Astrobiology and Planetary Sciences at Boulby

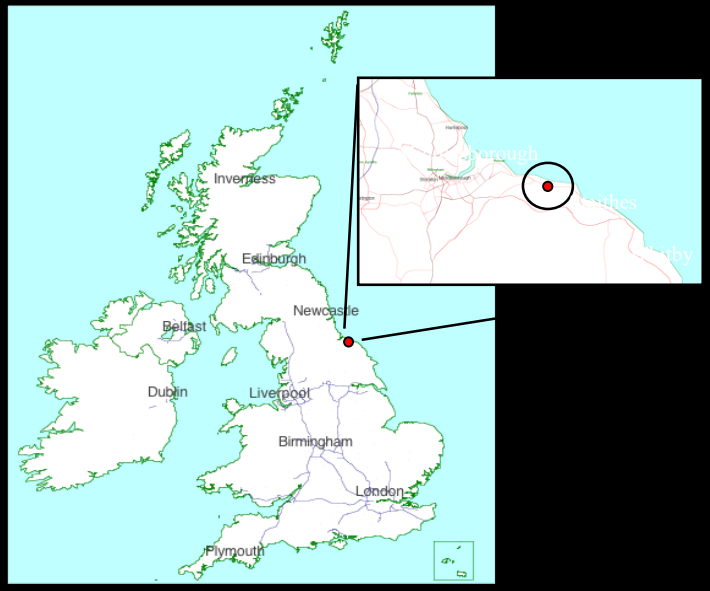
Charles Cockell
University of Edinburgh

DULIA-Bio
November 5th, 2019

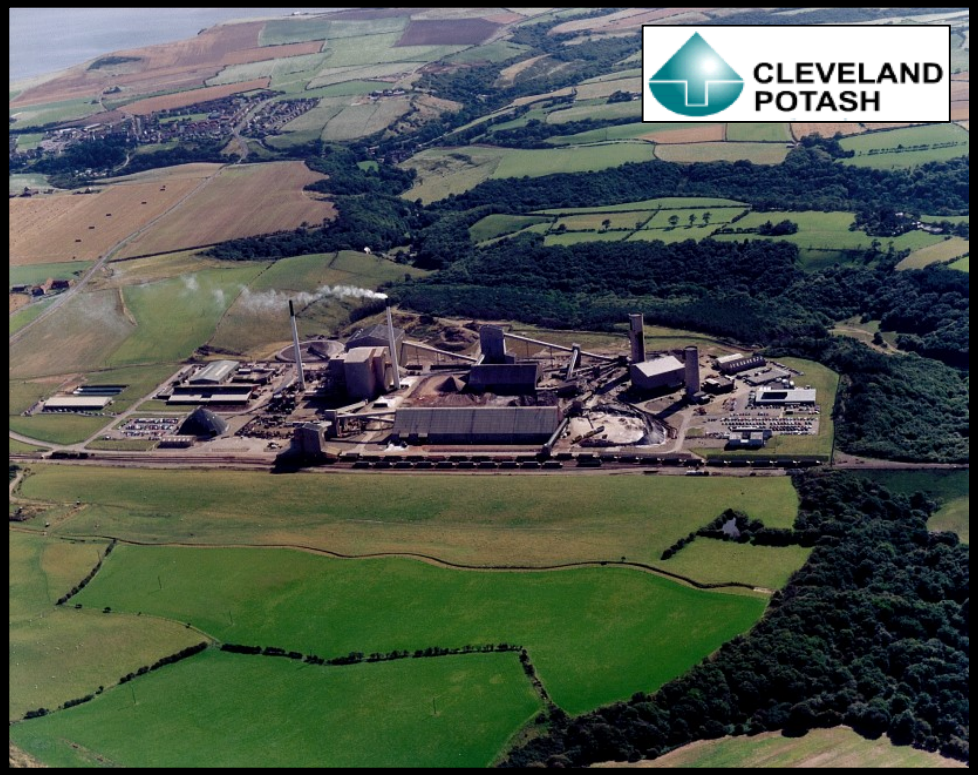
Boulby Mine – Astrobiology and Planetary Sciences

A working polyhalite mine on the North East of England.

Operated by ICL



Deepest mine in Britain – 1100m deep



Potash

`View from Staithes

A deep underground laboratory (that is very clean….)

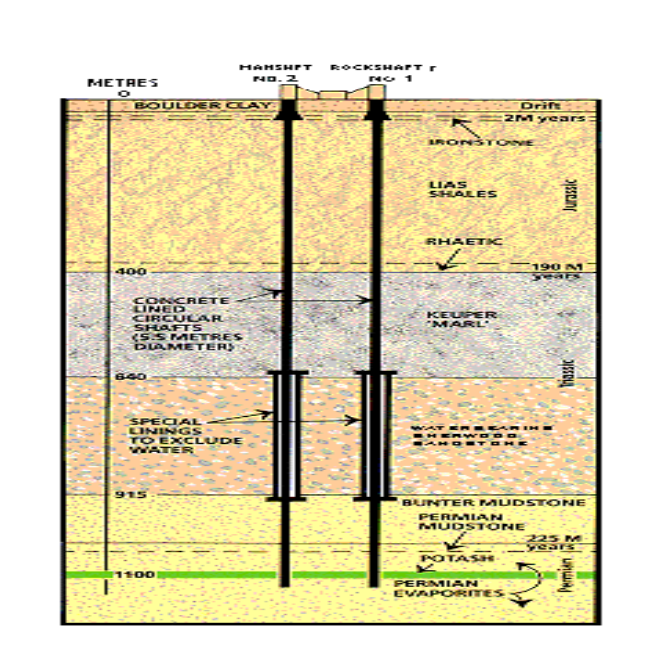
…is a place to prepare and test technology

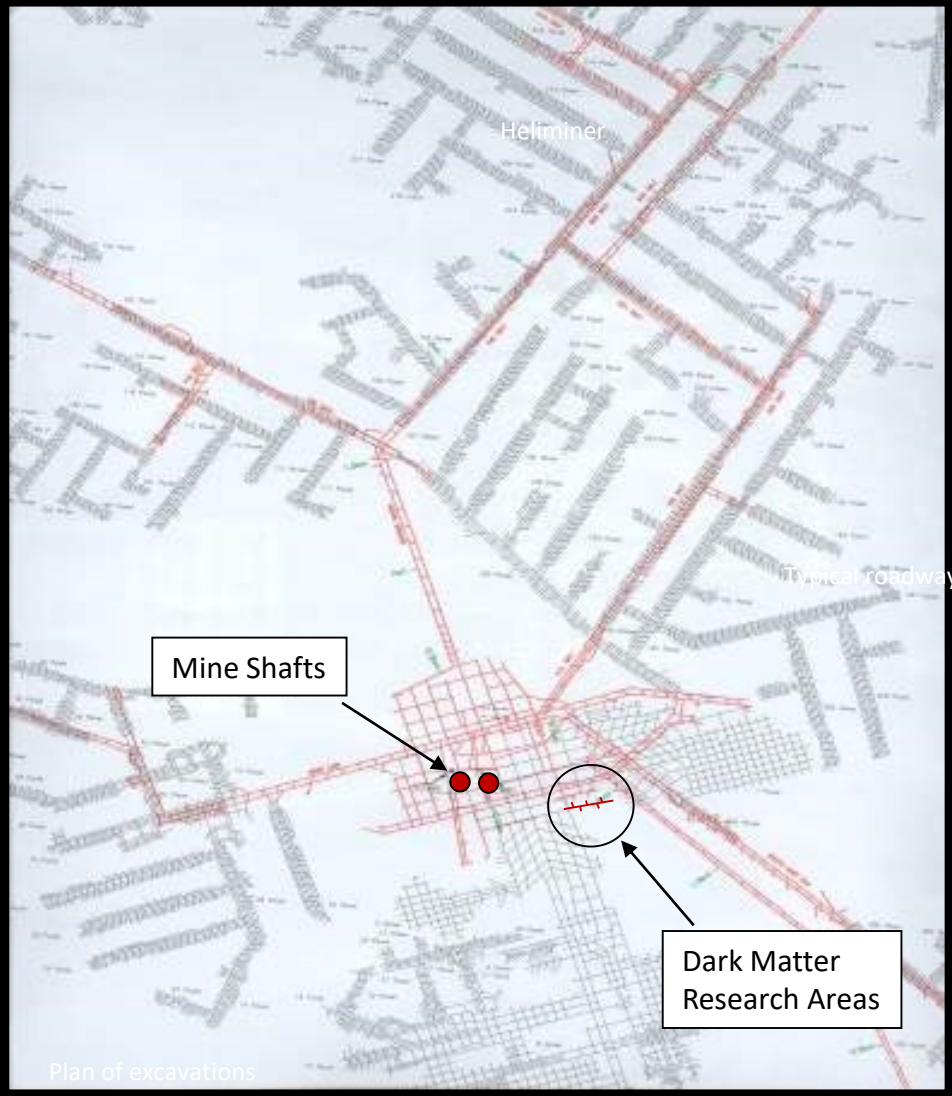
Science & Technology Facilities Council

Boulby Mine – Astrobiology and Planetary Sciences *- access to many varied environments*

Over 40 kms of tunnel mined each year (now >1,000kms in total)

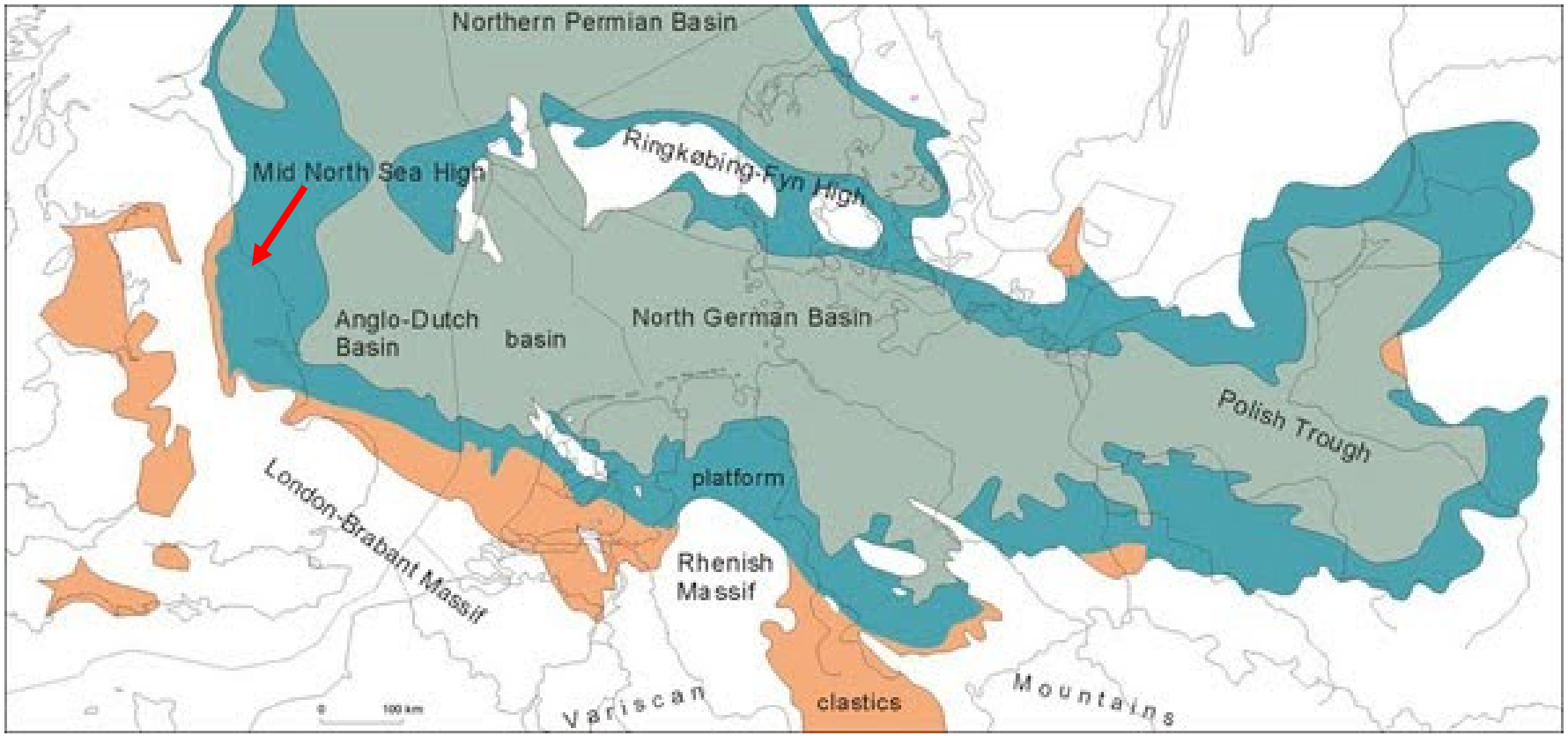
Long lived roadways cut in salt (NaCl) – giving access to potash (KCl) levels just above



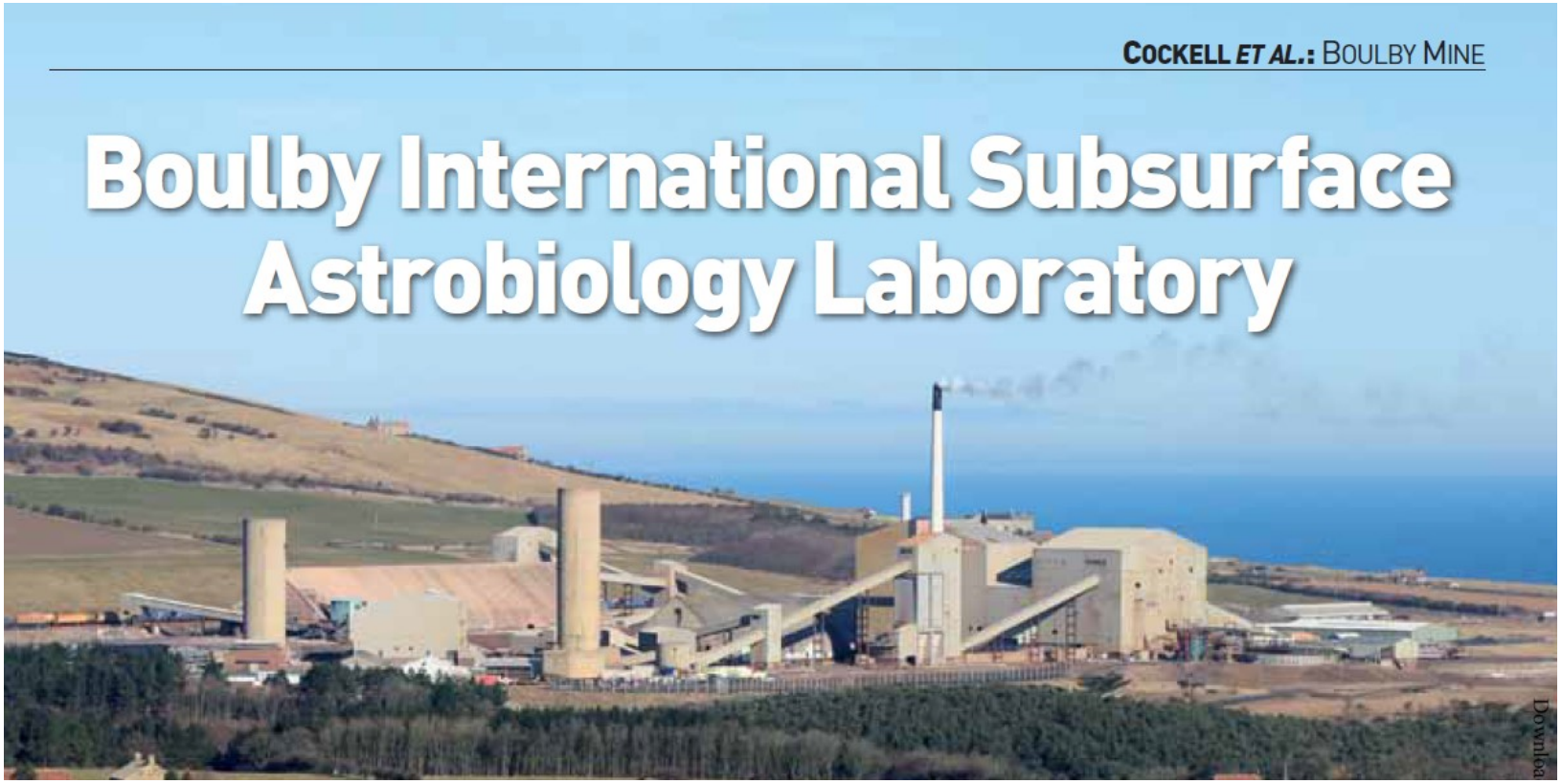


Boulby Mine

- In the deposits of the Permian Zechstein Sea (~250 Myr ago)



We established the world's first underground astrobiology laboratory in 2013

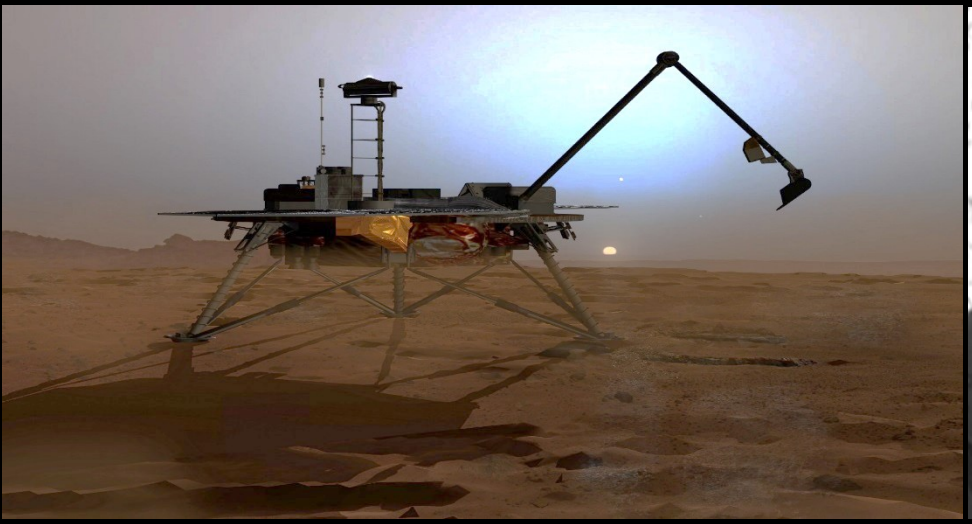


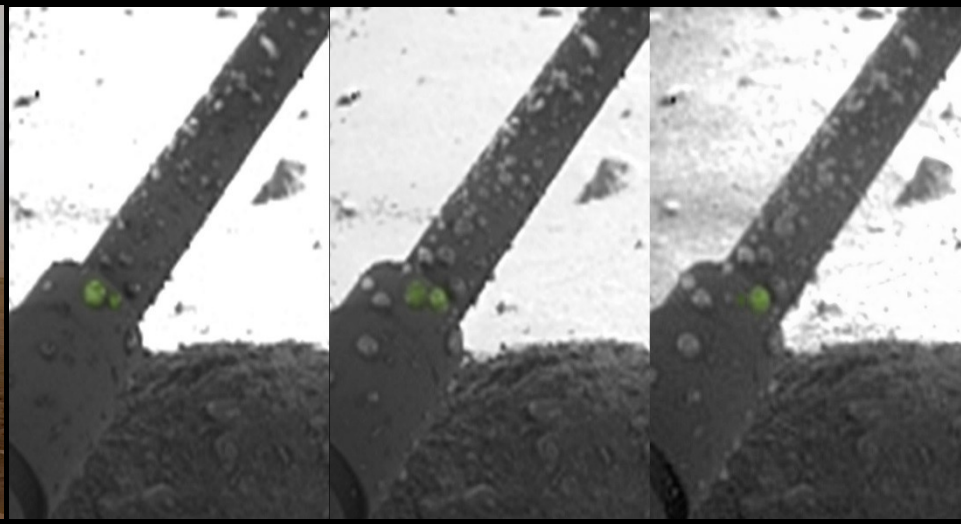
Cockell et al. (2013) *Astronomy and Geophysics* **54**, 2.25-2.27

Astrobiology undertaken in Boulby:

- Life in the deep subsurface (particularly brines)
- Geobiology, geochemistry and geophysics of deep subsurface environments
- Life at below background radiation
- Deep cycling of elements such as carbon
- Testing of methods for planetary exploration (MINAR)

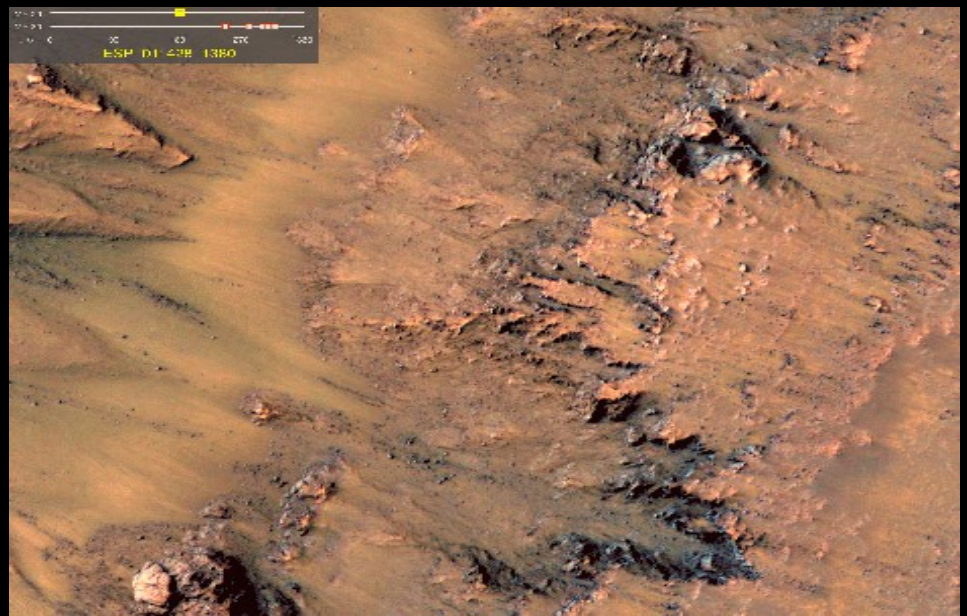
Brines on Mars?



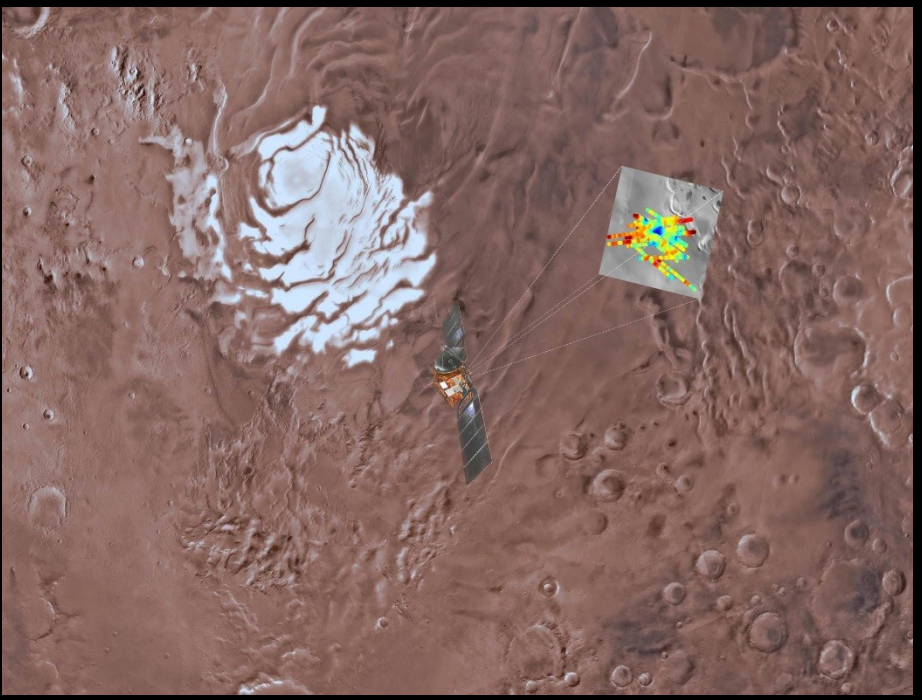


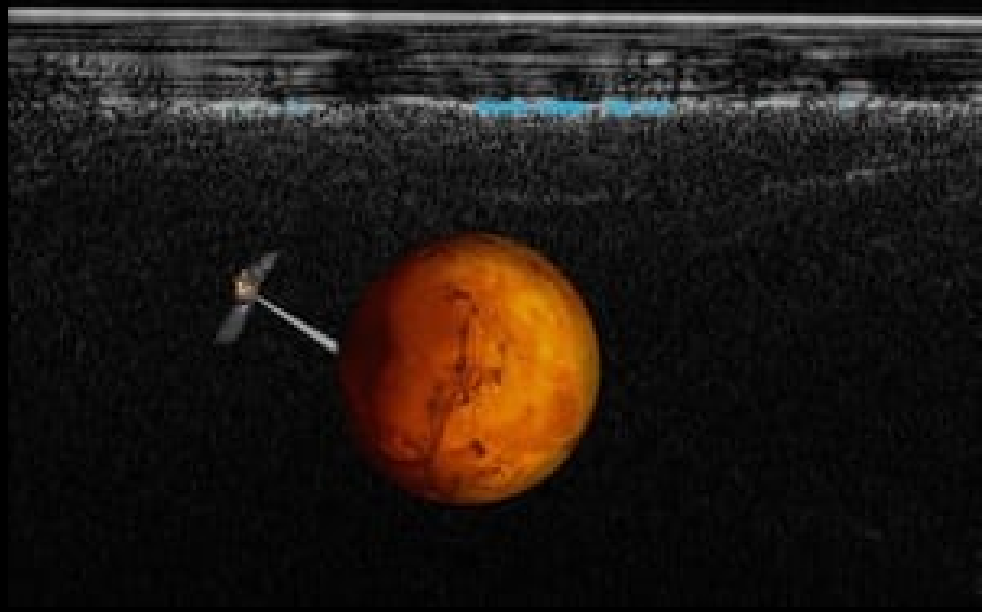
Phoenix lander salts

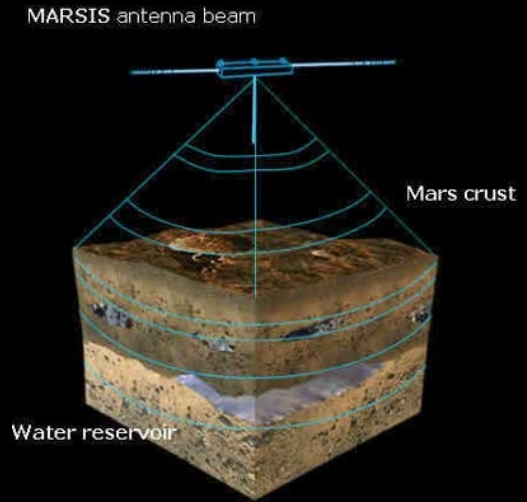
Salty streams?



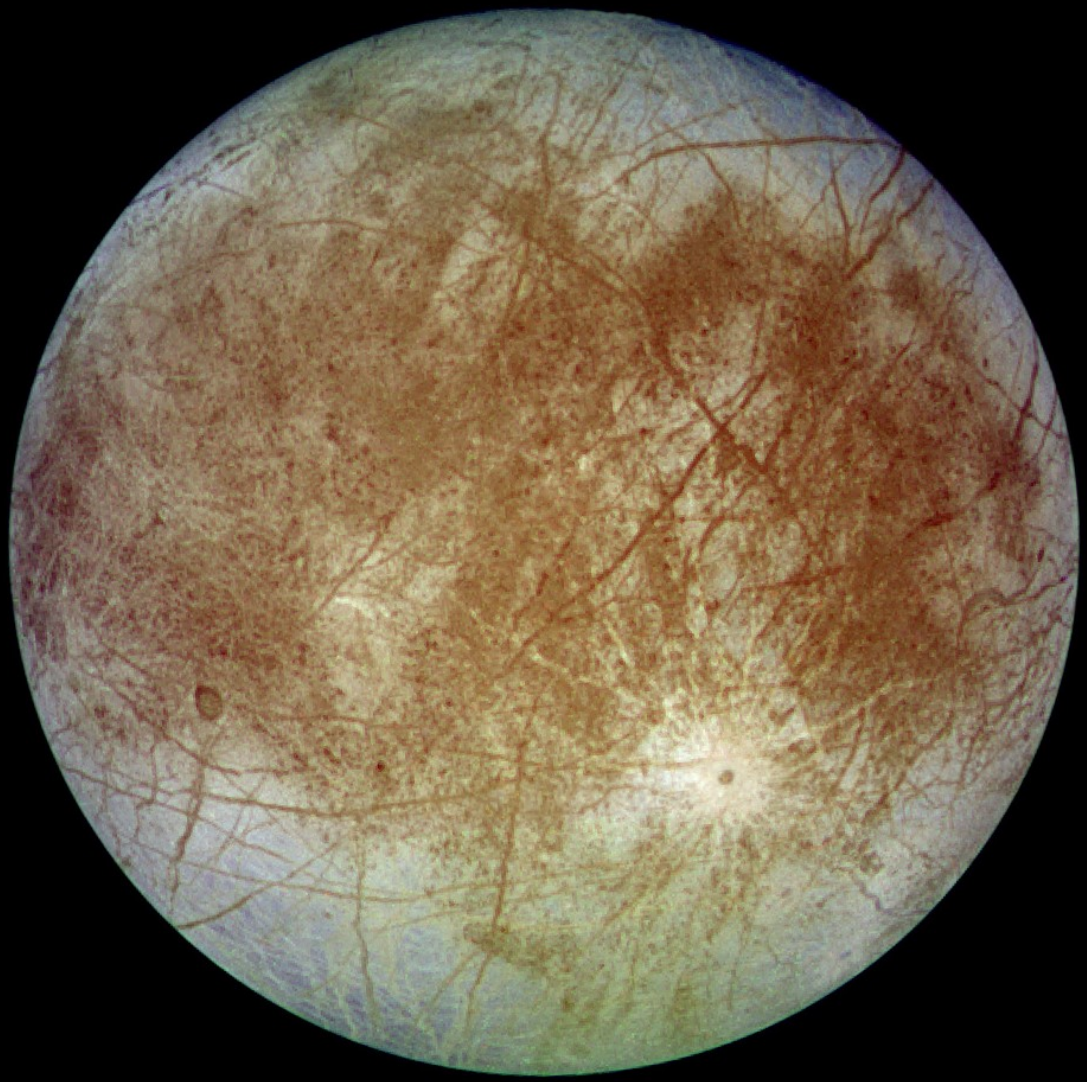
An underground salty lake?



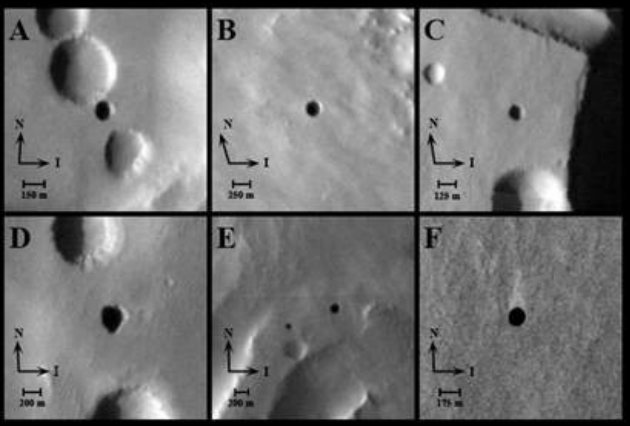




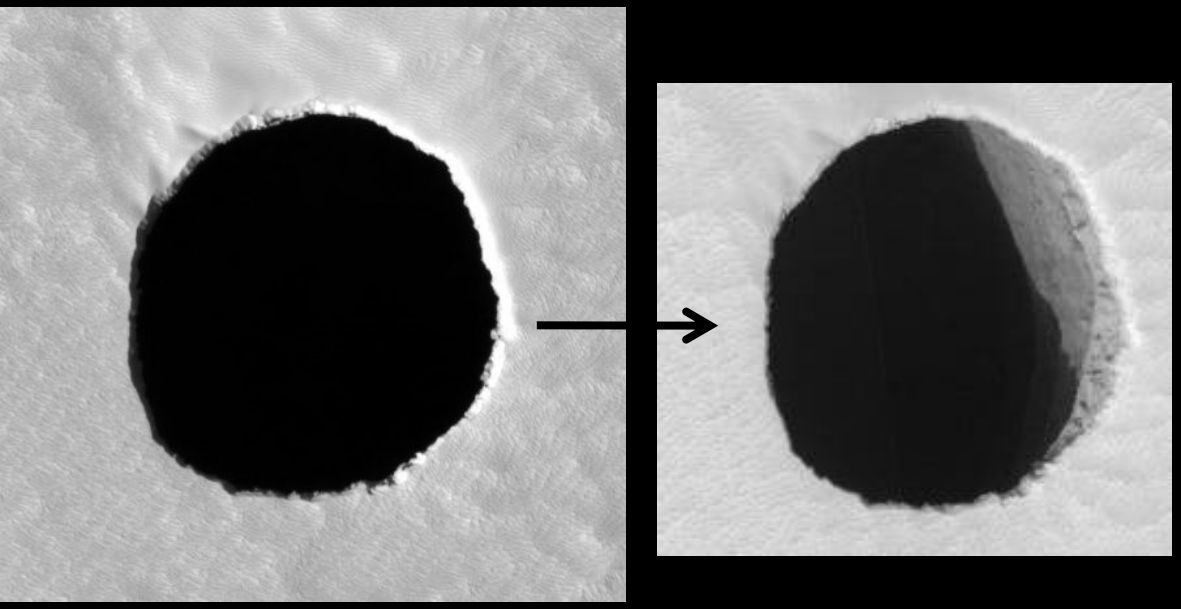
Europa



The subsurface – access to deep geology/habitability and sites for human exploration



e.g. Caves on Mars



Use of the lab to study life in extreme environments

- Life in brines and other subsurface salt environments.
- Limits of life

frontiers in Microbiology

ORIGINAL RESEARCH
published: 12 March 2019
doi: 10.3389/fmicb.2019.00426

An Ionic Limit to Life in the Deep Subsurface

Samuel J. Payler[1], Jennifer F. Biddle[2], Barbara Sherwood Lollar[3], Mark G. Fox-Powell[4], Thomas Edwards[5], Bryne T. Ngwenya[6], Sean M. Paling[7] and Charles S. Cockell[1]*

[1] UK Centre for Astrobiology, School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom, [2] College of Earth, Ocean, and Environment, University of Delaware, Lewes, DE, United States, [3] Department of Earth Sciences, Toronto, ON, Canada, [4] School of Earth and Environmental Sciences, University of St. Andrews, St. Andrews, United Kingdom, [5] Israel Chemicals Ltd. Group, Whitby, United Kingdom, [6] School of Geosciences, Kings Buildings, University of Edinburgh, Edinburgh, United Kingdom, [7] Boulby Underground Science Facility, Science and Technology Facilities Council, Swindon, United Kingdom

Investigating the habitability of brines

Some brines are uninhabitable to life…

		+/- growth in the brines for each triplicate	
Inoculant and its microbial community	Carbon Source	29 XC	101-P
215	Yeast	+/+/+	-/-/-
215	Na pyruvate and casamino acids	+/+/+	-/-/-
44 XC	Yeast	+/+/+	-/-/-
44 XC	Na pyruvate and casamino acids	+/+/+	-/-/-
Billingham	Yeast	+/+/+	-/-/-
Billingham	Na pyruvate and casamino acids	+/+/+	-/-/-
215, 44 XC, Billingham, yeast media enrichment cocktail	Yeast	+/+/+	-/-/-
215, 44 XC, Billingham, Na pyruvate and casamino acids media enrichment cocktail	Na pyruvate and casamino acids	+/+/+	-/-/-
Soil	Yeast	n/a	-/-/-
Soil	Na pyruvate and casamino acids	n/a	-/-/-
Billingham, 44 XC, 215 cocktail (anaerobic)	Yeast	n/a	-/-/-
Soil (anaerobic)	Yeast	n/a	-/-/-

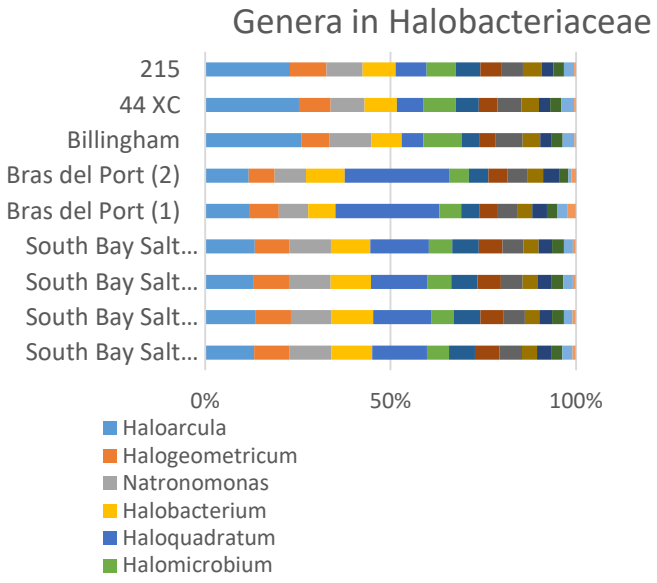
An ionic limit to life in the deep subsurface

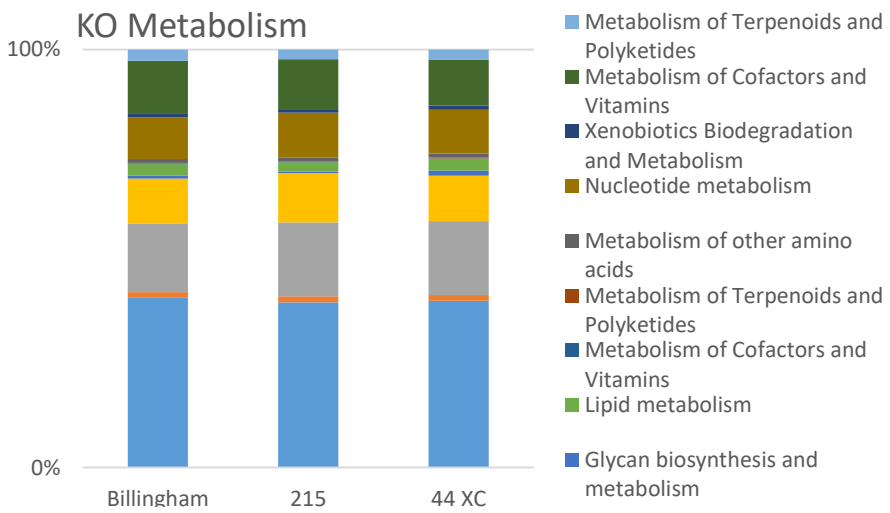
Caused by movement of fluids through specific salt types (Mg + Cl) resulting in specific ion combinations that are uninhabitable

Aqueous environments that are uninhabitable

Who is there (in the metagenome) and what are they doing?

> Investigating carbon cycling in the deep subsurface





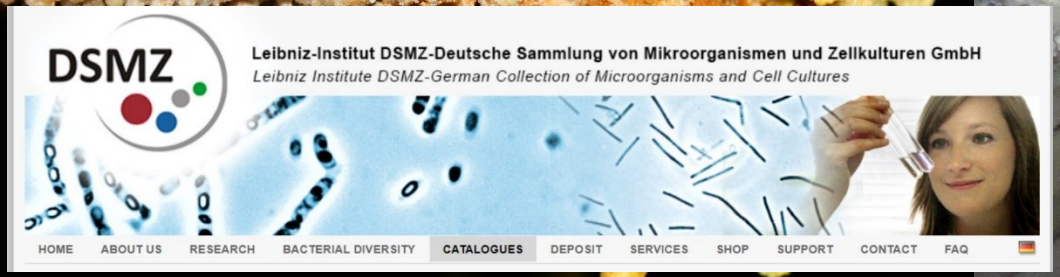
- Large number of genes for carbon degradation, both small carbon compounds and complex carbon compounds
- Carbon from aquifer and deep carboniferous hydrocarbons drives Boulby communities.

Understanding life in deep salty environments…

International Journal of Astrobiology 17 (4): 314–328 (2018)
doi:10.1017/S1473550417000246 © Cambridge University Press 2017

Anaerobic microorganisms in astrobiological analogue environments: from field site to culture collection

C. S. Cockell[1], P. Schwendner[1], A. Perras[2,3], P. Rettberg[4], K. Beblo-Vranesevic[4], M. Bohmeier[4], E. Rabbow[4], C. Moissl-Eichinger[2], L. Wink[2], V. Marteinsson[5], P. Vannier[5], F. Gomez[6], L. Garcia-Descalzo[6], P. Ehrenfreund[7], E.P. Monaghan[7], F. Westall[8], F. Gaboyer[8], R. Amils[9], M. Malki[9], R. Pukall[10], P. Cabezas[11] and N. Walter[11]

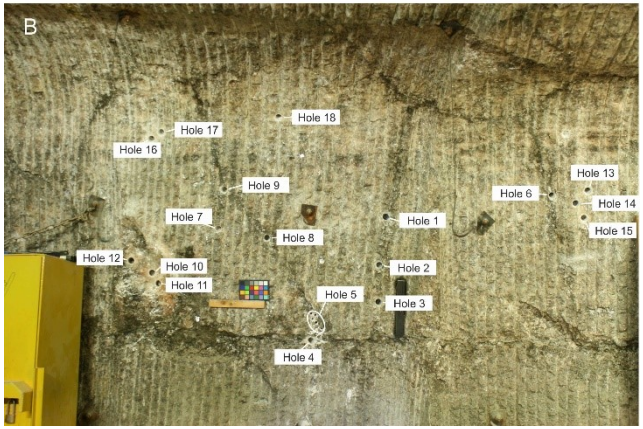


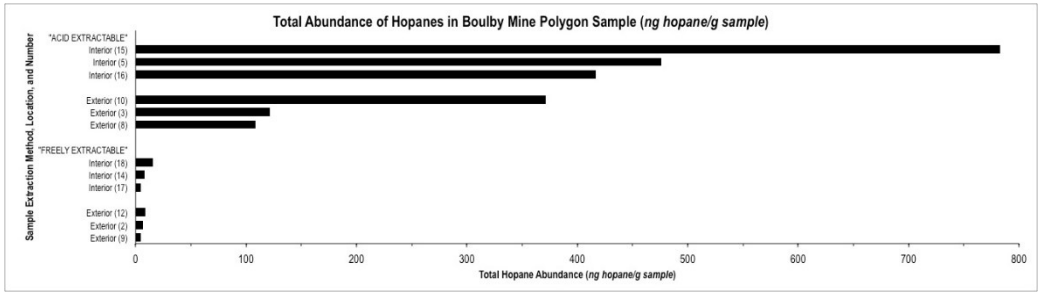
MASE
Mars Analogues for Space Exploration

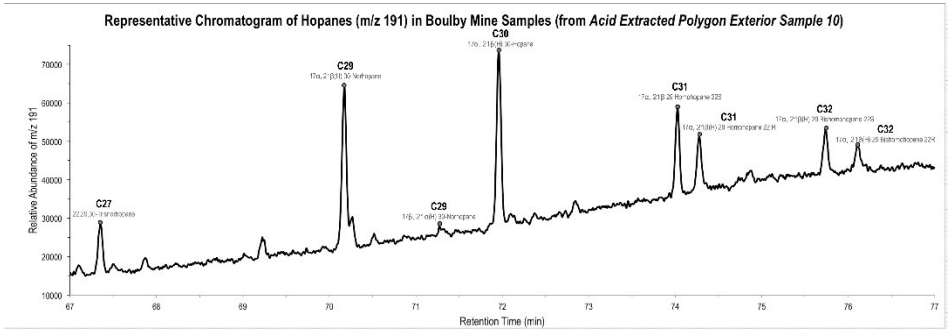
New microbes deposited in International Culture Collections

Use of Boulby to study signatures of life in extreme environments

- Investigations of biosignatures of life in ancient evaporites
- Study of degradation of lipids and other signatures







MINAR: Mine Analogue Research

- Space Exploration and Mining Hand-in-hand

Exploring Space to Help Mining
MINAR: An analogue programme at Boulby Mine

MINAR Objectives

- Test space technologies in a coordinated program
- Test technologies that might be used in mining applications
- Use this technology to search for and study life in the deep subsurface and investigate deep subsurface geology and geophysics

It’s all about collaboration…

- Europe, US, India, China, Africa etc

International Journal of Astrobiology 16 (2): 114–129 (2017)
doi:10.1017/S1473550416000045 © Cambridge University Press 2016

Planetary science and exploration in the deep subsurface: results from the MINAR Program, Boulby Mine, UK

Samuel J. Payler[1], Jennifer F. Biddle[2], Andrew J. Coates[3], Claire R. Cousins[4], Rachel E. Cross[5], David C. Cullen[6], Michael T. Downs[7], Susana O. L. Direito[1], Thomas Edwards[8], Amber L. Gray[9], Jac Genis[8], Matthew Gunn[5], Graeme M. Hansford[10], Patrick Harkness[11], John Holt[10], Jean-Luc Josset[12], Xuan Li[11], David S. Lees[13], Darlene S. S. Lim[13,14], Melissa Mchugh[10], David Mcluckie[8], Emma Meehan[15], Sean M. Paling[15], Audrey Souchon[12], Louise Yeoman[15] and Charles S. Cockell[1]

International Journal of Astrobiology

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Research Article

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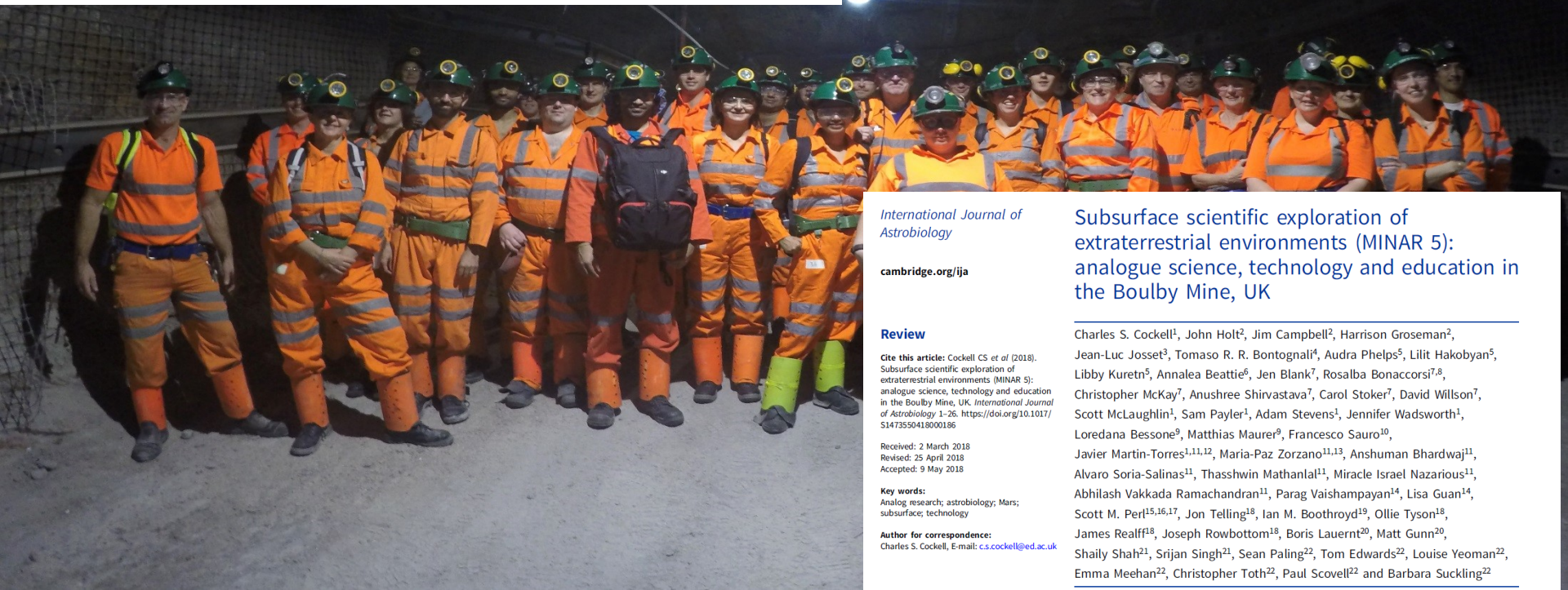
Subsurface robotic exploration for geomorphology, astrobiology and mining during MINAR6 campaign, Boulby Mine, UK: part I (Rover development)

Thasshwin Mathanlal[1], Anshuman Bhardwaj[1], Abhilash Vakkada Ramachandran[1], María-Paz Zorzano[2,1], Javier Martín-Torres[1,3], Charles S. Cockell[4], Sean Paling[5] and Tom Edwards[5]

[1]Group of Atmospheric Science, Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Luleå 97 187, Sweden; [2]Centro de Astrobiología (CSIC-INTA), Torrejon de Ardoz, 28850 Madrid, Spain; [3]Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR), 18100 Granada, Spain; [4]UK Centre of Astrobiology, SUPA, School of Physics and Astronomy, University of Edinburgh, Edinburgh, Midlothian, UK and [5]Boulby Underground Laboratory, Boulby, UK



International Journal of Astrobiology

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Review

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Subsurface scientific exploration of extraterrestrial environments (MINAR 5): analogue science, technology and education in the Boulby Mine, UK

Charles S. Cockell[1], John Holt[2], Jim Campbell[2], Harrison Groseman[2], Jean-Luc Josset[3], Tomaso R. R. Bontognali[4], Audra Phelps[5], Lilit Hakobyan[5], Libby Kuretn[5], Annalea Beattie[6], Jen Blank[7], Rosalba Bonaccorsi[7,8], Christopher McKay[7], Anushree Shirvastava[7], Carol Stoker[7], David Willson[7], Scott McLaughlin[1], Sam Payler[1], Adam Stevens[1], Jennifer Wadsworth[1], Loredana Bessone[9], Matthias Maurer[9], Francesco Sauro[10], Javier Martin-Torres[1,11,12], Maria-Paz Zorzano[11,13], Anshuman Bhardwaj[11], Alvaro Soria-Salinas[11], Thasshwin Mathanlal[11], Miracle Israel Nazarious[11], Abhilash Vakkada Ramachandran[11], Parag Vaishampayan[14], Lisa Guan[14], Scott M. Perl[15,16,17], Jon Telling[18], Ian M. Boothroyd[19], Ollie Tyson[18], James Realff[18], Joseph Rowbottom[18], Boris Lauernt[20], Matt Gunn[20], Shaily Shah[21], Srijan Singh[21], Sean Paling[22], Tom Edwards[22], Louise Yeoman[22], Emma Meehan[22], Christopher Toth[22], Paul Scovell[22] and Barbara Suckling[22]

A rover for mining and planetary exploration

- Sniffing gas and 3D mapping

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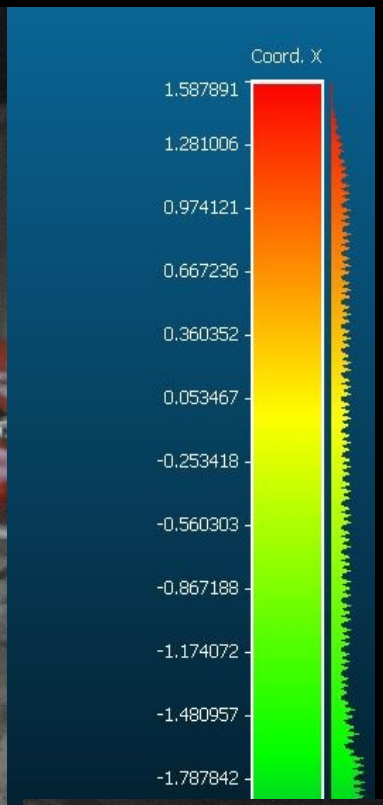
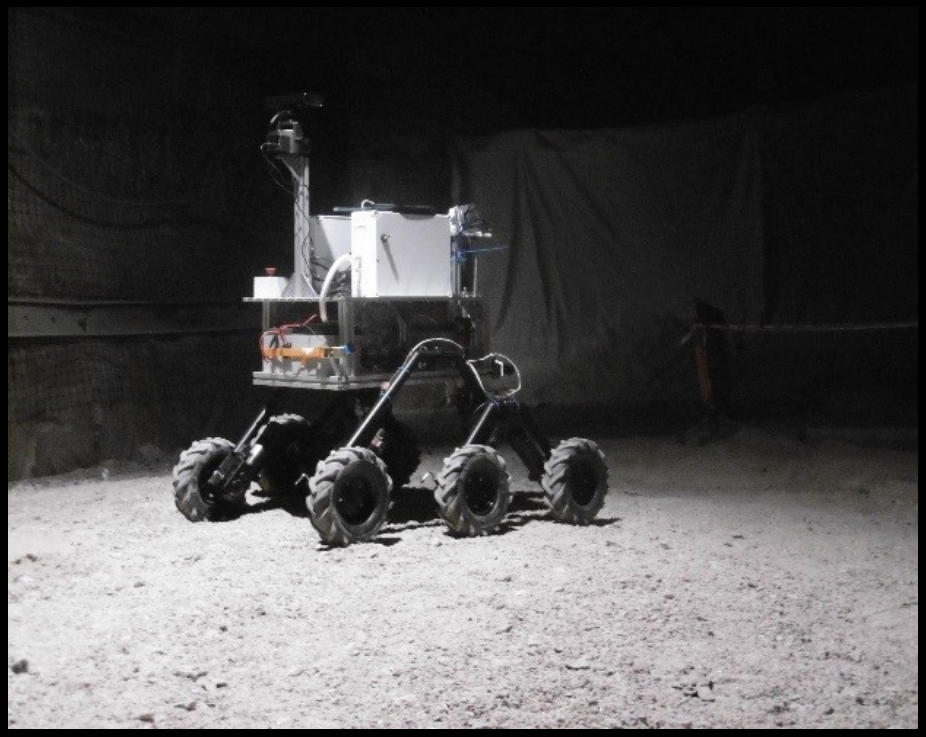


A rover for mining and planetary exploration

- Deploying sensor arrays into extreme habitats



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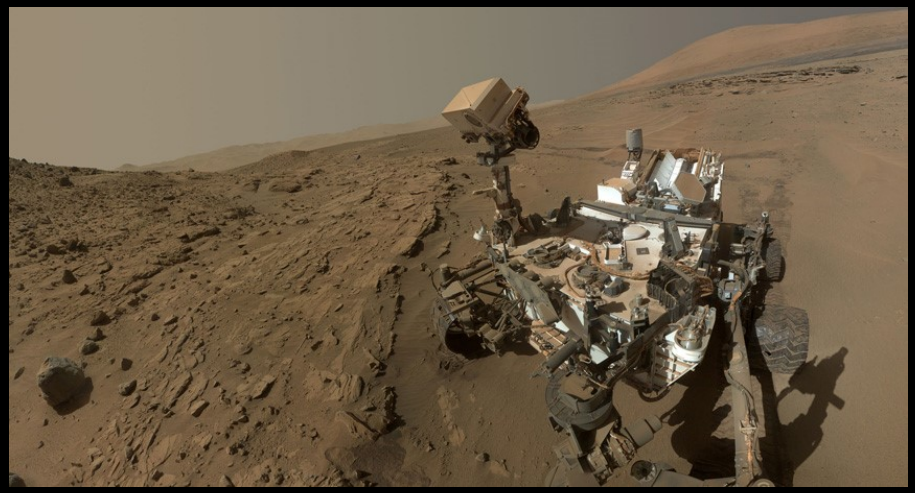
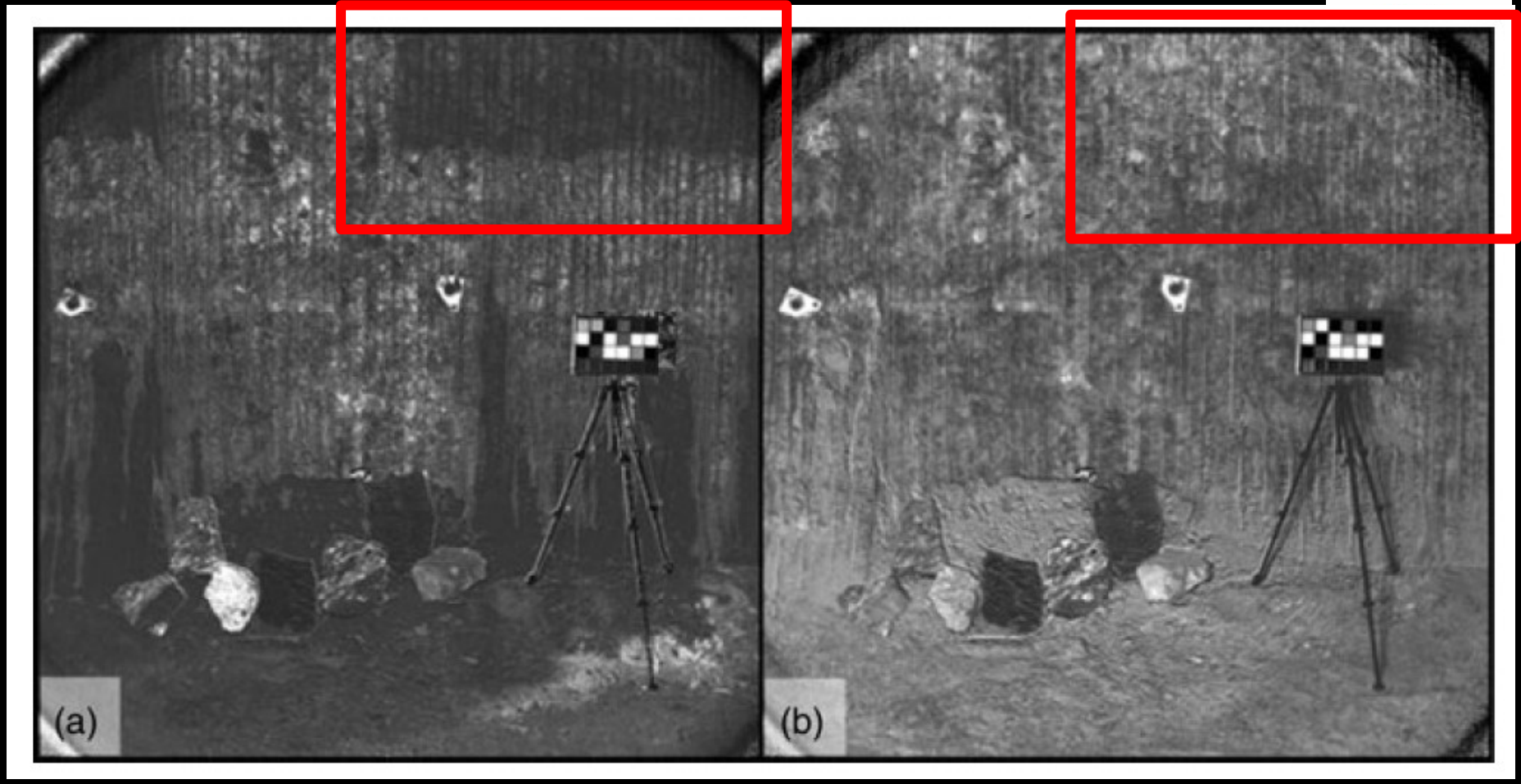
Robotic geologist's hammer….

UNIVERSITY OF LEICESTER



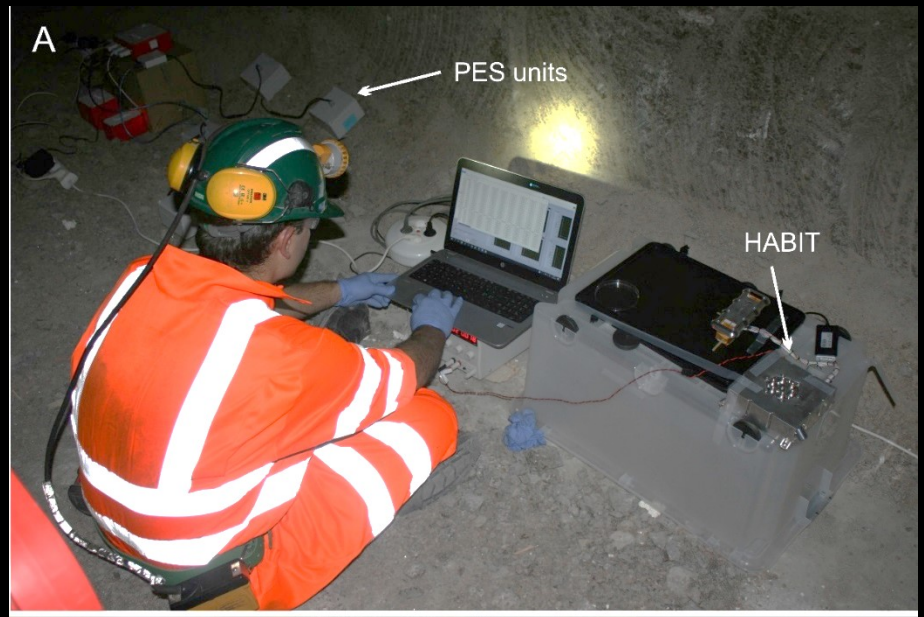
Cameras for mapping Mars

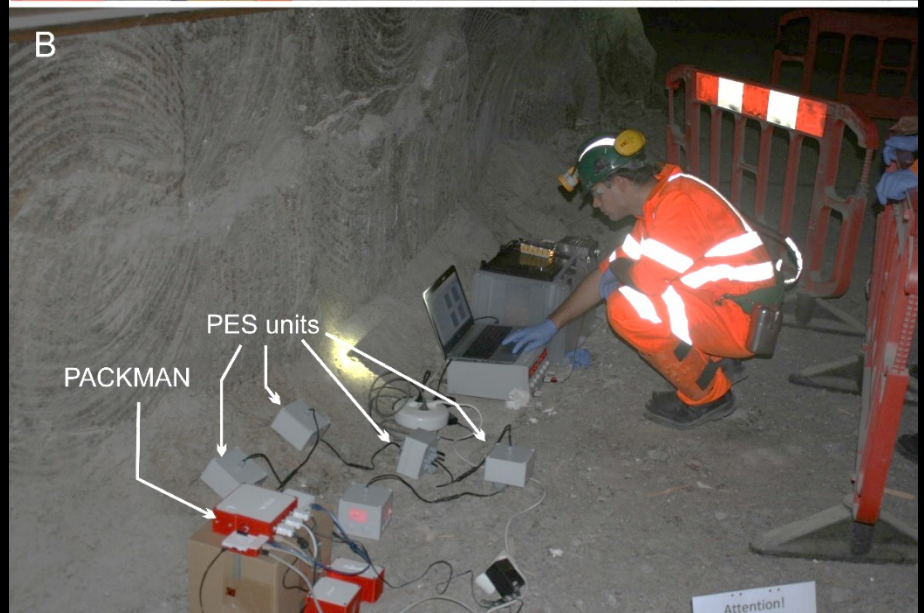


Application to economic mining – ‘seeing through the salt’

Environmental monitoring networks underground and on other planets

- To measure radiation, temperature, pressure etc underground





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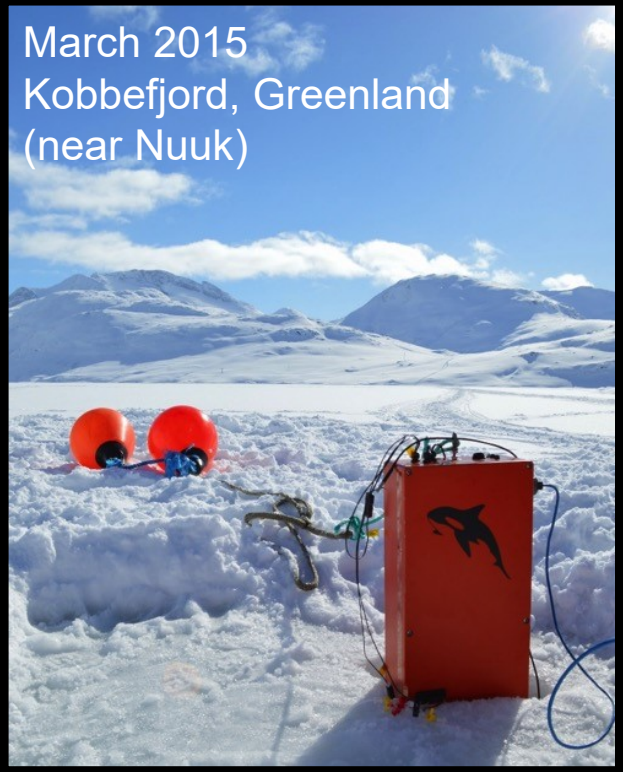
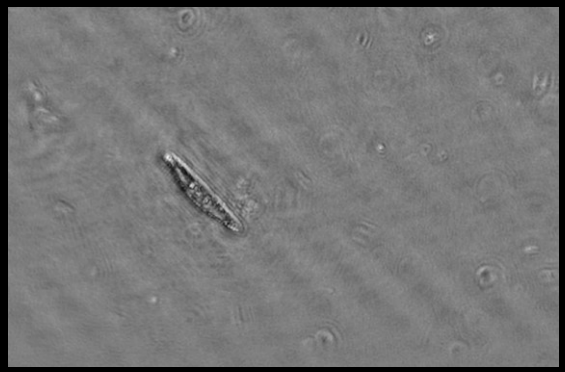
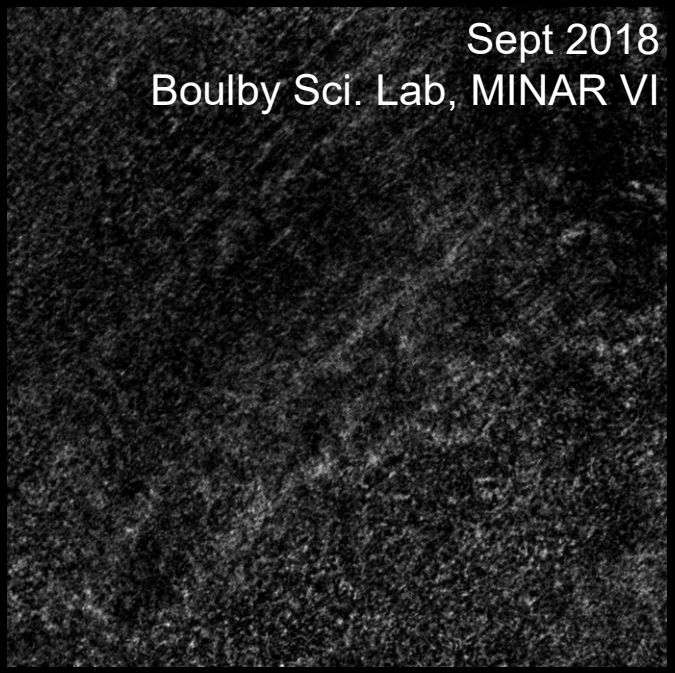
Holographic Microscopy for Life Detection

Chris Lindensmith[1], Eugene Serabyn[1], Manuel Bedrossian[2], Scott Perl[1], Stephanie Rider[2], Kurt Liewer[2], Jay Nadeau[3]
[1]Jet Propulsion Laboratory, California Institute of Technology, [2]GALCIT, California Institute of Technology, [3]Portland State University



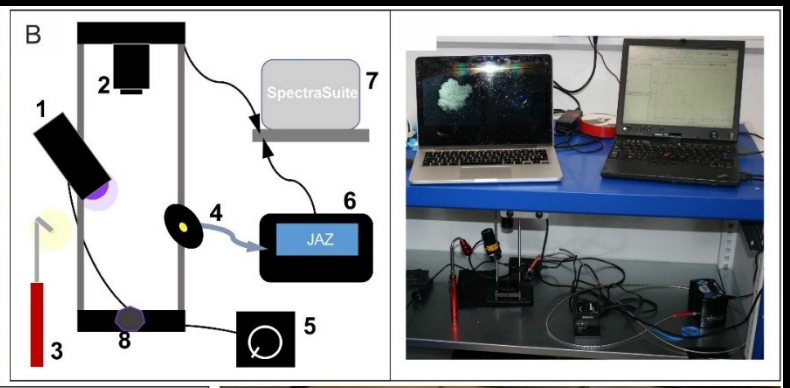


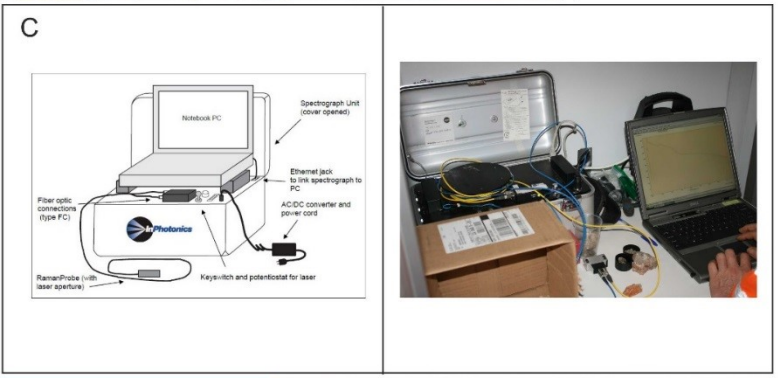
Brine pool (Death Valley)

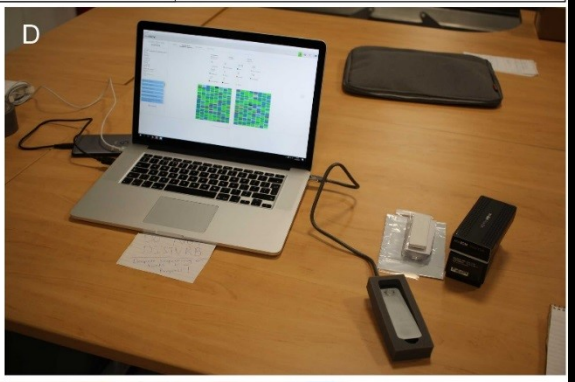


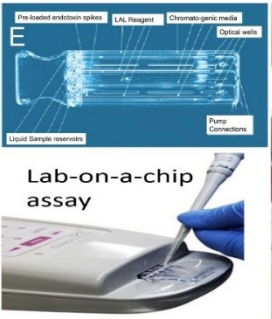
Hypothesis: **active microbes are an inherent feature of natural aquatic habitats, even extreme (subzero) ones**. Not all inhabitants may rely upon movement to complete their life histories, but some fraction of the community will have evolved the ability to achieve directed motion via swimming or gliding

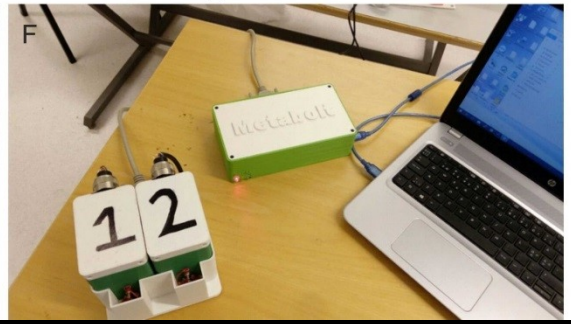
Instruments, instruments and more instruments!….



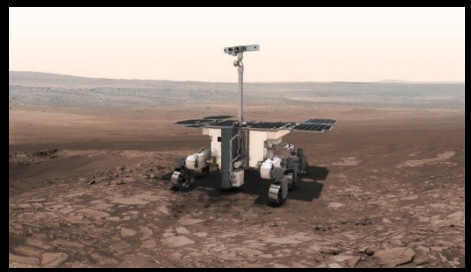




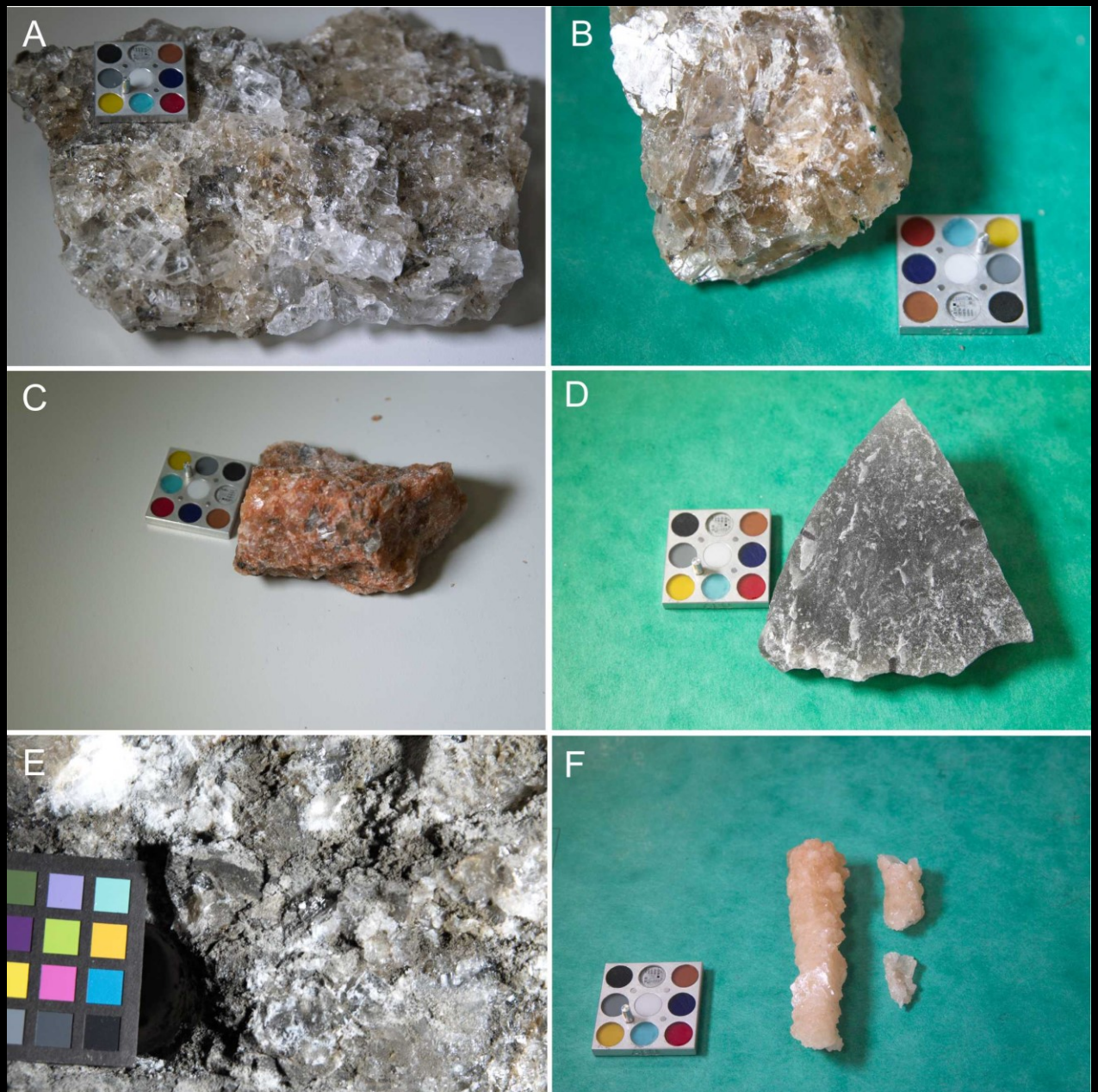




Raman spectroscopy
Close-up imager
Panoramic camera
HABIT instrument
….all going to Mars!



Boulby Mine – a huge showcase of planetary minerals…



Astronaut training in Boulby

Learning sample collection in Boulby…

Advancing the Indian Space Program at Boulby

- Testing rovers
- Advancing education

KALAM CENTRE
towards sustainable development

DR. A.P.J. ABDUL KALAM TECHNICAL UNIVERSITY, UTTAR PRADESH
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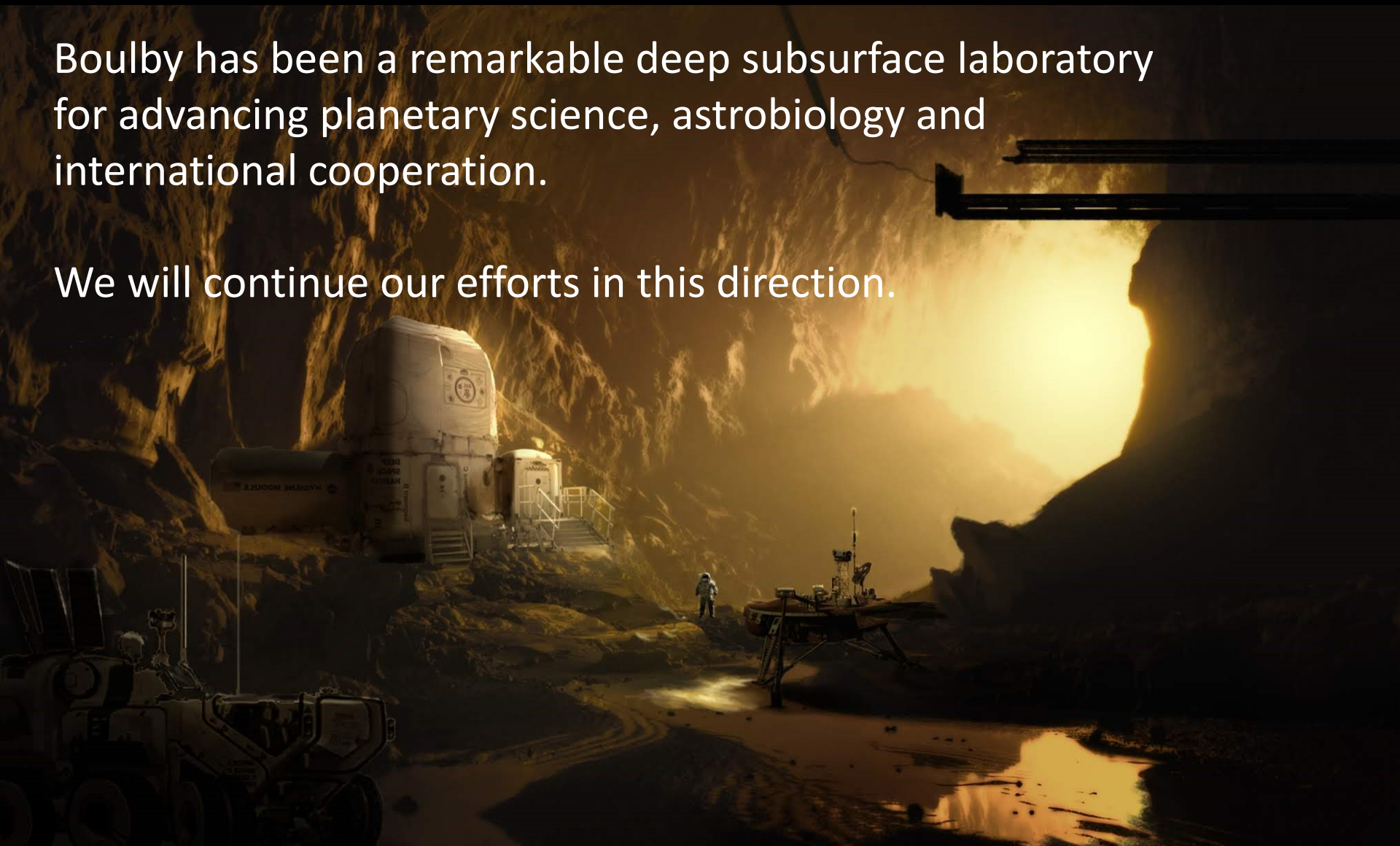
The future…



Boulby has been a remarkable deep subsurface laboratory for advancing planetary science, astrobiology and international cooperation.

We will continue our efforts in this direction.