EXPLORATION RADII FOR A CREWED MISSION TO A HUMAN LANDING AT TERRA MERIDIANI. J. D. A. Clarke[1] and D. Willson[2], [1]Australian Centre for Astrobiology, Macquarie University, NSW 2109, Australia, jdac@alphalink.com.au [2]SEMF Pty Ltd 2nd floor 44 Murray Street Hobart Tasmania 7000 Australia, willd@semf.com.au.

Introduction: Considerable research effort has been expended into how humans might travel to and land on Mars. Far less effort has been on how Mars might actually be explored once crews are on the surface. Conferences such as this are addressing this gap in understanding. This paper is in three parts. First, it looks at the some of the constraints on surface exploration radii round a Mars landing site, using Mars Society Australia's (MSA) MARS-OZ mission profile as a baseline. Second, it looks at these exploration radii when transferred to the Meridiani Planum land site. Third, it provides a terrestrial comparison for these radii in the Arkaroola Mars Analogue region.

Constraints For Exploration Radii: The MARS-OZ mission study has been describe elsewhere [1], in essence the concept is based on the 'Mars Semi-Direct' mission architecture, as used by NASA's design reference mission, resized to a four-person crew. It differs from most other studies in that the modules are based on horizontally landed bent biconic lifting bodies, rather than vertically landed and oriented cylinders. Two modules are used, a crew habitation module, and a cargo module that includes an ascent vehicle, ISRU plant and a detachable garage. We believe that the configuration has many advantages over others proposed with reference to both Mars landing and surface utilisation. The configuration is also used in the proposed MARS-OZ simulated base that MSA plans to deploy at a future date to Arkaroola [2]. The modules are designed to support field engineering, robotics, architectural, geological, biological and human factors research at varying levels of simulation fidelity. Non-Mars related research can also be accommodated, for example general field geology and biology, and engineering research associated with sustainable, low impact architecture. Crews of up to eight can be accommodated. In addition to its research function, the base also will serve as a centre of space education and outreach activities. The prime site for the MARS-OZ simulated base is located in the northern Flinders Ranges near Arkaroola in South Australia.

The MARS-OZ concept mission would be equipped with: Four astronauts with normally only two being away from the base at any one time, an ISRU plant capable of supplying propellant and power to support surface exploration for a minimum 600-day period, a small teleoperated rover, a single unpressurised rover similar to the Apollo LRV and capable of teleoperation, a single large pressurised rover, also capable of teleoperation.

Exploration Radii: We envisage exploration at four scales: short-range (walking distance), medium-range (unpressurised rover), long-range (pressurised rover), and extended range (two pressurised rovers or other exploration technologies) on later missions.

Short-range exploration. This is equivalent to the distance easily accessible on foot using a high mobility suit such as that based on mechanical counter-pressure suit (MCP) technology [3]. However, for conservative purposes we assume no greater mobility than that achieved on the moon using an Apollo EVA suit. We conservatively estimate this as 2 km, with an exploration area of ~12 km^2. Assuming an 8-hour EVA and an hour to reach the 2 km limit, this would give the crew 6 hours to work on the sites furthest from the base. We believe it is feasible for normal working EVAs to cover 3-4 km per sortie. This matches the longest pedestrian EVA on the moon, Apollo 14 EVA [4]. An essential aspect of Martian EVA planning that was not an issue on the moon will be the need to have the external crew back within a pressurized environment before nightfall. This is much less than could be covered by unencumbered geologists in similar terrain. The lead author's experience in the area indicates that a scientist working on foot and laden with 15-20 kg of equipment could expect to easily cover 5 to 15 km in the course of a day's fieldwork.

Although the size of the short-range exploration zone has been defined by distance of pedestrian EVAs, we are not implying that operations within two km of the base will be restricted to them, however. For most purposes we envisage the use of unpressurised rovers to increase the load carrying capability and minimise time spent traveling to sites. Crew EVAs will be supplemented and assisted by use of the small teleoperated rover.

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plemented and assisted by use of the small teleoperated rover.

Medium-Range Exploration: The medium-range exploration zone is equivalent to that which could be covered on daily traverses using an unpressurised rover similar in performance to the LRV during the last three Apollo missions. The LRV had a battery range of ~100 km but was constrained to a ~10 km radius to ensure that the crew would return to the LM on foot in the unlikely occurrence of the LRV being immobilised [5]. A 10 km radius equates to an exploration area of ~300 km^2. We envisage that only single day sorties will be performed using the unpressurised rover. Pedstrian EVAs may extend up to 2 km beyond the limit of the unpressurised rover in rough terrain. As with pedestrian EVAs, the need to have the outside crew back in a pressurized environment before night fall will be an important consideration to avoid traveling in darkness and in the very low nighttime temperatures. This is equivalent to field scientists using a light 4WD vehicle without overnight equipment.

Long-Range Exploration: A pressurized vehicle is the most expedient means of exploring of Mars beyond the range of single-day sorties with an unpressurised rover. For this study we assume of vehicle with a range of 500 km and is capable of staying away from the hab with a two-person crew for up to four days at a time with a 20% reserve [6]. The exploration radius has been fixed at 40 km, to allow an electric unpressurised rover to drive to an immobilised pressurized rover and return without recharging. An exploration radius of 40 km brings ~5000 km^2 into the exploration area. This is equivalent to what might be studied by a scientific party working from a vehicle equipped for camping for several nights in the field. Once again, in the , more distant sites, up to 200 km from the base, could be accessed, because of the track network. Were these absent, the practical limit would be closer to 40-50 km.

There are alternatives to the use of a pressurized rover. These include using a field camp as a temporary shelter [7] with the assistance of technologies such as the pressurized ball tent, a pair unpressurised rovers, and equipment trailers. We believe these technologies to be useful ancillaries to a fully pressurized rover, rather than a substitute for it.

As with unpressurised rovers, pedestrian EVAs offer the potential to explore areas too rugged for vehicle access. However, a 2 km radius beyond the limits of vehicle travel listed above would greatly restrict the range of interesting sites available for study. While this might be acceptable on early missions, increased experience and the demands to study scientifically valuable sites in difficult terrain will, we believe, lead to a relaxation of this limit. This will however make use of MCP technology over gas-pressurised suits imperative.

Extended Operations: There are a number of options that could be considered for extended range operations. If the unpressurised rover accompanies the pressurized rover on its traverse, then the exploration radius could be extended out to 100 km. Ball tents, supply caches and trailers could also be used to extend the exploration radius of even a single pressurized rover to 100 km or more [8]. An exploration radius of 100 km brings ~30,000 km^2 within operational reach and implies sorties of a week or longer.

However, the ideal approach for such extended range exploration on Mars, as on earth, is the use of two vehicles of equivalent performance. Within the framework of the MARS-OZ concept mission this implies that these extended exploration would occur on the second or third expedition to Mars with further deliveries of vehicles and other equipment. With two or more vehicles very long range traverses equivalent to the major terrestrial polar or desert crossings can be considered [9, 10].

Opportunity Landing Site (Meridiani Planum): The Opportunity rover bounced to a halt in Eagle crater on Meridiani Planum at 354.4742°E and 1.9483°S on January 25th 2004 [11]. In the 12 months since landing Opportunity has traveled approximately 2 km. The physiography and stratigraphy of Meridiani Terra as seen by the Opportunity rover is quite different to that of Gusev Crater. The landscape consists of a very flat and smooth plain of etched sediments overlain by a lag of ferruginous granules and sparse wind ripples. These have exposed the sedimentary succession of the plains forming unit. The stratigraphy is exposed in a series of craters visited by the rover – Eagle, Fram, and Endurance. At the time of writing (February 2005) Opportunity is on route to another larger crater, Victoria. The sediments at Meridiani may infill a subtle, 300 km-wide degraded impact basin in Noachian crust [12]. The sediments themselves are at least 600 m thick [13, 14] and have been variously interpreted as volcanic ash, fluvial, aeolian, and lacustrine deposits. Those observed to date by Opportunity consist predominantly of lacustrine evaporites. The sediments are thought to be of Hesperian age.

Everything explored to date by the rover is within the nominal 2 km radius of a pedestrian EVA. Increasing the radius to 10 km finds the exploration area still within the same sedimentary plains unit (P2) found at the site, however the presence of more and larger craters within the larger area would greatly increase the range of stratigraphic sections for study. Increasing the exploration radius to 40 km, as would be possible with a pressurized rover, brings into reach a ~20 km diameter crater to the south west which may have penetrated through to the deeper sedimentary units (units P1 and E) if present, or the Noachian basement. The edge of the Noachian cratered plains would also be reached to the southeast. An exploration radius of 100 km would bring more extensive exposures of the Noachian cratered plains to the south, the etched plains unit ("E") to the north with its numerous cliffs and mesas, the oldest layered unit (P1) to the northwest, and several large (20-35 km) filled craters to the west. There are a number of pedestal craters in this area also, hinting at the presence of localized zones of subsurface ice. Extending exploration radius beyond 100 km brings an even greater range of sedimentary and cratered highland terrain into range.

Comparison with the Arkaroola Mars Analogue Region: The Arkaroola Mars Analogue Region in the northern Flinders Ranges of South Australia was selected in 2001 by MSA as prime area for Mars analogue research in the field [15]. The area has many features relevant for such research, including sites of geological, geomorphological, palaeontological, biological and hydrological interest and a range of environments suitable for testing instruments, methodologies and equipment, as has been summarized elsewhere [16]. A wide range of other research, especially field science and engineering, can be carried out, of which deployment of the MARS-OZ simulated base is a prime example. The region is an ideal location to test the effects of different strategies, including exploration.

Short-range exploration. There are a considerable number of features of interest within a 2 km radius of the prime hab site. All of these are readily accessible on foot, they include: Late Proterozoic basalts, evaporitic, clastic, and carbonate sediments and stromatolites, Cretaceous marine sediments, pre and post-Cretaceous weathering surfaces, silcrete duricrusts, Pleistocene high level gravels of fans and pediments, Holocene creek gravels, and springs and seeps associated with major creeks.

Medium-range exploration. Sites of interest within a 10 km but greater than 2 km radius of the MARS-OZ site include: Late Proterozoic sediments, including glacials and stromatolitic carbonates, Pleistocene high-level gravels of fans and pediments, active neotectonic zones, Holocene creek gravels, and a range of springs, some of which are both hot and radioactive, and outcropping creek bed groundwater in waterholes.

Most of the area consists of flat or gently sloping surfaces covered in small gibbers. Locally steep creek banks and breakaway edges are present and, with the boulder-dominated creek beds, pose some challenges to mobility. (A much greater challenge to access is presented by the areas of Late Proterozoic sediments that form part of the Adelaide fold belt. They occur as areas of moderate to extremely steep relief, dissected by steep gorges cut by ephemeral creeks. Most of these areas are too steep and too rough for vehicular access. Foot access is mainly along the dry creeks that also provide excellent stratigraphic exposures. We assume that explorers operating under Martian EVA constraints would be able to travel up to two km past the last point accessible by unpressurised rover, at a minimum. This would greatly the limit the areas that could be explored in the region of high relief, despite the high geological interest of the stratigraphic sections and other exposures contained within them.

Long-range exploration. The number of additional features of interest within a 40 km radius of the prime hab site are proportionally greater than those at lesser radii. Some of the more important or interesting sites that can be accessed with this sort of capability are: Early and Middle Proterozoic granites and gneisses, more Late Proterozoic sediments, including glacials and stromatolitic carbonates, quartz-haematite high level hydrothermal breccias, distal fan deposits of sand and silt, seif dunes associated with the western margins of Lake Frome and the Strzelecki Desert and warm springs.

These features provide a diversity of geological analogues for Martian surface and sub-surface processes, especially the range of evaporitic sediments of Late Proterozoic and Cainozoic age exposed in the Adelaide fold belt and associated with the Frome Basin. Of particular interest are the haematite-bearing hydrothermal systems of Mt Gee and Mount Painter. As the case within the 10 km radius of the prime site, the extensive range of terrain and surfaces offers a diverse suite of environments for the full suite of analogue research.

Extended-range exploration. Within a 100 km radius from prime hab site, the Arkaroola region contains the following sites of interest: Early Cambrian fossiliferous carbonates and clastics, fossiliferous Cretaceous shoreline deposits, gibber plains on silcreted and ferricreted land surfaces, the Lake Frome playa lake system as associated fossil strandlines and spring deposits, dune fields of the Strzelecki Desert, artesian springs and seeps associated with the margin of the Great Artesian Basin. These features fill in significant details of the 2 billion year history of the region.

Discussion & Conclusions: Impressive though the twin rover's performance has been – in 12 months Spirit traveled approximately 4 km and Opportunity approximately 2 km – each has achieved the equivalent or less of a single day's pedestrian EVA with Apollo level suit mobility. This illustrates the greater area and the faster rate at which crewed exploration can occur compared to even the most basic human exploration team, the pedestrian EVA.

A greatly enhanced pedestrian EVA capability, for example one that offered an exploration radius of 10 km, would require great improved suit performance over those currently envisaged for gas pressurized suits, but is entirely feasible with MCP technology. It is perhaps on such long-range traverses that the greatest impact of increased suit mobility will be felt on Mars, as safety and engineering requirements mean that any landing site is likely to be smooth and flat at a scale of several km and therefore easily traversed even with gas pressure suits. The walk back restriction within daylight hours for unpressurised rovers will limit the distances that can be traversed in this case also. The ability to carry out pedestrian EVAs in rugged terrain up to 10 km from the forward base provided by a rover will greatly increase the range of scientific sites that can be studied. More capable suits will allow more extreme EVA activities akin to terrestrial mountaineering and open up still more areas for investigation [17, 18]. The impact of different suit mobilities on exploration and research can be quantitatively investigated at Arkaroola and its hinterland.

Diversity of sites of interest increases geometrically with increasing exploration radii from the landing site. This highlights the importance of having a capability to travel 10's to 100's of km from the initial landing site on any Mars landing.

The comparison also shows that even the most limited crewed exploration will greatly surpass the capabilities of the existing MER rovers with both respect to area covered and speed of exploration. Until human exploration is possible, robots with significant mobility are highly attractive surrogates, although the exponential cost increases that accompany increasing capability means that crewed mission costs will soon be approached for less than crewed mission returns.

The type of sites than can be reached by long range mobility during crewed exploration will require the development of high mobility space suits and operational strategy so because of the ruggedness, steepness, and roughness of Martian terrain at many of these sites will preclude easy access by vehicles. It would be pointless having the vehicles capable to traveling 100 km from the main Mars base to sites of interest and then not be able to study them adequately because the suits cannot support a pedestrian EVA through 5 km of rugged terrain. Development of such suits, which will probably require MCP technology, should be a high priority.

Analogue regions like Arkaroola, with their diversity of sites of interest and terrains, offer excellent places to test various exploration strategies at different exploration radii for human exploration under field conditions.

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