ROBOTIC AND MANNED LUNAR ROVERS OF THE XX CENTURY: THE VIEW FROM THE XXI CENTURY. D. R. Scott[1], M.I. Malenkov[2], J.W. Head[1], A.T. Basilevsky[3], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA, [2]Space Research Institute, RAS, Moscow, Russia, [3]Vernadsky Institute, RAS, Kosygin Str., 19, 119991, Moscow, Russia (atbas@geokhi.ru).

Introduction: For future exploration of the Moon it is important to utilize the experience of manufacturing and utilization of Soviet Lunokhods 1 and 2 and the US Apollo Lunar Roving Vehicle (Figs. 1 and 2). Lunokhods were robotic rovers operated by the team in an Earth Control Center based on transmissions from the Moon of images and rover orientation information [1,2]. The Lunar Roving Vehicle (LRV) used in the Apollo 15, 16 and 17 missions was operated by astronauts driving them on the lunar surface, guided in general by pre-mission traverse plans and scientific goals and objectives, their own observations and geologic interpretations, and their assessment of the trafficability as they traversed the surface [3,4]. It is interesting to note that in 1971 at the end of July - beginning August both Lunokhod 1 and Apollo 15 LRV were simultaneously operating on the Moon without any communication and coordination.

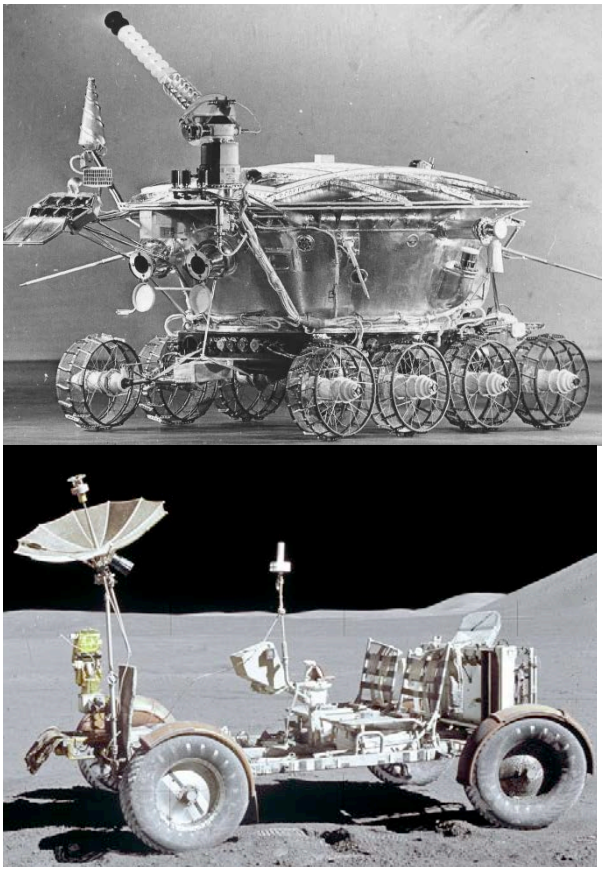

Fig.1 The Moon Rovers of the XX Century: Robotic Lunokhod-1 (top) and Manned Lunar Rover Vehicle (bottom).

Lunokhod 1 and 2 experience: The route of Lunokhod-1 (Fig. 2) was through a relatively flat plains-like region of Mare Imbrium, where relief of the terrain was mostly determined by relatively small craters of various, mostly degraded shape, on top of a regolith developed on an ancient Mare basalt layer. Areas in between craters had slopes no larger than 3^o-5^o and surface layer there had a bearing capacity in excess of 34 kPa. The latter was determined by numerous measurements taken by penetration of the conical tip, having a diameter 50 mm, down to a depth of 44 mm. Slipping of the wheels on such areas was less than 5%. The major problem was driving through relatively young craters having diameters 4 to 10 m. Regolith on the inner walls and rims of such craters was looseer and its bearing capacity significantly decreased at slopes as steep as 15^o-20^o; slipping there was higher than 50%. However because the total time driving through them was relatively small, these areas did not significantly influence the mean driving velocity, which in the total 10.5 km traverse, was 0.14 km/h. Specific consumption of energy along the route were 0.2 Wt·h/m.

The route of Lunokhod-2 (Fig. 2) during the first two lunar days of its activity (28 Earth days) was inside crater LeMonier which is a bay on the NE margin of Mare Serenitatis and the terrain there was generally similar to that in the Lunokhod-1 mare traverse area. But eventaully Lunokhod-2 came into a transitional zone from mare to highland and close to the Fossa Recta tectonic graben. Here we met rock talus and ejecta from craters which we had to drive around.

The most critical situation, however, happened to be in the 4th lunar day on April 20, 1973, when Lunokhod-2 had driven inside the an ~5 m diameter crater. In the maneuvers to get out of this crater the battery cap touched the crater wall and soil was deposited on top. Lunokhod-2 finally successfully got out of the crater, but in the lunar evening, the cap had to be closed and this caused the soil to be deposited on top of the radiator, so that by the next lunar day the rover had overheated and ceased functioning.

The total Lunokhod-2 traverse distance was 39.5 km; the mean velocity was 0.34 km/h, higher than that of Lunokhod 1 because of higher rate of rotation of electromotors. In addition, a third navigation camera was placed on Lunokhod-2, which was higher in position than previous cameras, and the crew could see better what was ahead and navigate more efficiently. Also, the, accumulated experience of the crew resulted in an increased duration of typical non-stop driving time from 50 s for Lunokhod-1 to 350 s for Lunokhod-2. Other

performance parameters of both Lunokhods 1 and 2: slope ascent angles, sleeping, specific consumption of energy, were approximately the same. A comparison of Soviet Lunokhod 1 and the Chinese Yutu 1 rover and scientific payload is also useful [5].

Lunar Roving Vehicle Experience: The LRV **(Fig. 1, bottom)** performed well during the A15 mission. During the three lunar surface extravehicular activities (EVAs), the vehicle traveled 27.9 km during 3 hours and 8 minutes of driving at an average speed of 9.2 km/h. A total of approximately 52 ampere-hours was consumed. Navigation errors were within expected tolerances with small distance errors and no apparent gyro drift. The combined wander and wheel slip factor was within predicted limits. The front-wheel steering was inoperative during the EVA 1, but operated normally for EVA 2 and 3. Simultaneous front- and rear-wheel steering was found to be more sensitive than desired, and difficulties were experienced with the seat belts.

The lunar terrain conditions in general were very hummocky, having a smooth texture and only small areas of fragmental debris. A wide variety of craters was encountered. Approximately 90% had smooth, subdued rims which were, in general, level with the surrounding surface. Slopes up to approximately 15% were encountered. The vehicle could be maneuvered through any region very effectively. The surface material varied from a thin powdered dust [which the boots would penetrate to a depth of 5 to 8 cm on the slope of the Apennine Front to a firm rille soil which was penetrated about 1 cm by the boot. In all cases, the LRV performance was changed very little.

The velocity of the rover on the level surface reached a maximum of 13 km/h. Driving directly upslope on the soft surface material at the Apennine Front, maximum velocities of 10 km/h were maintained. Comparable velocities could be maintained obliquely on the slopes unless crater avoidance became necessary. Under these conditions, the downhill wheel tended to dig in and the speed was reduced for safety. The general stability and control of the LRV was excellent. The vehicle was statically stable on any slopes encountered and the only problem associated with steep slopes was the tendency of the vehicle to slide downslope when both crewmen were off the vehicle. The rover is dynamically stable in roll and pitch. There was no tendency for the vehicle to roll even when traveling upslope or downslope, across contour lines or parallel to contour lines. However, qualitative evaluation indicates that roll instability would be approached on the 15-degree slopes if the vehicle were traveling a contour line with one crewmember on the downhill side. Both long- and short-period pitch motions were experienced in response to vehicle motion over the cratered, hummocky terrain, and the motion introduced by individual wheel obstacles. The "floating" of the crewmembers in the 1/6-g field was quite noticeable in comparison to 1- g simulations. Contributions of short period motion of each wheel were unnoticed and it was difficult to tell how many wheels were off the ground at any one time. At one point during the test run, all four wheels were off the ground, although this was undetectable from the driver's seat. Overall, the crew found that the performance of the LRV was excellent.

Suggestions for further work: Work on roving vehicles to support the activity of human expeditions on the Moon should consider the experience of Soviet Lunokhods and US Lunar Roving Vehicles. For extreme situations when it could be necessary to drive up and down steep slopes a type of wheel-walking rover may be considered. These can drive up 32°-34° slopes with low-cohesive soils [e.g. 6].

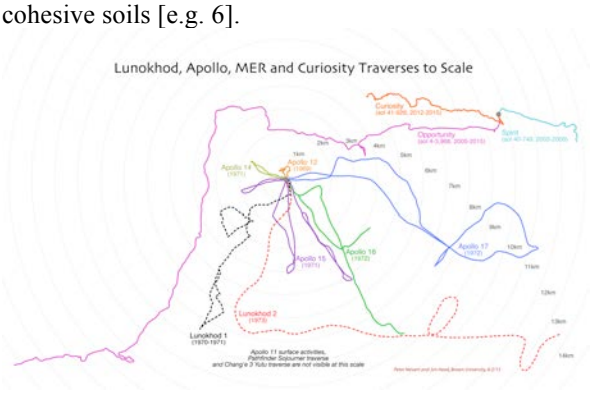

Fig. 2. Lunar and martian rover traverses to scale.

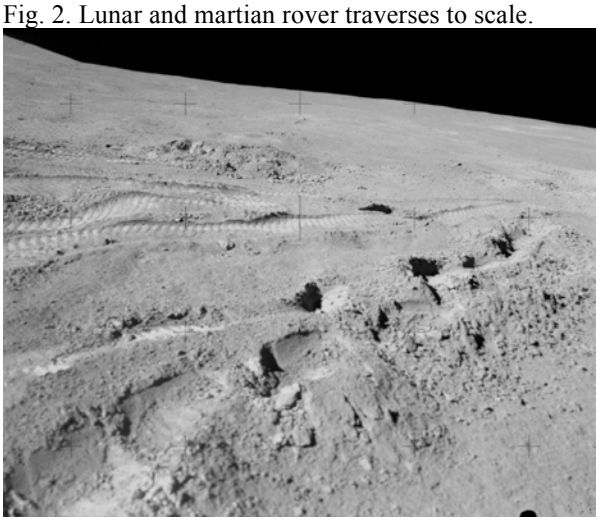

Fig. 3. A15 slope vehicle tracks and footprints.

References: [1] Vinogradov A. ed. (1971) Movable laboratory on the Moon 'Lunokhod-1'. V.1. Moscow, Nauka Press, 128 p.. [2] Florensky C. et al (1978) Proc. LPSC-9th, 1449-1458. [3] Apollo 15 Preliminary Science Report (1971) NASA SP-289. [4] Apollo 15 Technical Cre Debriefing (1971) MSC-04561. [5] Basilevsky, A. et al. Planetary and Space Science, 117, 385-400. [6] , Kemurjian A. (1990) The Planetary Report. Pasadena, USA. V. X, #4, 4-11. Malenkov M. et al. (2015) Russian Eng. Res., 35, No. 11, 824–831].