ATACAMA III: METEORITE SEARCH DURING THE NOMAD FIELD TESTS: PERSPECTIVES ON AUTOMATED FIELD OPERATIONS BY TELEOPERATED VEHICLES IN EXTREME ENVIRONMENTS. N. Cabrol[1], P. Lee[1], G. Chong Diaz[2], L. Pedersen[6], J. Dohm[3], M. Pereira Arredondo[2], G. Dunfield[1], V. Gulick[1,4], A. Jensen Iglesia[2], R. Keaten[5], C. Herrera Lamelli[2], R. Landheim[1,4], T. Roush[1], K. Schwher[7], C. Stoker[1], A. Zent[1]. [1]Space Science Division, NASA Ames Research Center, Moffett Field CA 94035, USA, [2]Universidad Catolica del Norte, Chile, [3]U.S. Geological Survey, Flagstaff AZ 86001, USA, [4]SETI Institute, NASA Ames Research Center, Moffett Field CA, USA, [5]U.S. Geological Survey, Menlo Park CA, USA, [6]FRC, Carnegie Mellon University, Pittsburgh PA, USA, [7]IMG, NASA Ames Research Center, Moffett Field CA, USA (ncabrol@mail.arc.nasa.gov).

Exploring ways to use automated vehicles to search for meteorites in extreme environments was one of the components of the 1997 Nomad Field Experiment. The purpose of this operation was to test visual and instrumental methods that will help to identify meteorites, and to explore new strategies that could benefit the meteorite search program in regions were sustaining the human presence is associated with risks. The rover located in the Atacama desert, Chile [1], was remotely operated from the NASA Ames Research Center. Two different types of operations were planned: (1) a visual search, using the imaging system onboard Nomad of meteorites planted on the field, (2) an instrumental search, using a magnetometer (see figure below).

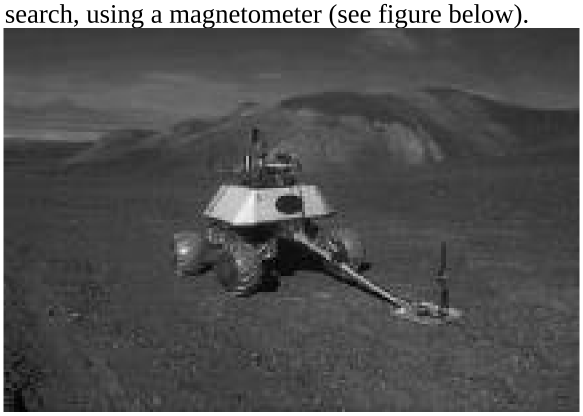

Fig.: The sensor was pulled behind Nomad, a position which proved not being optimal for a precise localization of the suspected meteorites. The presence of the panospheric camera minimized the inconvenience by enabling the Science Team to look backward.

Rover Search Equipment: For the search in visual mode, the Science Team was using the rover imagery system capabilities [1], including the panospheric, stereo-color, stereo black and white, and close-up cameras. For the instrumental mode, Nomad was equipped with a towed sensor sled, with the following specifications: (a) Sled: about 15 cm thick 0.30 x 0.30 m HDPE (non metallic) sliding platform with a 2.40 m towbar, attached to the rear of Nomad, 0.9 m lip around front and side to surmount obstacles, (b) JW Fisher Pulse 8x metal, 0.20 m diameter search coil in the center of the platform. The sensitivy varied depending on the size and composition of the target, and was particularly sensitive to iron, (c) Two applied Physics Systems 3 axis magnetometers. The FSD was 1/6th of the earth field. They were mounted on post at the rear of the sled, behind the metal detector. One was mounted 10 cm from the ground (search sensor), and the other was about 5 cm up (reference sensor). The data were processed onboard the rover. The positioning of the sensor at the rear of the rover induced specific maneuver constraints that led the Science Team to recommend the sensor setting on the front of the vehicle for future operations. For instance, backward maneuvers were to be avoided, and the rover could not execute prolonged tight (inferior to 5-m radius) turns, as the towbar could have been snagged by the wheel. **The Visual Search Strategy:** The operation was limited to a 500 m^2 area, in which three meteorites had been planted randomly. The number, size, composition, and position of the meteorites were not known by the Science Team at NASA Ames. Without this information, the strategy used was to try first to characterize the local geology in order to identify the meteorites, (i.e., by they morphology, texture, color that might be different from local rocks). The geology and morphology were, thus, analyzed in the surroundings of the search area, and also jointly during the search operation as the rover was moving along. The local geology at the base of the hills (see figure) was defined as colluvial and alluvial material. [2] Then, the Science Team decided to conduct the meteorite search following the standard strategy adopted by the US Antarctic Search for Meteorites program, ANSMET, (i.e., to perform a grid search by examining the ground in the immediate vicinity of the rover while traversing the search area in a zigzag pattern). Forward-facing high-resolution images of the ground were acquired at each stop, and every image was examined for any unusual object (i.e., morphology, geology, or texture) of resolvable size. Given the limited time available the stopping interval was relaxed to stopping only when a candidate meteorite was spotted while roving continuously. Although this approach might lead to overlooking a number of smaller-sized meteorites, this strategy was deemed preferable as it maximized the area covered in the time available, and hence, optimized chances of finding larger, easier-to-recognize meteorites. **Results of the Visual Search Mode:** Three candidate meteorites, hereafter designated M1, M2, and M3 were encountered during the second track. The rocks were first seen in the forward direction in panoramic scenes, and then scrutinized using the close-up high-resolution color imagery, for shape, and texture characteristics. They appeared as relatively large and dark objects, contrasting with the smaller-sized, and/or lighter-colored background. M1 was revealed to be a dark-brown object, about 10 cm across, with relatively planar facets, rounded angles, and distinct thumb-sized (1-2 cm across) dimples on the facets (see figure below), suggesting the possibility of an iron-meteorite, the dimples being the reminiscent of regmaglyphs (shallow depressions characteristic of iron-meteorites, formed by erosion of their surface by turbulent vortices during atmospheric entry).

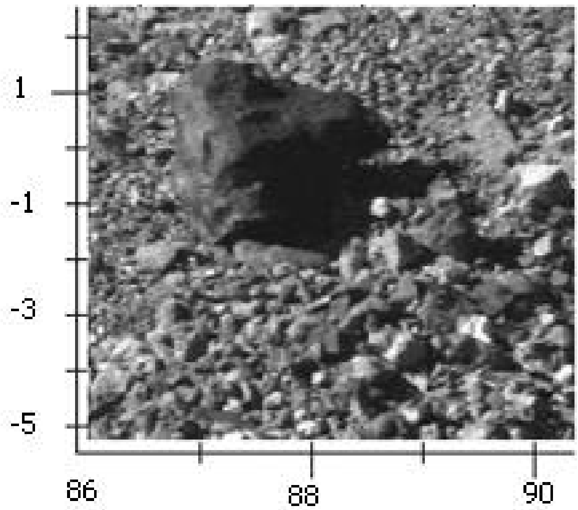

Fig.: M1 candidate, which proved to be a meteorite

Another large and dark rock was spotted (M2), but examination of a single monochromatic high-resolution image revealed a planar-cleavage morphology and roundness unlikely to correspond to meteorite characteristics. A basalt interpretation was tentatively proposed for M2. The M3 candidate, also a dark and large rock, with a mat, grayish brown surface appeared in the high-resolution full color imagery, not unlike observed in chondrites such as Allende. However, the presence of a body-wide facet with apparent angular edges suggested that the dark appearance was likely due to a shadowing. The visual mode search was then discontinued, and the ground-truthing from the field Science Team confirmed the three conclusions of the NASA Ames Science Team: M1 was one of the planted meteorites (iron-type), M2 (basalt) and M3 (sedimentary rock) were naturally occurring local terrestrial rocks. The key parameters of the success of this operation seemed to have been: (1) the imagery capabilities of the rover, especially its ability to go from large scene to high resolution color close-up, (2) the presence in the Science Team of one member being familiar with meteorite-types, (3) a favorable terrain for operation. The results of the visual teleoperated mode search are obviously encouraging, though the use of this technique is subject to limitations related to the access to the site: for instance, the flat area of the Atacama was a favorable environment, as could be icy-plains in Antarctica or Arctic. However, it is known that meteorites can be found in blocky, boulder-rich environments, in which case the use of a rover might be limited, or even precluded. **The instrumental mode:** At the end of the visual search mode, the meteorites were randomly buried 20-cm deep in the same search area by the Field Science Team. The rover pulling the metal detector was sent on linear traverses to detect signals from the instrument. The numerical data received at NASA Ames were converted into graphics showing potential spikes.

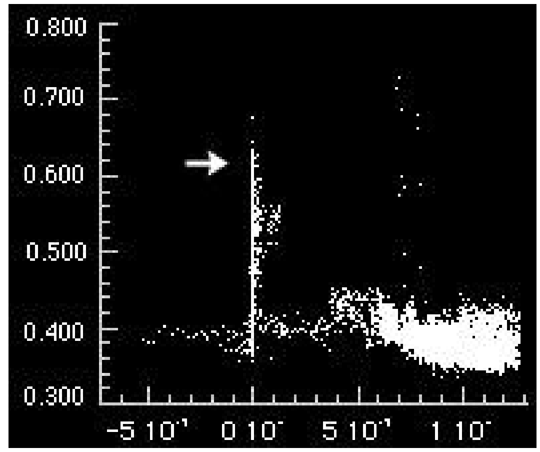

Fig.: meteorite spotted (spike) during the rover traverse

The data were received with a delay at Ames(in the mean time the rover was still moving along), and translated into plots. The spike shown above was interpreted as a possible evidence of a buried meteorite. The position of the meteorite was reconstructed using the time spent between the reception of the data, and the average speed of the rover. Both interpretation of the spike, and its origin were confirmed.

Conclusion: [2] The meteorite search experiment demonstrated the feasibility, in at least some conditions, of carrying out a field search for meteorites by remote control. Of vital importance to the search team at the Ames Operation Center at, was the acquisition of data of sufficient quality and diagnostic content (spectral range, i.e., color, spatial resolution, magnetic sensitivity) to allow the remote identification of the candidate-meteorites. While visual information is important, a broader range of the diagnostic properties as they are available in the field to meteorite hunters, must be provided to lab-bound scientists to help them ascertain the nature of a rock. Integrating the range of diagnostic information into an automated system will be critical to the implementation of an automated meteorite search. Field testing of range of techniques, tools, and strategies for identifying meteorites in the field is one of the prime goals of the 1997 NOMAD expedition to the Patriot Hills, Antarctica.

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References: [1] Cabrol, N. A. 1997. Nomad Atacama Desert trek: Science Plan (Mars, Moon, and Antarctica Simulated Operations. *NASA ARC Int. Report.*. [2] Lee, P. C. 1997. Nomad Search for Meteorites, in *Atacama Desert Rover Field Experiment Final Report* , Cabrol N. A. Ed. NASA Ames Research Center, *in progress*.