From Cave Man to Cave Martian

Living in Caves on the Earth, Moon and Mars

The *Springer-Praxis Space Exploration* program covers all aspects of human and robotic exploration, in earth orbit and on the Moon and planets. Books tell behind the scenes stories of the early missions, both manned and unmanned, covering the human and engineering aspects of the space programs of all the leading spacefaring nations. Accounts of planetary exploration encompass the very early missions through to the very latest results received from space probes to the planets and their moons.

The books are well illustrated with figures and photographs, with targeted use of color throughout. They feature recommended further reading and glossaries and appendices where appropriate.

The books are written in a style that space enthusiasts and historians, readers of popular magazines such as *Spaceflight* and readers of *Popular Mechanics* and *New Scientist* will find accessible.

More information about this series at http://www.springer.com/series/4138

Other Springer-Praxis books by Manfred "Dutch" von Ehrenfried

Stratonauts: Pioneers Venturing into the Stratosphere, 2014
ISBN: 978-3-319-02900-9

The Birth of NASA: The Work of the Space Task Group, America's First True Space Pioneers, 2016
ISBN: 978-3-319-28426-2

Exploring the Martian Moons: A Human Mission to Deimos and Phobos, 2017
ISBN: 978-3-319-52699-7

Apollo Mission Control: The Making of a National Historic Landmark
ISBN: 978-3-319-76683-6

Manfred “Dutch” von Ehrenfried

From Cave Man to Cave Martian

Living in Caves on the Earth, Moon and Mars

Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

Manfred “Dutch” von Ehrenfried
Leander, TX, USA

SPRINGER-PRAXIS BOOKS IN SPACE EXPLORATION

Springer Praxis Books
ISBN 978-3-030-05407-6 ISBN 978-3-030-05408-3 (eBook)
https://doi.org/10.1007/978-3-030-05408-3

Library of Congress Control Number: 2019930634

Cover design: Jim Wilkie. Cover Images used under license from Shutterstock.com.
Project Editor: David M. Harland

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Hole in Mars. Art by Ron Miller, 2014.

Dedication

This book is dedicated to all those scientists and students who have gotten "down and dirty" crawling around caves and lava tubes seeking life and understanding of the subterranean world. Call them cavers, spelunkers, geologists, biologist, or scientists, they are the ones looking for knowledge and understanding. Hopefully, some of that knowledge will help future astronauts crawling around the Moon and Mars. Just as the Apollo astronauts walked around sites ranging from Hawaii to Iceland studying geology half a century ago, future crews will do the same thing one day. In fact, this book describes what some of the ESA astronauts are doing now; getting down and dirty in caves and lava tubes conducting analog studies to benefit future astronauts on the Moon and Mars.

This book is also dedicated to the hundreds of scientists, engineers, and mission planners defining the next steps back to the Moon and the first steps to Mars and its small moonlets. Hopefully, they will conduct the initial studies of "precursor" missions as well as the "grand" missions that seem to drive the imagination. My previous book, *Exploring the Martian Moons: A Human Mission to Deimos and Phobos*, defined a precursor mission to the satellites of Mars. Likewise, this book describes a precursor mission to the Moon and to Mars; but one that utilizes the natural environment for protection rather than solely relying upon extensive and costly "Made on Earth" resources.

This book is also dedicated to those people in a position to guide NASA in its planning; be they members of the National Space Council, legislators, politicians, administrators, or advisory councils. As the details are worked out by the various NASA working groups, there are others that guide the space policy.

If indeed the next humans to go back to the Moon will be approximately in the year 2023 and to Mars in 2033, then those lunar astronauts are currently aged about 30 and the Martian astronauts are about 25; and neither group has been selected yet. If the missions slip, they could be even younger now. They actually could be reading this book in the future. If so, then my thoughts will have taken the ride with them. That would make me very happy, because I knew I would get there one way or another!

Acknowledgements

It takes a lot of input from people all over the world to write a book about a topic that is barely on NASA's radar. In some corners, the mission concept proposed is hardly given much thought, let alone serious consideration. Nevertheless, it will clearly make sense to use caves and lava tubes as protection from the hazards of space radiation, micrometeoroids, thermal extremes and, in the case of Mars, dust storms. This will be particularly attractive for the early missions to the Moon and to Mars. The concept seems to solve a lot of problems, can be implemented years ahead of the current schedule, and certainly saves many billions of dollars in total mission costs.

This book provides some thoughts for consideration when NASA is updating their Design Reference Mission document; that is, to conduct the requisite studies that identify "Short-Stay" precursor missions to the Moon and Mars which utilize caves and lava tubes for the initial protection shelters. I find encouraging support from some in the scientific community to do just that. Because such a mission is many years out, the timing is right to formalize the detailed mission planning and modify the likely flight schedule. Moreover, the economic timing is also good, in that money which has already been spent for the major space exploration elements and systems is directly applicable to a precursor mission. The size of the national debt could also be a driver that curtails NASA's budget and concepts and designs for deep space missions. In fact, the economic and political "stars" might also be aligned in support of this idea.

Firstly, let me acknowledge those that reviewed my proposal to the publisher, Springer-Praxis. They are: Dr. David M. Harland, Glasgow, Scotland; Dr. Pascal Lee, Director, Mars Institute; Dr. J. Judson Wynne, Northern Arizona University; and one other reviewer who remained anonymous. Also, many thanks to Dr. Lee for his Foreword and thoughts about the use of caves in exploring the Moon and Mars.

There were many others who provided me input, or leads to others who are, or where active in cave and lava tube research. To my surprise, there are hundreds of people in this field all across the world. Not all are thinking about the Moon and Mars but many are engaged in space analogs, not only here in the U.S.A. but also in Europe. Many more people are working in the field of inflatables and habitats for in-space and surface

applications without realizing that these structures might also be perfect for subsurface use. The same is true for the hundreds of people all over the country who are working to develop space related technologies, many of them state-of-the-art, some of which hold out the prospect of making space travel safer and possibly cheaper.

I would also like to acknowledge all those that have contributed to hundreds of research papers related to cave and lava tube research; many of these are listed in the Reference section. While most are focused on geology and biology, they have relevance to the exploration of the Moon and Mars because they investigate space analogs and add elements to the knowledge base for future expeditions.

List of Contributors

(In alphabetical order by group)

NASA/JPL

Dr. Dean Eppler, Johnson Space Center, Houston, Texas
Marc A. Gibson, Glenn Research Center, Cleveland, Ohio
Dr. Robert L. Howard, Johnson Space Center
Dr. Diana Northrup, Jet Propulsion Laboratory, Pasadena, California
Dr. Aaron Parness, Jet Propulsion Laboratory
Dr. Noah E. Petro, Goddard Space Flight Center, Greenbelt, Maryland
Larry Toups, Johnson Space Center
Rob Wyman, Langley Research Center, Langley, Virginia

USGS

Dr. Glen E. Cushing, Astrogeology Science Center, Flagstaff, Arizona
Dr. Laslo Kestay, Astrogeology Science Center, Flagstaff, Arizona

Institutes

Sandra Cherry, Lunar and Planetary Institute, Houston, Texas
Dr. Sarah A. Fagents, Hawaii Institute of Geophysics and Planetology, Honolulu, Hawaii
Dr. Pascal Lee, Mars Institute/SETI Institute, Moffett Field, California
Dr. Peter J. Mouginis-Mark, Hawaii Institute of Geophysics and Planetology, University of Hawaii, Manoa
Dr. George Veni, National Cave and Karst Research Institute, Carlsbad, New Mexico

Universities

Dr. Philip Christensen, Arizona State University, Tempe, Arizona
Dr. Saugata Datta, Kansas State University, Manhattan, Kansas
Dr. Nels Forsman and Dr. Jaakko Putkonen, University of North Dakota, Grand Forks, North Dakota
Dr. Yongli Gao, University of Texas, San Antonio, Texas
Dr. Pablo de León, University of North Dakota, Grand Forks, North Dakota
Dr. Evelynn J. Mitchell, St. Mary's University, San Antonio, Texas
Dr. Thomas Turner and Dr. Diana Northup, University of New Mexico, Albuquerque, New Mexico
Dr. William "Red" Whittaker, Carnegie Mellon University, Pittsburgh, Pennsylvania

Dr. David A. Williams, Arizona State University, Tempe, Arizona
Dr. J. Judson Wynne, Northern Arizona University, Flagstaff, Arizona

Corporations
Bret G. Drake and Jeff Hanley, Aerospace Corporation, Houston, Texas
Mike Dunn, 4th Planet Logistics, Illinois
Ron Miller, South Boston, Virginia
Pat Rawlings, Visioneering, LLC, Kimberly, Texas
William Studebaker, Richard Lightbound, Erin Sheperd and Frank Tobe, ROBO Global, Dallas, Texas
Dr. R. Roy Whitney, BNNT, LLC, Newport News, Virginia
Keith Splawn, ILC Dover, Houston, Texas

Foreign
Monica Fischer, Austrian Space Forum, Innsbruck, Austria
Bernhard Kaliauer Design Studio, Linz, Austria

Many other scientists are mentioned in the Reference section, along with their reports. In addition to contributions from many individuals, I acknowledge the help of Wikipedia and Google, which allowed me to fill in the pieces of the puzzle on just about any subject. Their inputs are woven into many sections. I also thank NASA and ESA for their websites and helpful inputs.

Finally, many thanks go to the people who helped me in turning my ideas into this book, particularly Maury Solomon and Hannah Kaufman of Springer in New York, Clive Horwood of Praxis in Chichester, England, and cover designer Jim Wilkie in Guildford, England. A special thanks to David M. Harland in Glasgow, Scotland, who edited this, my fifth Springer-Praxis book. After over five years of communications solely by email, I hope finally to meet him in Glasgow in 2019.

Foreword

We were at Lofthellir in Iceland. The entrance to the lava tube was a circular hole in the ground, approximately 20 meters across. It was in the middle of a young lava flow, with volcanoes in the distance but none immediately nearby. Using a ladder, we climbed down into the pit to its sandy floor. Below the mounds of windblown sand were large blocks of rock which had fallen when the roof of the lava tube collapsed and created the "skylight" that now served as its entrance.

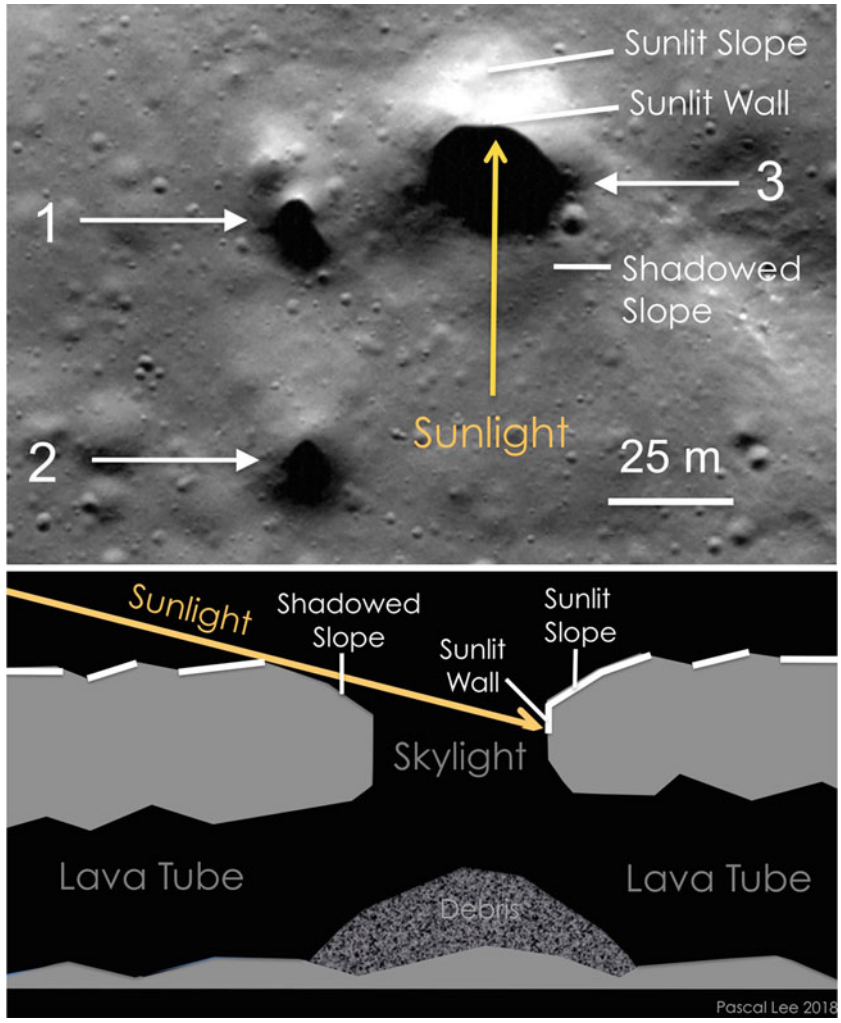
Beneath the skylight, the lava tube extended in two directions. The darkness beyond the twilight zone in either direction looked ominous. As we made our way into the cave in its upstream direction, the passage quickly narrowed from 20 meters to about 1 meter. This lava tube was no subway tunnel. Instead, over its accessible length of 200 meters it would prove to be a 3D maze of crawl spaces, narrows, attics, cellars, ledges, ramps, and cavernous chambers.

But the challenge of squeezing through was amply rewarded. Soon after entering the darkness, the beams of our helmet lamps caught intensely bright reflections. We had encountered ice. *Massive Ice!* Not just veneers on the walls, and icicles dangling from the ceiling, or ice stalagmites rising from the floor, but entire underground mini-glaciers, with accumulation, ablation and melt zones, lateral moraines, and terminal aprons. This was the stuff of Jules Verne.

It is difficult to describe the awe, thrill, and wonder of caving, particularly inside lava tubes. But lava tubes filled with massive ice add an entirely new dimension to the whole experience. More importantly, had we been on the Moon or Mars, such ice would have been a holy grail. Finding massive ice in a cave could potentially mean having readily accessible water for hydration, fuel production (by breaking down H_2O into hydrogen and oxygen), cleaning, diluting, irrigation, heat exchange, and more. In the case of Mars, finding ice might also mean the possibility of finding extant *alien* Life.

We know for certain today, thanks to remote-sensing imaging from orbital spacecraft, that there are caves on the Moon, and also on Mars. Many if not most of these caves are lava tubes formed in volcanic lava fields or in impact-melt lava sheets.

Earlier this year, after examining hundreds of images of the Moon's polar regions, both north and south, taken by NASA's Lunar Reconnaissance Orbiter (LRO), I reported finding candidate skylights and associated lava tubes in the impact-melt deposits within Philolaus crater, a 70-km-wide impact structure located just 500 km from the north pole of the Moon. If confirmed, these features would be the highest latitude caves known on the Moon. They would be at such a high latitude that the Sun's grazing rays would never enter the caves and warm up the rocks on their floor. Instead, the caves would remain in perpetual, complete darkness, the underground equivalent of the permanently shadowed regions at the actual lunar poles. The Philolaus caves would be so cold that, if water were available, it could be cold-trapped as ice in these caves and remain stable for eons.



Possible skylights into lava tubes on the floor of the crater Philolaus, located near the north pole of the Moon. Image courtesy of Pascal Lee.

But caves, including lava tubes, even with ice, are not all good news. Many are prone to collapse, possess terribly jumbled floors, abrasive ceilings and walls, and downright awkward geometries. While caves on the Moon or Mars are often touted as obvious natural shelters, as they would protect humans and their assets against ionizing radiation, wide diurnal temperature swings, micrometeorite bombardment, and even rocket exhaust sandblasting, not all are ready for us to just move into. In fact, based on our terrestrial experience (but with the caveat that caves on the Moon and Mars might be different from those on Earth) most caves might not be occupation friendly. Finding the right caves on the Moon and Mars could take some time and a good measure of resources. And we must recognize there is no guarantee of finding a suitable location. Of course, this is not meant to discourage the search, rather it is to instill a dose of realism in our expectations and thus our planning.

In this exceptional book, the first one dedicated to the topic of exploring and settling caves on other worlds, "Dutch" von Ehrenfried has a plan, and takes us on an exciting journey through space and time to show us how it could unfold. It is a well-researched account of how caves provided natural shelters to early humans before they developed abodes of their own, and proposes that caves on the Moon and Mars be considered as analogous first dwellings for future space explorers. How caves will be scouted out, then explored and prepared in advance of human occupation is examined in unprecedented detail. Throughout the book, Dutch's brilliant mind shines.

What I find compelling in Dutch's ideas, insights, and proposals are the pragmatic thinking that he puts behind them and the depth of his firsthand real-life experience with space exploration. Dutch was directly involved in Mercury, Gemini, Apollo, Skylab, and the International Space Station programs, including being an Apollo Pressure Suit Test Subject and Mission Control flight controller. He was there when it happened. He helped make it happen. He knows how to make it happen again! Dutch's book is a must-read for all forward thinkers, as it offers truly new perspectives, prospects, and priorities for our human future in space. Amazingly, while it is well known that history repeats itself, Dutch shows us that prehistory might too.

Pascal Lee
Director, Mars Institute
Planetary Scientist, SETI Institute
NASA Ames Research Center, Moffett
Field, CA, USA
December 2018

Preface

Isn't it ironic that in planning to leave Earth and explore our solar system we find ourselves reconsidering the practicality (if not the necessity) of returning to living in caves. While most people cannot comprehend living in caves, currently over 30 million people do so all across the world! Indeed, some caves have been occupied for generations.

We regard living in a beautiful home as the highest form of human habitation evolution. Some people have large and beautiful houses equipped with all of the latest amenities, sometimes including several robots such as a smart refrigerator, smart washer/dryer, and a smart air conditioner to relieve them of undue work or stress. We might also have a beautifully landscaped yard, a pool, and clubhouse for our personal use. We have arrived! We don't need these things; we just desire them. Most people do not have this luxury. Some people just want to have a roof over their heads, even if it is a cave.

But no so fast! Now we want to go to the Moon and Mars, and maybe beyond. What do we need now? Well, there are a few little problems such as there being no air, no water, little or no pressure, large temperature extremes, a lot of deadly radiation, and a flux of micrometeoroids. On Mars, there are blowing winds and dust storms that last for very long times. Forget the amenities; we need survival gear! But we shall still require the robots and all of the advanced technology. We are going to need all the help we can get if we are to live on these hostile worlds; even for short periods of time.

Prehistoric man didn't have the luxury of the very best of caves to shelter his entire family from the elements and predators, they needed to make do with what they could find.

Spacefaring humans will find that in order to provide the absolute basic life-support elements for extended operations, even the simplest of shelters will be complex and expensive. Although we don't think we will need protection from predators, we will need protection from the potentially deadly environment. And, in reverse, any indigenous life on the planets we settle will certainly require to be protected from us.

It is evident that habitats of some form or another will be needed on the Moon and Mars. Efforts are now well underway in the USA, Europe, and Asia to define them. Unlike Earth, astronauts on the surfaces of the Moon or Mars will not be protected from space radiation by global magnetic fields. While astronauts will necessarily work on the surface, they will be obliged to retreat into a protected environment for some activities, particularly to eat and sleep. The choices are to make use of the natural geology to find shelter, to manufacture and send habitats from Earth, or to build them in-situ once there.

Actually, working underground may provide us the best chance of finding life, because the radiation on the surface may well have either killed it off or driven it deep into the soil eons ago. Similarly, water ice is more likely to be found below the surface. Ice that is accessible to a habitat is key to obtaining drinking water, as well as fuel for vehicles. Having a readily available water source means less mass needs to be transported from Earth, and so be less costly. Exploration of caves on Earth has found water and life in abundance and in very strange forms, as well as yielding insight to geological structures not damaged by the surface environment. Why not first go to where you can get shelter and find water ice and perhaps even indigenous life; underground in caves or lava tubes, not on the surface! Ideally, NASA will take note, and consider using caves in mission planning for the return to the Moon and the early trips to Mars.

Finding a suitable underground place for habitation will require a considerable effort. The low gravities of the Moon and Mars may enable some of the lava tubes and caves to be huge. On the Moon, they could be measured in kilometers (miles) and on Mars up to 250 m (820 ft); as large as two World Cup football fields. One report estimates lunar caves could be large enough to hold a city! We do not need that much, though. For those early missions, we would want the "optimum" cave. The cave research effort will go on for a very long time before actual exploration gets underway on the Moon and Mars. Satellite imagery has already shown many potential caves on both bodies, as well as elsewhere. We see collapsed sections of lava tubes that open up "skylights" into black pits. When the illumination is right, we can see details of the interior. The satellites which discovered these structures were not designed to seek caves. There are proposals for satellites that will carry special radar instruments just for that purpose.

And there are efforts underway to develop specific and unique technologies to work in these caves. Earthly analogs are already being explored to determine how caves can be formed from volcanic lava tubes or by water dissolving the geology. These can easily be seen in Hawaii, Iceland, the Canary Islands, Australia, Spain, Germany, Sicily, and the Galápagos Islands. Of course, there are caves elsewhere on Earth; probably thousands of them. As it turns out, some of these caves can be very hostile and cannot be entered without wearing protective gear, and some can be downright deadly and have proven to be so.

The optimum caves on the Moon and Mars must be deep enough to provide a level of radiation protection that is equivalent to that here on Earth. There is also extensive research into developing radiation shielding materials that can be used in transit, as well as on and in the Moon and Mars. When the crew enters a cave, how can they assure themselves that it is safe from collapse and be safely cleared of rubble? There are other concerns. Special tools and equipment may be needed. In most concepts, a suitable cave will be outfitted with portable inflatable habitats that are pressurized with airlocks and then

interconnected for various functions such as sleep quarters, personal hygiene, research, galleries, and food production. Over time, this type of habitat system can be expanded by later missions. There is even one study group that is looking at special coatings that can be applied to the cave in order to seal and pressurize it.

There are many lessons being learned from current cave exploration that may be useful on the Moon and Mars. Terrestrial cave research, called "speleology," has been underway all across the world for decades. It is primarily for studies of biology and geology, but there is an emphasis on advance technology to enable the research. NASA, the Mars Institute, the SETI Institute, the Planetary Society, the US Geological Survey, ESA, Japanese institutions, and many universities and organizations are actively involved. Examples of their research projects are also included in this book. An extensive Reference section is provided which also includes links and videos. Not only have new life-forms been discovered but new methods for exploration. Although most of these people are scientists, some are recreational cavers. There is even an International Speleological Society and an International Union of Speleology. Their members include explorers as well as entire groups of scientists that are exploring caves with the latest technologies at their command. It is most likely that the first crews to return to the Moon and go on to Mars will include a geologist/biologist who has spent considerable time in caves as part of their education and training.

This book starts with a short history on the use of caves by humans. It spans a great period of time. We have been using caves much longer than was originally believed; perhaps 300,000 years. It will also briefly describe the types of human beings that anthropologist have found in caves. It will describe various types of caves and in order to give the reader a sense of scale, it will highlight those which set the records for being the deepest, the longest, and the largest. Other caves of interest are also mentioned. Even caves occupied by present-day "Troglodytes" are included.

This book will describe current research into caves, pits, tunnels, lava tubes, and skylights, and the associated technologies that pertain to potential lunar and Mars exploration and habitation. The work of noted scientists and technologists will be described with emphasis on extraterrestrial applications. This continuing work is more extensive than one would think, and is directly applicable to longer-term habitation and exploration of the Moon and Mars. While directly related to the search for life, emphasis is also given to the operational aspects of working and living in caves and lava tubes on the Moon and Mars. Just how will the first crew find the right cave and prepare it for habitation? What are the dangers for EVA astronauts poking around holes, seeking an entrance to a potential place in which to work and live? What kind of robots will they need to explore unknown areas? What kind of tools will they need? How will they get inside safely? Once inside, how are they to clear away rubble and prepare the surface for equipment and supplies? How are they to prepare a volume for a pressurized environment? Will they use an inflatable structure fitted with an airlock? Will they be able to get support from Mission Control? These and other questions will require to be answered before we can realistically plan to go there.

So let us look for shelter in the caves and lava tubes of the Moon and Mars, and then propose a precursor mission that will make use of them!

Manfred “Dutch” von Ehrenfried
Leander, TX, USA
Nearing the 50th Anniversary of the first lunar explorers!

Contents