**ATACAMA I: SCIENCE RESULTS OF THE 1997 NOMAD ROVER FIELD TEST IN THE ATACAMA DESERT, CHILE.**

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The Nomad rover was deployed for 45 days in the Atacama Desert, Chile, during the summer of 1997. During this period, the rover set the record of the longest traverse ever performed by an automated vehicle (220 km), while controlled by operators either at NASA Ames and Carnegie Mellon. During this traverse, between June 20th and 27th, the rover was used to perform science experiments. Both Science and Operation Team controlling the rover were located at NASA Ames, while a Field Science Team was in the Chilean Desert to ground-truth the operations.

**The Atacama Desert:** The Atacama desert includes a variety of features and characteristics that make this site a unique place to perform experiments on planetary-analog surfaces (i.e., Mars and the Moon): craters from meteoritic impacts, volcanoes, rocks and sand fields, total lack of vegetation due to the absence of rain (1 cm/year from fog), ancient - and now dry - lake beds and sea floor. The average elevation of the test area (23°20'N/68°37'W) was 2400 m, and the diurnal temperature variation from 0° to 25°C. The terrain offered challenges to test the vehicle mobility and trafficability capacities, with a succession of soft surfaces due to the accumulation of smooth materials, and ravines left by ancient channels currently dry which eroded the desert in the past.

**Overall Project and Science Objectives:** The field test was designed to demonstrate and validate: (a) robust locomotion, navigation, visualization, and communication in a long-distance, long-duration traverse in Chile's Atacama desert, (b) perform end-to-end trial under remote control; teleoperation and autonomous control with simulated time delays.

The objectives pertaining to the NASA Ames science field experiment were to: (1) provide realistic desert experience for remote operators through high-quality imagery, (2) simulate NASA missions (Mars, Moon, and Antarctica) by: (a) training scientists, (b) evaluating control environment appropriateness, (c) developing and evaluating exploration strategies, (d) evaluating best interaction by distributed science teams, (3) evaluate the importance of various image techniques, i.e., panospheric imaging, pan/tilt camera, stereo imaging, close-up imagery, (4) understand the reasons of data misinterpretation in previous field experiments by ground-truthing with feedback to the Science Team at NASA Ames, and careful evaluation of scientists' procedures and protocols.

**Nomad Rover: Capabilities and Science Package:** Nomad is a four-wheel drive, four-wheel steer robust rover (wheel diameter: 76.2 cm), of 2.4 x 2.4 x 2.4 m deployed, and 550 kg mass, with a transformable chassis. The rover used an actively pointed antenna to support high-bandwidth telemetry [1], [2]. Nomad's average speed was 0.3 m/sec, though it was able to sustain 0.5 m/sec during the simulated Mars and Moon operations in open terrain. Navigation was enabled by Inertia Measurement Unit, Gyrocompass, and Global Positioning System (GPS), with a precision of about one meter. The imagery system included a panoramic camera with an ultrawide field of view (360° x 40° above horizontal) using a spherical mirror mounted above the vertically oriented digital camera [3]. The science imaging system (high resolution cameras) was designed to reach the resolution of the human eye (see specifications below):

- Color Stereo Cameras: 640x480 pxl; 0.29865 mrad/pxl; 8 x 11° FoV; 8 bit per color (24 total); left/right stereo separation: 25 cm;
- Black and White Stereo Cameras: 640x480 pxl; 0.895 mrad/pxl; 25 x 33° full FoV; left/right stereo separation: 12.5 cm;
- Panospheric Camera: 1024 x 1024 pxl; 360° FoV; 1 Mbyte per image;
- Science Instrument: Magnetometer: sled dragged behind Nomad on rigid towbar; sensor footprint: 8" at 13 cm.
- Aerial Photos: 1 m/pxl resolution
- Weather Sensors: Temperature; humidity, wind velocity.

**Exploration Strategies:** The goal was to prepare near-term planetary missions by testing different exploration strategies. The planetary mission scenarios included: (1) Mars Caching Samples by a thorough examination of the sites, with and without panospheric camera, and with and without time delay), (2) Science "on the fly", while keeping the rover in motion 75% of the operation time to determine whether or not successful interpretation of the environment is related to the time spent on a target, (3) Exploring strategies (visual and instrumental) to remotely identify meteorites in an extreme environment (i.e., in Antarctica).

**Results:** (a) The Science Team at NASA Ames properly identified the geologic environment, often to detail, when compared with the ground-truth provided later in the operation by the notes from the Field Science Team, (b) the science "on the fly" successfully showed that the selection of appropriate targets might be even more critical than the time spent on a study area to reconstruct the history of a site. This operation also allowed the Nomad Team to set a new record of traverse-length for a one-day operation (1.3 km), and during the same day, a new rock unit was discovered by the Science Team using the rover in a local Jurassic outcrop, (c) both visual and instrumental modes demonstrated the feasibility, in at least some conditions, of carrying out a field search for meteorites by remote control. Further field tests of a range of techniques, tools and strategies for the identification of meteorites in the field is one of the prime goals of the 1997 Nomad expedition to the Patriot Hills, Antarctica, that is following the Atacama Field experiment.

**Conclusion:** The Atacama Field experiment was able to finally breach the barrier of geologic misinterpretation often encountered in previous field tests. Sedimentary, metamorphic, and igneous rocks were properly identified using only visual instruments, and the main lines of the site's recent geologic history ( 250 Myr) were reconstructed. The human-eye resolution camera, the panospheric camera providing the Science Team the feeling of being in the field by enabling a 360° observation of the study area (even with the rover in motion), and terrain models comparable to those used two weeks later during the Pathfinder mission, were important to the success of the Nomad mission. The individual benefit and value of these instruments and techniques will be assessed in future studies.

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Figure: Nomad on a rocky field heading to the salar (ancient lake now dry). The association of ancient aqueous sedimentary deposits, channels, rocky and sandy fields, and volcanoes provided a good analog to planetary missions. The Andes in the background.

Figure: The succession of ancient dry channels, often associated with loose material provided challenges for the navigation team.