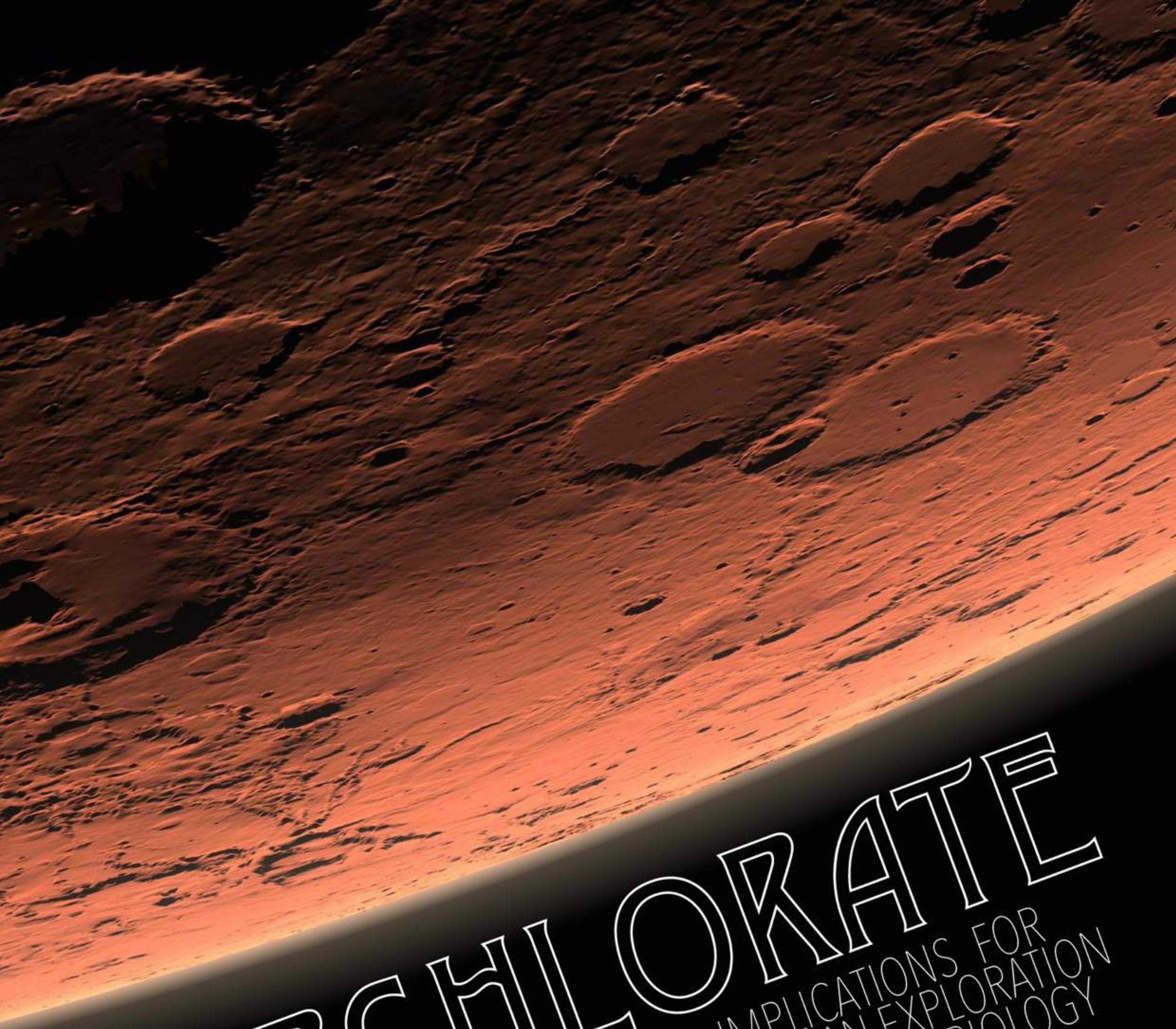

PERCHLORATE ON MARS

IMPLICATIONS FOR HUMAN EXPLORATION AND ASTROBIOLOGY

NASA RESEARCH PARK - MOFFETT FIELD - CA

DEC 13 & 14 - 2014

Office of the Chief Scientist
NASA Ames Research Center

CONTENTS

PERCHLORATE ON MARS

IMPLICATIONS FOR HUMAN EXPLORATION AND ASTROBIOLOGY

THE WORKSHOP:

Several Mars missions have confirmed the presence of high concentrations of perchlorate in the Martian regolith. For human exploration of Mars, perchlorate may pose a significant hazard but may also be a resource. The origin, threat and opportunity of perchlorate are at the core of this workshop.

The perchlorate phenomenon will be addressed via three core sessions: Perchlorate on Earth, Perchlorate on Mars, and Implications for Human Exploration and Astrobiology. These sessions will cover the origin and distribution on Earth and Mars; chemistry, biochemistry and microbiology; toxicology and human health issues; and the detection, protection and remediation of perchlorate.

The workshop structure will consist of presentations, panel discussions, and breakout sessions with subject matter experts focused on examining the presence of perchlorate on Mars and its implications.

OUTCOME:

- Networking with NASA scientists, university professors, etc.
- Open access workshop report with abstracts and presentations.
- Publication opportunity in the *International Journal of Astrobiology*.

LOCATION:

NASA Research Park, Building #152,
Moffett Field, California 94035

POINT OF CONTACT:

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SPONSORED BY:

The Office of the Chief Scientist
NASA Ames Research Center
Moffett Field, California

AGENDA SATURDAY DEC. 13

8:00 am	**Registration**	
8:30	Introduction	Jacob Cohen - NASA Ames
8:40	Welcome remarks	S. Pete Worden - NASA Ames
8:50	Keynote: Oxychlorine Phases (Perchlorates) in Sedimentary Deposits, Gale crater, Mars	Doug Ming - NASA JSC
9:20	**Session One: Perchlorate on Earth**	Lynn Rothschild - NASA Ames
9:30	Terrestrial Perchlorate and Chlorate: Origin and Production	Andrew Jackson - Texas Tech
9:50	Terrestrial Perchlorate: Distribution and Isotopic Composition	Neil Sturchio - Univ. of Delaware
10:10	Phylogeny and Physiology of (Per)chlorate Reducing Bacteria	Charlotte Carlström - UC Berkeley
10:30	Perchlorate Toxicology: Lessons Learned from Studies on Wildlife	Todd Anderson - Texas Tech
10:50	Current Practices for the Detection and Treatment of Perchlorate	Todd Webster - Envirogen Technologies
11:10	**Break**	
11:30	**Session One Table Discussion**	
12:30 pm	**Lunch Break**	
1:30	**Session Two: Perchlorate on Mars**	Chris McKay - NASA Ames
1:40	The Origin of Perchlorate on Mars	Megan Smith - Univ. of Washington
2:00	Evidence for Distribution of Perchlorates on Mars	Ben Clark - Space Science Institute
2:20	Martian Perchlorate Chemistry	Richard Quinn - NASA Ames
2:40	Human Health Concerns of Perchlorate on Mars	David Loftus - NASA Ames
3:00	State of Knowledge of Detecting Oxychlorine Species on Mars and Possible Remediation	Brad Sutter - NASA JSC
3:20	Can Mars Exploration be Powered by Pee and Perchlorate?	Jonathan Trent - NASA Ames
3:40	A Roadmap for Perchlorate Utilization on Mars	Lee Cronin - University of Glasgow
4:00	**Break**	
4:10	**Session Two Table Discussion**	
5:00	Concluding remarks	Jacob Cohen - NASA Ames
6:00	**Dinner - Moffett Field Golf Course**	

AGENDA SUNDAY DEC. 14

8:30 am	**Welcome Remarks**	Jacob Cohen - NASA Ames
8:40	Keynote: Perchlorate and Long Term Planetary Ecosynthesis on Mars	Chris McKay - NASA Ames
9:10	**Panel One: Implications for Mars exploration**	Alfonso Davila - NASA Ames Doug Archer - NASA Ames John Hogan - NASA Ames Digby MacDonald - UC Berkeley Michelle Rucker - NASA JSC
10:10	**Break**	
10:30	**Panel Two: Implications for Astrobiology**	Rocco Mancinelli - NASA Ames John Coates - UC Berkeley Max Coleman - NASA JPL Kosuke Fujishima - NASA Ames Ronald Oremland - USGS
11:30	**Break**	
11:40	Summary of table sessions	Monica Ebert - NASA Ames
11:50	Conclusion and path forward	Jacob Cohen - NASA Ames
12:00 pm	**Adjourn**	

LOGISTICS

FOOD

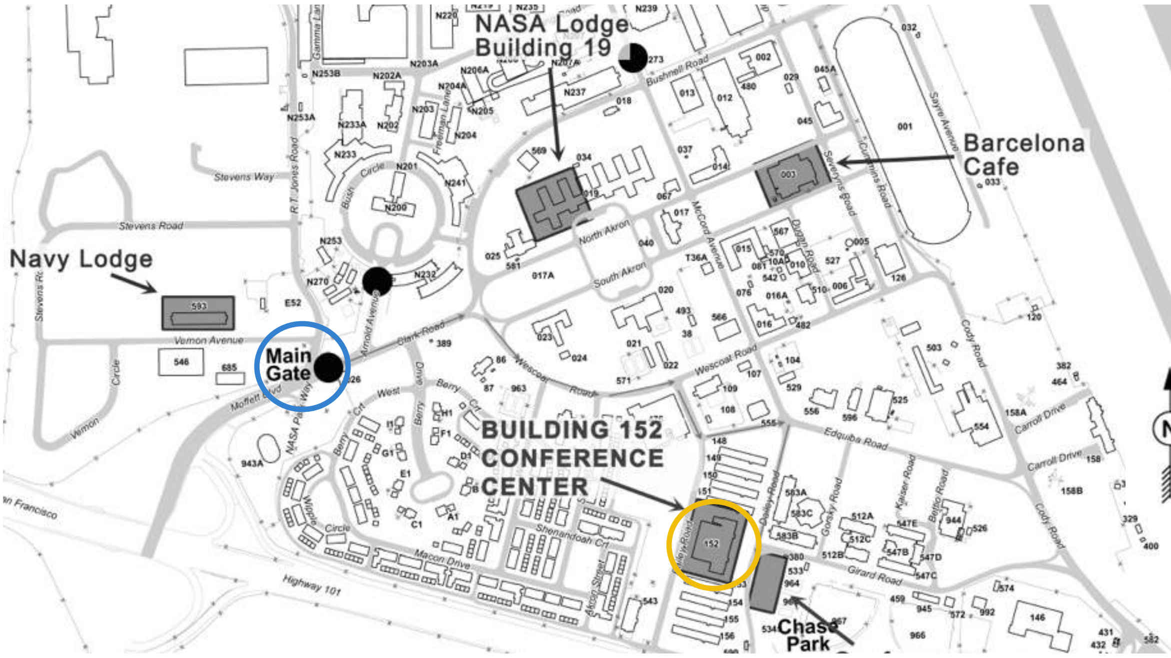
Lunch will be delivered to the workshop at 12:30pm on Saturday. **Dinner** will be held at the Moffett Field Golf Club at 6:00pm on Saturday. Payment for meals will be collected during registration.

ENTRY

A government-issued **photo ID** is required for entry into the NASA Research Park. Driver's must present their **driver's license** to guards at the Main Gate circled in blue. Non-US citizens are required to bring a passport and/or permanent residency documents (i.e. Green Card).

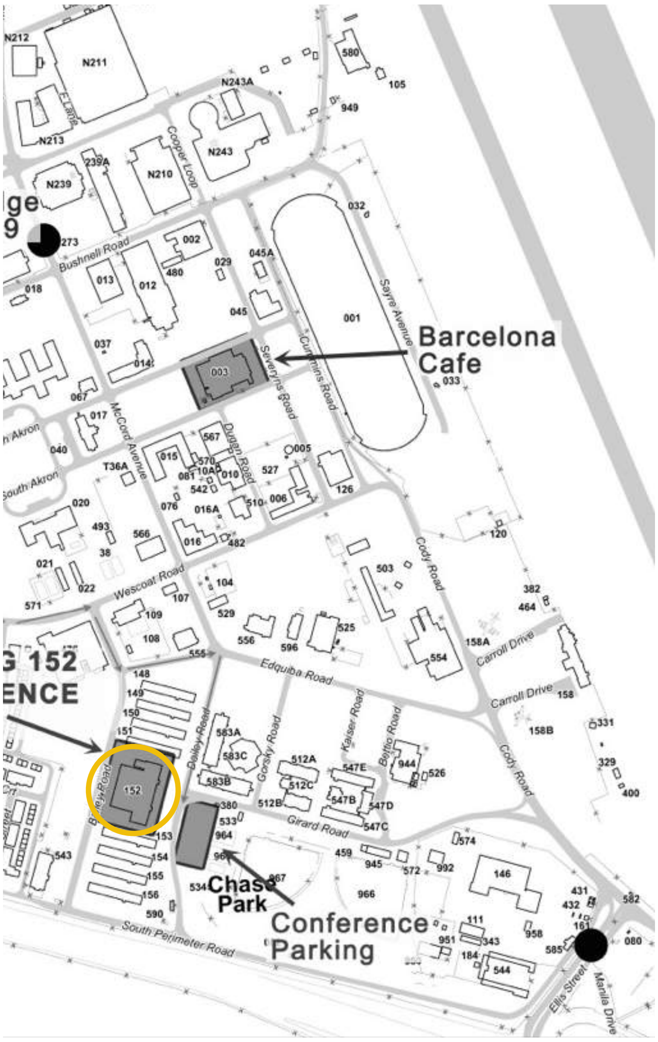
MAP

Workshop Building #152 is circled in yellow.



GOLF COURSE

The Moffett Field Golf Course is circled in blue and the workshop building #152 is circled in yellow. Follow Macon Road around the airfield until you see the golf course and T-1 Bar and Grill on your right. Be prepared to show your driver's license and provide your name to the security guard at the Macon Gate.



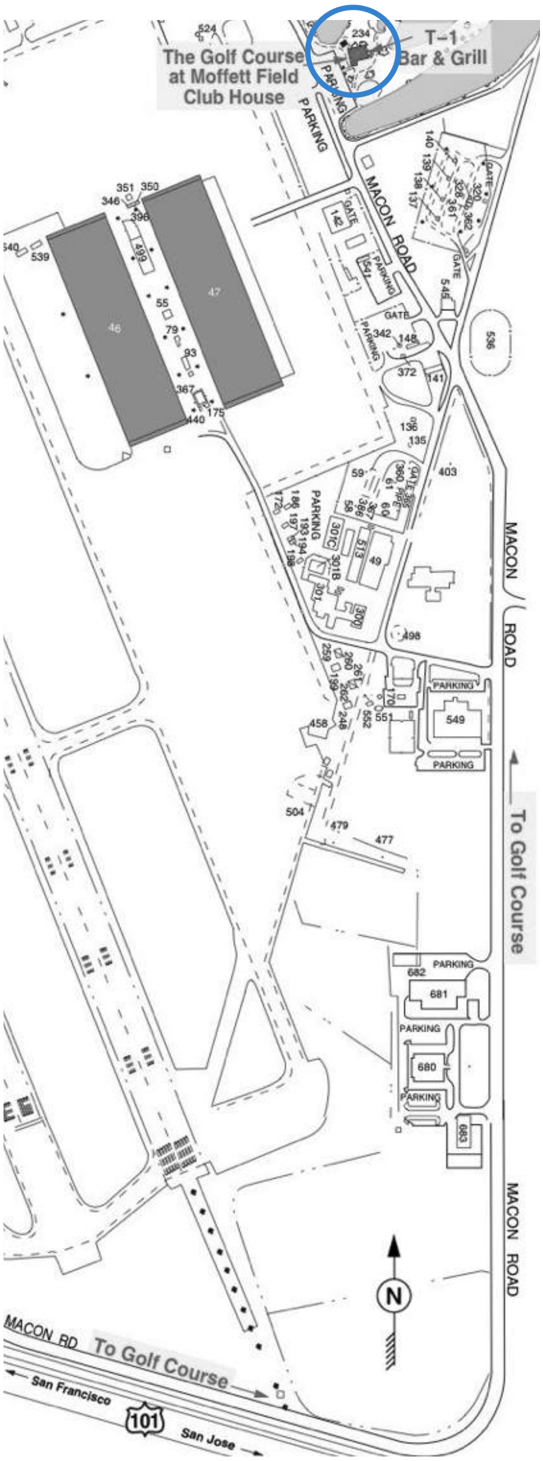


TABLE SESSIONS

On the backside of your name tag is your workshop number and assigned room for each table discussion session. Workshop numbers below correspond to the rooms for your table discussion.

#	Session One	Session Two
1	Curiosity	Curiosity
2	Curiosity	Curiosity
3	Curiosity	Pathfinder
4	Curiosity	Spirit
5	Curiosity	Spirit
6	Curiosity	Prop-M
7	Curiosity	Phoenix
8	Curiosity	Phoenix
9	Curiosity	Opportunity
10	Curiosity	Viking
11	Curiosity	Viking
12	Curiosity	Polar Lander
13	Pathfinder	Curiosity
14	Pathfinder	Curiosity
15	Pathfinder	Pathfinder
16	Pathfinder	Spirit
17	Pathfinder	Spirit
18	Pathfinder	Prop-M
19	Pathfinder	Phoenix
20	Pathfinder	Phoenix
21	Pathfinder	Opportunity
22	Pathfinder	Viking
23	Pathfinder	Viking
24	Pathfinder	Polar Lander
25	Spirit	Curiosity
26	Spirit	Curiosity
27	Spirit	Pathfinder
28	Spirit	Spirit
29	Spirit	Spirit
30	Spirit	Prop-M
31	Spirit	Phoenix
32	Spirit	Phoenix
33	Spirit	Opportunity
34	Spirit	Viking
35	Spirit	Viking
36	Spirit	Polar Lander
37	Prop-M	Curiosity
38	Prop-M	Curiosity
39	Prop-M	Pathfinder
40	Prop-M	Spirit
41	Prop-M	Spirit
42	Prop-M	Prop-M
43	Prop-M	Phoenix
44	Prop-M	Phoenix
45	Prop-M	Opportunity
46	Prop-M	Viking
47	Prop-M	Viking
48	Prop-M	Polar Lander

#	Session One	Session Two
49	Phoenix	Curiosity
50	Phoenix	Pathfinder
51	Phoenix	Pathfinder
52	Phoenix	Spirit
53	Phoenix	Prop-M
54	Phoenix	Prop-M
55	Phoenix	Phoenix
56	Phoenix	Opportunity
57	Phoenix	Opportunity
58	Phoenix	Viking
59	Phoenix	Polar Lander
60	Phoenix	Polar Lander
61	Opportunity	Curiosity
62	Opportunity	Pathfinder
63	Opportunity	Pathfinder
64	Opportunity	Spirit
65	Opportunity	Prop-M
66	Opportunity	Prop-M
67	Opportunity	Phoenix
68	Opportunity	Opportunity
69	Opportunity	Opportunity
70	Opportunity	Viking
71	Opportunity	Polar Lander
72	Opportunity	Polar Lander
73	Viking	Curiosity
74	Viking	Pathfinder
75	Viking	Pathfinder
76	Viking	Spirit
77	Viking	Prop-M
78	Viking	Prop-M
79	Viking	Phoenix
80	Viking	Opportunity
81	Viking	Opportunity
82	Viking	Viking
83	Viking	Polar Lander
84	Viking	Polar Lander
85	Polar Lander	Curiosity
86	Polar Lander	Pathfinder
87	Polar Lander	Pathfinder
88	Polar Lander	Spirit
89	Polar Lander	Prop-M
90	Polar Lander	Prop-M
91	Polar Lander	Phoenix
92	Polar Lander	Opportunity
93	Polar Lander	Opportunity
94	Polar Lander	Viking
95	Polar Lander	Polar Lander
96	Polar Lander	Polar Lander

SPEAKER ABSTRACTS & BIOS

Todd Andersson

Perchlorate Toxicology: Lessons Learned from Studies on Wildlife

ABSTRACT: Thyroid hormones (TH) act on multiple systems in the body, which are ultimately critical for metabolism and growth. A wealth of data exists on thyroid function (particularly in mammals) and the consequences of a disruption in TH synthesis. Perchlorate (ClO_4^-) exerts its adverse biological effects by blocking iodide (I^-) uptake by the thyroid gland. The potency with which ClO_4^- blocks I^- uptake has made it a useful experimental tool for exploring basic thyroid function as well as a historical clinical tool for treating thyroid gland disorders. Thus, risks from ClO_4^- exposure can largely be predicted from several decades of these clinical and laboratory research results. In addition, some of the more subtle adverse effects of TH disruption (development, thermoregulation) from ClO_4^- exposure can be gleaned from laboratory and field studies on wildlife. Information on the potential pathways of ClO_4^- exposure, as well as the mechanisms and effects of ClO_4^- will be presented.

BIO: Todd Anderson is a professor in the Department of Environmental Toxicology and The Institute of Environmental and Human Health (TIEHH) at Texas Tech University. He currently serves as the Chair of the Department and the Interim Director of TIEHH. He received his M.S. and Ph.D. from the University of Tennessee, Knoxville under Dr. Barbara Walton at Oak Ridge National Laboratory (ORNL); he did postdoctoral research in pesticide toxicology at Iowa State University with Dr. Joel Coats. He has co-authored 170 peer-reviewed journal articles, including 4 "citation classics" (journal articles cited more than 400 times) according to Google Scholar.

At Texas Tech, Dr. Anderson has received the President's Excellence in Teaching Award, the Chancellor's Council Distinguished Research Award, and was named a Provost's Integrated Scholar in 2014. In addition, he has received the department's Outstanding Faculty Award (by graduate student vote) 7 times. In 2005, he was elected Fellow of the American Association for the Advancement of Science. His collaborative research on the natural occurrence of perchlorate received an editor's award from *Environmental Science & Technology* as the Environmental Science Paper of the Year (2005), and was selected as the SERDP Environmental Restoration Research Project of the Year (2007).

Charlotte Carlström

Phylogeny and Physiology of (Per)chlorate Reducing Bacteria

ABSTRACT: Microorganisms have evolved that can grow by respiring perchlorate (ClO_4^-) and chlorate (ClO_3^-) [collectively denoted (per)chlorate] in the absence of oxygen. These microorganisms, known as dissimilatory (per)chlorate reducing bacteria (DPRB), are metabolically and phylogenetically diverse. Approximately 80 strains of DPRB in 24 genera have been isolated, with most belonging to the Betaproteobacteria, Alphaproteobacteria, and Gammaproteobacteria classes. Many of these isolates have been obtained from freshwater, mesophilic, neutral pH environments, and as a result, few tolerate high salinities or extreme temperatures.

Nearly all DPRB reduce (per)chlorate to the toxic intermediate chlorite (ClO_2^-) using perchlorate reductase (Pcr), which is then detoxified into Cl^- and molecular oxygen by chlorite dismutase (Cld). Genes encoding the key enzymes Pcr (*pcrABCD*) and Cld (*cld*) have been shown to be part of a 10-25 kb perchlorate reduction island (PRI) that is horizontally transferred across phylogenetic boundaries. Because oxygen is produced from chlorite dismutation, DPRB display a high level of metabolic versatility and can act as either aerobes or anaerobes while growing on (per)chlorate. Unlike other DPRB, the archaeon *Archaeoglobus fulgidus* VC-16 does not rely on Pcr or Cld and instead uses NarG-type nitrate reductase to reduce ClO_4^- to ClO_2^-, which is abiotically detoxified by reacting with sulfide.

BIO: Charlotte Carlström is a microbiology graduate student at UC Berkeley, focusing on the isolation and characterization of novel dissimilatory perchlorate reducing bacteria. She earned her Bachelor of Science degree in Biology from Emory University in 2009, and will receive her PhD this month under the guidance of Dr. John Coates. Her research has focused on the physiological and phylogenetic diversity of marine perchlorate reducing bacteria. Of the 24 genera containing perchlorate reducing isolates, her work is responsible for the discovery of five of them, including the only perchlorate reducing bacterium in the Epsilonproteobacteria in pure culture. As a graduate student, she has received several awards, including the UC Berkeley Chancellor's Fellowship and the National Science Foundation's Graduate Research Fellowship.

Ben Clark

Evidence for distribution of perchlorates on Mars

ABSTRACT: The first in situ measurements on Mars discovered the high sulfur and chlorine content of global-scale soils at two widely separated landing sites. A variety of circumstantial evidence led to the conclusion that soil S is in the form of sulfate, and the Cl is probably chloride. An early hypothesis postulates that these volatiles are emitted as gases from magmas, and quickly react with the surfaces of dust particles, soil grains, and exposed rocks. Wet chemistry analyses by the high latitude Phoenix mission discovered not only chloride but also perchlorate and possibly chlorate in soils. MSL's SAM data now also implicate perchlorate at low latitudes. When exposed to liquid water, Phoenix samples released electrolytes, indicating that the soils have not been subsequently leached by rain or fresh groundwater. Some chloride deposits, have now been discovered by remote sensing. Landed missions have discovered Cl-enrichments and ferric, Mg, Ca and more complex sulfates in a variety of modalities. Virtually all Cl-salts produce extreme depression of freezing point which should have mobilized Cl to produce concentrated evaporite sequences. Whether brines are habitable depends on the relative abundance of liquid H2O and the panoply of salts therein.

BIO: Ben Clark became involved in space exploration in 1961, soon after Sputnik. In addition to numerous satellite experiments, he provided radiation instrument clusters for two Gemini flights. He completed a PhD in Biophysics from Columbia University, and has since concentrated on research in planetary geochemistry and astrobiology. He developed the inorganic analyzer on Viking and is a member of Science Teams for the rovers named Spirit, Opportunity and Curiosity. He also is a Co-I for the PIXL micro-XRF on the future Mars 2020 Rover. Specializing in geochemical analysis using x-ray fluorescence and LIBS data, he employs correlation and trends analysis to infer mineralogies from elemental chemistry results, and compares those with other circumstantial evidence on mineralogical makeup of rocks, sediments and soils. He is interested in sulfur and chlorine chemistry in soils, rocks and on rock surfaces, and how they and other elemental enrichments or depletions are indicative of past aqueous alteration, the diversity of such activity, and how they may have influenced prebiotic chemistry and the evolution of life. He also studies comets, and how their accretion to the planets may have created habitable environments as well.

Lee Cronin

A roadmap for perchlorate utilization on Mars

ABSTRACT: The high abundance of perchlorates on Mars offers a great deal of potential for its exploitation as a feedstock that could be crucial for colonization. For instance perchlorates could be used as food to grow microbes, in microbial fuel cells for power, and as oxygen producing candles, and as propellant. However perchlorates in high concentrations represent an explosion hazard. In this talk I will outline a possible roadmap for the safe use perchlorates in a range of technologies, as well as a discussion of the underlying electrochemistry that will govern the construction of technologies suitable for use on Mars including the use of 3D printed electrochemical cells. Finally I will outline some speculative ideas for the use of redox-mediators to safely couple perchlorate chemistry to other systems that could lead to the emergence of Martian-Perchlorate-Economy.

BIO: Lee Cronin FRSE. Professional Career: 2013- Regius Professor of Chemistry. Alexander von

Humboldt research fellow (Uni. of Bielefeld); 1997-1999: Research fellow (Uni. of Edinburgh); 1997: Ph.D. Bio-Inorganic Chemistry, Uni. of York; 1994 BSc. Chemistry, First Class, Uni. of York. Prizes include 2013 BP/RSE Hutton Prize, 2012 RSC Corday Morgan, 2011 RSC Bob Hay Lectureship, a Wolfson-Royal Society Merit Award in 2009, Election to the Royal Society of Edinburgh in 2009. The focus of Cronin's work is understanding and controlling self-assembly and self-organisation in Chemistry to develop functional molecular and nano-molecular chemical systems (including solar fuel systems); linking architectural design with function and recently engineering system-level functions (e.g. coupled catalytic self-assembly, emergence of inorganic materials and fabrication of inorganic cells that allow complex cooperative behaviours). Much of this work is converging on exploring the assembly and engineering of emergent chemical systems aiming towards 'inorganic biology'. This work has been presented in over 300 papers and 250 lectures worldwide. It is also worth pointing out that the Cronin group (which numbers over 50 people and > £10 M in funding) is unique bringing together inorganic / synthetic chemists, chemical engineers, complex system modelling, evolutionary theory, robotics and AI.

Andrew Jackson

Terrestrial Perchlorate and Chlorate: Origin and Production

ABSTRACT: (W. Andrew Jackson, J.K. Böhlke, N. C. Sturchio, Alfonso Davila, P. B. Hatzinger, and B. Gu). Perchlorate (ClO_4^-) and chlorate (ClO_3^-) are ubiquitous throughout the terrestrial surface environment at trace concentrations, but can accumulate to near percent levels in hyper-arid areas. In arid regions, the ClO_3^- concentration is typically 1-10 X the ClO_4^- concentration. The occurrence of both ClO_4^- and ClO_3^- is significantly correlated to the occurrence of NO_3^-. This strong correlation is likely related to a common atmospheric production mechanism as well as similar biogeochemical stability in areas largely devoid of plants. ClO_4^- and ClO_3^- are deposited in both wet and dry deposition. ClO_4^- isotopic composition supports a stratospheric source including variable involvement of O_3-mediated oxidation reactions and perhaps other non-O_3 photochemical pathways. Heterogeneous photochemical reactions may also occur at the Earth's surface, although their overall significance is unclear. Lab studies have demonstrated the production of ClO_4^- by both UV- and O_3-mediated oxidation of Cl^-, $HOCl/OCl^-$, ClO_2^-, and ClO_2, but not ClO_3^-. In systems with available water, ClO_3^- production is much greater than that of ClO_4^-, whereas in dry systems, (e.g., oxidation of solid phase NaCl), ClO_4^- and ClO_3^- production is roughly equal. Stable isotopic composition of experimentally produced ClO_4^- is consistent with the observed variations in natural isotopic composition, although extreme negative $\delta^{37}Cl$ values of Atacama ClO_4^- have not been experimentally reproduced, and post-depositional O exchange has not been excluded.

BIO: Andrew Jackson is a Professor of Civil and Environmental Engineering at Texas Tech University. Dr. Jackson received his B.S. degree in Biology from Rhodes College and a M.S. and Ph.D. from Louisiana State University in Engineering Science with an emphasis in Environmental Engineering. Dr. Jackson is very active in the general area of fate of contaminants in natural environments, along with development of methods to study these processes at appropriate scales. His group has also been instrumental in advancing the understanding of sources, fate, and impacts of perchlorate in the environment. His group led the earliest quantification of perchlorate exposures unrelated to military/industrial point sources, including those from low level natural occurrences, edible plants, trophic transfer, and *in situ* production by oxidants and corrosion protection systems. His group has significantly contributed to our current understanding of the production and occurrence of natural perchlorate and chlorate and survey of natural perchlorate stable isotopic composition.

David Loftus

Human Health Concerns of Perchlorate on Mars

ABSTRACT: (David J. Loftus, Jon C. Rask, and Dale W. Porter). Widespread distribution of perchlorate in the surface regolith of Mars raises a number of important health concerns that NASA must address in order to plan for human exploration of Mars. For example, perchlorate anion has long been recognized as an inhibitor of iodide uptake in the thyroid gland. Although the effect is reversible, chronic exposure to perchlorate can lead to hypothyroidism, a complex illness with widespread metabolic consequences. A more recently recognized issue with perchlorate is the potential to cause pulmonary inflammation and fibrosis after inhalation exposure. In the context of Mars exploration, lung exposure to perchlorate could potentially take place via inhalation of respirable size particles of Mars regolith containing perchlorate. With this scenario in mind, both the intrinsic mineral constituents of Mars regolith (silica and other metal oxides) as well as the perchlorate component could potentially contribute to inflammatory and fibrogenic processes. Skin and ocular effects may be pertinent as well. The discussion of the health effects of perchlorate will incorporate "lessons learned" from NASA's evaluation of the potential health effects of lunar dust, and will include recommendations for ground-based studies that are needed to pave the way for human missions to Mars.

BIO: David J. Loftus, M.D. Ph.D. is a physician scientist at NASA Ames Research Center, with extensive experience in studies of biological systems and their response to novel materials, including lunar dust, lunar soil and other planetary material analogs. Dr. Loftus led the NASA Ames component of the *Lunar Airborne Dust Toxicity Assessment Group* (LADTAG) studies that examined the biological effects of authentic Apollo 14 lunar dust and soil. This work involved studies of the toxic response to chemically reactive lunar dust in the lungs, examined in rodents, carried out in collaboration with NASA Johnson Space Center and the National Institute of Occupational Safety and Health. Dr. Loftus is a member of the *Topical Team for the Toxicity of Lunar Dust,* a European Space Agency (ESA) advisory group charged with identifying critical scientific issues related to lunar dust and other planetary materials, and making recommendations for experimental work needed to support ESA plans for lunar exploration. Dr. Loftus earned M.D. and Ph.D. (Molecular Biology–Biophysics) degrees from the *Medical Scientist Training Program* at Washington University, and completed medical training in internal medicine and hematology at Stanford.

Chris McKay

(Session Two Chair)

Perchlorate and long term planetary ecosynthesis on Mars

ABSTRACT: The evidence that Mars was habitable in the past is important in two ways to the question of planetary ecosynthesis. First, it provides a proof in principle that Mars can support a habitable state on timescales that, while short over the age of the solar system, are long in human terms. Second, past habitability suggests that the compounds necessary to build a biosphere, water, carbon dioxide, and nitrogen, may still be present on Mars is quantities adequate to restore habitability. The transformation of chlorine on the surface of Mars to perchlorate provides at once both an obstacle to future habitability and an resource for energy and oxygen.

BIO: Chris McKay is a research scientist with the NASA Ames Research Center. His research focuses on the evolution of the solar system and the origin of life. He is also actively involved in planning for future Mars missions including human exploration. Chris been involved in research in Mars-like environments on Earth, traveling to the Antarctic dry valleys, Siberia, the Canadian Arctic, and the Atacama, Namib, & Sahara deserts to study life in these Mars- like environments. He was a co-investigator on the Huygens probe to Saturn's moon Titan in 2005, the Mars Phoenix lander mission in 2008, and the current Mars Science Laboratory mission, launched in 2012.

Doug Ming

Oxychlorine Phases (Perchlorates) in Sedimentary Deposits, Gale crater, Mars

ABSTRACT: (D. W. Ming, P. D. Archer, Jr., B. Sutter, and the MSL Science Team). The Mars Science Laboratory rover *Curiosity* has successfully explored Gale crater for over 2 Earth years. Curiosity has discovered fine-grain sedimentary deposits that appear to have been deposited in ancient lake environments. These fine-grained sediments contain clay minerals, sulfides, amorphous materials and oxychlorine phases along with primary igneous minerals. Oxychlorine phases (i.e., perchlorate and chlorate) were inferred phases based on evolved O_2 from thermal decomposition of perchlorate or chlorate salts, analogy with other analyses on Mars, bulk compositions of the sedimentary deposits, timing of chlorinated hydrocarbon and HCl releases, and on laboratory experiments with perchlorate salts. Perchlorate was definitively identified in soil at the Mars Phoenix landing site, and O_2 releases from Gale crater sediments during Sample Analysis at Mars (SAM) thermal/evolved gas analyses are roughly consistent with the thermal decomposition of perchlorate and/or chlorate. Oxychlorine phases have been identified in a windblown deposit (Rocknest) and four sedimentary deposit drill samples (John Klein, Cumberland, Windjana, and Confidence Hills) in Gale crater. The presence of oxychlorine compounds has complicated the search for organic materials. Although organic compounds such as chlorinated hydrocarbons have been detected in SAM analyses, the C source for the chlorinated hydrocarbons is not definitively of martian origin.

BIO: Doug Ming is the Chief Scientist for the Astromaterials Research and Exploration Science Division at NASA Johnson Space Center. He has participated on the science teams (Co-Investigator/ Participating Scientist) for the Mars Polar Lander (MPL), Mars Exploration Rovers (MER), Mars Phoenix Scout, and Mars Science Laboratory (MSL) missions. Doug has been involved in the development, testing, and operations of numerous flight instruments including the Thermal Evolved Gas Analyzer on MPL, the Mössbauer and Alpha Particle X-ray Spectrometers on MER, the Thermal Evolved Gas Analyzer and MECA Wet Chemistry Laboratory (WCL) on Phoenix and most recently the Sample Analysis at Mars (SAM) and Chemistry and Mineralogy (CheMin) instruments on MSL. He led tactical science operations on Phoenix in the role of Science Lead and he currently leads tactical science operations for MSL as a Science Operations Working Group Chair. Doug received a Ph.D. in Soil Science from Texas A&M University in 1985. He is an expert in Mars surface chemistry and mineralogy. Doug has published over 165 peer-reviewed journal articles and book chapters, including the lead author of a paper in the journal *Science* that describes the detection of oxychlorine compounds in a sedimentary rock examined by *Curiosity* in Gale crater.

Richard Quinn

Martian Perchlorate Chemistry

ABSTRACT: (R. C. Quinn, B. L. Carrier, R. V. Gough, S. P. Kounaves, B. A. Parkinson, B. Sutter, J. D. Toner). Three decades after the results of Viking biology experiments indicated the presence of oxidants on Mars, the Wet Chemistry Laboratory (WCL), a component instrument of the Microscopy, Electrochemistry, and Conductivity Analyzer (MECA) on the Mars Phoenix Lander, revealed that the surface material contained high levels of perchlorate. More recently, samples that have been collected by the Mars Science Laboratory (MSL) and analyzed using the Sample Analysis at Mars (SAM) instrument contain perchlorate and these results suggest that there are significant differences in sample chlorine chemistry, even between samples collected in close proximity (e.g., MSL John Klein and Cumberland samples). Additionally, perchlorate and chlorate have been found in the EETA79001 Mars meteorite. In this presentation, some of the current research related to chemical aspects of perchlorates and related species on Mars will be overviewed. Aspects of martian perchlorate chemistry that will be discussed include: perchlorate parent salts, perchlorate formation and decomposition including the formation of reactive intermediates, and perchlorate deliquescence and brine formation.

BIO: Richard Quinn is a Principal Scientist with Leiden Measurement Technology (San Carlos, CA), and a Principal Investigator with the SETI Institute (Mountain

View, CA) working in the Planetary Sciences Branch at NASA Ames Research Center. He received his B.S. in chemistry from the George Washington University and his Ph.D. in chemistry from Leiden University, Netherlands. His research interests include the study of biomarker preservation potential in planetary and space environments, modeling of chemical processes occurring on planetary surfaces, and the development of technologies for in-situ planetary exploration. His experience includes instrument and sensor development for NASA and ESA space missions, nanosatelites, and the International Space Station. Currently, he is developing solid phase extraction technology for in-situ chemical analysis under a NASA Small Business Innovative Research contract (Leiden Measurement Technology) and developing the ORganic Exposure in Orbit (OREOcube) experiment for the International Space Station with funding from the NASA Astrobiology Science Technology and Instrument Development program (SETI Institute).

Lynn Rothschild

(Session One Chair)

BIO: Lynn Rothschild has been a leader of NASA's efforts in synthetic biology since 2010. She is an evolutionary biologist/ astrobiologist at NASA Ames, and Professor (Adjunct) at Brown University and the University of California Santa Cruz. She has broad training in biology, with degrees from Yale, Indiana University, and a Ph.D. from Brown University in Molecular and Cell Biology, and a love for protistan evolution. Since arriving at NASA Ames in 1987, her research has focused on how life, particularly microbes, has evolved in the context of the physical environment, both here and potentially elsewhere, and how we might tap into "Nature's toolbox" to advance the field of synthetic biology. Field sites range from Australia to Africa to the Andes, from the ocean to 100,000 feet on a balloon. In the last few years Rothschild has brought her expertise in extremeophiles and evolutionary biology to the field of synthetic biology, addressing on how synthetic biology can enhance NASA's missions. Since 2011 she has been the faculty advisor of the Brown-Stanford award-winning iGEM team, which has pioneered the use of synthetic biology to accomplish NASA's mission, particularly focusing on the human settlement of Mars, astrobiology and biodegradable drones. Her lab is working on expanding the use of synthetic biology for NASA with projects as diverse as recreating the first proteins de *novo* to biomining to using synthetic biology to precipitate calcite and produce glues in order to make bricks on Mars or the Moon. Rothschild is a Fellow of the Linnean Society of London, the California Academy of Sciences and the Explorers Club.

Meg Smith

The origin of perchlorate on Mars

ABSTRACT: Perchlorate has been detected at the Phoenix and Curiosity sites and is inferred at the Viking sites. This suggests a globally distribution of perchlorate on Mars' surface. The origin and distribution of perchlorate has implications for atmospheric chemistry, aqueous history, and habitability on Mars; however, despite its significance, the formation mechanism of perchlorate remains uncertain. A handful of studies have investigated the origin of perchlorate since its initial detection by the Phoenix lander. Laboratory investigations have shown that irradiation of natural semiconductors in chlorine-bearing solutions produce perchlorate, and more recently, the irradiation of CO_2-rich chlorine-bearing ice has been shown to release chlorine volatiles. Theoretical investigations into the origin of perchlorate point towards an atmospheric origin, similar to the atmospheric perchlorate formation on Earth. However, results from recent 1-D photochemical modeling have challenged the efficacy of purely gas-phase atmospheric perchlorate formation and perhaps point to gas-solid chemistry that is, as yet, unknown.

BIO: Meg Smith is currently a graduate student at the University of Washington, working on completing her PhD with Prof. David Catling. She received her bachelor's degree in Meteorology from Penn State University, where her research focused on radiative cooling of early Mars by elemental sulfur aerosols. Her current research focuses on the photochemistry of early Mars and Earth, as well as the redox evolution of Earth over time. She authored a paper earlier this year about the formation of perchlorates, sulfates, and nitrates in the atmosphere of Mars. This work

challenges the hypothesis that perchlorates could have formed through the gas-phase reaction of volatile chlorine and oxygen-bearing compounds.

Neil Sturchio

Terrestrial Perchlorate: Distribution and Isotopic Composition

ABSTRACT: (N. C. Sturchio, J.K. Böhlke, W. Andrew Jackson, P. B. Hatzinger, and B. Gu). Perchlorate (ClO_4^-) is widely distributed throughout the near-surface terrestrial environment. Concentrations of ClO_4^- in temperate soils are typically 1 – 10 ng/g, but may be much higher in hyperarid soils (e.g., Atacama Desert, Antarctica Dry Valleys). The concentration range of ClO_4^- in surface waters and groundwaters in temperate regions is 0.1 – 1.0 ng/g, but higher in arid regions and in locations where groundwater is contaminated by anthropogenic activity (e.g., aerospace, agriculture, road flares, pyrotechnics). Rainfall ClO_4^- concentration ranges from <0.01 – 0.1 ng/g. Plants are commonly enriched in ClO_4^- through bioaccumulation from soil, precipitation, and groundwater.

Isotopic compositions of Cl and O were measured for natural ClO_4^- in soils, groundwaters, and surface waters from four continents, and for synthetic ClO_4^- products. Natural and synthetic ClO_4^- samples are isotopically distinct. Natural ClO_4^- has elevated ^{17}O abundance ($\Delta^{17}O$ up to +18 per mil), whereas synthetic ClO_4^- has $\Delta^{17}O$ = 0.0 +/- 0.1 per mil. Natural ClO_4^- $\delta^{37}Cl$ ranges from –4 to +6 per mil, with the exception of Atacama Desert ClO_4^-, which ranges from -20 to -10 per mil, whereas synthetic ClO_4^- $\delta^{37}Cl$ ranges from 0 to +2 per mil. Values of $\delta^{18}O$ and $\Delta^{17}O$ are correlated in natural ClO_4^- extracted from arid soils and caliches. Recently formed (e.g., Late Pleistocene) natural ClO_4^- has elevated ^{36}Cl abundance, with $^{36}Cl/Cl$ ratios ranging from about 3×10^{-12} to 3×10^{-11}, whereas synthetic ClO_4^- has much lower $^{36}Cl/Cl$ ratios ranging from 1 – 40 x 10^{-15}.

BIO: Neil C. Sturchio is currently Professor and Chairperson of the Department of Geological Sciences at the University of Delaware. His principal research interests are in environmental biogeochemistry, tracer applications of radioactive and stable isotopes, and mineral-water interfacial processes. He received his PhD in Earth and Planetary Sciences from Washington University in St. Louis, MO, where his dissertation focused on the geology, petrology, and geochronology of a key Neoproterozoic terrane in the central Eastern Desert of Egypt. His first professional appointment was with Argonne National Laboratory (1983-2000), where his research focused on trace element and isotopic redistribution in groundwater aquifers and geothermal systems, stable isotope methods for investigating chlorinated solvent behavior in groundwater aquifers, and synchrotron X-ray scattering studies of mineral-water interfaces. Following this, he moved to the University of Illinois at Chicago (2000-2014), where he established the Environmental Isotope Geochemistry Laboratory. His research team developed and applied methods for stable isotopic analysis of perchlorate and RDX in groundwaters, as well as methods for sampling and purification of Kr from groundwaters and geothermal fluids for laser atom-trap analysis of the radiokrypton isotopes. Prof. Sturchio is a Fellow of the Geological Society of America and was the first elected Secretary of the Geochemical Society.

Brad Sutter

The state of knowledge of detecting oxychlorine species on Mars and possible oxychlorine remediation strategies.

ABSTRACT: (B. Sutter, D.W. Ming, R.C. Quinn, D.A. Archer, P.R. Mahaffy, W.V. Boynton, and R.V. Morris). Oxychlorine (e.g, perchlorate, chlorate) species have been detected in the sediments of the Northern Plains (Phoenix Lander) and Gale Crater [Mars Science Laboratory, (MSL)]. Perchlorate (up to 0.6 wt.%) was detected in the Phoenix landing site soil solutions by the Wet Chemistry Laboratory (WCL) Hofmeister anion selective electrode. Thermal analytical techniques [Phoenix Lander, Thermal Evolved Gas Analyzer (TEGA) and MSL Sample Analysis at Mars (SAM)] have also detected oxychlorine phases (up to 1.5 wt. %) in Mars sediments. Sediments were heated at a constant rate from ambient up to ~1000°C and evolved oxygen was detected by a mass spectrometer at temperatures consistent with the thermal decomposition of perchlorates and in some cases chlorates. Evolved HCl

has been detected in the SAM data further supporting the presence of an oxychlorine phase. The interaction of Fe phases (e.g., hematite, poorly crystalline Fe-oxides) present in the Mars sediments can lower the thermal decomposition temperature of oxychlorine phases, which can complicate the identification of oxychlorine species present. The Chemistry and Mineralogy (CheMin) x-ray diffraction instrument aboard MSL has not detected any oxychlorine phases but has potential for such a detection. Higher oxychlorine concentrations (~2 wt.%) may be required for detection by CheMin.

Techniques can be employed to minimize exposure of humans and plants to oxychlorine phases and other soluble salts. Soil or sediment used as a medium for enclosed crop growth can be leached with water to remove soluble oxychlorine phases and other salts that may cause salinity problems for plants. The leached solution can be collected and either boiled or freeze dried to separate the water from the salts. Strategies already being planned to minimize dust and soil from entering enclosed living and operations habitats should be able to contend with any issues related to airborne oxychlorine toxicity to astronauts.

BIO: Brad Sutter is a soil scientist at NASA Johnson Space Center where he researches the geochemistry and mineralogy of Mars soils and sediments. He holds undergraduate and graduate degrees in soil science from UC Davis and Texas A&M and has been working at NASA for 14 years. Past work include evaluating hyper-arid Atacama Desert soil formation processes as analogs to processes that may occur on Mars. He was part of the Phoenix Lander's Thermal Evolved Gas Analysis (TEGA) team evaluating carbonates as the source of CO_2 releases detected by TEGA. He is currently a team member of the Sample Analysis at Mars instrument which is aboard the Mars Science Laboratory, Curiosity rover. His duties involve making contributions to determining what volatile bearing minerals are present as indicated by the evolved gas (e.g., H_2O, CO_2, SO_2, O_2) releases from sediments analyzed by SAM. Specifically he has been leading laboratory studies that are assessing the source of the O_2 releases detected by SAM.

Jonathan Trent

Can Mars exploration be powered by pee and perchlorate?

ABSTRACT: (H. Kagawa and J. Trent). The ubiquitous presence of magnesium and calcium perchlorate in the Mars regolith is a challenge for human exploration (perchlorate is toxic) but it is also an opportunity for in situ resource utilization for making fuel. Fuel can be made from ammonium perchlorate, but while the perchlorate is abundant on Mars, the ammonium is not. Ammonium can be made however, from the urine (pee) produced by the Mars explorers. Pee is 95% water, which will presumably be recovered and recycled on Mars. Urea(CH_4N_2O) is the most abundant solute in pee at approximately 9.3 grams/liter and it is possible to convert urea into ammonia using enzymes called ureases. These enzymes are produced by bacteria on the human body. We evaluated the bacteria in the urine obtained from men and women and the relative rates of urea conversion into ammonia, using agar plates containing urea and pH indicator dye. These plates were incubated at body temperatures. The practical aspects of using waste products and microbes from astronaut/Mars explorers and converting perchlorate into fuel will be discussed.

BIO: Jonathan Trent. After earning a Ph.D. in marine biology at Scripps Institution of Oceanography, Jonathan did postdoctoral research at the Max Planck Institute for Biochemistry in Germany, the University of Copenhagen in Denmark, and the University of Paris in France. He returned to the USA to work at the Boyer Center for Molecular Medicine at Yale Medical School and then Argonne National Laboratory before moving to NASA Ames Research Center in 1998. In addition to working at NASA, Jonathan is an adjunct professor at UC Santa Cruz and a fellow of the California Academy of Sciences. Jonathan's research has ranged from marine biology to molecular medicine, from astrobiology to nanotechnology. He recently started a grass-roots movement called "Global Research into Energy and the Environment at NASA (GREEN) and has a long-standing interest in Mars exploration.

Todd Webster

Current Practices for the Detection and Treatment of Perchlorate

ABSTRACT: The presence and subsequent treatment of perchlorate on Earth has only been documented for a relatively short period of time. Since the late 20th Century, improvements in analytical technologies and methodologies have allowed for the detection of perchlorate at concentrations in the low µg/L to ng/L range. These improvements in detection limits have uncovered numerous areas on earth where perchlorate was previously unknown to exist, often requiring extensive remediation efforts to protect sensitive habitats and drinking water aquifers. Since the number of perchlorate contaminated areas has increased, so has the need for cost-effective, efficient treatment technologies. Traditional technologies such as carbon adsorption, reverse osmosis membranes, and single pass ion exchange have found a niche in the treatment arena for low levels of perchlorate in the presence of other oxyanions and lower total dissolved solids (TDS). For areas of higher contaminant concentrations and TDS, technologies such as regenerable ion exchange and biological treatment have proven to be better applied treatment methodologies. Using case studies, a focus of this discussion will be to expound on the methods used to detect perchlorate and define the most promising treatment technologies available for remediation on earth, along with their potential applicability for Mars.

BIO: Todd Webster is the Western Regional Vice President for Envirogen Technologies, Inc., based out of Rancho Cucamonga, California. He obtained his Ph.D. in Civil/Environmental Engineering from the University of Southern California in 1996 and is registered Professional Civil Engineer in the State of California. Dr. Webster has been with Envirogen Technologies for 17 years and involved in all aspects of perchlorate treatment system design, installation, and operation. His background in research and modelling has allowed Dr. Webster to bring remediation strategies for perchlorate from conceptual design at the laboratory bench-scale level to the full-scale implementation in the field. Over the past decade, he has spearheaded the design, installation and operation of the largest perchlorate treatment facility in the world located in Nevada, as well as the first biological perchlorate treatment system to produce potable water in the United States.

PANELIST BIOS

Doug Archer

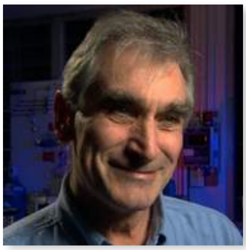
BIO: Doug Archer is a Mars research scientist who currently focuses on detecting and identifying volatile-bearing minerals through evolved gas analysis. These minerals, including perchlorate, provide a windows into past and present environmental conditions on Mars. Doug holds a B.S. in Physics from Brigham Young University in Provo, UT and a PhD in Planetary Science from the University of Arizona in Tucson, AZ. Doug was a science team member on the Phoenix Mars Scout Mission, the mission that discovered perchlorate on the martian surface. He is currently a member of the Mars Science Laboratory science team and a member of the Sample Analysis at Mars (SAM) instrument team. Through evolved gas analysis, SAM has detected oxychlorine species and Doug is involved in identifying the particular species present. One of his roles in analyzing SAM data is to convert the evolved gas signal into a molar abundance in order to establish the concentration of perchlorate (and other minerals) in martian samples. Doug is also interested in how the presence of perchlorate can affect the decomposition of other minerals as well as its impact on the UV photolysis of organic molecules.

John Coates

BIO: John D. Coates is a Professor of Microbiology at University of California, Berkeley. He also holds a joint appointment as a Geological Scientist Faculty in the Earth Sciences Division at the Lawrence Berkeley National Laboratories. He was co-founder and Board Member of *BioInsite LLC* a company geared towards the use of microorganisms for solutions to environmental contaminant problems. He is Director of the UC Berkeley Energy Biosciences Institute *microbial enhanced hydrocarbon recovery (MEHR)* program; Director of the UC Berkeley Energy Biosciences Institute *soured systems biology program (SSPB);* a member of the Energy Biosciences Institute Executive Committee; Chairman of the joint UC Berkeley-LBNL/BP committee on oil reservoir souring cause and control; a member of the Scientific Advisory Committee, University of Montréal GenoRem program; and a member of the Scientific Advisory Committee, Universal Bio Mining, LLC.

He obtained an Honors B.Sc. in Biotechnology in 1986 from Dublin City University, Ireland and his Ph.D. in Microbiology in 1991 from University College Galway, Ireland. His major area of interest is geomicrobiology applied to environmental problems. Specific interests include diverse forms of anaerobic microbial metabolism such as microbial perchlorate reduction, microbial iron oxidation and reduction, and microbial humic substances redox cycles. Other interests include early Earth and evolution, alternative renewable energies, bioremediation of toxic metals, radionuclides, and organics. He has won several awards for research and mentorship including the *1998 Oak Ridge Ralph E. Powe Young Faculty Enhancement Award*, the *2001 DOD SERDP Program Project of the Year* award, and the 2002 *SIUC College of Science Researcher of the Year Award*. He has given more than 150 invited presentations at national and international meetings. He has authored and co-authored more than 120 peer-reviewed publications and book chapters. He has published one book and has 12 patent submissions based on technologies developed in his lab several of which have been applied commercially. He has been on the editorial boards of the journals *Frontiers in Microbiology, Applied and Environmental Microbiology*, and *Applied Microbiology and Biotechnology*. He is an editorial scientist for the *Faculty 1000* review database and is a member of the *American Society for Microbiology, the American Chemical Society, the American Geophysical Union,* and the *International Humic Substances Society*. In addition to his traditional teaching at UC Berkeley, Dr. Coates is continuously involved in various outreach programs supporting high school and community college students. He has mentored many high school students and science projects in his laboratory and was a recipient of the University of California Berkeley Summer Research Opportunity Program Recognition award for mentorship.

Max Coleman



BIO: Max Coleman's training combined chemistry, geology and isotope geochemistry at London and Leeds Universities, but he found that he needed to encompass microbiology too when studying sedimentary rocks. He has applied multidisciplinary fundamental scientific research to elicit solutions to practical problems in petroleum exploration and production, environmental pollution, radioactive waste storage and forensic science. He now uses the same approaches to search for life on other planets. After ten years at the British Geological Survey, where he ran a national isotope analysis facility, he joined BP Research to start a new geochemical research group. He then moved to the University of Reading in 1995 as Professor of Sedimentology. Prof. Coleman was enticed to join the NASA Jet Propulsion Lab, Caltech, in 2003, to be Director of the Center for Life Detection and Leader of the Astrobiology Research Group. In the last few years, he spent sabbatical periods in Paris where he worked on aspects of capture and storage of carbon dioxide, related to climate change research. This led to his developing the concept of using attenuation of the cosmic ray muon flux to monitor subsurface storage of carbon dioxide. He returned to JPL to focus again on looking for life outside the Earth by developing mineral biosignature approaches and instruments to detect them.

Alfonso Davila

BIO: Alfonso F. Davila is an Astrobiologist at the SETI Institute and NASA Ames Research Center in California. As an undergraduate in Spain, he studied marine sciences and was trained in marine biology, chemistry, geology and physics, with a later focus in marine geology and physics for his Masters degree. He obtained a PhD in Germany studying bio-geophysics, and the interactions between the Earth's magnetic field and biological systems. His Post-Doc at NASA Ames in California, brought him to work on the habitability of Mars through the study of Mars Analog Environments on Earth. Alfonso's research interests are broad, spanning from planetary habitability, geology and geochemistry, to the origin and evolution of life on Earth, and the origin and evolution of the Solar System. He is particularly interested in the geologic, geochemical, and climatic evolution of Mars, and how this evolution affected the habitability of the planet from its origins and up to the present. He is also interested in comparing the evolution of Mars and Earth through field research in Mars Analog Environments such as the Antarctic Dry Valleys, the high Arctic, or the Atacama Desert, combined with laboratory work, numerical modeling, and the analysis of remote sensing data. He is currently working in several international science and engineering projects in the field of planetary sciences. Alfonso has been a guest speaker in international conferences and a guest lecturer in universities and research institutes in the US, Canada, South America and Europe, and has published more than 50 scientific papers and book chapters in these fields.

John Hogan

BIO: John A. Hogan Ph.D. is an environmental scientist working in the Bioengineering Branch at NASA Ames Research Center, Moffett Field, CA. His research supports NASA's Life Support Program and involves the development of sustainable systems for extended extraterrestrial human habitation. Major areas of research and technology development have included integrated biological and physico-chemical technologies for regenerative air, water and solid waste treatment systems, plant growth, systems analysis and integration, planetary protection, and data systems development. His interests also include investigating how NASA systems engineering principles may be applied to large-scale terrestrial operations. Prior to joining NASA, Dr. Hogan was research faculty at Rutgers, The State University of New Jersey in the Department of Environmental Sciences. At Rutgers, he participated in a NASA funded, multidisciplinary NSCORT program developing biologically-based, sustainable systems for long-term planetary bases.

Kosuke Fujishima

BIO: Kosuke Fujishima is a Synthetic biologist and an Astrobiologist working at Lynn Rothschild lab at NASA Ames Research Center. He received his Ph.D degree in Systems Biology from Keio University, Japan in 2009. His current research focuses on using Synthetic biology as a toolkit to tackle various topics in the field of Astrobiology; from understanding the functions of abiotic peptides for origins of life, developing new analytical methods for detecting extraterrestrial biosignatures, and to support future human settlement on Mars by creating genetically engineered microorganisms. He is currently working closely with a Japanese visiting scholar Toshitaka Matsubara from Tokyo Tech University to turn salt-loving halophiles into a model organism for human support on Mars, given their natural resistance towards radiation, desiccation and high salinity.

Digby Macdonald

BIO: Digby D. Macdonald. Born in Thames, New Zealand, December 7 1943, Professor in Residence Macdonald gained his BSc and MSc degrees in Chemistry at the University of Auckland, New Zealand, and his Ph.D. degree in Chemistry from the University of Calgary in Canada. He has served as Director and Professor of the Fontana Corrosion Center, Ohio State University, Vice President, Physical Sciences Division, SRI International, Menlo Park, California and has been Professor and later Distinguished Professor of Materials Science and Engineering at Pennsylvania State University since 1991, before joining UC Berkeley in 2013. Professor Macdonald has received numerous awards and honors, including the 1991 Carl Wagner Memorial Award from The Electrochemical Society; the 1992 Willis Rodney Whitney Award from The National Association of Corrosion Engineers for "contributions to the science of corrosion"; the W. B. Lewis Memorial Lecture from Atomic Energy of Canada, ltd., for his "contributions to the development of nuclear power in the service of mankind"; the H. H. Uhlig Award from The Electrochemical Society; the U. R. Evans Award from The Institute of Corrosion, UK; the 20th Khwarizmi International Award in fundamental science in 2007; The Faraday Gold Medal from SAEST in India in 2010; the Gibbs Award from IAPWS in 2013, and the Frumkin Medal for the International Society of Electrochemistry in 2014. He is an elected fellow of NACE-International; The Electrochemical Society; the Royal Society of Canada; the Royal Society of New Zealand; ASM International; the World Innovation Foundation; the Institute of Corrosion (UK); and the International Society of Electrochemistry. From 1993 to 1997 he was a member of the US Air Force Science Advisory Board with the protocol rank of Lieutenant General. He was awarded the US Air Force Medal for Meritorious Civilian Service in 1997. Dr. Macdonald was a Trustee of ASM International and has recently been inducted Doctuer Honoris Causa by INSA-Lyon, Lyon, France. He was a recent recipient of the Lee Hsun Research Award of the Chinese Academy of Sciences. Dr. Macdonald has published more than 900 papers in peer-reviewed scientific journals, books, and conference proceedings, plus four books, one of which ("Transient Techniques in Electrochemistry") established an important area of electrochemical research, and has 10 patents and numerous invention disclosures credited to his name. Finally, under his tutelage, more than 150 students have graduated with advanced degrees in Chemistry and Materials Science and Engineering over the past four decades.

Ronald Oremland

BIO: Ronald Oremland received his BS in Biology from Rensselaer Polytechnic Institute in 1968. He briefly attended graduate school at the Institute of Marine Sciences of the University of Miami, FL (1968 - 1969), but this was interrupted by military service. He was commissioned an ensign in the US Navy in November 1969 and thence graduated the Naval School of Diving and Salvage, serving in the capacity of a ship's diving and salvage officer aboard the USS Utina (ATF-163). He was released from active duty at the end of 1971.

He returned to grad school in Miami, receiving his PhD in marine sciences from the Rosenstiel School of Marine & Atmospheric Sciences in 1976. Dr. Oremland did a brief postdoc at the NASA Ames Research Center (1976 - 1977), after which he began working at the US Geological Survey in Menlo Park, CA where he is still employed as a Senior Scientist. He has adjunct faculty appointments at University of Miami and University of California Santa Cruz, and is a Fellow of the American Academy of Microbiology, the American Geophysical Union, and of the International Society for Environmental Biogeochemistry.

Dr. Oremland works with anaerobes, chemo/photo-autotrophs, and extremophiles, especially those that metabolize gases or toxic metalloids (e.g., As, Se, Te, Sb). He is particularly fond of Mono Lake, California as a research site.

Rocco Mancinelli

BIO: Rocco L. Mancinelli is a Senior Research Scientist with the Bay Area Environmental Research Institute. He obtained his B.A from the University of Colorado Boulder in Molecular , Cellular and Developmental Biology, and his Ph.D. from the Department of Environmental, Population and Organismic Biology also from the University of Colorado, Boulder. His research interests are broad, encompassing ecology, physiology, and biogeochemistry. Specifically he studies microbe-environment interactions with emphasis on the environmental limits in which organisms can live. He currently uses three systems in these studies: 1) Halophiles in evaporitic salt crusts that form along the marine intertidal and in salterns; 2) Microbial mats inhabiting diverse environments (e.g., the intertidal area of the Baja coast, and the alkaline and acid hot springs of Yellowstone National Park); and 3) The space environment in Earth orbit. He has flown organisms aboard the European Space Agency's BioPan facility, NASA's GeneSat and O/OREOS as well as the International Space Station. In addition, he has written extensively on the potential for the origin and evolution of life on Mars.

Michelle Rucker

BIO: Michelle A. Rucker is a 28-year veteran of NASA. She began her engineering career designing down-hole oil field sensors in Houston, while pursuing Bachelor's and Master's degrees in Mechanical Engineering from Rice University. Michelle joined NASA in the aftermath of the space shuttle Challenger accident, supporting the investigation team by conducting booster material test and analysis at NASA's White Sands Test Facility. During her 12-year service at White Sands, Michelle managed a range of projects, from failure analysis and subsequent recovery of the Gamma Ray Observatory propulsion system, to developing two-stage light gas guns for use in hypervelocity impact research. In 1998 Michelle transferred back to NASA's Houston facility to serve as Deputy Subsystem Manager for the International Space Station's (ISS) environmental control and life support system. After tours of duty as deputy branch chief for the EVA and spacesuit systems branch, and deputy system manager for the ISS exercise equipment, Michelle joined the Constellation Program where she worked on both the Orion and Altair projects. She currently works in the Exploration Integration and Science Directorate, developing crewed Mars mission concepts. Michelle holds two U.S. patents and has received numerous NASA awards.

HOST BIOS

S. Pete Worden

Director, NASA Ames Research Center

BIO: Simon P. Worden (Brig. Gen., USAF, ret.) is the center director at NASA Ames Research Center where he leads a staff of nearly 2,500 civil servants and contractors and oversees an annual budget of approx. $800 million providing the critical R&D support that makes NASA's and the nation's aeronautics and space missions possible. In just three years, Worden has completely transformed Ames, reinvigorating the center's workforce and taking a leadership role in important, cost-effective small satellite mission

Worden has also put Ames on the critical path for all major NASA space exploration missions through effective use of the center's unique wind tunnels, arc jets, intelligent systems and supercomputer facilities and capabilities. Worden's 'GreenSpace' initiative has brought Ames' remote sensing capabilities to bear on air traffic safety, fighting forest fires, and the study of climate change. And Ames' new Sustainability Base facility will serve as a model for future eco-friendly, high-performance federal buildings. In recognition of these outstanding achievements, Worden was named the Federal Laboratory Consortium's Laboratory Director of the Year for 2009.

Prior to becoming Ames' director, Worden was a Research Professor of Astronomy, Optical Sciences and Planetary Sciences at the University of Arizona where his primary research direction was the development of large space optics for national security and scientific purposes and near-earth asteroids. Additionally, he worked on topics related to space exploration and solar-type activity in nearby stars. He is a recognized expert on space issues - both civil and military. He has authored or co-authored more than 150 scientific technical papers in astrophysics, space sciences, and strategic studies. Moreover, he served as a scientific co-investigator for two NASA space science missions.

In addition to his former position with the University of Arizona, Worden previously served as a consultant to the Defense Advanced Research Projects Agency (DARPA) on space-related issues. In 2004, he worked as a Congressional Fellow and chief advisor to the Chairman of the US Senate Subcommittee on Science and Space regarding NASA and space issues.

Worden retired in 2004 after 29 years of active service in the United States Air Force. His final position was Director of Development and Transformation, Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, CA.

Jacob Cohen

Chief Scientist, NASA Ames Research Center

BIO: Jacob Cohen is currently the Chief Scientist at NASA Ames Research Center. In this capacity, Dr. Cohen provides advice and oversight for research programs and serves as the principal Center official in the administration of long term, high risk, and creative/inventive research programs. Dr. Cohen evaluates proposals for new programs, keeps abreast of ongoing work, and establishes priorities to assure that Center research programs contribute effectively to national aerospace and scientific objectives. Dr. Cohen serves as the chief advisor to the Center Director on all areas affecting the science at the Center. As part of his interest in the utilization of space and aeronautics for scientific and technology advancements, Dr. Cohen facilitates and develops international, inter agency, academic and commercial collaborations to sustain new research initiatives. Dr. Cohen serves as the Center representative to the Agency Chief Scientist and the NASA Research Council and is the conduit for the Agency Office of the Chief Scientist at the Center. Dr. Cohen received his Doctorate from New York University in the area of molecular evolution. He then completed a postdoctoral fellowship at Cedars-Sinai Medical Center's Ophthalmology Research Laboratories in the area of viral host relationships. Dr. Cohen has held various research and management positions both in industry and government. For his numerous contributions, Dr. Cohen has received various NASA and external awards and honors. Mentoring, teaching and inspiring the next generation of scientists and managers are continuous roles Dr. Cohen pursues.

ACKNOWLEDGMENTS

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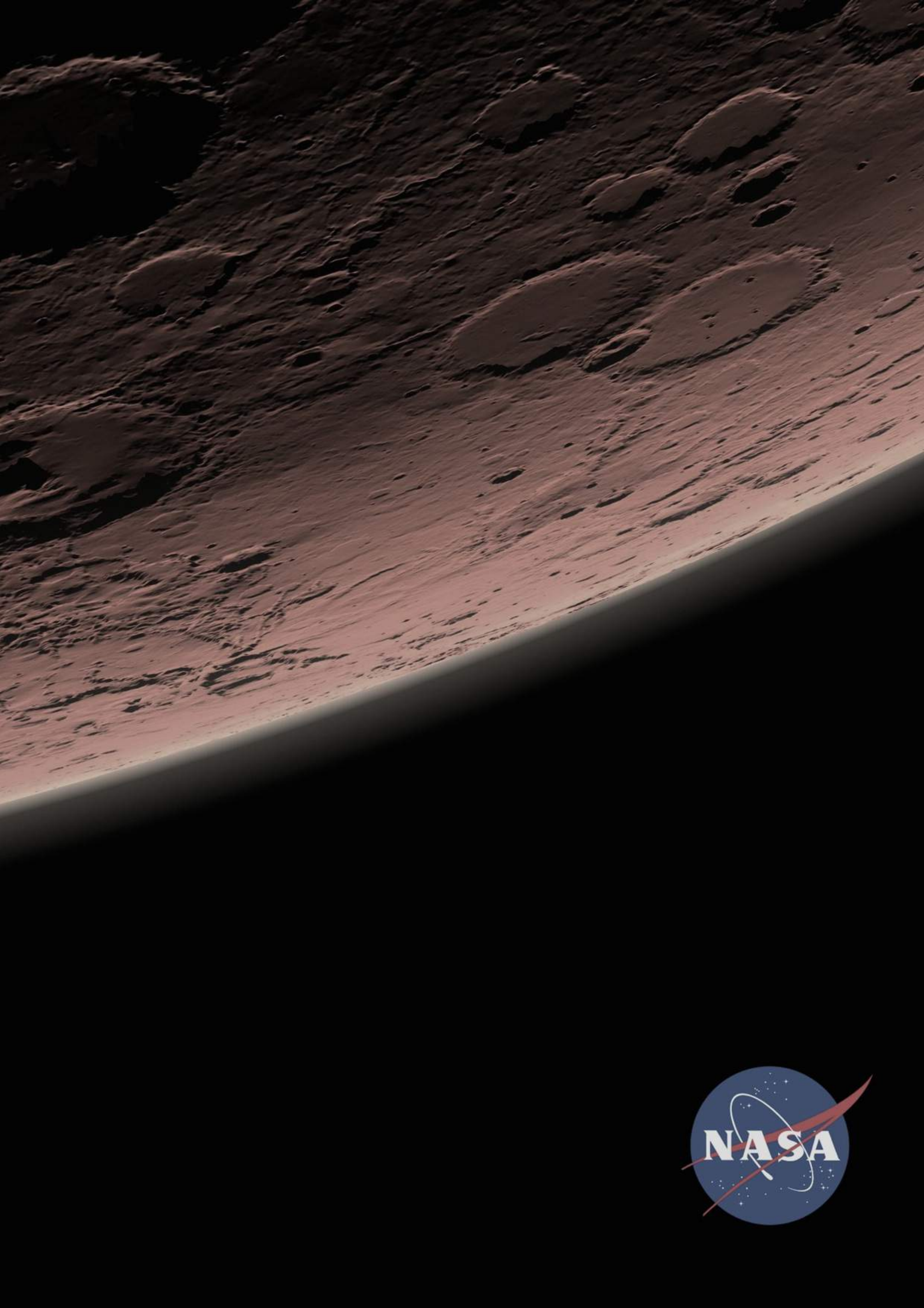
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