One of the greatest achievements of the 20th century was the safe landing of human beings on the Moon. Between 1969 and 1972, 12 astronauts explored the lunar surface from six landing sites. They spent a cumulative 12.5 days on the Moon, of which 3.4 days were spent undertaking extravehicular activities (EVAs): moonwalks. During this time, the astronauts travelled a cumulative distance of 95.5 km across the lunar surface, deploying surface experiments and collecting geological samples (figure 1; Orloff & Harland 2006). Whereas the initial motivation for landing on the Moon was largely geopolitical (see Chaikin 1994, Burrows 1998, Orloff & Harland 2006), the scientific potential of lunar exploration was fully recognized in the planning stages of the Apollo programme, and implemented into lunar surface and Earth–Moon transfer operations. The programme of placing science at the centre of an exploration architecture culminated in the Apollo 17 mission, in which astronaut Harrison “Jack” Schmitt had the honour of being the only professionally trained scientist to visit the Moon. Today, within the scientific community and within society in general, we are still benefiting from the legacy of the Apollo programme. On this 50th anniversary of Apollo 11, we take a look back at some of the major scientific advances made possible by the Apollo programme and look to the future, assessing how Apollo has shaped our exploration of the wider solar system.

Apollo’s scientific achievements
In total, 382 kg of rock and soil (sampled from more than 2000 individual samples on the
surface of the Moon) were returned to Earth during the Apollo missions. These samples provided invaluable insights into the geological history of the Moon, revealing insights into the formation of the solar system and the evolution of planetary bodies. The samples also contain evidence of life on Earth’s early history, including potential fossils of early life forms. The Apollo programme also conducted extensive experiments and experiments designed to understand the physical properties of the Moon, its interior structure, and the processes that have shaped its surface. These experiments included studies of the Moon’s magnetic field, seismology, and remote sensing of the lunar surface.

On the 50th anniversary since humans first set foot on the Moon, John Pernet-Fisher, Francesca McDonald, Ryan Zeigler and Katherine Joy take a look back at the legacies of the Apollo programme.
locations) were gathered from the lunar surface. This was supplemented by the collection of 6000 images of the surface and the deployment of 2100 kg of scientific equipment (Crawford 2012; see table 25.2 in Crawford et al. 2014 for a full list of the experiments deployed by Apollo). For an excellent archive (including all photographs and transcripts) detailing lunar surface operations, see Jones and Glover (2019). Science analysis from the Apollo Lunar Surface Experiments Packages (ALSEP) are still going on today (described below). Furthermore, despite the fact that the geological sample collection is five decades old, these materials are still being used to test key lunar and comparative planetary science questions (described in table 1). Continued study of the Apollo samples has been made possible as analytical techniques have improved and new laboratory experiments have been invented. This long-term legacy of a well-curated collection of lunar samples is evidenced by the continued and growing number of requests made to NASA from scientists around the world (figure 2). Below is a brief summary of what represents the most important scientific achievements that have resulted from the Apollo sample collection over the last 50 years.

**Lunar origins**

Understanding lunar formation is not only important for understanding the Earth–Moon system, but also helps shape our general understanding of planetary formation models (Wetherill 1990). Currently, a giant impact is the favoured scientific hypothesis for the formation of the Moon (e.g. Canup 2004). First put forward in the 1970s (Cameron & Ward 1976, Hartmann & Davis 1975), this model states that the Moon formed from debris resulting from a Mars-sized object (often dubbed Theia) colliding with the early Earth at ~4.5 Ga. Many numerical models of this hypothesis have been presented to account for the present-day physical characteristics of the Earth–Moon system, such as the resulting angular
momentum and the unusually large size of the Moon relative to the Earth (e.g. Canup & Asphaug 2001, Canup 2004). However, one of the strongest lines of evidence to support this hypothesis comes from the Apollo sample collection. Without the quantity and diversity of the Apollo samples, it is unlikely that we would have sufficient geochemical evidence to evaluate theories of lunar formation. For example, analysis of the Apollo sample collection displays remarkable key similarities and discrepancies between them and terrestrial samples in element and isotope systematics. The Moon is significantly depleted in iron relative to the Earth, suggesting that it has a much smaller core than anticipated for its size. Furthermore, the Moon displays significant depletions in volatile elements relative to the Earth (Wolf & Anders 1980, Taylor et al. 2006, Papiolo et al. 2012). This is consistent with a highly energetic collision resulting in a Moon formed from an ejected debris disc that had lost its water and other volatiles (Canup 2004, Canup et al. 2015).

However, not all geochemical systematics from the Apollo sample set are consistent with a giant impact. Some elements – oxygen, silicon and titanium – have very similar isotope compositions in Earth and Moon rocks (Wiechert et al. 2001, Young et al. 2016). Thus, the giant impact model is continually evolving to account for newly reported chemical constraints. Currently, ideas are emerging that suggest a chemical exchange took place within the superheated vapour cloud that encapsulated both the Earth and the Moon after the collision (called a synestia; Lock et al. 2018), or that maybe the collision occurred when the Earth’s surface was partially molten rather than a solid body (Hosono et al. 2019). Although the Apollo sample collection is key to understanding these different proposed mechanisms, at the current level of analytical precision many chemical systematics of the Earth–Moon system remain open to question. This highlights the value of revisiting Apollo samples and the need to collect new samples from different regions of the Moon to test ideas about its origins.

**Water in the mantle**

If the Moon formed in a high-energy collision event, it should have lost a lot of its water and other volatiles. However, the past 10 years have turned a new page in our understanding of the Moon’s hydrological cycle. New high-precision laboratory techniques have shown that water (in the form of OH) is bound within Apollo sample volcanic glass beads and in some water-bearing minerals (Saal et al. 2008, McCubbin et al. 2010). One of the key minerals in this story, apatite, Ca$_5$(PO$_4$)$_3$(OH,F,Cl), is one of the final minerals to crystallize out of a magma and can incorporate volatile elements such as OH that do not typically form part of the major rock-forming minerals.

---

### 1 Outstanding lunar and planetary science questions

<table>
<thead>
<tr>
<th>lunar science questions</th>
<th>comparative planetary perspective</th>
<th>proposed mission scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding the origin of the Earth–Moon system</td>
<td>● enables us to compare the Earth–Moon system with other inner solar system bodies and exoplanetary systems</td>
<td>● sample-return mission to key geological locations to constrain geochemistry and chronology by collecting materials not sampled by Apollo</td>
</tr>
<tr>
<td>Understanding the impact of bombardment history of the Moon as a witness-plate to solar system processes</td>
<td>● helps understanding of the dynamical history of the solar system, particularly placing into context the impact records of inner solar system bodies</td>
<td>● global geophysics network on landers to monitor present day impact flux of the Moon</td>
</tr>
<tr>
<td>Understanding the origin(s) of lunar volatiles</td>
<td>● enables us to understand the origin of Earth’s water and early conditions for life</td>
<td>● high spatial and spectral orbital measurements of regolith volatile content (notably shadowed polar craters) to map lateral extent of volatiles/water distribution</td>
</tr>
<tr>
<td>Understanding how the Moon is affected by exogenic processes</td>
<td>● enables us to understand regolith development on other airless bodies</td>
<td>● in situ characterization of volatile-rich areas by rovers and landers with drills to map distribution with depth, coupled with sample return in order to precisely measure the isotopic composition of volatiles and water-ice</td>
</tr>
<tr>
<td>Understanding what the Moon tells us about fundamental physical processes in the universe</td>
<td>● enables us to understand planetary interaction mechanisms that can be applied across the solar system</td>
<td>● lander instrumentation to measure present-day surface environment and solar and galactic high-energy fluxes</td>
</tr>
<tr>
<td>How do the Earth and Moon interact with each other?</td>
<td>● enables us to understand how the Moon interacts with the Earth</td>
<td>● lander/rover with ground-penetrating radar to identify location of ancient regolith layers and sample return to collect ancient regolith layers to precisely measure solar wind/cosmic-ray compositions from different temporal horizons</td>
</tr>
<tr>
<td>How can the Moon be used to investigate deep space?</td>
<td>● helps understanding ages derived from crater counting across the solar system</td>
<td>● landers/rovers to deploy laser retroreflector network to precisely measure how the Moon interacts with the Earth</td>
</tr>
</tbody>
</table>

Summary of outstanding questions and how they might be addressed by future missions (questions based on NRC 2007, Crawford et al. 2014 and ESA 2019).
such as olivine, pyroxene and plagioclase. Early studies reported apatite from lunar basalts that contained OH at similar abundances toapatites from terrestrial basalts, leading some to speculate that the Moon’s mantle may in some localized regions be as hydrous as the Earth’s mantle (McCubbin et al. 2010). However, as our understanding of OH behaviour in magmas under lunar conditions has improved through new laboratory experiments, our current estimates for water concentrations in some parts of the Moon’s mantle is in the tens of parts per million (ppm) (McCubbin et al. 2015). This is an order of magnitude lower than typical water abundances in the Earth’s mantle, but several orders of magnitude higher than the earlier “canonical” water abundances in the interior of the Moon (<1 ppm; Taylor et al. 2006). Moreover, understanding the nature of volatiles (and in particular water) in the Moon is important, because volatiles have a significant impact on how magmas melt, crystallize and behave during volcanic eruption. Therefore, understanding which volatiles are present in lunar magmas is critical for correctly interpreting the volcanic samples brought back by Apollo.

**Lunar crust formation**

Much of our understanding of how young planets develop, such as the formation of a primary crust, is based on what we have learnt about the early history of the Moon. The canonical view states that following the giant impact, the young Moon had a global magma ocean (Wood et al. 1970, Snyder et al. 1992). It is the crystallization of this magma ocean that was subsequently responsible for the formation of the lunar mantle and crust. This hypothesis was first proposed by Wood et al. (1970) following the return of the Apollo 11 samples, specifically the identification of plagioclase-rich lithologies (i.e. anorthosite) within the Apollo 11 soils. In this lunar magma ocean model, minerals rich in iron and magnesium (olivine and pyroxene) are the first to crystallize from the superheated melt. These minerals sink and accumulate over time to form the lunar mantle. Once plagioclase starts to crystallize, when the magma ocean is between about 70 and 80% solid, the density difference between plagioclase and the crystallizing magma means that these crystals float and accumulate over time to form the Moon’s primary crust. This crust is still visible today, making up the bulk of the white-coloured lunar highlands. Fifty years on, this lunar evolution model has generally stood up to scrutiny. However, as we have gained a better understanding of the subtle chemical differences in the Apollo collection (specifically from Apollo 16, the only mission that directly sampled the primary crust), refinements have been made and argued about (see Pernet-Fisher & Joy 2016, Gross & Joy 2016). The idea of a crystallizing magma ocean has since been extrapolated to all inner solar system bodies (Elkins-Tanton 2012) and now forms the backbone of how we think planets developed their primary crusts. This underpins the value of understanding the Moon’s crust and how it formed: it represents a record from a time period that is no longer accessible on geologically active bodies such as the Earth or Mars.

**Geophysics experiments**

During the Apollo missions, a wide range of geophysics experiments were carried out, including passive and active seismology, surface gravimetry and magnetometry, and deployment of laser reflectors (Jaumann et al. 2012). One of the key findings from these experiments is the confirmation that the Moon is a differentiated body consisting of a crust, mantle and core. Whereas a differentiated Moon is implied by the chemistry of Apollo samples, geophysical data offers a direct way to observe the internal structure of the Moon. While these data are now 50 years old, advances in seismic interpretation and numerical computation techniques mean that they continue to yield new insights into the interior structure of the Moon (e.g. Wieczorek et al. 2006, Jaumann et al. 2012, Watters et al. 2019). For instance, the discovery of moonquakes by seismic stations deployed during Apollo 12, 14, 15 and 16 has allowed estimates of the lunar crustal thickness. Most recent estimates based on Apollo data suggest a crust between 30 and 38 km thick (Khan & Mosegaard 2002, Lognonné et al. 2003). This is similar to crustal thickness estimates from space missions such as GRAIL that have estimated crustal thickness from orbit (Matsumoto et al. 2015). Constraining lunar crustal thickness is important in the context of models of magma ocean solidification based on the Apollo sample set. These results place important constraints on unknowns such as the depth of the magma ocean or the efficiency with which the lunar crust formed (e.g. Solomatov 2000).

**Lunar impact history**

The Moon is the most accessible body in the solar system on which to study the process of impact cratering. The scars of past impact collisions cover the Moon’s ancient surface (Stöffler et al. 2006). Indeed, many of the rocks that were collected by Apollo were produced by impact cratering events, or have been modified by the effects of impact shock metamorphism (high pressures and/or high temperatures). There is still a lot of controversy surrounding the Moon’s early impact history – early studies of Apollo samples suggested that there may have been an intense period of bombardment at about 3.9 billion years ago in an era termed the late heavy bombardment (Tera et al. 1973, Turner et al. 1973). Such an epoch would be significant in potentially modifying the crusts and affecting early atmospheres and hydrospheres (and maybe early life) on inner solar system bodies. Furthermore, such an epoch has implications for the dynamical evolution of the solar system, in particular accounting for the current location of the giant planets (as described by the Nice model; Crida 2010). However, it has been suggested that maybe not as many impact basins formed in this period as we originally thought and that we need to re-examine some of our long-held views on the impact bombardment history of the inner solar system (e.g. Chapman et al. 2007, Marchi et al. 2013).

Finding the age of impact cratering events also serves a much wider scientific purpose. From the innermost planet Mercury to Pluto in the Kuiper Belt, impact crater counting is a tool that is used to estimate
the age of planetary surfaces. This approach is based on the principle that a new surface will contain no craters and an old surface will contain a high density of craters. One of its major pitfalls is that all derived ages are relative rather than absolute. An important outcome of the Apollo sample collection is that radiometric chronometers have been used to accurately calculate absolute crystallization ages and surface exposure ages for many samples; these ages have then been used to anchor the crater-derived chronology (e.g. Neukum & Ivanov 1994, Stöffler & Ryder 2001). In this way the Moon is exceptional; it represents an important cratering record of the Earth–Moon system and can help in constraining the inner solar system impact flux over geological time (Stöffler et al. 2006). There are many places on the Moon where we need to sample key “stratigraphic marker” impact basins and craters for absolute dating in order to more robustly constrain the lunar cratering calibration curve (described in more detail in table 1).

Apollo’s human legacy

The Apollo programme has touched our society in profound ways. Not only did it capture the imagination of the public through famous images such as the “Earthrise” photographs taken by Apollo11, but it has also influenced our technological advances, many of which we now take for granted. The Apollo 11 mission received a lot of attention from the general public: it is estimated that 600 million people watched Neil Armstrong set foot on the lunar surface. However, as the Apollo programme advanced, public interest dwindled and events such as the Vietnam war moved to the forefront. By the time of Apollo17 in 1972, television networks no longer broadcast moonwalks live in their entirety, despite the fact the quality of TV pictures beamed back to Earth had greatly improved (Chaikin 2007). As the public’s collective memory of the Apollo programme and its astronauts slowly receded into 1960s nostalgia, it is perhaps the technological advances that have left the largest impact on society.

Much of these advances stem from the requirement for computing capability and miniaturization in the Apollo spacecraft design and the need to monitor the health of astronauts (Sadegh 2006). They range from the mundane to the potentially life-changing. An excellent summary of the impact that NASA technological advances have had on commercial products can be found in NASA’s annual Spinoff publication series (NASA 1976 to 2019). Some of the most impactful advances include: the incorporation of digital imaging processing into medical CATscan and MRI imaging; advances in fire-retardant fabrics and lightweight breathing apparatus to help tackle fires; and insulation material made of aluminum foil laid over Mylar widely used in first aid responses (widely called “space blankets”). At the more mundane end of the spectrum, Apollo-era technologies such as Moon boot design and materials revolutionized athletic footwear (improving shock absorption), retractable roofs in sports stadiums made use of spacesuit fabrics, and corderless drills and vacuum cleaners all incorporate NASA technology.

The Apollo era also saw the start of routine launches of satellites to space, which ultimately led to the ~5000 satellites currently in orbit. The impact of these satellites above us has been profound and have helped society in a range of ways from enabling access to better communications and cartographic mapping tools (such as global navigation satellite systems), to providing better weather forecasts and natural disaster monitoring.

Legacy for modern planetary missions

Whereas the Apollo programme was ultimately cut short after Apollo17 (it was originally planned to run to Apollo20), it laid down the foundations for modern planetary science and space exploration. In the immediate aftermath of the Apollo programme, NASA moved away from lunar exploration. Unused Apollo modules were used instead to transport astronauts to Skylab, the world’s first crewed space station. Skylab re-entered the Earth’s atmosphere in 1976, but it had enabled the technical groundwork for the Mir space station and later the International Space Station (ISS). By the late 1970s, NASA shifted focus to the development of the space shuttle, with the first flight in April 1981, after a six-year hiatus in American human spaceflight. Since this era, the USA and Russia have continued crewed spaceflight, with emerging scientific, cultural and economic benefits for the UK (Close et al. 2005). Helen Sharman became the first British person in space and the first woman to visit the Mir space station in 1991, through a privately funded venture. Opting into ESA’s human spaceflight programme in 2009 resulted in Tim Peake being selected as the UK’s first ESA astronaut, visiting the ISS for six months in 2015 in the Principia mission. As part of this mission Peake played a key role in promoting science, literacy and numeracy in primary schools across the UK, helping to inspire the next generation of planetary scientists. Scientists in the UK also have an opportunity to fly their experiments on the ISS and are involved with planning for science activities on the future crewed missions beyond low Earth orbit.

During the Apollo era, the UK established a vibrant planetary science community

“During the Apollo era, the UK established a vibrant planetary science community”

“During the Apollo era, the UK established a vibrant planetary science community”

“During the Apollo era, the UK established a vibrant planetary science community”

Since this era, the USA and Russia have continued crewed spaceflight, with emerging scientific, cultural and economic benefits for the UK (Close et al. 2005). Helen Sharman became the first British person in space and the first woman to visit the Mir space station in 1991, through a privately funded venture. Opting into ESA’s human spaceflight programme in 2009 resulted in Tim Peake being selected as the UK’s first ESA astronaut, visiting the ISS for six months in 2015 in the Principia mission. As part of this mission Peake played a key role in promoting science, literacy and numeracy in primary schools across the UK, helping to inspire the next generation of planetary scientists. Scientists in the UK also have an opportunity to fly their experiments on the ISS and are involved with planning for science activities on the future crewed missions beyond low Earth orbit.

During the Apollo era, the UK was establishing its own vibrant planetary science community. The UK-based pioneers that received some of the first Apollo sample allocations included, among others, Geoffrey Eglinton (University of Bristol), Colin Pillinger (University of Cambridge, then the Open University), Grenville Turner (University of Sheffield, then University of Manchester) and Keith Runcorn (University of Newcastle). Photogeologists including John Guest (University College London) helped provide context for Apollo landing sites, resulting in the establishment of many new research groups across the UK. This expertise in extraterrestrial sample analysis led to UK institutions being involved in analysis of material from every sample-return mission to date, including missions such as Stardust (collecting cometary material) and Genesis (collecting solar wind particles). Currently, about 10% of Apollo samples available to the community are
on loan to UK institutions, highlighting the strength of the new generation of UK Apollo principal investigators.

The UK has also developed strengths in space instrument and mission development over the past few decades, stemming from the Beagle 2 Mars lander led by Colin Pillinger, launched in 2003. This heritage has seen the UK making contributions to instrument packages on ESA’s Rosetta mission, ESA’s ExoMars Trace Gas Orbiter, NASA’s Insight seismometry mission, ESA’s SMART-1, ISRO’s Chandrayaan-1 mission to the Moon, ESA’s BePICO mission to Mercury, and the upcoming ExoMars Rosalind Franklin rover.

**Future lunar science objectives**

Once again, we are looking to the Moon to not only address the key outstanding science questions surrounding the formation and evolution of the Earth–Moon system, but also all inner solar system bodies (NRC 2007; Crawford et al. 2012; Jawin et al. 2019). It wasn’t until the late 1990s that lunar exploration underwent a resurgence, with the launch of high-profile remote-sensing orbital missions Clementine and Lunar Prospector, followed in the next decade by the international SMART-1 (ESA), Kaguya (Japan), Chandrayaan-1 (India), and Lunar Reconnaissance Orbiter (NASA) spacecrafts. These missions carried a wide array of instruments including visible, infrared, X-ray and gamma-ray mapping spectrometers. This resulted in a wealth of chemical and mineralogical information, mapping the entire lunar surface (e.g. Jolliff et al. 2000, Pieters et al. 2009, Yamanoto et al. 2010). These missions have helped further address some of the key lunar science questions (table 1) that the Apollo sample collection has not been able to address due to their geographic restriction to the central near side region of the Moon. Notably, remote-sensing missions have demonstrated that the lunar near side is actually chemically distinct from the lunar far side (figure 3; Jolliff et al. 2000), suggesting that the Apollo missions actually sampled quite a geologically anomalous region of the Moon.

If lunar missions have undergone a renaissance over the past few decades, so too has the study of the Apollo collection. Every year, NASA’s Curation and Analysis Planning Team for Extra-terrestrial Materials (CAPTEM) allocates samples of Apollo material to international scientific investigators. Since the mid-2000s, each year has seen an increasing number of successful sample allocations (figure 2). In this respect, the Apollo sample collection is the scientific gift that keeps on giving but, ultimately, it can only tell us a finite amount about lunar evolution. For instance, our current understanding of the far side of the Moon relies upon the lunar meteorite collection (for which sample provenance is not constrained; Korotev 2005) and from orbital remote-sensing data. Thus, future sample-return missions (particularly sampling from diverse locations representing the Moon globally) will be critical for the growth of lunar science and exploration.

The science that can be achieved from analysis of future returned samples is dependent on understanding a sample’s life cycle from when it was collected at the lunar surface through to entering a laboratory on Earth. It is therefore imperative to identify lessons learned from the Apollo and Soviet Union Luna sample-return missions in order to develop appropriate processes for future sample extraction, handling and curation that better preserves the integrity of a sample. Defining such lessons, along with learning more about local geology and the overall thermal, volcanic and chemical evolution of the Moon, is currently the goal of a US-led international consortium that is part of the exciting Apollo Next Generation Sample Analysis (ANGSA) programme (Shearer et al. 2019). This consortium will address its goals through analysis of specially curated Apollo samples, including an Apollo 17 drive core segment that has remained vacuum sealed to present day, or Apollo 16 samples that have been kept in cold storage since their return from the Moon in 1972 (Shearer et al. 2019).

In addition to sample science there is a wealth of complementary scientific investigations to be conducted from the Moon, using the lunar surface as a unique laboratory. The Apollo ALSEP instruments left on the lunar surface (see figure 1) are still yielding high-profile science results. For example, recent re-examination of the ALSEP passive seismometers has shown that the Moon’s core might still be partially molten rather than completely solidified (Weber et al. 2011), and that detected moonquakes might be linked to shallow level fault systems that are still tectonically active (Watters et al. 2019). Both these results have important implications for understanding how planets retain and lose heat through time. There is now a need for an international team to deploy a global geophysics network and astronomy instrumentation on the Moon, building on the foundation of ALSEP from the Apollo era and on the success of modern-day highly sensitive seismometers such as those currently deployed on Mars (Lognonné et al. 2019).

**Using the Moon for exploration**

A sustained human presence on the lunar surface is currently a shared international goal. For instance, permanent research stations are being factored in to longer-term mission architectures (figure 4) supporting a lunar hub for transporting humans from the Earth to the Moon.

However, achieving any extended human presence on the Moon’s surface will require us to generate shelter, propellant and energy from local resources (e.g. Taylor & Carrier 1993, Anand et al. 2012). Of prime interest is the extraction of oxygen and water from the regolith and permanently shadowed craters at the lunar poles to create rocket propellants and sustain human life. Many missions currently in development include prospecting payloads designed to constrain the scale and composition of water reservoirs on the Moon. For instance, missions such as the ESA-led PROSPECT instrument package (due to fly with Luna 27 in ~2024, Carpenter et al. 2014) will drill into the lunar surface to extract samples expected to contain water ice.

Terrestrial developments in resource extraction and purification have also been...
Future of lunar exploration

Although geopolitical factors will always play a role, our current renewed interest in the Moon is not just the start of another space race; rather the modern era of lunar exploration has been made possible by cooperation between many nations. Indeed, there is currently considerably more scientific interest in the Moon globally than there was during the Apollo era. This is reflected by the number of countries currently involved with lunar missions. The early 2020s will see countries including China, Japan and South Korea with active lunar missions, and the first attempt by India at a lunar landing (Chandrayaan 2). The USA has also announced its intention to return humans to the lunar surface by 2024 in the new Artemis programme. Recent headlines that highlight this new era of lunar exploration include China’s Chang’e-4 mission and Israel’s debut lunar exploration. Chang’-4 achieved a major milestone in lunar exploration as it became the first mission to achieve a soft landing on the lunar far side, touching down in Von Kármán crater within the South Pole-Aitken basin in January 2019.

As the largest (2500 km in diameter) and oldest (estimated to be >4.2 billion years old) impact basin on the Moon, it serves as a prime target for accessing deep crustal and potentially upper mantle lithologies of the Moon (Jolliff et al. 2000). Most recently, in April 2019, came the Israeli Beresheet Moon lander mission, led by the non-profit organization SpaceIL. Despite not achieving a soft landing, it has pioneered privately funded lunar exploration. Indeed, the emergence of commercial businesses investing in the future of lunar exploration is also becoming a driving force in its own right. Initially, such commercial companies can provide early opportunities for delivering small science, technology and communication payloads to the Moon, either through orbiting satellites or on surface landers. Starting as soon as next year, such payloads may be delivered via NASA’s Commercial Lunar Payload Service (CLPS) Programme, for example, or via the commercially led Lunar Pathfinder Mission in partnership with ESA. It is these commercial partnerships that will contribute to generating a modern space economy, while helping to lay architecture for future longer-term missions to the lunar surface.

The Apollo programme remains a unique event in our history, whose legacy still continues to benefit us both in everyday life and in helping to pave the way for future space exploration. Through recognizing its achievements and building on the lessons learned, we are excited for the next 50 years of lunar exploration and potential long-term human presence on the Moon.

The legacy of the Apollo programme continues to benefit us in everyday life