APOLLO LUNAR SURFACE OPERATIONS AS A BASIS FOR CHALLENGES IN FUTURE HUMAN AND ROBOTIC GEOLOGICAL EXPLORATION OF THE MOON. S.C. Chevrel1,2, P.C. Pinet1,2. 1Université de Toulouse; UPS-OMP; IRAP; Toulouse, France, 2CNRS/CNES; IRAP; 14, avenue Edouard Belin, F-31400 Toulouse, France (serge.chevrel@irap.omp.eu).

Introduction: Key technical and scientific aspects of the lunar surface operations have been designed, experimented and validated during the Apollo missions on the Moon (1969-1972). These missions constitute an invaluable information, resource and a base for future in situ lunar scientific exploration by humans. Consequently the preparation of future exploration on the Moon should be done in the light of a re-examination and an improvement, including robotic assistance, of the surface operations conducted by the astronauts during the Apollo missions.

The Apollo legacy: During the 14 extravehicular activities (EVA) conducted on the lunar surface it has been shown that complex tasks for science objectives can be achieved by astronauts exploring large areas of landing sites, using unpressurized lunar roving vehicle (LRV). These tasks covered sampling (including drilling) and deploying instrumentation of the ALSEP and experiments such as the Lunar Seismic Profiling Experiment (LSPE) on Apollo 17. Some major improvements in lunar science have been made in real time during the geological field works on the Moon. For instance during Apollo 16 it has been recognized that both the Cayley and the Descartes Formations consist of deposits of impact materials resulting from the Imbrium basin event, rather than volcanic materials as it was thought prior to the mission. During Apollo 17 the astronauts discovered that the dark mantling material (DMD) in the Taurus-Littrow valley is an old pyroclastic volcanic unit mixed in the regolith rather than a discrete and young unit.

Improvements in lunar geological field work: In the Apollo era, collecting documented samples (description and photography to record the geological context), drilling (deep core samples and HFE-heat flow experiment) and making experiments on the lunar surface, were complex tasks that could only be performed by astronauts. Some tasks were time consuming and required the presence of the two men to assist each other. The presence of the man on the Moon is still essential for geological field work. However, in the future, robotic assistance for each astronaut would be required in order to work independently and safely from his partner, and in order to save time since the EVA duration cannot be extended to more than seven hours to avoid excessive tiredness. For instance most of the procedures (photography, carrying samples) for the documented samples could be performed by robotic means. This robotic assistant for each astronaut could be a strong link between the astronaut and geologists in the backroom. Sending the pictures and other data, it would allow them to know the exact location of the astronauts and consequently of the sampled rocks. The robotic assistant could for instance carry a small camera and spectrometer for a real time analysis (texture and composition) of the rock which has been just collected, thus giving invaluable information to scientists in the backroom. This might help to decide whether a sample should be kept for further investigations or discarded. This would also make the EVA more flexible, with real time decision to spend more time at the current station, or save time for the next or define a new one. Furthermore, the robotic assistants could perform investigations either prior or after an EVA, thus increasing the scientific outputs.

Impact craters as new challenging targets: Since Apollo, lunar exploration has been conducted by remote sensing techniques from orbit, from Clementine (1994) to Lunar Reconnaissance Orbiter (2009-present). We identified places to go for sampling and to conduct other surface geological activities, both to answer key questions (concerning the lunar crust, volcanism, cratering processes...) and to better interpret remote sensing data, e.g., spectral data relying on composition. Among these places are the impact craters which give access to the nature of deep-seated materials and the structure of the target at different scales. Craters are indeed complex formations showing a great diversity of morphological features and compositions for their materials, thus requiring detailed investigations. Crater materials present a large degree of melting and mixing, raising issues in the interpretation of remote sensing multispectral data. We currently need to link the compositional information to small scale morphological observations and ground truth by sampling [1,2]. Among scientists there is a consensus that small and large impact craters are still poorly documented and must be explored in situ. However, so far, the largest impact crater visited by astronauts (Apollo 16) is North Ray crater (40-60 Ma) [3] about 1 km in diameter. It excavated materials 250 meters into the subsurface at Smoky Mountain, giving
a stratigraphic information on the enigmatic Cayley formation, at that time. At Stations 11 and 13, Young and Duke investigated the southern rim crest of the crater. North Ray shows a rounded rim but its walls rapidly fall with slopes ranging from 27° to 34° (Fig. 1A), preventing to see the lower part of the crater walls, only the upper 60%, being observable from the vantage point at Station 11 (see Fig. 1, frame 3B).

Although not planned, it was not possible for safety reasons for the two astronauts to venture themselves into the walls. Instead of being sampled, boulders on the walls (Fig. 1, frame 3C) were only photographed using a 500 mm tele lens. This showed that the investigation of a relatively simple crater proved to be indeed quite a difficult task. Exploring large craters (e.g. Aristarchus or Copernicus) appears even more challenging. The navigation across craters is not possible using the Apollo techniques (i.e., walking or roving). The central peak access is difficult because of steep slopes. On the terraced walls and on the floor (hummocky terrains), as well on the slopes and very blocky continuous ejecta, the trafficability is greatly reduced for long distances.

The investigation of lunar craters is therefore a big challenge which demands new techniques to be developed. Crew exploration vehicles would have the ability to take off and land from place to place, with high capabilities in hovering to carefully selected safe areas to land. Given the low gravity environment, this technique of locomotion is quite adapted to the Moon [4]. For instance one objective would be to sample large boulders (up to 100 m in size), most of them being embedded and mantled with dark melt deposits (Fig. 2) [2], on the north-eastern terrace of Aristarchus. Spectral signature [5,6], showing anorthositic signatures mixed with pyroxenes, may arise from these boulders and/or from partially crystallized melts [6].

Interestingly enough, in 1969, North American Rockwell Space Division made a study of a one-man, rocket-powered lunar flying vehicle (LFV - hopper), providing mobility for lunar exploration [7]. Without the development of such a vehicle, lunar craters will remain poorly investigated, strongly limiting advances in lunar science. The strategy would be first to use reliable unmanned hopper vehicle, flying from one spot to another for detailed reconnaissance in craters and collecting samples, followed by manned vehicles. This approach would also qualify for other lunar formations presenting a strong interest but difficult to explore, such as massifs surrounding the impact basins, volcanic domes and sinuous rilles.