A 5-DAY MARS-ANALOG PRESSURIZED ROVER MISSION

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Most explorers on Mars will seek to travel considerable distances away from a base habitat. A large, self-contained pressurized vehicle with accommodations for three was used in field trials of the exploration strategy developed over the course of a Mars analog mission. The first 5-day Mars-analog pressurized rover mission was conducted to compare the science return and the amount of territory explored. Results suggest that without improved exploration strategies, during a long surface stay on Mars of about 560 days, only 40 sites selected from 100 areas scouted could be studied thoroughly. Spacing of these sites within a few kilometres defines a minimum exploration circle of about 80 km in diameter. Mission architectures calling for ranging up to 500 km with rovers are pessimistic in estimating how sparse features of interest would be, while optimistic about how much territory could be studied within the span of a single expedition. Future rover investigations will define the time-limited operational constraints on scientific exploration.

INTRODUCTION

The first long-duration mission of an analog rover was successfully accomplished using the University of Michigan's Analog Mars Rover Everest[1], from March 10 – 14, 2003. The three-person crew consisted of a geologist, a biologist and an engineer. The engineer served as rover pilot, navigator, and health and safety officer. On simulated extra vehicular activities (EVAs), analog mechanical counter-pressure (MCP) spacesuits called MarsSkins[2] were worn. The geologist and biologist alternated leading each EVA with either the other scientist or the engineer as a field assistant. This mission represented the culmination of the science operational studies executed for Expedition One[3].

A base camp was selected at a distance of about 12 km from MDRS. At the site a gasoline generator was delivered by engineers of the Expedition One Phase 4 habitat crew, and set up for the rover team in about an hour from departure. This "fuel depot" was the location where the rover crew would return each night to obtain power to run the Everest electrical systems, allowing use of the rover kitchen and toilet facilities, hot food, and computer access for writing up reports and recharging batteries for field equipment. The use of a portable generator cached at a fixed site was necessary due to the original Everest generator being at the manufacturer for repairs. The MDRS backup generator

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was used instead in order to continue the rover mission that had been planned months in advance. It was unsafe to mount the generator on the vehicle itself, so necessitated caching it, as well as three large canisters of gasoline, at a location central to the study.

Past research at the Mars Desert Research Station has been limited by several factors. The most critical is the lack of an organized research program. While each crew should be and is encouraged to pursue research of their own choice, an overall science program at MDRS would greatly improve both the rigor of the science being done and the ability of crews to advance the science instead of repeating what has already been investigated. Additionally, early crews had only two modes of transportation to sites of interest—travel by foot or by all-terrain vehicle (ATV). While both were adequate and preferable for exploring the immediate vicinity, the restrictions they imposed meant EVAs needed to be kept short and not much in the way of equipment could be taken into the field. In addition, as simulations tested the use of light single-person unpressurized all-terrain vehicles, the time an EVA crew could be in the field was limited by the oxygen constraints built into the exercise. The fourth crew rotation at MDRS was the first to use an analog pressurized exploration vehicle, or PEV, in the field[4]. The vehicle was an unmodified SUV that could, in simulation, hold two crewmembers for an overnight EVA and increase both time spent and distance travelled in the field. Several later crews also used a PEV during their rotations, but it was not until Expedition One (Crew 14) that vehicles specifically modified for Mars analog research were used. The arrival of both the ARES[*] and Everest meant that crews could, for the first time, travel farther and longer than ever before. After initial operational tests, including both daytime and overnight EVAs, to determine what was needed to accomplish science while using either of the two larger, better designed rovers, it was time to test the rovers on a longer EVA. Since the ARES was not completed sufficiently for long-term occupancy, and was built for two persons, the Everest was used on this first ever multi-day 3-person mission.

Mission Scenario

The focus of the rover mission field science was based on recommendations from the planetary science community as expressed at a 2001 workshop.[5] Science best accomplished by humans in the field requires observation, pattern recognition, and a synthesis of a broad experience base. Field work is most needed for the measurement of parameters (like bedding attitude and layering thickness), reconnaissance, site-specific field studies, and mapping of features geologic interest and biologic potential.

Figure 1 below is the schedule first established by the rover team on Sunday, March 9, 2003 for the subsequent 5 days, and which was modified during daily consultations. It was decided to conduct the first two days as mission analogs, and the last three days as mission simulations. The difference between the two was that on analog days only the EVAs were conducted as simulations, but without radio protocols, while on sim days, both EVAs and rover operations (with airlock procedures) were conducted as holistic simulations, including the use of radios for communication between rover team members.

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[*] http://engsoc.queensu.ca/ares/

The mission scenario applied was based on lessons learns from research conducted over earlier phases of Expedition One. Exploration was divided into broad-ranging scouting and localized science surveys of features of biological and/or geological interest. Scouting can be accomplished most effectively with geologists and biologists working together, each focusing on their own goals but ready to consult with each other. Localized science surveys are best focused on the goals of either a biologist or a geologist, but not simultaneously, with the other scientist, or the engineer, acting as a field assistant.

The intent during mission planning was to divide every day into morning scouting EVAs and afternoon site data-acquisition surveys. However, as the mission proceeded, the urge to range further ahead to see new vistas compelled changing plans every day. Changes were strategically considered. In the end, a better scenario emerged: scouting as much territory as quickly as possible in early EVAs, and then returning later to selected sites for localized science surveying. However, areas such as Salt Wash that were fairly distant from the fuel depot (or base camp) compelled data-acquisition EVAs immediately after scouting.

ExOne Rover Mission Phase 4 Schedule

		Analog	Analog	Sim	Sim	Sim
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
7:00 AM		Wake-up	Wake-up	Wake-up	Wake-up	Wake-up
8:00 AM		Breakfast Meeting	Breakfast Meeting	Breakfast Meeting	Breakfast Meeting	Breakfast Meeting
9:00 AM		EVA60 Base Scouting Shannon Rocky Jennifer	EVA62 Scouting Salt Wash Shannon Rocky Jennifer	EVA64 Surveying Coal Mine Canyon Shannon Jennifer	Rover Maintenance and Crew Changeover	CogState and Social-Psycho Study
10:00 AM						EVA67 Scouting Caineville Reef
11:00 AM						
12:00 PM		Lunch	Lunch	Lunch	Lunch	
1:00 PM		CogState and Social-Psycho Study		CogState and Social-Psycho Study		
2:00 PM		EVA61 Scouting Factory Butte Road Shannon Rocky Jennifer	EVA63 Surveying Salt Wash Jennifer Rocky	EVA65 Surveying Neilson Wash Shannon Rocky	EVA66 Scouting Horse Mesa Road Rocky Matt Shannon	Return to MDRS. End Rover Mission.
3:00 PM						
4:00 PM						
5:00 PM						
6:00 PM		Dinner Meeting	Dinner Meeting	Return to Hab Dinner	Dinner Meeting	
7:00 PM	Rover Mission Prep	Scouting Report Writing / Mapping			Science Report Writing / Mapping	
8:00 PM			Science Report Writing / Mapping	Crew Meeting		
9:00 PM		Entertainment		Entertainment	Rover Maintenance	
10:00 PM			Rover Maintenance		Narrative Report Writing	
11:00 PM	Sleep	Sleep	Sleep	Sleep	Sleep	

Figure 1: The rover mission schedule for Sunday March 9 to Friday March 14, which number EVAs (continuing the sequence from the whole of Expedition One), and time alloted for rover maintenance, meals, meetings, report writing, entertainment, and sleep.

Description of Field Site

A pressurized rover offers the opportunity for long distance exploration. Our field site consisted of an area in Wayne and Emery counties, Utah, U.S.A. identified on U.S.

Geological Survey topographical maps as Factory Butte, Skyline Rim, Little Wild Horse Mesa and Hunt Draw. Part of the Colorado Plateau, the area is temperate desert, with an annual total rainfall of less than ten inches, most of which falls in late summer thunderstorms. The study area, however, had abundant water sources. Muddy Creek and Salt Wash both held flowing water and ponds were found near Coal Mine Wash and at the base of Factory Butte, one of which was still ice covered. The Bureau of Land Management has designated the area for multi-use and that currently includes recreational use, a designated off-road vehicle park, cattle grazing and mining interests.

Previous crews at MDRS had focused on these areas only as a long distance challenge to be attempted using all-terrain vehicles (ATV). Using the Everest as a base presented the opportunity to systematically explore along the roads and tracks within this area without having to return to MDRS after every EVA. Particular attention was paid to the Salt Wash area, as it proved rich in sites of both biological and geological interest. As its name suggest, Salt Wash contains abundant salt deposits over much of its surface, and should support the growth of halophilic microorganisms, of interest because their extremophilic adaptations may have analogs on Mars. In addition, the slightly dipping beds of siltstone, sandstone and gypsum were very well exposed in canyon walls and allowed for detailed stratigraphic mapping. This mission accomplished the first simulated explorations of sites (Salt Wash and Little Wild Horse Mesa) far more distant from MDRS than ever attempted by earlier crews.

Biological Field Work

Since it had been decided that the mission would focus on long-distance scouting and limited surveying, the biology goals for the mission were simple. Objectives were:

1) Scout for sites of biological interest, more specifically sites for microbial richness and halophile/extremophile studies, and record the GPS coordinates of these sites from the road.

This distinction was important to the overall operational studies. Since the goal was to determine the optimal way to scout for sites from the confines of the rover, it was important that coordinates were recorded from the roads along which the rover traveled.

2) Survey a subset of the scouted sites to determine if first impressions made at the roadside were valid once outside the vehicle.

3) Determine how best the science team, comprised of a biologist and a geologist, could scout and survey sites together, in a manner that complimented, not compromised the science goals.

Over the course of the five-day mission, eight EVAs were completed. Of these, five were scouting EVAs and none of the crew exited the Everest. The rover engineer drove while the scientists took notes and photos from the vehicle cab, and recorded GPS coordinates. The remaining three EVAs were site-localized science EVAs, one for geology, one for biology and one with combined geology/biology focus. Two crewmembers left the rover for each of these EVAs, while the remaining crewmember stayed in the rover.

A total of 32 sites for possible biological study were identified and recorded during the eight EVAs.* This does not include the area known as Little Wild Horse Canyon. Many possible sites were visually identified in the canyon, but nothing was recorded. Three of the recorded sites, Coal Mine Wash, Salt Wash and Neilson Wash, were later explored on foot during the site-localized EVAs. So how successful was the scouting for sites that were valid in terms of biological significance? Of the three sites explored on foot, all showed promise. Coal Mine Wash could be a possible extremophile site due to coal deposits and the pond, and also held potential for microbial richness studies. Salt Wash, with its abundant salt deposits, is a good site for studies of halophilic microorganisms. In addition to Salt Wash, both Muddy Creek and the flats between these two water sources have scattered salt deposits, and so all of the study area holds potential for halophile studies. At Neilson Wash, desert varnish was found. None of the possible water mapping sites was surveyed, but these were also the easiest to identify from the road, since varied terrain and soil types are the required components for the study.

There is one potential drawback to doing biological studies throughout the area covered during this mission. As mentioned earlier, there are cattle grazing on these lands, and so any studies done would have to factor out contamination due to their presence. This should not be a problem, as long as experiments were designed to take this into account. For example, any richness studies done in the area should be significantly different from those done around MDRS, and indeed, results from the 2002 field season suggest this is the case.[6] Any extremophile studies should be carried as far from contaminated areas as possible. However, as an analog for Mars, studies here will still be valid, provided the presence of the cattle is noted in all reported results.

Geological Field Work

The 5-day rover mission focused on the ExOne geology goals of determining the stratigraphy of the area and studying past depositional environments. There were 18 sites of geological interest found during the 5 scouting EVAs.† Two sites were selected for measurement of stratigraphic sections on two different surveying EVAs in Neilson Wash and Salt Wash. Units were sampled, and photos were taken for reference.

The Salt Wash section held two massive gypsum deposits sandwiching a muddy / silty layer penetrated with gypsum veins. These were used as a marker bed for observations of the section for a few meters above, and several meters below. Sandstone, siltstone and shale layers alternated throughout the 30-35 m section. The section indicates a past shallow near-shore environment that underwent periods of evaporation.

The Neilson Wash section held mainly siltstone, sandstone and shale alternating over 8 meters, with two 8 and 30 cm coal beds near the base. Lots of crossbedding was

* http://marssociety.senecac.on.ca/ExpeditionOne/030315/biorover.html
† http://marssociety.senecac.on.ca/ExpeditionOne/030315/georover.html

evident in the sandstone beds. The section suggests an ancient deltaic environment that at times experienced flooding of surrounding land when delta switching occurred.

In other areas investigated, strata was mostly covered by talus and debris, but with time could be assembled into sections for mapping. Measurements of paleocurrent directions would be more profitably pursued at exposed outcrops in these smaller canyons in Coal Mine Wash and Neilson Wash.

Field work while making observations in the MarsSkin analog MCP suits was not difficult, despite having to climb steep debris slopes to get close to cliff walls. It was obvious that this sort of map work would be impossible for robots to even begin. Human observation of the relationships of geologic units is absolutely essential for interpretation. Overall, limiting rover travel to easily passable terrain to scout for sites was not overly restrictive, as plenty of sites allowing for geological measurement could be easily discovered within view. For surveying work, an all-terrain-vehicle towed behind the pressurized rover would be ideal for quick mobility between closely spaced sites, or sites away from the passable terrain, but pedestrian EVA work was adequate as there were not too many geological tools that needed to be carried.

Evaluation of the Amount of Science Return

Scouting without leaving the vehicle was effective, especially from the raised perspective offered by the Everest cab, with eye level approximately 2.5 meters above ground level. One scientist sat in the passenger seat and made use of the fold down desk for note-taking and map consultation, while directing the rover pilot to desired paths. The second scientist used the middle seat, which sat higher and farther back than the driver and passenger seats, to take photos and make notes with a voice recorder. From this vantage, the scientists could look for the most easily assessable sites that would serve the required purpose: the possibility of having scientific significance.

Using a rover for initial scouting over a large area resulted in the discovery of many more potential, and possibly better, study sites than could have been located by ATV or on foot. When scouting during pedestrian and ATV EVAs, the distance travelled is limited. The advantages of the Everest are that explorers can go farther afield in less time, in relative comfort and with all the necessary equipment.

Once scouting is completed, a rover crew can drive directly to sites of interest without having to carefully observe and document the landscape they pass again. Travel times between sites of course then decreases, yet still consumes the time of the crew. Effective traverse strategies can reduce this by attempting to travel over a specific path not more than twice. The simplest strategy might be to scout along a path for sites in one direction, and study a selection of the best sites when returning along it. In this case, an overall exploration strategy would be to take radiating paths from a central base, such as an asterisk (*) search pattern. A more effective strategy might be, when topographically convenient and environmentally acceptable, to slightly alter the returning path so as to scout for new sites at that time too, following an elliptical path (like a long-period comet around the sun), or even a many-pointed star pattern. Topographic barriers would disrupt all idealized search patterns. It would take some careful planning, but in order to maximize the science return, search patterns specific to local topography could be designed from satellite data before an expedition is launched. In this case, exploration would have to be scheduled and perhaps fairly scripted for the majority of the mission. To accommodate extra EVAs required to revisit sites of particular significance, time would have to be budgeted periodically between scripted exploration stages. To keep the crew agreeable to these scripts, they must lead the exploration planning.

The Salt Wash section was about half completed, while the Neilson Wash section was merely begun. Each section required 1 or 2 more EVAs in the vicinities to obtain enough data for completion of the stratigraphic columns. The Little Wild Horse Mesa, Coal Mine Wash, and Caineville Reef areas were rich in areas for surveying, but time for this was not available. Assuming the other 16 geology sites scouted would similarly be measured, 36 to 54 EVAs would be adequate. Adding to that total the number of scouting EVAs, this indicates that between 40 and 60 EVAs would be necessary for pursuit of this geological goal over the entire area explored. Resulting would be a detailed map of the regional structure and stratigraphy, allowing interpretation of past depositional environment. For the area explored, this would take about 20-30 days, assuming two 2-hour EVAs per day. However, only perhaps half of the geology sites are worth visiting, so two weeks should be enough time to accomplish this.

A conservative estimate of the biology sites that need to be surveyed would be half of all sites identified in the initial scouting. Since the biologically significant sites that were identified on this mission were for three separate investigations—biological richness, water mapping and halophilic diversity, a minimum of ten sites would need to be surveyed to accomplished the biology goals. Since only one-third of the required surveys were completed, an estimated of the time necessary for sufficient sampling of the area, assuming two 2-hour EVAs per day, is a minimum of 15 days. Quite probably, all scouted sites would have to be visited on foot to determine their suitability, slightly increasing the time requirement. The results of such an effort would be a database with sufficient information to characterize the microbial distribution of the region, and identify areas with halophilic/extremophilic microorganisms. This would require that the samples collected in the field be processed in the laboratory, either aboard the rover or back at the base habitat, and as such, any planned research should factor this additional activity in scheduling. Future research should focus first on refining site selection procedures, perhaps by spending more time on scouting from the rover with a pair of binoculars, to select the most promising sites. In addition, a general understanding of how local microbial life is distributed due to water availability and regolith type would also increase the effectiveness of scouting sites from the rover.

In total, to meet both biological and geological goals, two to four weeks would be required for the entire area scouted by the 5 reconnaissance EVAs of this rover mission. The two week estimate depends on an effective work strategy that would accommodate both the biologist and geologist working simultaneously and together, at a set of 10 common sites.

Evaluation of the Amount of Territory Explored

Figure 2 below indicates the areas that can be considered "explored" by the rover crew. Using the GIS software DeLorme XMap, the GPS coordinates for waypoints and feature points were plotted. To approximate the actual paths taken, the map was divided into triangular areas (in a hexagonal pattern) 2 km on a side, each cell covering 1.7 km^2. The triangular cells offer a more realistic and convenient way to visualise the actual territory explored than a rectangular cell grid, since paths traveled are not typically orthogonal. Any triangular cell in which a waypoint resides was darkened to indicate that area as explored territory.

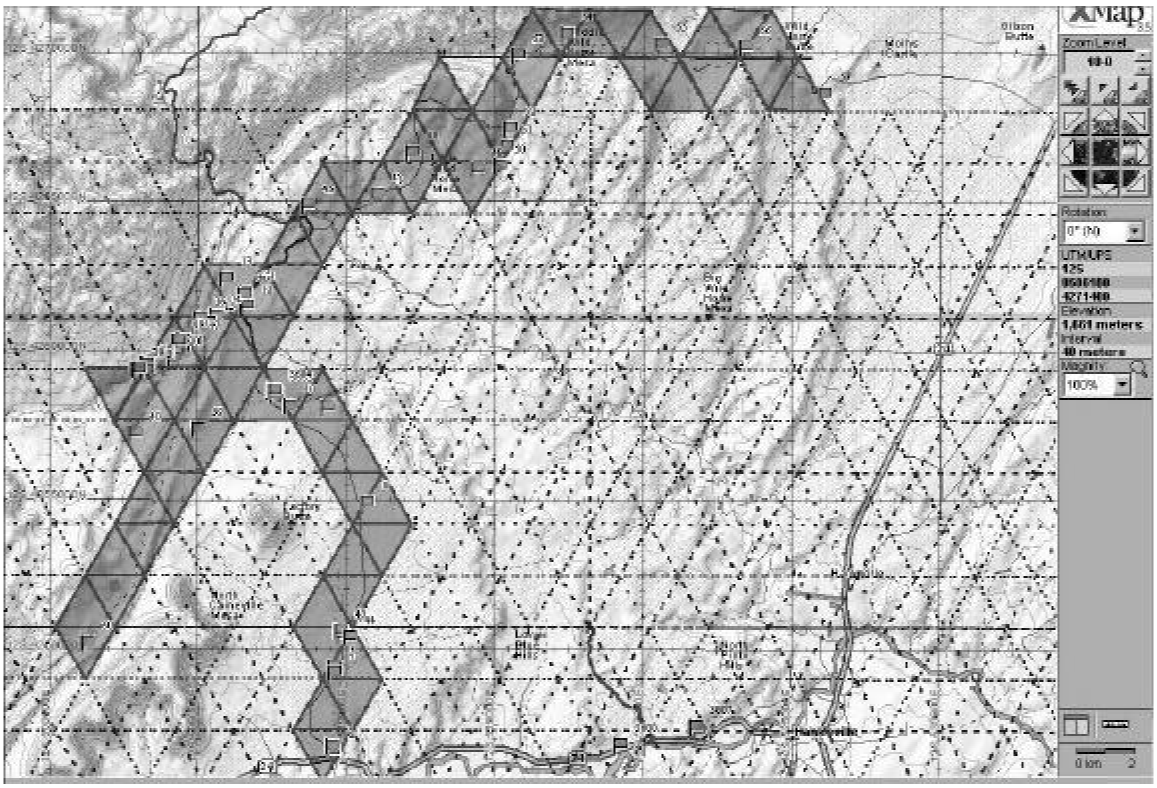

Figure 2: Map of the region near MDRS where the Everest Rover mission occured. Darkened areas represent explored territories where observations were made and GPS coordinates recorded. Mapwork by Frank Crossman using DeLorme XMap.

Most of the area south of San Rafael Reef, west of Skyline Rim/ Middle Wild Horse Mesa, north of Highway 24 and east of the Moroni Slopes / Wood Bench was explored. As can be seen, 66 cells have been darkened indicating a total area of approximately 114.3 km^2 explored over 5 scouting EVAs, and 3 site-surveying EVAs in one week. One surveying EVA was about 2.5 hours in length, but the other two were about 1 – 1.5 hours. Using the above estimate of science return, similar 115 km^2 areas could be explored thoroughly in about two weeks.

The total map area shown is 935 km^2. This is equivalent to an "exploration circle" roughly 35 km in diameter surrounding a human outpost. Based on the above numbers, an optimistic estimate of 16 weeks would be required to completely explore and survey it. However, better scenarios can be found. For example, it is imagined that a photographic camera taking images with 60 degree fields of view could be used to assemble panoramic images to document each hexagonal area up to the range of the horizon. With panoramic images taken by precursor reconnaissance robots at each node in the triangular mesh, there would be a thorough overlap of the landscape so that details of features from multiple angles could be seen sufficiently to assess the scientific value of a site, eliminating the scouting phase of human expeditions. But humans tend to need to see the landscape in their own eyes to appreciate and understand its significance.

Extrapolating to Mars

Given a similar number of science goals, similar exploration strategies, and with about 5 sites studied intensively per week (each site requiring 2 to 3 EVAs), selected from a few dozen sites scouted, then given 80 weeks (560 days) on Mars, an 80 km in diameter area surrounding a human outpost would be a minimum exploration circle. This is a 4,600 km^2 territory. The number of sites investigated would be about 400 selected from nearly 2000 scouted. The exploration circle could be expanded only by situating those 400 sites more sparsely, skipping over vast areas where it is assumed there is nothing of interest based on satellite data.

As more data becomes available, these numbers will have to be refined. But for a first approximation upon which to design exploration strategies, it is adequate. No doubt in the future more efficient science/exploration work processes will be established to produce the same science return in a shorter period.

Future Rover Mission Investigations

A long term series of Mars analog expeditions are anticipated to be conducted by the Mars Society national chapters of Canada and Australia, with participation of other research organizations invited.[7] Expedition Two will focus almost entirely on rover-based studies, featuring the Starchaser Marsupial Rover.[8] Investigations to follow up the rover mission reported here are needed to confirm and refine estimates of amount of science returned for area explored. These future investigations will likely be over longer durations, with improved scouting strategies and science operations, and be conducted to efficiently explore a specific territory as quickly as possible. Targets will be picked from satellite imagery, and how the ground exploration experience alters the selection of target sites during the mission will be documented. Also, the regional landscape will possibly be thoroughly documented at each node for the triangular grid with panoramic images, in order to test the usefulness of precursor reconnaissance robots for advance study site selection. A second rover mission to the area covered in this study is recommended. It is sufficiently close to MDRS for contact with the habitat crew in an emergency, is large enough to support a mission of a week or longer and has several scientifically significant sites for conducting research.

CONCLUSIONS

The goal is to maximize the amount of science returned during human Martian expeditions. Exploration strategies with rovers should be studied further, optimizing tactics for specific kinds of terrains and topographic restrictions. Science operations in the field also need to be studied to reduce the time spent on EVA performing site studies while keeping the quality and quantity of research accomplished high. Given an expedition limited to 500 or 600 days, not a lot of time for exploring is available. At minimum, an exploration circle of 80 km in diameter is achievable. The maximum exploration circle needs to be defined with future investigations.

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