did not last long.

It was followed by the arid and cold era still dominating, characterized by the slow oxidation of surface dust into nanophase hematite, an anhydrous ferric oxide responsible for Mars being reddish. This oxidation does not result from the action of liquid water, but likely from that of atmospheric peroxidic agents such as H_2O_2, which requires billions of years to penetrate a few tens of micrometers only. This era is named Siderikian (after siderikos, ferric oxides in Greek). During this era, a variety of transient processes have modeled the surface, of primarily two distinct origins: volcanic activity and obliquity changes. Without moons of sufficient mass to stabilize the planet obliquity, it entered oscillation of up to several tens of degrees over millions of years timescales; these changes triggered the sublimation of polar ices, their condensation in a number of sites down to equatorial latitudes, then follow-on sublimations and re-condensations. The net result is a variety of glacial features readily identified.

Since Mars has not undergone global resetting, it still exhibits surface units and features acquired over its entire History; the present missions have greatly contributed to detect and characterize Mars environmental changes, primarily preserved in distinct mineralogies. One of the most promising findings is the discovery of phyllosilicates still recording the ancient era during which Mars might have harbored habitable conditions. They pave the way for the upcoming NASA/MSL, ESA/ExoMars then MSR missions. If ever life emerged elsewhere than on Earth, we now know where to search for potential biorelics. Astrobiology is truly entering its scientific era.



[Fig. 2]

Fig. 1*: OMEGA map of hydrated minerals.*
Fig. 2*: OMEGA coupled maps of the nanophase hematite (top) and pyroxene (bottom).*

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