Chandrayaan-1: Unveiling Lunar Mysteries through Orbital Exploration and Scientific Discoveries

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ABSTRACT

The simultaneous chemical, mineralogical, and high-resolution topography mapping of the lunar surface is one of the main goals of the Chandrayaan-1 project. These findings should help us better grasp the compositional variance of the main elements, which will help us comprehend the stratigraphic links between the many litho units that make up the lunar surface. The first Indian planetary exploration mission, Chandrayaan-1, will conduct high resolution remote sensing. study of the moon to deepen our knowledge of its genesis and development. Hyperspectral photography Three imaging spectrometers and a low energy X-ray spectrometer will be used to provide high spatial resolution information on the lunar surface's chemical and mineralogical composition in the UV-VIS-NIR region.Chandrayaan-1, India's first lunar mission, marked a significant milestone in the country's space exploration endeavours. Launched on October 22, 2008, this ambitious mission aimed to explore and unravel the mysteries of the Moon through a combination of orbital observations and scientific experiments. Equipped with advanced instruments and technologies, the spacecraft successfully reached the lunar orbit on November 8, 2008.

Keywords: Chandrayaan-1, payloads, water on lunar surface, mission profile

INTRODUCTION

With a modest start roughly 60 years ago, the Indian Space Research Organisation (ISRO) went on to create rockets, satellite construction, communication, and remote sensing technologies. When the Polar Satellite Launch Vehicle (PSLV) was put into service in 1995, it gained the potential to carry out planetary research missions and at the turn of the century began an ambitious programme for studying the planets in the solar system. Chandrayaan-1, an orbiter mission to the Moon, which was completed in late 2008, was the first planetary mission.On October 22, 2008, Chandrayaan-1 was launched by an Indian Polar Satellite Launch Vehicle (PSLV-XL) version. On November 8, the spacecraft was placed into an elliptical lunar polar orbit, and on November 12, it was moved into the target 100-kilometer orbit. The Chandrayaan-1 mission ran smoothly up until August 28th, 2009, when a communication breakdown resulted in a loss of contact, and the mission was aborted on August 30th.The Indian Space Research Organisation (ISRO) launched the Chandrayaan-1 mission to kick off India's planetary exploration effort. It also carried two Indo-Foreign collaboration payloads (C1XS and SARA), four foreign payloads (M3, mini-SAR, SIR-2 & RADOM), and five Indian-built payloads (TMC, HySI, LLRI, HEX, and MIPS) [1]. A true worldwide effort in planetary exploration can be seen in the Chandrayaan-1 project.

More than any other celestial body, the moon, which is nearest to us, has piqued our curiosity. The largest impact of a planetesimal the size of Mars with Earth, which ejected a massive amount of material to form the Moon, is the most plausible theory for how the Moon formed. After that, the Moon underwent phases of partial melting that resulted in the formation of a magma ocean, solidification of the crust, delayed impacts of numerous extra-terrestrial bodies that left impact basins on the crust, and volcanism that caused the filling of these basins.The primary objectives of Chandrayaan-1 were to create a comprehensive map of the lunar surface, analyze the mineral composition, and search for signs of water-ice in the polar regions. The mission also aimed to investigate the lunar exosphere and study the moon's radiation environment. Over the course of its operational period, which lasted till August 29, 2009, the spacecraft transmitted a wealth of valuable data and images, contributing significantly to our understanding of the Moon.

As a result of the ground-breaking observations made by the Apollo, Luna, Clementine, and Lunar Prospector missions as well as the laboratory examination of lunar materials, a substantial amount of data about the Moon spanning chemical, geophysical, and geochronological elements are now available. These facts, which are important to understanding the Moon's formation, have been covered in [2,3]. The necessity for additional lunar exploration has been outlined by [4,5] and some of the key facts.The Moon is the second-brightest object in the night sky after the Sun, the fifth-largest satellite in the solar system. With a diameter of 3,476 km, a mass of 7.35x1022 kg, and a mean density of only 3.35 gcm-3 as opposed to the Earth's 5.52 gcm-3, the Moon orbits the planet at a distance of around 384,400 km. It has no atmosphere, and very little surface outgassing occurs. Since the Moon's gravitational pull is only onesixth that of the Earth's, it cannot support an atmosphere.The Moon experiences temperature extremes because it lacks an atmosphere. The lunar side that receives sunlight gets extremely hot, reaching 130 °C. The Moon's nightside hits a bone-chilling low of -180 °C. The Moon lacks an intrinsic magnetic field because it lacks an extensive core of molten iron, unlike the Earth. Instead, it possesses weak, dispersed, localised magnetic anomalies.

Why did India Launch Chandrayaan-1?

In an interview, the mission's director, recalled how Dr. K. Kasturirangan was responsible for the mission's conception. Kasturirangan wants the Indian Space Research Organisation (ISRO), which he led from 1994 to 2003, to have a tiny part in India's goal of becoming a superpower. This sowed the seeds for carrying out more challenging missions. A Moon orbiter was suggested, and everyone agreed that it was a good concept.At the time, ISRO already had satellites with geostationary orbits that could accommodate a large amount of fuel. The only modification needed was to modify a geostationary satellite for the Moon because the fundamental infrastructure was already in place. The PSLV rocket from India, according to preliminary estimates, may deliver an Earth-bound orbit beyond which the fuel on the spacecraft might be utilised to travel to the Moon and perform orbital capture. Chandrayaan-1 was an all-around logical advancement of ISRO's capabilities.

Chandrayaan-1 Mission Profile

The Indian Space Research Organisation plans to use the Polar Satellite Launch Vehicle to launch Chandrayaan-1, a remote sensing mission, from Sriharikota's Satish Dhawan Launch Station in 2007. It will be launched into an elliptical transfer orbit (ETO) measuring 240–36,000 km around the Earth and then placed into a circumlunar orbit (LOI) using a lunar transfer trajectory (LTT) [6].It will descend in one or two phases to a polar circular orbit of 100 km after entering the lunar orbit at a height of roughly 1000 km. The lunar craft is intended to orbit the moon for two years while conducting topographic, chemical, and mineralogical research on the lunar surface.

Chandrayaan-1 Mission Objectives

The mission's primary goal is simultaneous topography, chemical, and mineral mapping with the express purpose of comprehending the Moon's early evolution. The average lunar composition and the processes causing the Moon's chemical differentiation can be better estimated using chemical stratigraphy. By employing radon and its daughter nuclide 210Pb as tracers, it is possible to understand the transport of volatiles, particularly water, and their deposition in the cooler areas of the Moon as well as the degassing of the Moon.

Formation of the Moon

According to one theory, the Moon formed from the pile of material ejected from the Earth after a huge (0.1ME) differentiated interplanetary body (called Thiea) collided with the Earth at the Earth's last stage of formation [7,8]. The Giant Impact Hypothesis is a simulation of this scenario, and [9,10] have demonstrated that the debris expelled from the Earth following the impact can fast gather in a moon-sized body. However, there are still a number of issues that are unclear. First, from where did the Thiea originate? Since the Earth and the Moon share a similar oxygen isotopic composition and Thiea differs significantly from the other types of known meteorites (with the exception of enstatites), it is likely that Thiea formed close to the Earth at the beginning of its history. Some have claimed that Thiea developed at the Earth's L4 or L5 Lagrangian point. If both L4 and L5 are equally stable, then bodies must have formed at both Lagrangian points. If one has been perturbed by an impact with Earth, then what happened to the other?Will the other possibly sweep the material that was expelled and create the Moon's core? Second, since there are stable orbits (Keplerian, horseshoe, and corotating orbits) around every body in a system where planets are formed by the accretion of several planetesimals, several bodies can be captured in planetocentric orbits. In reality, a number of asteroids have recently been found in brief geocentric orbits.

Chandrayaan-1

India's first instrumented lunar mission is called Chandrayaan-1. The spacecraft is cube-shaped, has a side length of around 1.5 metres, weighs 1380 kg at launch, including 820 kg of propellant mass, and can hold eleven science payloads. On October 22, 2008, the 1380 kg spacecraft's 256 x 22866 km Elliptical Parking Orbit (EPO) was created using the PSLV-XL (PSLV-C11) rocket.

The spacecraft's 440N liquid motor was then utilised for both the Lunar Orbit Insertion (LOI) and injection into the Lunar Transfer Trajectory (LTT). On November 12, 2008, Chandrayaan-1 was finally positioned in a 100-kilometer circular polar orbit around the moon. The first Indian object to strike the lunar surface, the Moon Impact Probe (MIP), was launched from Chandrayaan on November 14th.

Description

The mission gave the Indian space programme a significant boost because India successfully studied and domestically built the technology to study the Moon. The mission's main goals were to: * Conduct various scientific experiments using the spacecraft's instruments to produce data for studies * Create a 3-D atlas of the moon's near and far sides * Provide high-resolution chemical and mineral imaging of the entire surface * Learn more about lunar volatiles by observing X-ray spectra in the energy range of 10-200 keV * Find evidence of water on the moon.On November 8, 2008, Chandrayaan-1 was launched aboard the PSLV-C11 launch vehicle, which successfully sent the spacecraft into lunar orbit. India became the fourth nation in the world to raise its flag on the lunar surface on November 14, 2008, after MIP (Moon Impact Probe) was successfully detached. MIP had previously made a controlled impact on the lunar South Pole. Due to a number of technical problems and a contact failure on August 29, 2009, the mission was officially deemed a failure after almost a year. Despite operating for only 312 days instead of the two years anticipated, Chandrayaan was a success since it met 95% of its intended goals. The most important finding made by Chandrayaan-1 was the abundance of water molecules in the lunar soil.

Fig. 1 Chandrayaan- 1 Spacecraft

Water on Lunar Poles

Water (ice or H2O in any form) is a crucial resource on the Moon, not only for building human bases but also for gaining insight into the behaviour and transportation of volatiles there.We can anticipate finding water on the Moon because:

- Water must have been present in the material that made up the Moon;
- Water may have been left behind on the Moon by asteroids and comets that have impacted it over time; and
- Water may be produced chemically when solar wind hydrogen degrades lunar silicate.

Despite these possibilities, neither the Apollo nor Luna samples, which represented nine different places on the Moon's front side, had any water or even water that had crystallised. But both the lunar poles appeared to have a lot of water, according to Clementine and Lunar Prospector.Two findings from the Lunar Prospector suggest that the Moon's north and south poles could both contain water or hydrogen-containing molecules. The neutron spectrometer's finding that the epithermal to fast neutron ratio at the poles has significantly decreased provides the strongest support [11].According to a theory put forth in [12], the lunarly implanted hydrogen from solar wind impacts is sufficient to produce the necessary signal for neutron spectrometer detection. Additionally, determine that a 7-year solar wind exposure is enough to deposit enough hydrogen to be consistent with the results.

Bistatic radar testing on Clementine provides additional proof that there is water present. We were also able to demonstrate the possibility of water at the lunar south pole based on the polarisation of the reflected to the incident signal [13]. The observation made by the Lunar Prospector as it passed close to the south pole, where it picked up a positive signal for the presence of water, served as a supporting piece of evidence.This evidence has been debunked by observations made from Earth using the Arecibo telescope, when it was discovered that there was no proof of water at the south pole [14]. The signal is noticeably different from Mercury's pole measurements, where the same technique has been used to demonstrate the existence of water. One of the main scientific goals when ISRO was developing Chandrayaan-1 was to find water on the Moon. Global space organisations were eager to establish the presence of water, ideally in significant quantities, as it would have consequences for both potential future human settlements and the genesis of the Moon. Two of the water-seeking devices that NASA proposed to fly on Chandrayaan-1 were accepted.They discovered that the patterns of reflected signals from more than 40 polar craters were consistent with water ice using a small synthetic aperture radar (Mini-SAR). But just like other attempts, like NASA's Clementine Moon-mapping satellite, the mini-SAR data wasn't infallible on its own. But Chandrayaan-1 also has a tool that could distinguish between ice, liquid water, and water vapour based on how the lunar surface reflected and absorbed infrared light: NASA's Moon Mineralogical Mapper (M3). The discovery that our Moon contains water was made definitively by M3, which also revealed that the majority of the water is localised at the poles.

The joint instrument SARA from the European Space Agency (ESA) and the Indian Space Research Agency (ISRO) stands out among the many more scientific findings from other Chandrayaan-1 equipment. SARA assisted scientists in making more accurate estimates of the quantity and distribution of water or hydroxyl locked in the soil across the Moon by examining how protons (hydrogen nuclei) in the solar wind impact and get reflected. The discovery came just in time for ESA's Bepi Colombo mission to explore Mercury, which has two sensors that are identical to one another for detecting water.

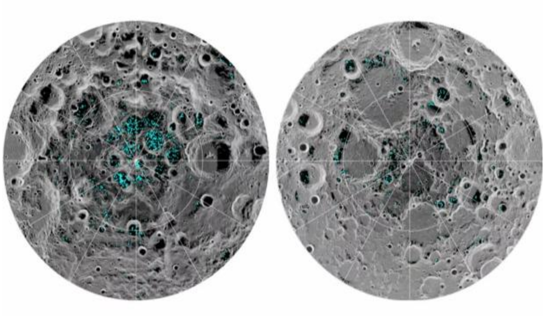

Fig. 2 Locations of water ice at the Moon's South Pole (left) and North Pole (right) as indicated by NASA's M3 instrument onboard India's Chandrayaan-1 spacecraft. The ice lies in permanently shadowed regions (Credit: NASA)

The Mission Details

The Moon Impact Probe (MIP) was launched on November 14 to travel to a predetermined spot near the South Pole after reaching the planned lunar polar orbit and undergoing inspections of various spacecraft sub-systems and parameters. The camera on board MIP took pictures that made it possible to locate its crash spot. The scientific payloads' commissioning came after this. Soon after launch, one of the payloads, the Radiation Dose Monitor (RADOM), was turned on, and the Terrain Mapping Camera (TMC), during one of the early earthbound orbits.Between November 16 and December 9, the other eight payloads were commissioned one by one. Up until April 26th, 2009, the mission operation went quite smoothly, however a star sensor malfunction prompted the decision to change the spacecraft's orbit from 100 km to 200 km in order to minimise the number of manoeuvres required for orbit maintenance. Mission termination was caused by a break in communication with the spacecraft on August 28.

Lunar Coverage

Despite the mission's early conclusion, the majority of the payloads collected a significant amount of high-quality data. Soon after launch, the radiation dose monitor (RADOM) began keeping an eye on energetic proton and electron fluxes, which it did throughout the duration of the mission. With extensive coverage of the polar region, the imaging equipment Hyper-Spectral Imager (HySI) and Terrain mapping Camera (TMC) covered around 50% of the lunar surface. More than 90% of the lunar surface was covered by the Moon Mineralogy Mapper (M3), while high spectral resolution data were being gathered by the infrared spectrometer (SIR-2).The lunar polar regions were thoroughly covered by the Lunar Laser Ranging Instrument (LLRI) and the Miniaturised Synthetic Aperture Radar (Mini-SAR). With its wide range of view, the Sub-keV Atom Reflecting Analyzer (SARA) has examined the whole lunar surface. Despite the lack of the anticipated high degree of solar activity, the Chandrayaan-1 X-ray Spectrometer (C1XS) produced extremely high-quality data. Due to insufficient detector cooling, the High Energy X-ray Spectrometer (HEX) was unable to operate during the noon–midnight orbit and only gathered a small amount of data.

Chandrayaan-1 Payloads

These goals have been taken into consideration when designing the Chandrayaan-1 payloads. There are two sets of payloads that are now being considered: the baseline payloads that the Moon Mission Task Force first suggested, and the payloads that the international community suggested in response to an ISRO statement of opportunity.

Terrain Mapping Camera (TMC)

To get a stereoscopic image of the lunar surface, TMC has three cameras: one for forward looking, one for nadir observation, and one for aft viewing. In push-broom mode, it will capture images of the lunar surface in the panchromatic spectral range between 0.5 and 0.85 m. With respect to the nadir, the fore and aft view angle is 25 degrees. From a nominal height of 100 km, it is anticipated to deliver a spatial resolution of 5 m and a swath area of 20 km.Because the Moon's lighting conditions are so variable, it is possible to change the gain and integration times to increase the signal-to-noise ratio [15]. For optimal performance, it needs solar illumination; hence the two-year observation period is separated into numerous imaging seasons depending on the solar aspect angle [16].

Hyper-Spectral Imager (HySI)

The Hyper-spectral Imager is made to map with high spatial resolution and analyse the composition of the main minerals found on the Moon, including olivines, pyroxenes, feldspars, and water ice.It uses a wedge filter with 64 continuous bands and a spectral resolution of roughly 15 nm that is sensitive between 0.4 and 0.92 m. It will have a 20 km sweep and an 80 m spatial resolution.An interference filter with a thickness gradient along one dimension is the wedge filter.An area array detector picks up the signal in such a way that various pixels of the 256 512 APS detector in a row will all receive irradiance from the same spectral region, but different spatial regions in the opposite track direction and different columns will all receive irradiance from various spectral and spatial regionsareas along the track direction. The imaging device operates in push-broom mode. This apparatusalso depends on the solar illumination; hence a solar aspect angle-based imaging approach has been created [17].

Lunar Laser Ranging Instrument (LLRI)

In Chandrayaan-1's payloads, a laser altimeter for topographic mapping has been added. It should be able to deliver a digital elevation map of the Moon with a 5 m spatial resolution when combined with TMC. The shadowed regions of the Moon can also be mapped because LLRI observations are not reliant on solar illumination. In order to adjust the data collected by other equipment for viewing geometry, altimetry information will be used. The 1064 nm Nd-Yag laser beams transmitting and receiving optics are used by the LLRI to measure the roundtrip travel time, which is then converted into altitude data. The instrument has been thoroughly explained elsewhere [18].

X-ray fluorescence spectrometer (LEX)

By measuring the flux of the distinctive K-ray X-rays of different elements like Mg, Al, Si, Ca, and Fe, an X-ray spectrometer sensitive in the 1 to 10 keV region would determine the main element composition of the lunar surface material. A solar X-ray monitor (SXM), consisting of two Si pin diodes orthogonally positioned and each covering a field of view of 90 degrees, will continuously monitor the Sun because fluorescent X-rays are excited by the solar flare X-ray flux.

The solar cycle's phase affects the frequency and energy range of solar flares.This method allows for the measurement of the distribution of Mg, Al, Si, and possibly Ca, Ti, and Fe during powerful X-ray flares.A spectrometer with an active area of 50 cm2 like the one in the Smart-1 mission [19]

Should work well for this.A sweeping charge device is used by the spectrometer to maximise the signal to background ratio. It is anticipated to have a spatial resolution of 20 kilometres with a 5 collimator. An imaging approach has been created because the X-ray spectrometer's operation depends on solar illumination, but it will only produce relevant data while flares are active.

High Energy X-ray spectrometer (HEX)

Inherent radioactivity (such as K, U, and Th decay nuclides) and cosmic ray interactions in the lunar surface material cause the high energy X-rays and gamma rays above roughly 20 keV to be created.In the upper metre or two of the lunar surfaces, primary and secondary cosmic ray nuclear interactions with lunar material produce gamma rays by de-excitation, spallation, radionuclide decay, neutron capture reactions, and other processes. As a result, their flux bears a distinctive lunar compositional character. Therefore, the Chandrayaan-1 payloads contain an X-ray spectrometer that is sensitive in the 20–250 keV range.

The flow of gamma rays from radon-decaying radionuclides, including 210Pb, depends on both in situ synthesis at the lunar surface and radon degassing from the moon's interior [20]. Once in the lunar atmosphere, radon decomposes to 210Pb while being trapped in cold regions of the moon, such as the poles or the cool night side. Radon (210Pb) can be employed as a tracer for the transfer of volatiles on the lunar surface because it is predicted to accumulate and peak near the morning and evening terminators [21].

Infrared spectrometer (SIR-2)

The infrared spectrometer was developed by U Mall and H U Keller of the Max Planck Institute in Germany. It is a grating spectrometer with a spectral resolution of 6 nm and an angular resolution of 1.11 milirad, and it covers the wavelength range of 0.93 to 2.4 m.The Smart-1 infrared spectrometer, as described [22], is comparable to it. The spectrometer gathers the sunlight that has been reflected, which is then scattered by a grating with the aid of proper optics and evaluated by photosensitive pixels. In addition to lunar material mapping, which is carried out by pointing the spectrometer towards nadir, it has the ability to actively monitor certain features of interest for a while.

Moon mineral mapper (M3)

The Hyper-spectral Imager (HySI) and the SIR-2, which were previously mentioned, give lunar reflectance spectra that can be utilised for moon mineral mapping and cover a spectral range from 400 nm to 2400 nm. A moon mineral mapper (M3), proposed by the American group of Carle Pieters, has been added to the Chandrayaan payloads because there is crucial information beyond 2400 nm that may be useful in identifying previously unidentified minerals or potential polar resources, such as volatiles and organic compounds, if they are deposited on the lunar poles. M3 operates with a 10 nm resolution between 700 and 3000 nm. It has a 20 km sweep and a 30 m spatial resolution.

Through an f/2.7 three mirror telescopes, the sun light that is reflected enters the M3 instrument, which has a field of view of 12 inches. Through a slit, the telescope's focused light enters the high-efficiency offner spectrometer. To improve design uniformity, the spectrometer also makes use of an electron beam printed convex dual blaze grating.A 640 spatial by 231 spectral HgCdTe detector array, sensitive from 700 to 3000 nm, is situated at the spectrometer's focus.The detector array is kept cool using a cryocooler. The long wavelength component, which has a wavelength range of 2600–3000 nm, is especially made for polar resource research. It will share some data with HySI and SIR-2, and the three instruments taken together will provide a complete set of payloads for lunar surface material mapping.

Miniature Synthetic Aperture Radar (Mini SAR)

The radar has a maximum peak RF output of 20W and operates at 2.5 GHz. The main antenna sends a signal that is right circularly polarised (CP) and receives a dual-polarized signal that is both right and left circularly polarised. The radar records echoes in both orthogonal directions while scanning the lunar surface at a 45° incidence angle to produce an image. Although it has a resolution of 100 metres per pixel, when used in low-light or spotlight conditions. It has a 10 m/pixel resolution. The system will be pointing in the nadir in the scatterometer/altimeter mode, which also serves as a backscatter imaging mode300 m/pixel resolution radar.The radiometer, which measures RF surface emissivity, has an accuracy of 1 K and a spatial resolution of 1 km, and it can measure lunar surface temperatures in the range of 100–400 K. The footprint will be used to measure the surface roughness at the metre scale. The dielectric constant and porosity of the lunar surface, as well as other physical characteristics, can be determined using the circularly polarised ratio (CPR).

Sub Atomic Reflection Analyser (SARA)

Low energy neutral atoms (up to iron) in the energy range of 10 eV to 2 keV will be used by the SARA to photograph the surface. It consists of a solar wind monitor and a low energy neutral atom sensor. The neutral atoms enter the sensor after being transformed into positive ions on an ionisation surface by an electrostatic deflector, which removed the surrounding charged particles. Time of flight measurements are used to determine the particle velocity, and electrostatic analysers are used to determine the particle's energy and mass. The H, O, Na-Mg, K-Ca, and Fe group elements can be distinguished due to the mass resolution.Neutral atom density in the Moon's environment is extremely low since it lacks a magnetosphere and an atmosphere, and it is mostly produced by sputtering caused by solar wind ions.In this low energy region of interest, it is expected that the contributions from solar photon simulated desorption and micrometeorite vaporisation are negligible. Since the solar wind flux depends on the cosine of the sun zenith angle, LENA imaging of the neutral atoms will therefore offer maps of the sputtered elements that can be turned into surface composition maps. These maps will then reflect the sputtering yield and the solar wind flux with the appropriate corrections.

Radiation Dose Monitor (RADOM)

The Chandrayaan-1 payloads now contain an equipment for monitoring radiation dose (RADOM), which was proposed by T. Dachev of the Bulgarian Academy of Sciences. The RADOM system is made up of a semiconductor detector that tracks the incident particle flux (ions, electrons, and gamma rays) from solar and galactic cosmic rays, as well as the rate of cumulative dose absorption and the energy spectrum that is absorbed. A multichannel analyser and a charge-sensitive preamplifier are included in the Si detector's 2 cm2 surface area. It has an 8 keV threshold. As the spacecraft descends from the lunar capture orbit to its final altitude of 100 km, it will make the measurement in the lunar environment as a function of altitude.

CONCLUSION

The Chandrayaan-1 mission stands as a remarkable achievement in India's space exploration program. The mission's objectives of mapping the lunar surface, analysing its composition, and investigating the presence of water-ice have been met with resounding success. The valuable data and insights obtained from Chandrayaan-1 have significantly advanced our understanding of the Moon's geology, evolution, and potential for future exploration.Furthermore, Chandrayaan-1's comprehensive mapping of the lunar surface has provided scientists with detailed information about the Moon's topography, geology, and mineral distribution. This data has enhanced our understanding of the Moon's geological history and evolution, shedding light on processes such as volcanism, impact cratering, and the formation of lunar features.

The successful execution of the Chandrayaan-1 mission also underscores India's capabilities in space technology and exploration. The mission demonstrated the country's ability to design, develop, and operate a sophisticated spacecraft, navigate through challenging lunar orbits, and collect high-quality scientific data. Chandrayaan-1 served as a testament to India's growing presence in the global space community and its commitment to pushing the boundaries of scientific knowledge.Chandrayaan-1 has made significant contributions to lunar science, expanding our understanding of the Moon and its potential for future exploration and human habitation. The mission's achievements serve as a foundation for future endeavours, inspiring scientists, engineers, and space agencies worldwide to continue exploring and unlocking the mysteries of our celestial neighbour.

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