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AEGORA

INTRODUCCIÓN A LA EXPLORACIÓN ESPACIAL Y SU UTILIZACIÓN

Lección 12. Meteoritos, Luna y minería espacial – Valentín García Baonza

Cráter Barringer (Arizona)

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PROGRAMA:

Parte I: Contexto general

- Recursos minerales en el espacio.
- Meteoritos y cráteres de impacto.
- Ejemplos de fenómenos de impacto.

Parte II: Instrumentación: diagnóstico, análisis y simulación

- Estudios en tierra
- Misiones espaciales

Parte III: Debate y perspectivas

Recursos minerales en el espacio cercano

El espacio cercano (la Luna, asteroides y otros cuerpos celestes), contiene una variedad de recursos minerales que podrían ser de interés para la exploración y la minería espacial. Algunos de los recursos más importantes incluyen:

- **Agua** (soporte para la vida, producción de oxígeno e hidrógeno para propulsión)

- **Elementos (**He-3**), metales preciosos** (Au, Pt y Pd) **y más básicos** (Fe, Ni, Co, Si, Al). **Regolito Lunar**: capa superficial de polvo y rocas en la Luna, contiene una mezcla de minerales que podrían ser extraídos y procesados para obtener diversos recursos.

- **Carbono y Compuestos Orgánicos**: Algunos asteroides contienen carbono y compuestos orgánicos, de gran importancia astrobiológica.

- **Recursos Volátiles**: amoníaco, metano y dióxido de carbono, que podrían ser utilizados en la fabricación y producción de combustibles.

Recursos minerales y misiones espaciales

Misiones más relevantes:

- Asteroides: OSIRIS-Rex (NASA, Bennu), Hayabusa2 (JAXA, Ryugu)
- Lunares: Artemis (NASA), Chang’e (CSNA)

Requerimientos:

- Sistemas de Propulsión, Navegación y Control, Robótica, Comunicaciones, Extracción, Separación, Procesamiento y Recolección de muestras (contenedores sellados para preservar las muestras durante el retorno a la Tierra), etc.
- Tecnologías Energéticas (almacenamiento y suministro) , Soporte (humanos o robóticos), Reciclaje y/o Reutilización, Defensa y mitigación (e.g. colisión de asteroides), etc.
- **Instrumentación**: espectrómetros, cámaras de alta resolución para la cartografía y navegación, etc.

Meteoritos y cráteres de impacto

- Los meteoritos son fragmentos cuerpos celestes que han llegado a la Tierra (a otros planetas o lunas) después de ser expulsados de su cuerpo de origen.
- El estudio de meteoritos generalmente **se realiza en la Tierra**, después de su impacto, y no directamente en el espacio.

CNEOS is NASA's center for computing asteroid and comet orbits and their odds of Earth impact.

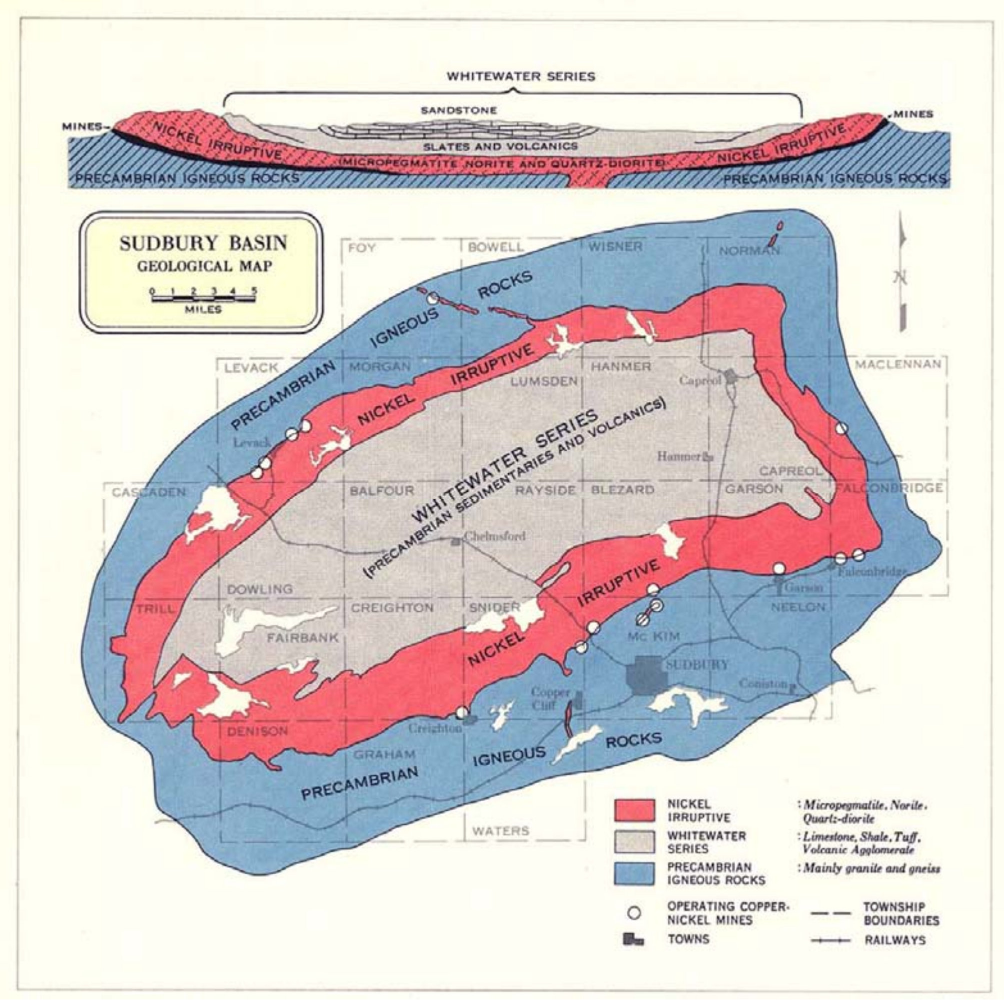
https://cneos.jpl.nasa.gov/

Meteoritos y cráteres de impacto

http://passc.net/EarthImpactDatabase/New%20website_05-2018/Index.html

Cráteres de impacto:
- Análogos para otras superficies planetarias.
- Ayudan a comprender la naturaleza y la escala del riesgo de un impacto (y a mitigarlo).
- Ayunad a comprender el proceso de formación de nuestro planeta y del sistema solar.
- Cuantificar los flujos de energía pasados y presentes en los entornos planetarios.
- Localizar recursos (tanto en la Tierra como fuera de ella).

Meteoritos y cráteres de impacto



Los cráteres de impacto han desempeñado un papel crucial en la exploración geofísica de: petróleo, gas, carbón, elementos de tierras raras, cobre, níquel, bario, zinc, hierro, plata, oro, platino y agua.

Por ejemplo, el cráter Sudbury (Ontario, CA) es una de las principales fuentes actuales de Ni del planeta.

Cono de fragmentación de una impactita de Sudbury.
(Museo de Historia Natural, Cleveland)

Meteoritos y cráteres de impacto

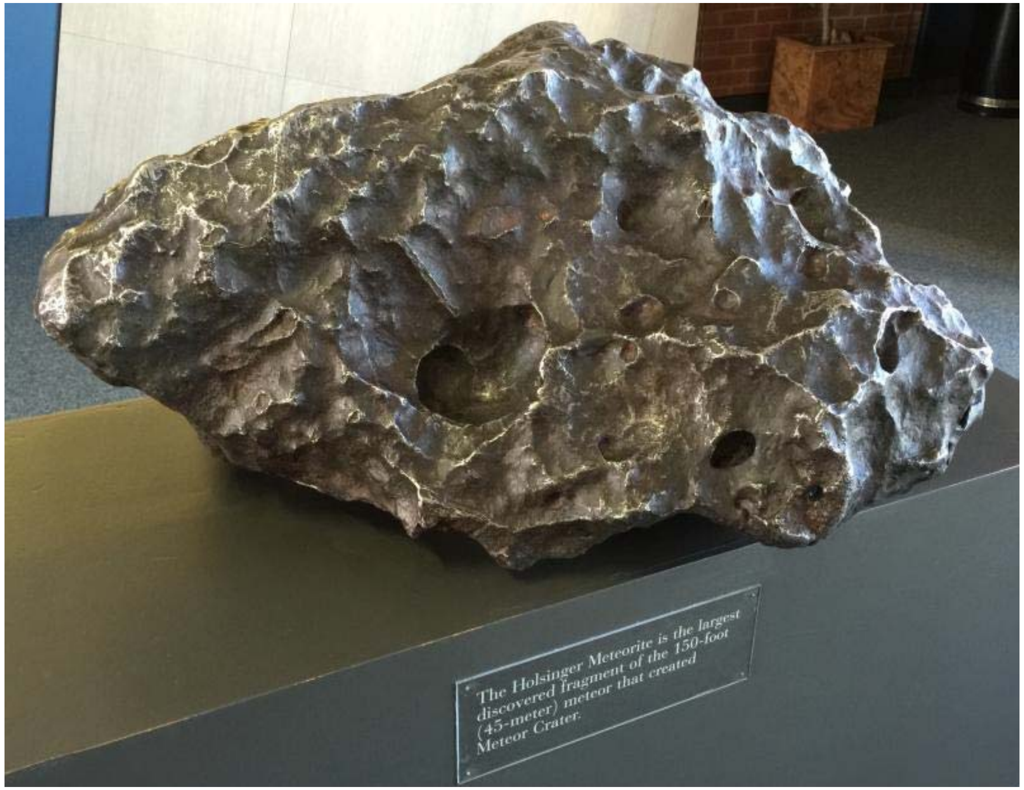
Barringer Impact Crater, Arizona

~1.2 km diameter, exposed, nearly pristine condition
49,000 (±3000) years old, simple crater, sub-aerial at time of formation
35° 01′ 39″ N. Latitude, 111° 01′ 20″ W. Longitude; Coconino County, Arizona, USA
Facts from: Kring, 2007, and references therein; Google Earth.

El cráter Barringer se formó por el impacto de un pequeño asteroide, cuyos restos se conocen como meteorito Canyon Diablo, un meteorito de Fe y Ni (Tipo IAB-MG).

El mayor fragmento del impactador hallado hasta la fecha es el meteorito Holsinger, que pesa unos 639 kg.

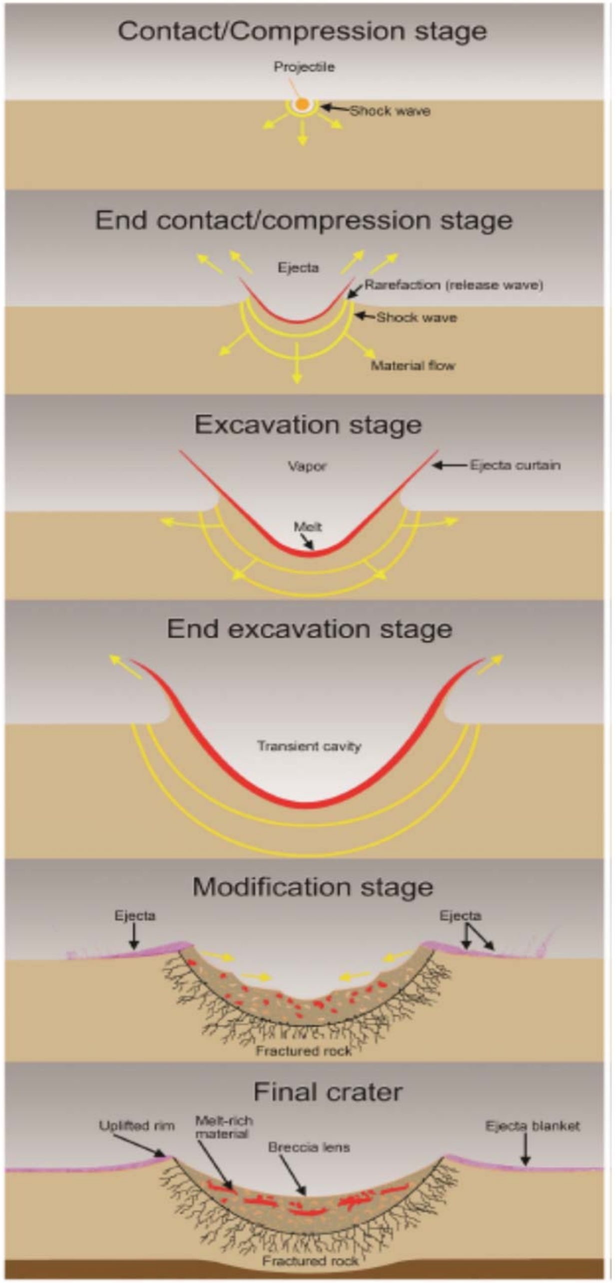
https://impactcraters.us/barringer_arizona

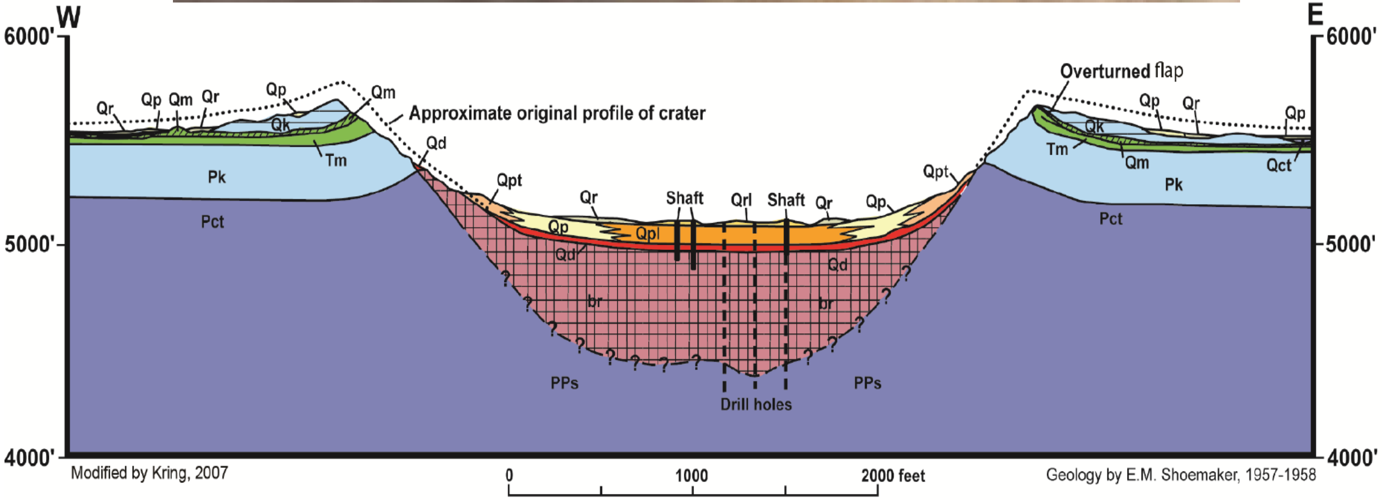


COLLEGE OF SCIENCE
LUNAR & PLANETARY LABORATORY

https://www.lpl.arizona.edu/

Meteoritos y cráteres de impacto

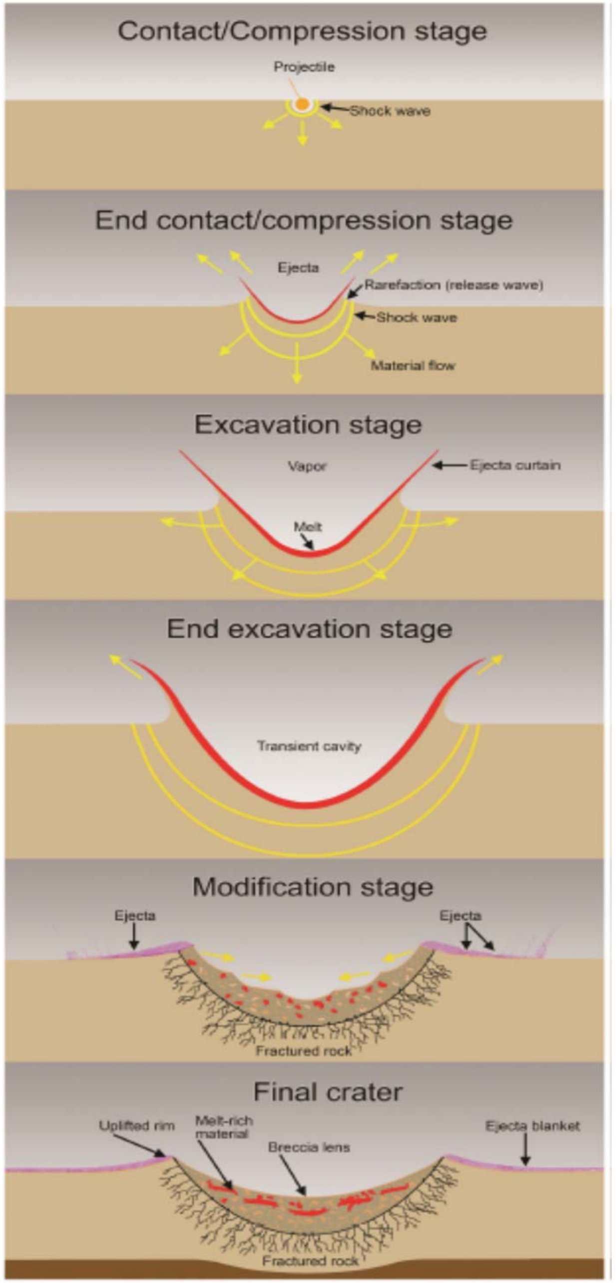


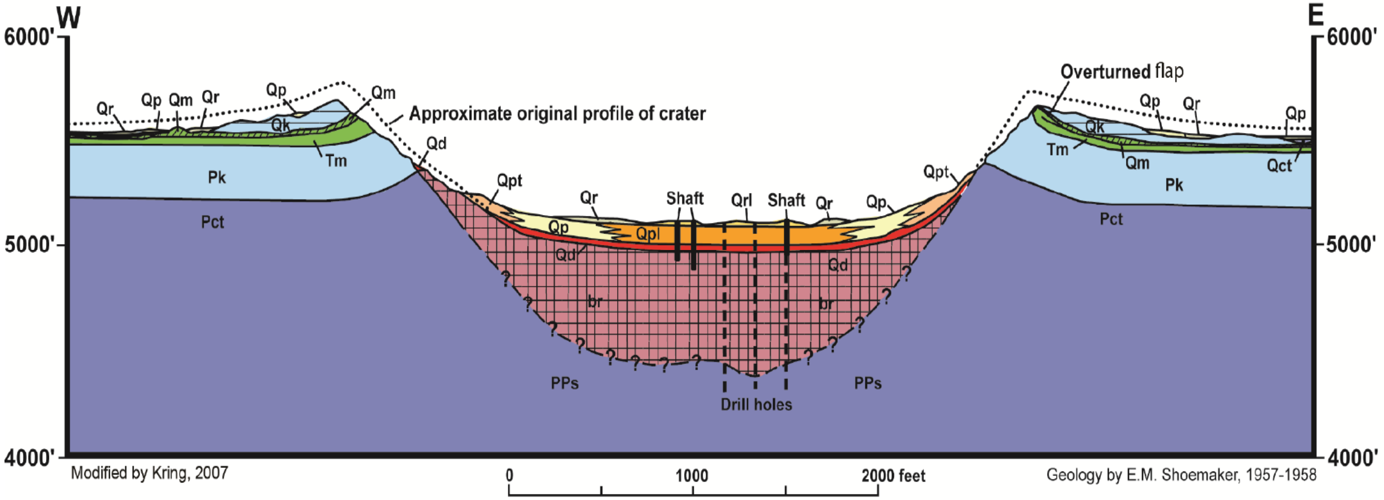


Modified by Kring, 2007

Geology by E.M. Shoemaker, 1957-1958

Meteoritos y cráteres de impacto

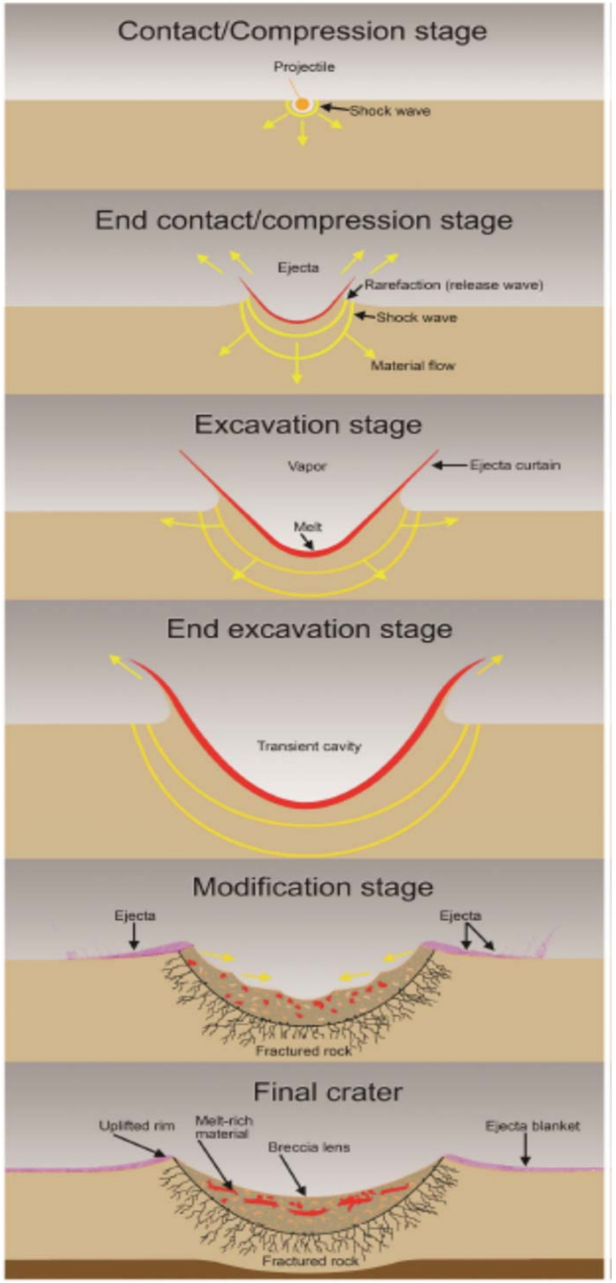


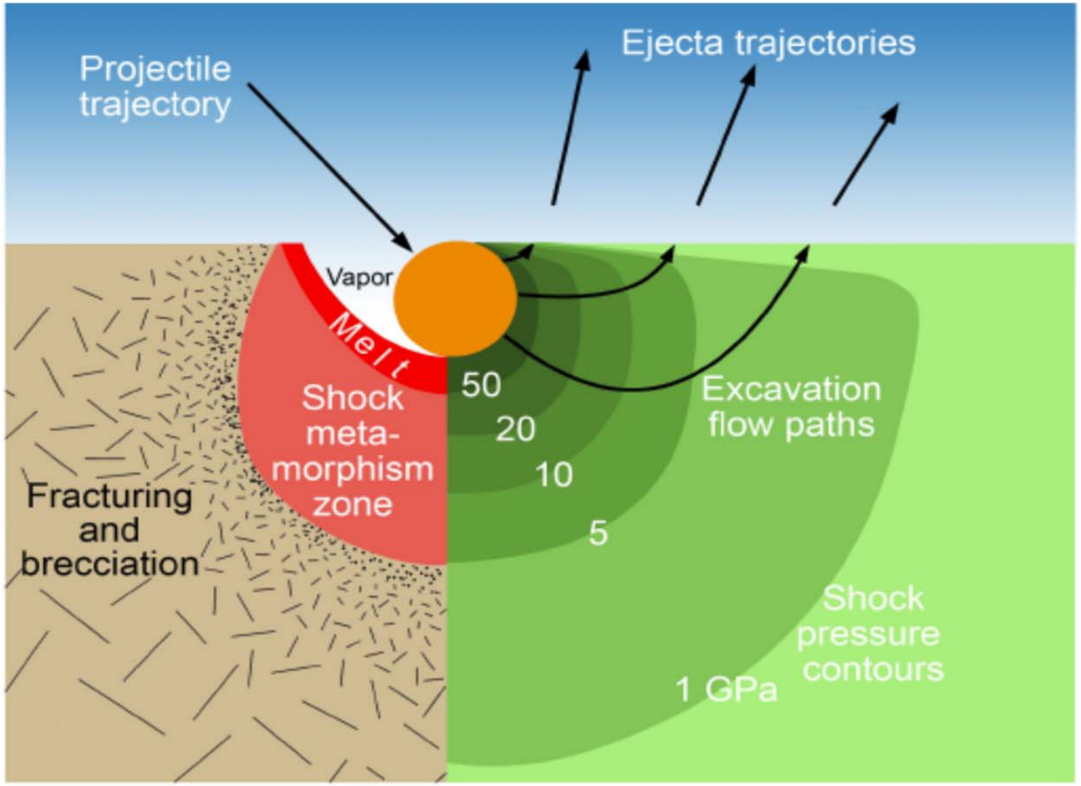


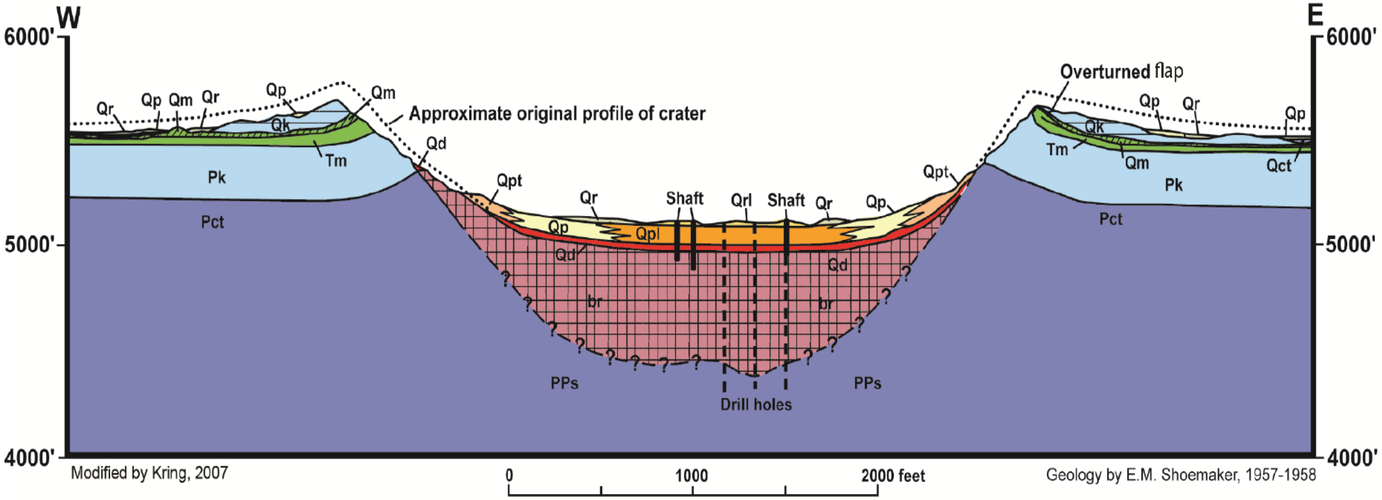
Modified by Kring, 2007

Geology by E.M. Shoemaker, 1957-1958

Meteoritos y cráteres de impacto





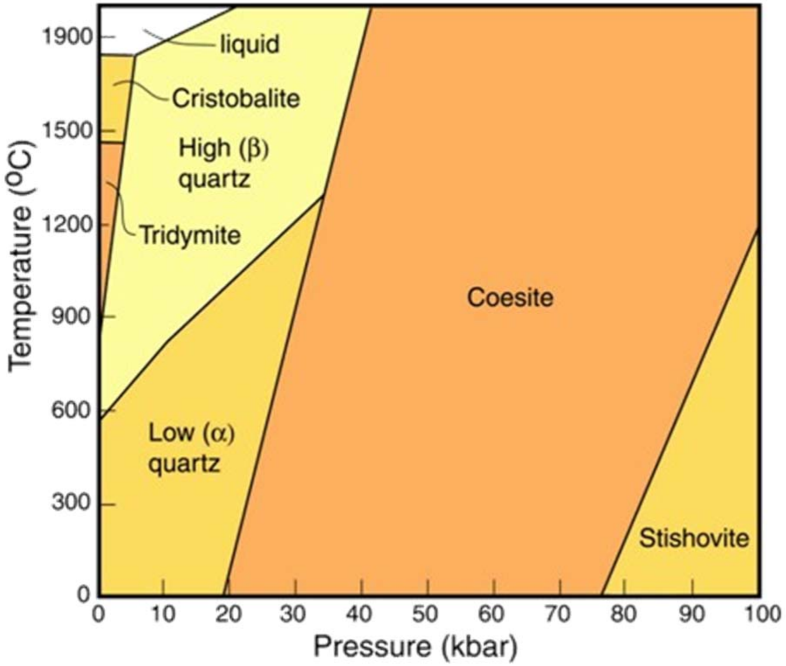


Modified by Kring, 2007

Geology by E.M. Shoemaker, 1957-1958

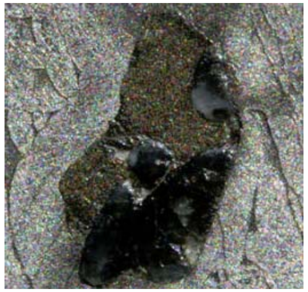
Meteoritos y cráteres de impacto

Barringer Impact Crater, Arizona



Lorin Coes sintetizó en 1953 una nueva fase del SiO_2 a alta presión, denominada **cohesita**, que se encontró en 1960 en el cráter Barringer (Chao et al., First natural occurrence of coesite. Science, 132, 220-222).

Dos años más tarde, se encontró la fase **stishovita** (Chao et al., Stishovite, SiO_2, a very high pressure new mineral from Meteor crater, Arizona. J Geophys. Res., 67, 419-421.



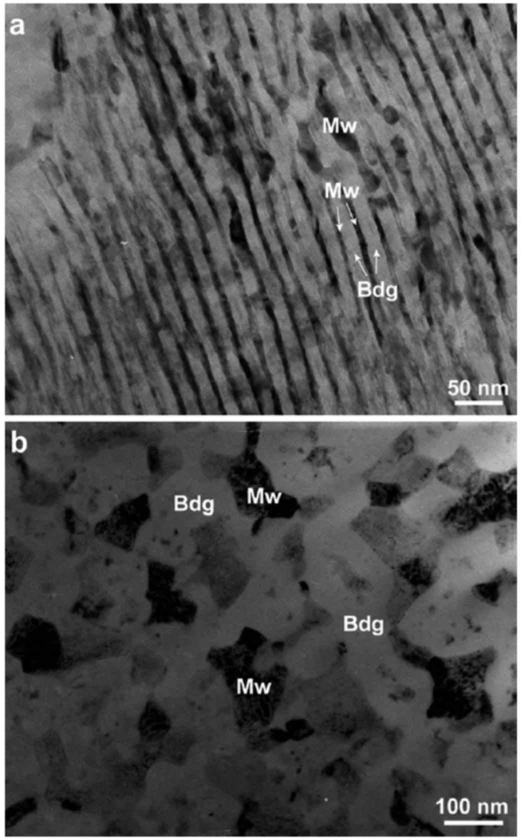
Fenómenos de impacto

The Meteoritical Society

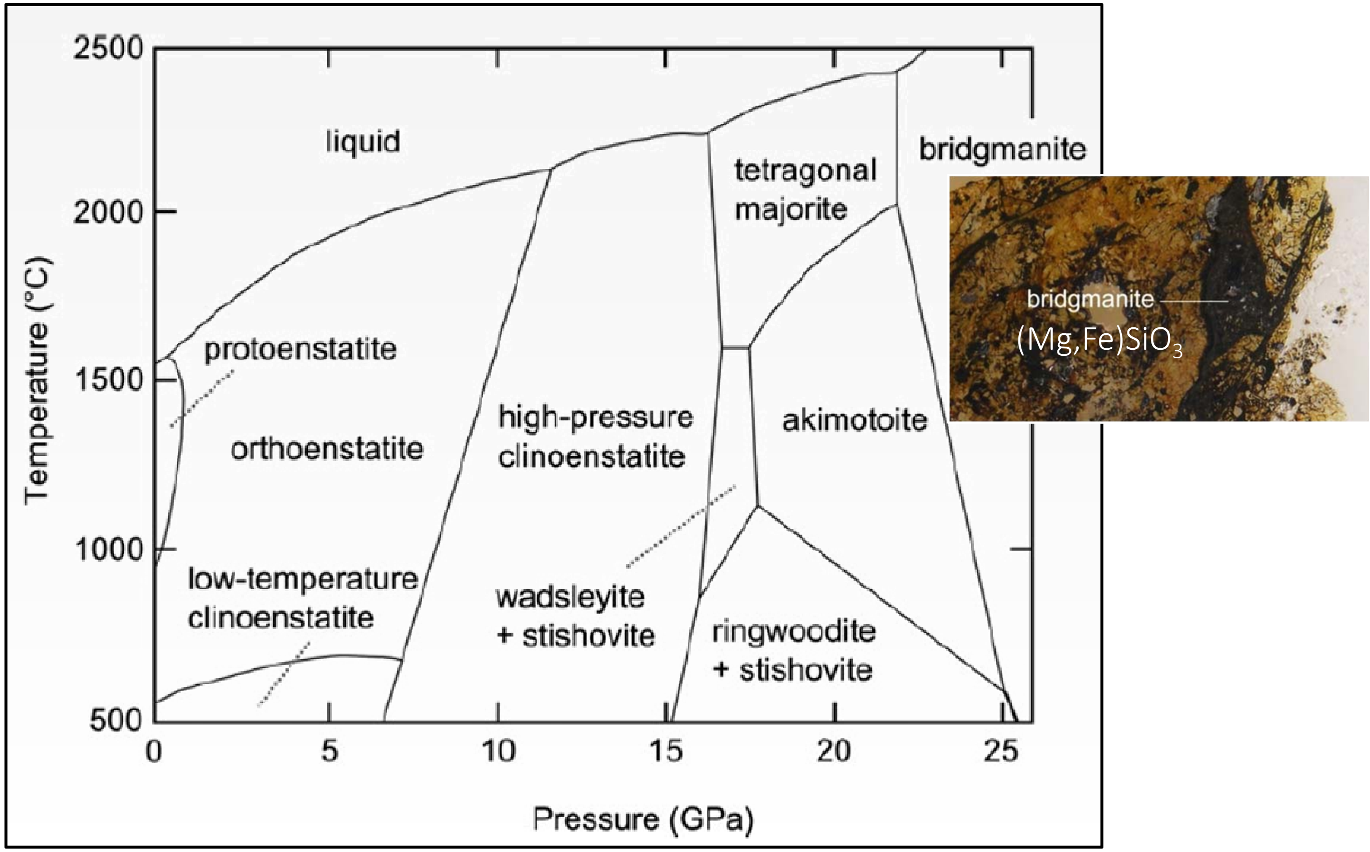
Meteoritics & Planetary Science 52, Nr 9, 2017–2039 (2017)
doi: 10.1111/maps.12902

High-pressure minerals in shocked meteorites

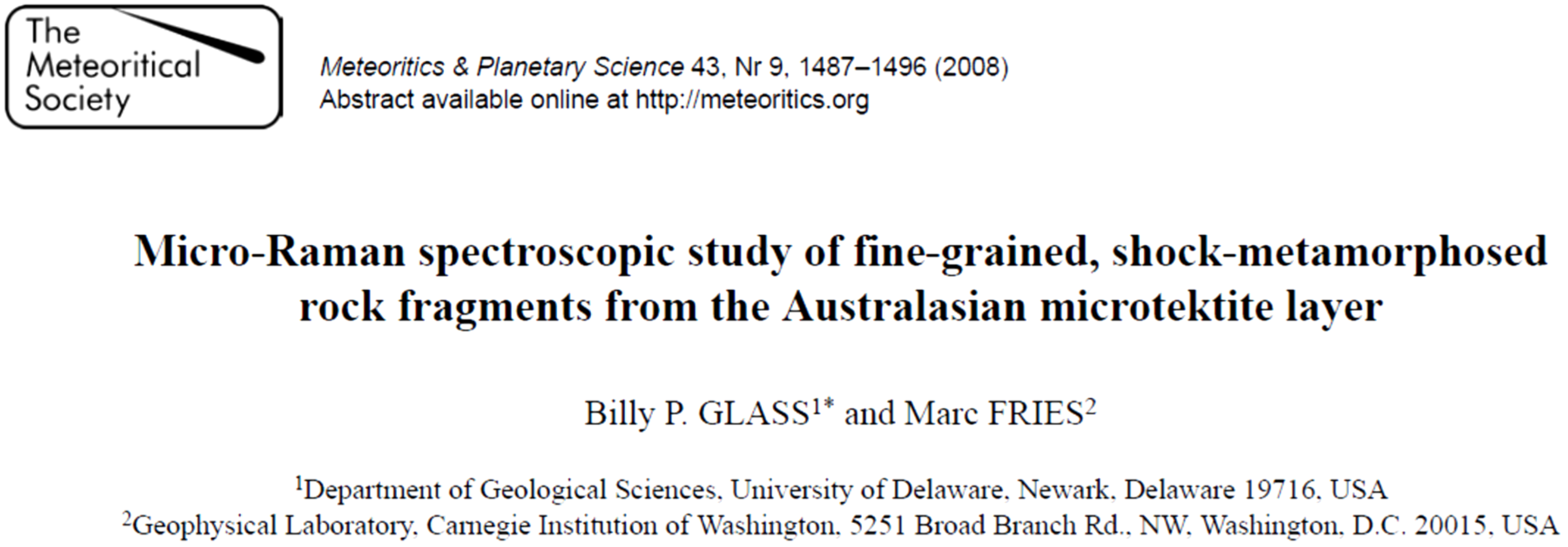
Naotaka TOMIOKA[1,*] and Masaaki MIYAHARA[2]



HIGH-PRESSURE POLYMORPHS OF PYROXENE



Fenómenos de impacto



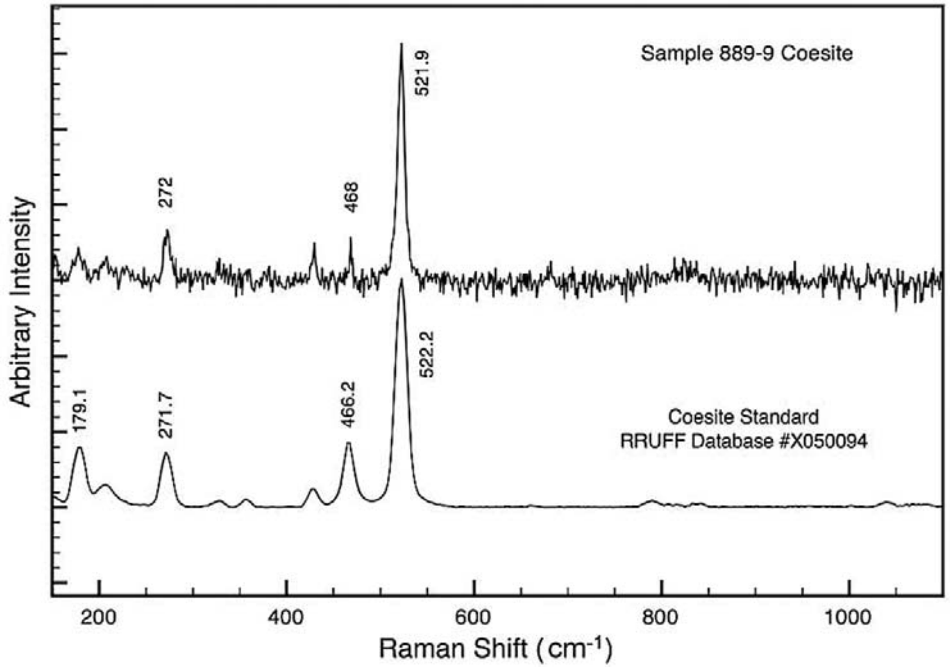
The Meteoritical Society

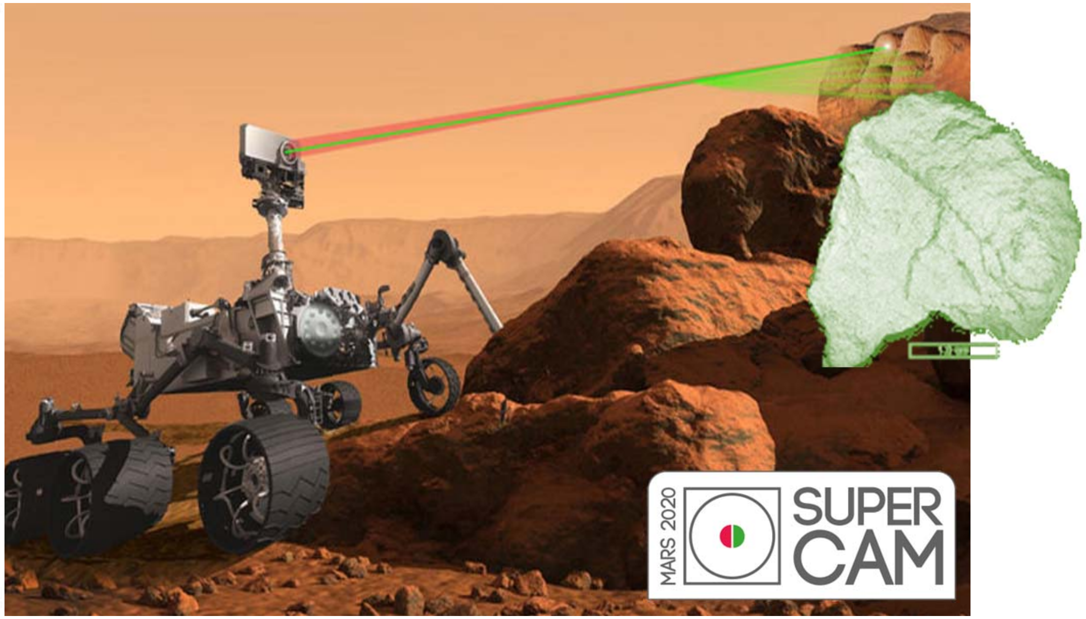
Meteoritics & Planetary Science 43, Nr 9, 1487–1496 (2008)
Abstract available online at http://meteoritics.org

Micro-Raman spectroscopic study of fine-grained, shock-metamorphosed rock fragments from the Australasian microtektite layer

Billy P. GLASS[1]* and Marc FRIES[2]

[1]Department of Geological Sciences, University of Delaware, Newark, Delaware 19716, USA
[2]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd., NW, Washington, D.C. 20015, USA





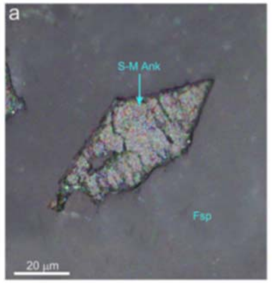
Fenómenos de impacto

Natural diamond formation by self-redox of ferromagnesian carbonate

Ming Chen[a,b,1], **Jinfu Shu**[c], **Xiande Xie**[b,d], **Dayong Tan**[b,d], **and Ho-kwang Mao**[c,e,1]

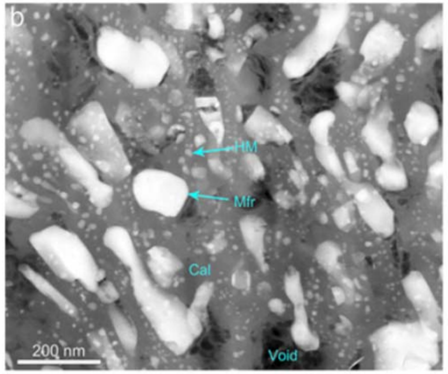
[a]State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 510640 Guangzhou, China; [b]Key Laboratory of Mineralogy and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 510640 Guangzhou, China; [c]Center for High Pressure Science and Technology Advanced Research, 201203 Shanghai, China; [d]Guangdong Provincial Key Laboratory of Mineral Physics and Materials, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 510640 Guangzhou, China; and [e]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015

Contributed by Ho-kwang Mao, January 31, 2018 (sent for review November 28, 2017; reviewed by Eglantine Boulard and Alexander V. Soldatov)



Formation of natural diamonds requires the reduction of carbon to its bare elemental form, and pressures (*P*) greater than 5 GPa to cross the graphite–diamond transition boundary. In a study of shocked ferromagnesian carbonate at the Xiuyan impact crater, we found that the impact pressure–temperature (*P-T*) of 25–45 GPa and 800–900 °C were sufficient to decompose ankerite $Ca(Fe^{2+},Mg)(CO_3)_2$ to form diamond in the absence of another reductant. The carbonate self-reduced to diamond by concurrent oxidation of Fe^{2+} to Fe^{3+} to form a high-*P* polymorph of magnesioferrite, $MgFe^{3+}{}_2O_4$. Discovery of the subsolidus carbonate self-reduction mechanism indicates that diamonds could be ubiquitously present as a dominant host for carbon in the Earth's lower mantle.

diamond | self-redox | ferromagnesium carbonate | shock-metamorphism | lower mantle



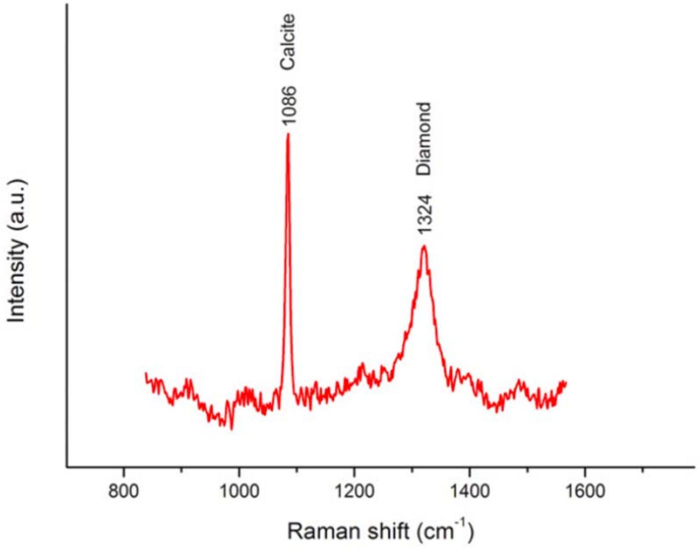


Fig. 2. Raman spectrum (laser 638 nm) of diamond from shock-metamorphic ankerite. The broadened peak around 1,324 cm^{-1} is attributed to ultratiny crystallites of diamond. The peak at 1,086 is assigned to calcite.

$$6\left(Fe_{2/3}Mg_{1/3}\right)^{2+}CO_3 \rightarrow 2MgFe_2^{3+}O_4 + C(\text{diamond}) + 5CO_2$$

Fenómenos de impacto

Article

Moon-forming impactor as a source of Earth's basal mantle anomalies

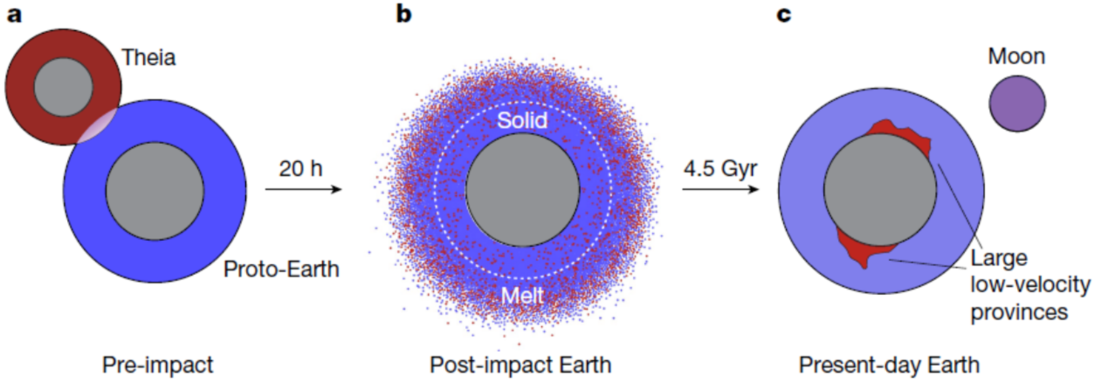
Nature | Vol 623 | 2 November 2023 | **95**

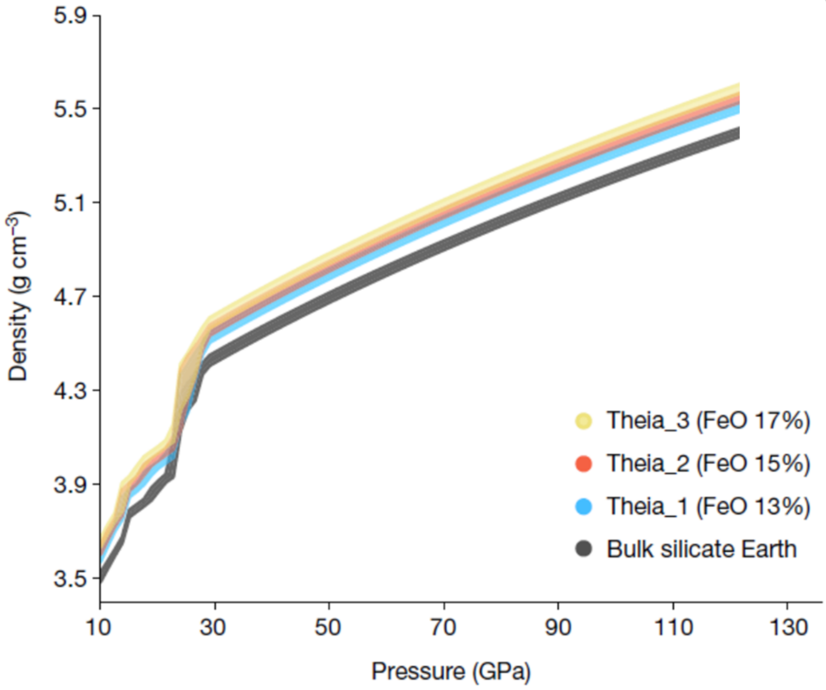
https://doi.org/10.1038/s41586-023-06589-1

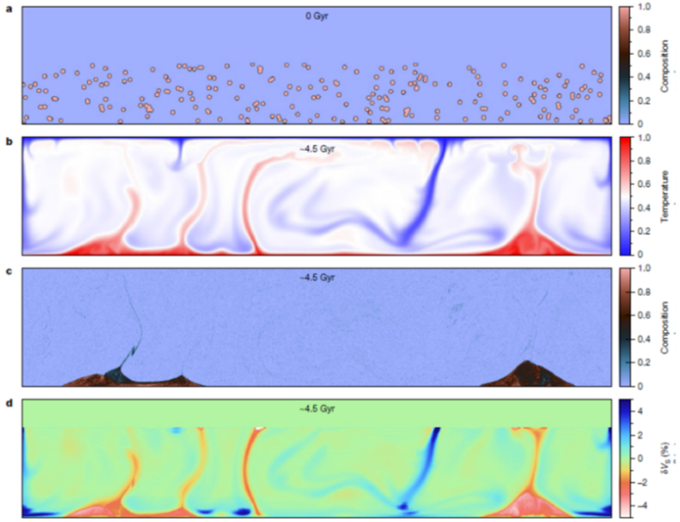
Received: 4 February 2022

Accepted: 30 August 2023

Qian Yuan[1,2]✉, Mingming Li[1], Steven J. Desch[1], Byeongkwan Ko[1,3], Hongping Deng[4], Edward J. Garnero[1], Travis S. J. Gabriel[5], Jacob A. Kegerreis[6], Yoshinori Miyazaki[2], Vincent Eke[7] & Paul D. Asimow[2]







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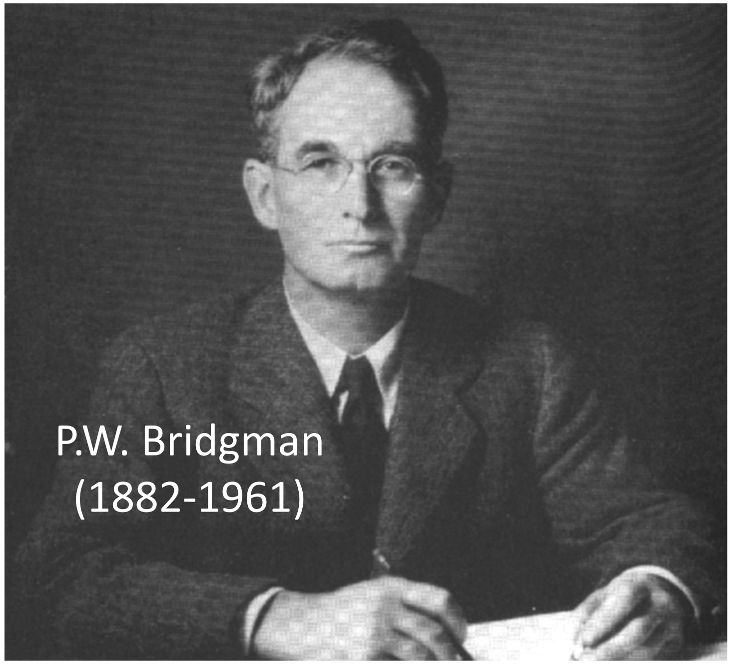
Instrumentación: técnicas de diagnóstico, análisis y simulación (tierra)

El legado de Percy W. Bridgman



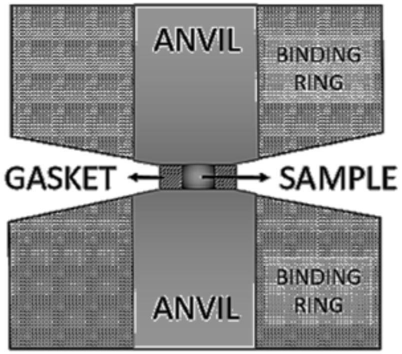
Nobel Prize in Physics (1946)

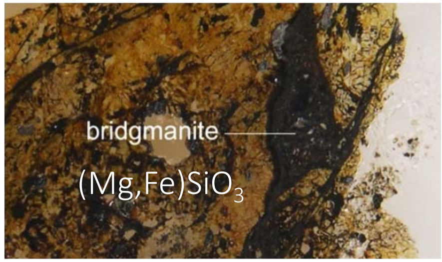
Scientist Makes Miniature Earthquake

Aur 11/29/35

(Picture from International News Photogra

Reproducing the gigantic strains which result in earthquakes within the earth. Prof





"...It is well known that under ordinary conditions water is abnormal in many respects. The effect of high pressure is to wipe out this abnormality..."
Proc. Am. Acad. Arts Sci. **48**, 309 (1911).

"...If the white of an egg is subjected to hydrostatic pressure at room temperature, it becomes coagulated, presenting an appearance much like that of a hard boiled egg... The effect of temperature, which is not large, seems to be such that the ease of coagulation increases at low temperatures, contrary to what one might expect..."
J. Biol. Chem. **19**, 51 (1914).

La celda de yunques de diamante (Diamond Anvil Cell)

Alvin van Valkenburg
(NBS, 1958)

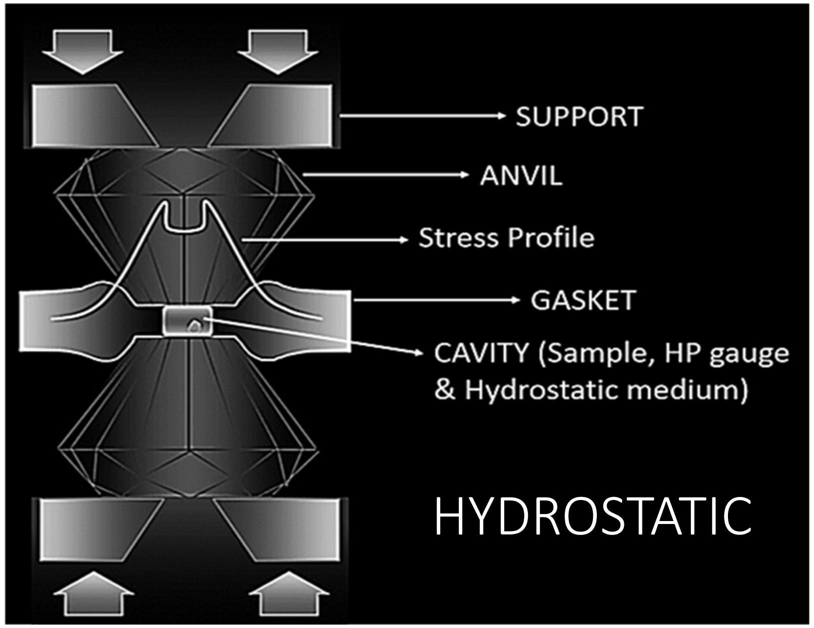
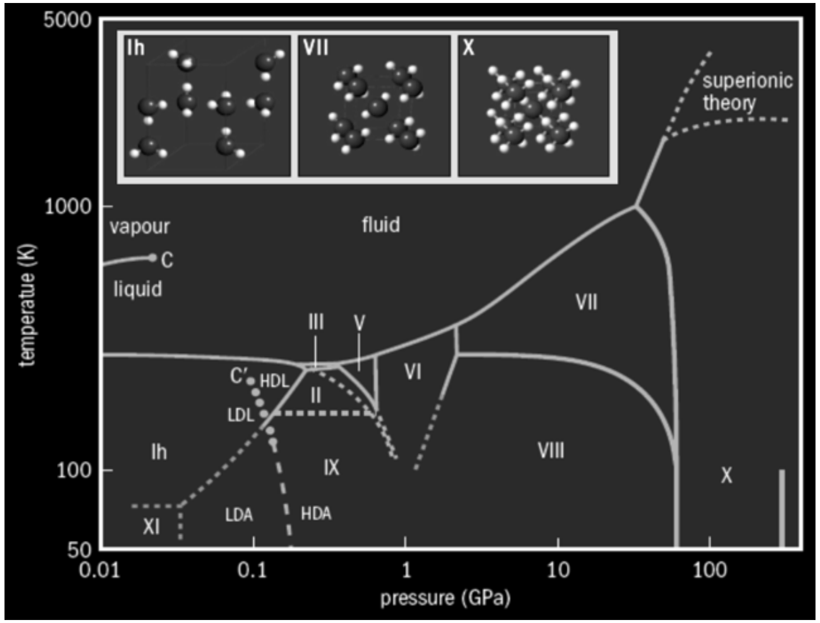


Diagrama de Fases del H_2O



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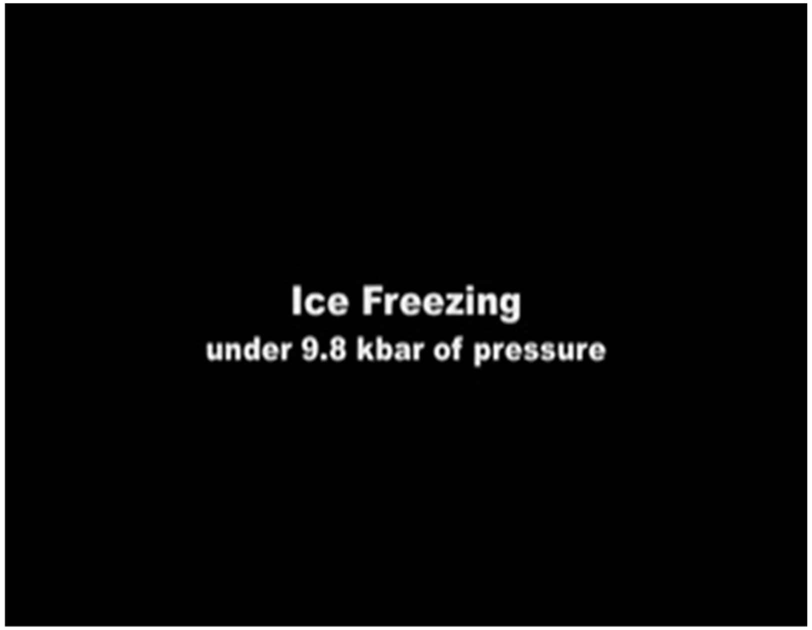
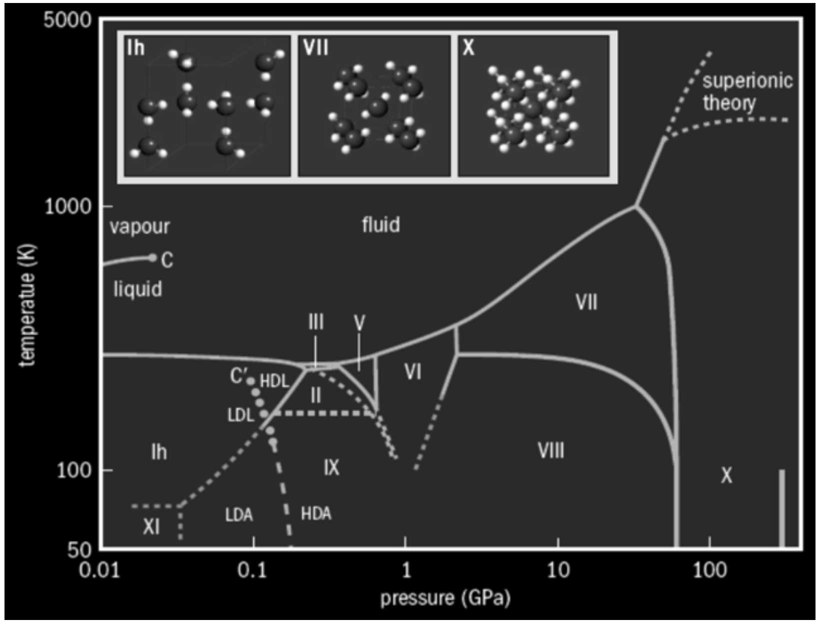
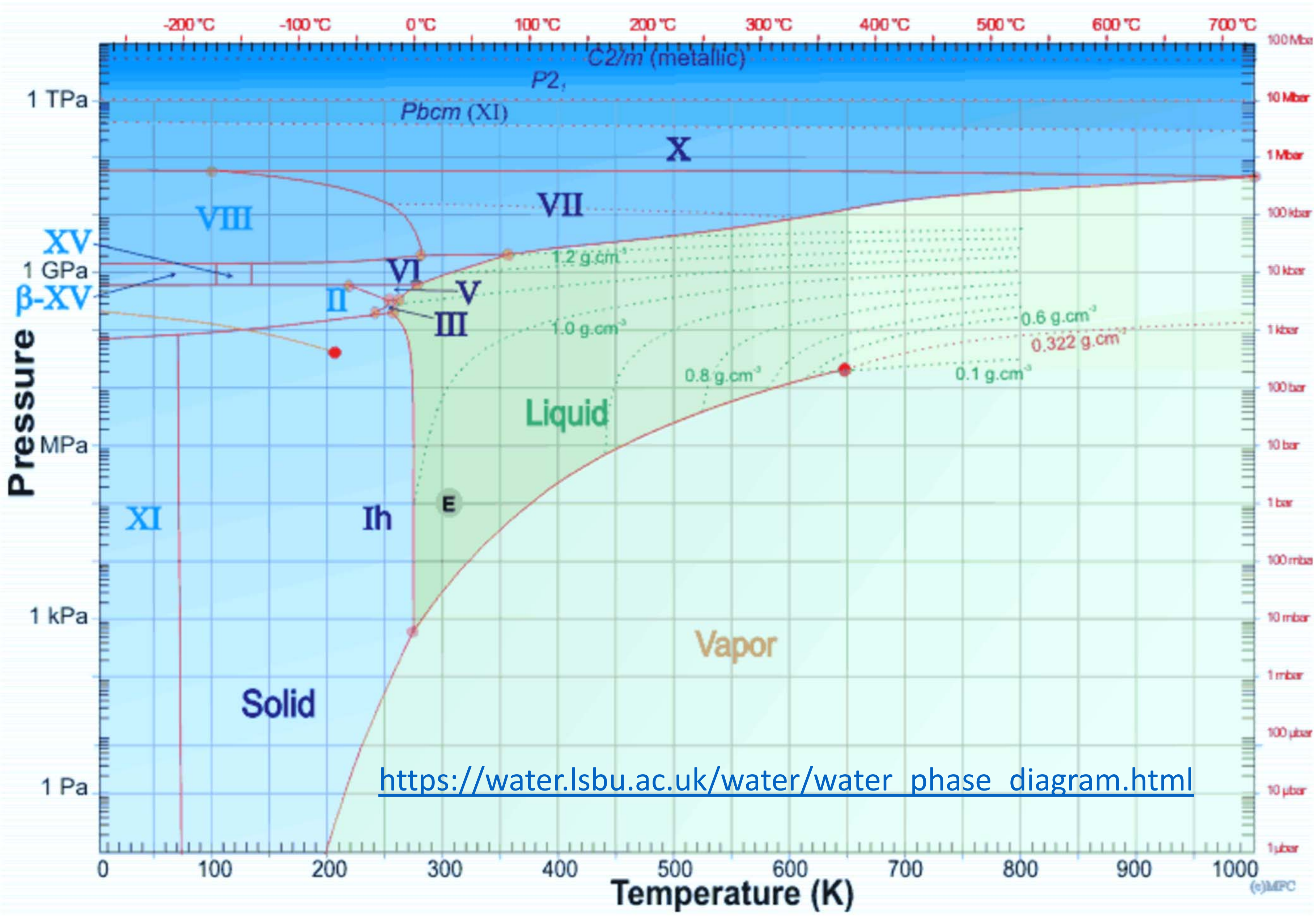


Diagrama de Fases del H_2O



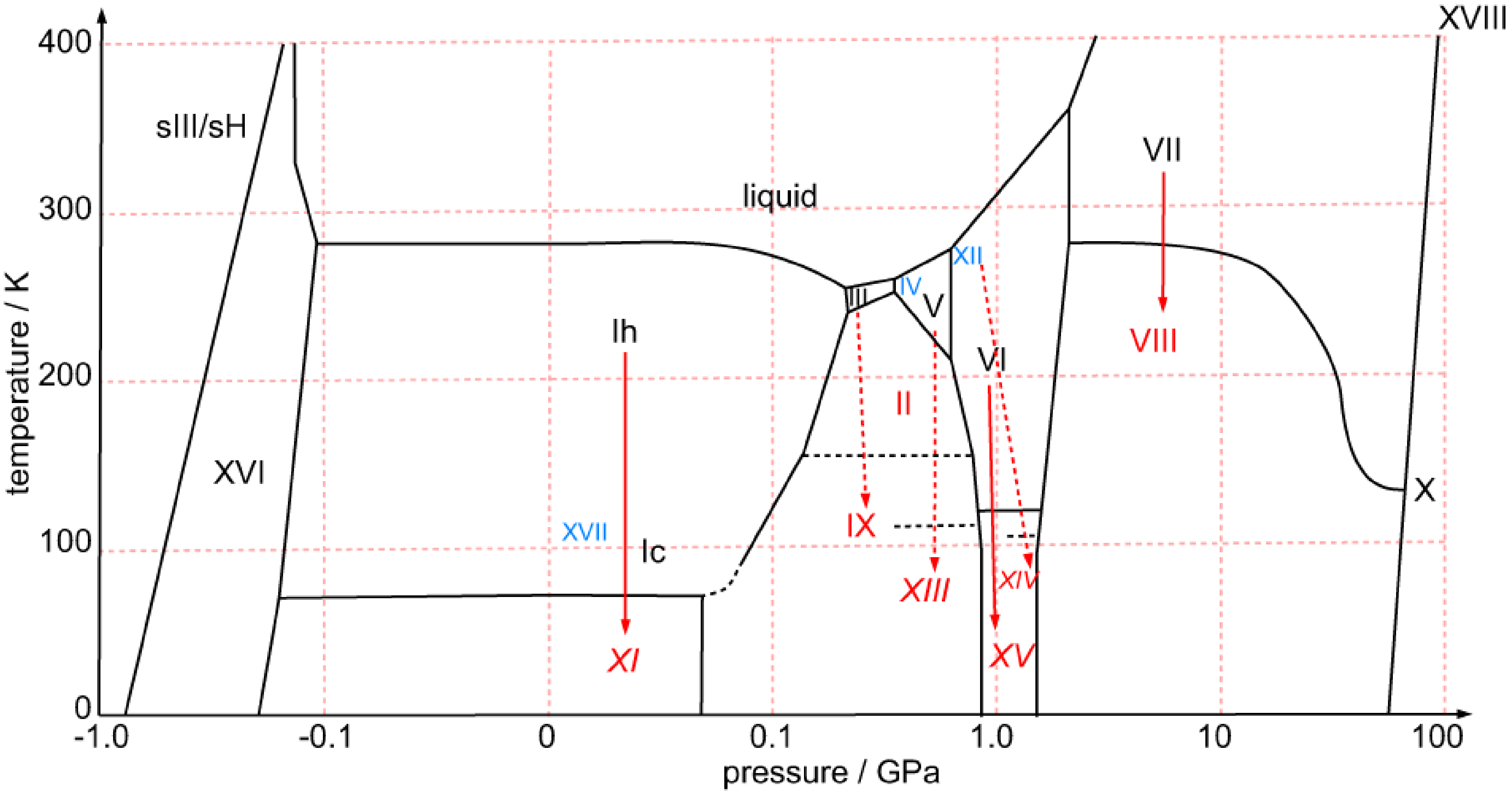
El diagrama de fases del agua



https://water.lsbu.ac.uk/water/water_phase_diagram.html

El diagrama de fases del agua

Water ice exists in hugely different environments, artificially or naturally occurring ones across the universe. The phase diagram of crystalline phases of ice is still under construction: a high-pressure phase, ice XIX, has just been reported but its structure remains ambiguous.



T. C. Hansen, The everlasting hunt for new ice phases, Nature Communications, 12 (2021) 3161.
https://doi.org/10.1038/s41467-021-23403-6

La celda de yunques de diamante (Diamond Anvil Cell)

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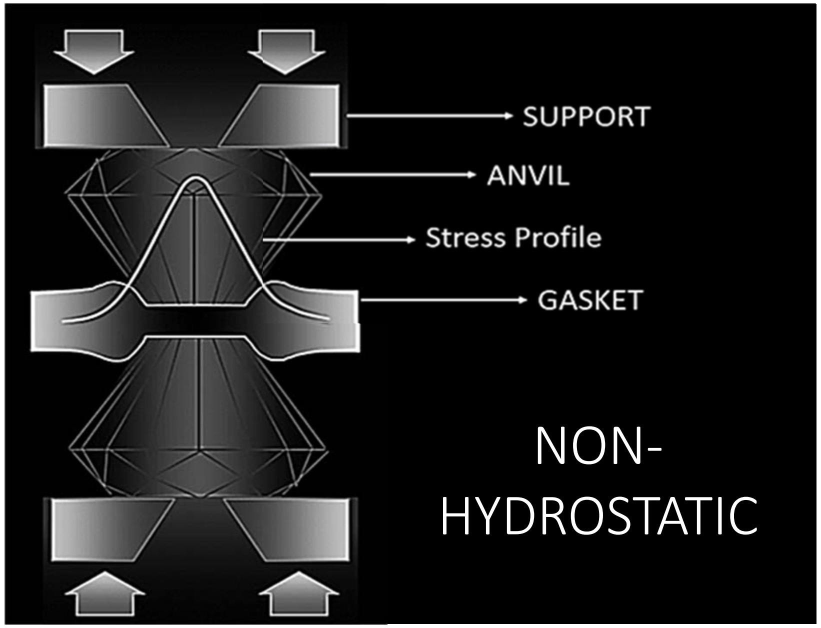
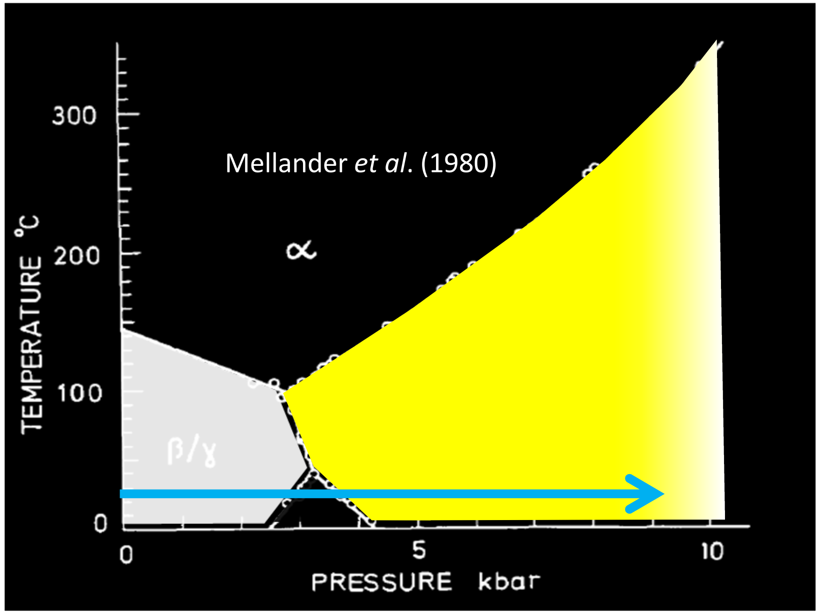


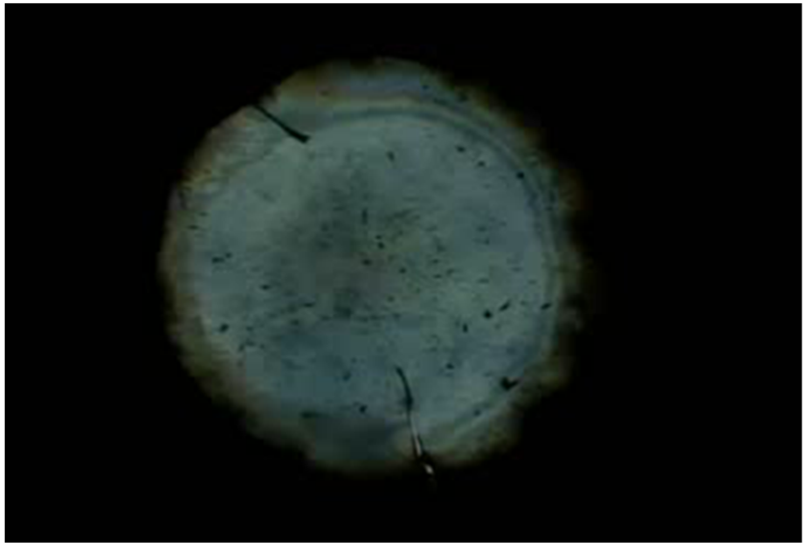
NON-HYDROSTATIC

Diagrama de Fases del AgI


Mellander *et al.* (1980)

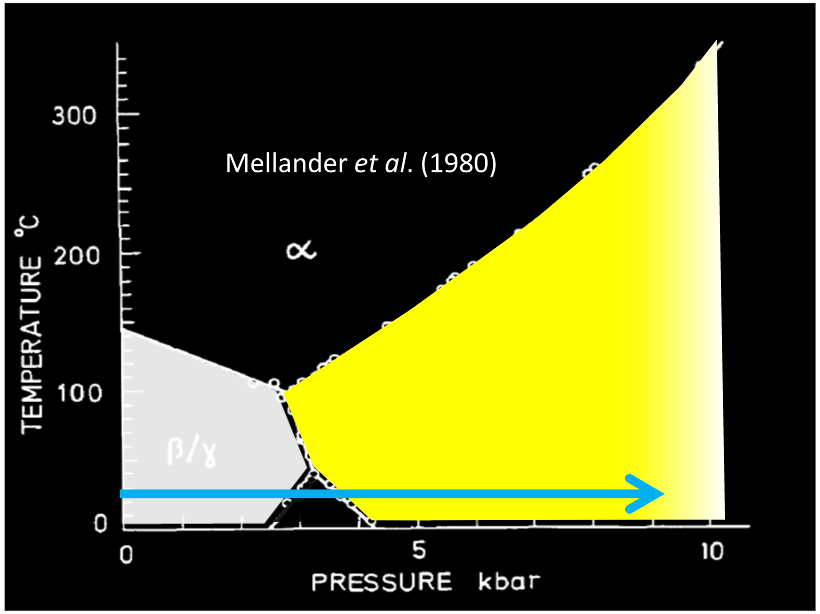
La celda de yunques de diamante (Diamond Anvil Cell)

Alvin van Valkenburg
(NBS, 1958)



https://www.youtube.com/watch?v=er7Hlr-_wH0

Diagrama de Fases del AgI



Mellander *et al.* (1980)

Técnicas dinámicas (shock)

JASPER (Joint Actinide Shock Physics Experimental Research) is a two-stage light gas gun, about 20 meters long, with a target chamber inside an 8-foot diameter containment chamber at the end.

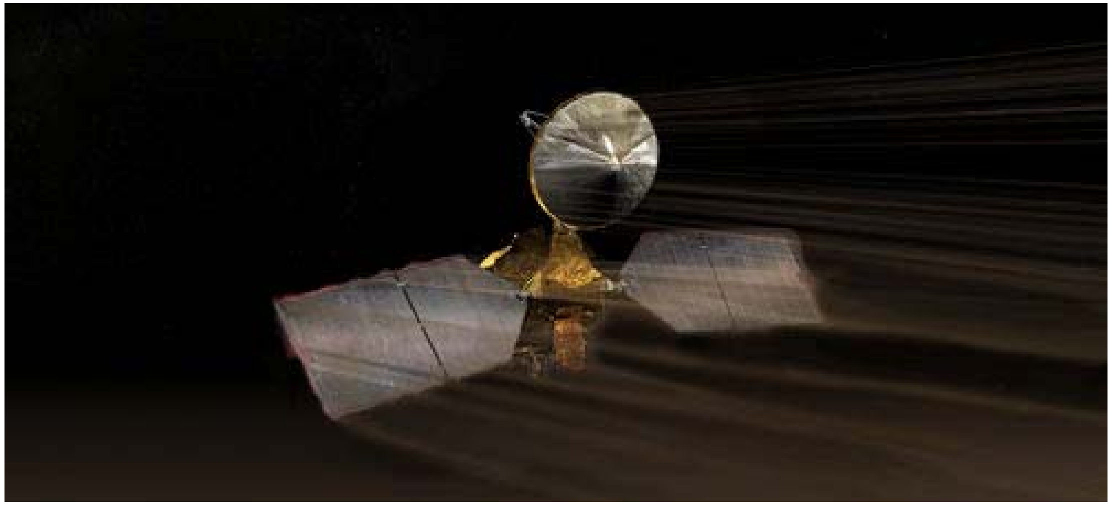
Lawrence Livermore National Laboratory

https://www.llnl.gov/

The High Explosives Applications Facility (HEAF) has activated an additional, higher velocity research gun to be used for shock physics research. Such guns are used to study the behavior of materials under sudden high pressure and temperatures.

The new gas gun, which utilizes two stages, can launch a projectile to velocities of 8,000 meters/second. (In comparison, a typical rifle bullet is about 1,000 meters/second.) This gives it the ability to generate precision one-dimensional shock waves up to several millions of atmospheres of pressure.

Instrumentación: técnicas de diagnóstico, análisis y simulación (espacio)



The Mars Reconnaissance Orbiter Mission Contributes to Four Science Goals for Mars Exploration

SCIENCE GOAL 1:
Determine Whether Life Ever Arose on Mars

SCIENCE GOAL 2:
Characterize the Climate of Mars

SCIENCE GOAL 3:
Characterize the Geology of Mars

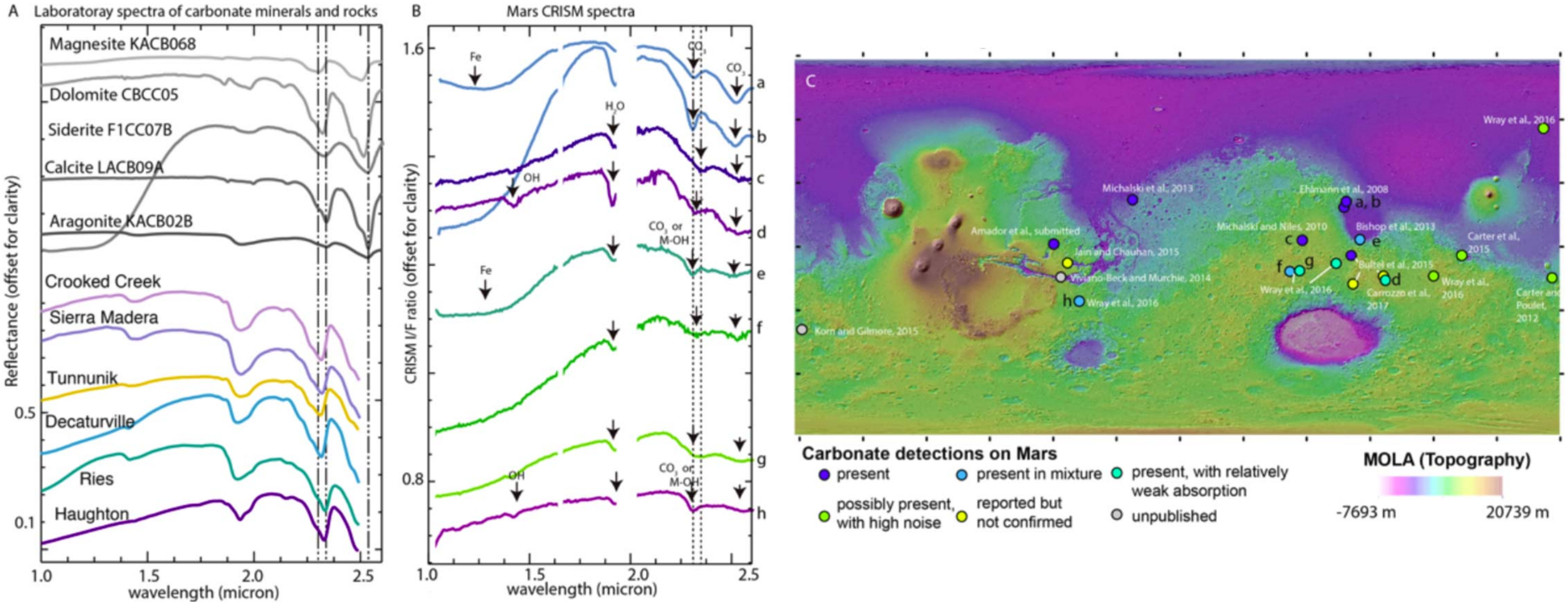
SCIENCE GOAL 4:
Prepare for Human Exploration

Instrumentación: técnicas de diagnóstico, análisis y simulación (espacio)

49th Lunar and Planetary Science Conference 2018 (LPI Contrib. No. 2083) **1896.pdf**

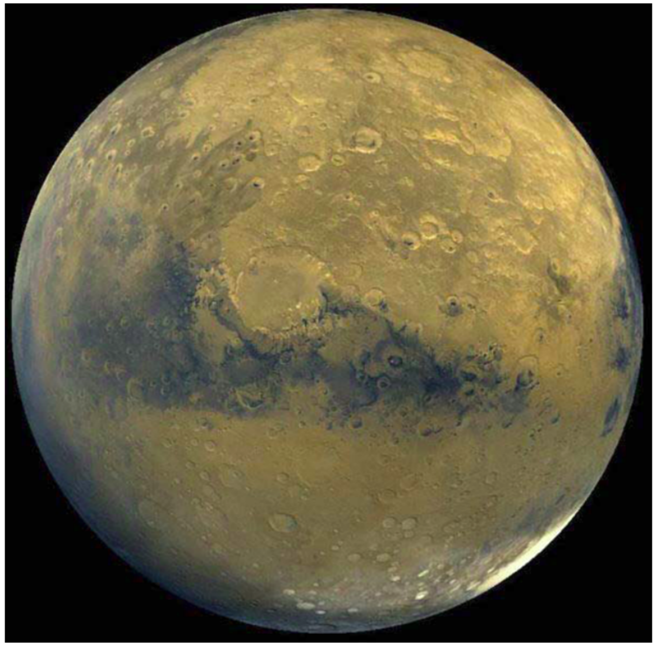
AN INFRARED SPECTROSCOPY STUDY OF IMPACT SHOCKED CARBONATES AND IMPLICATIONS FOR MARS.

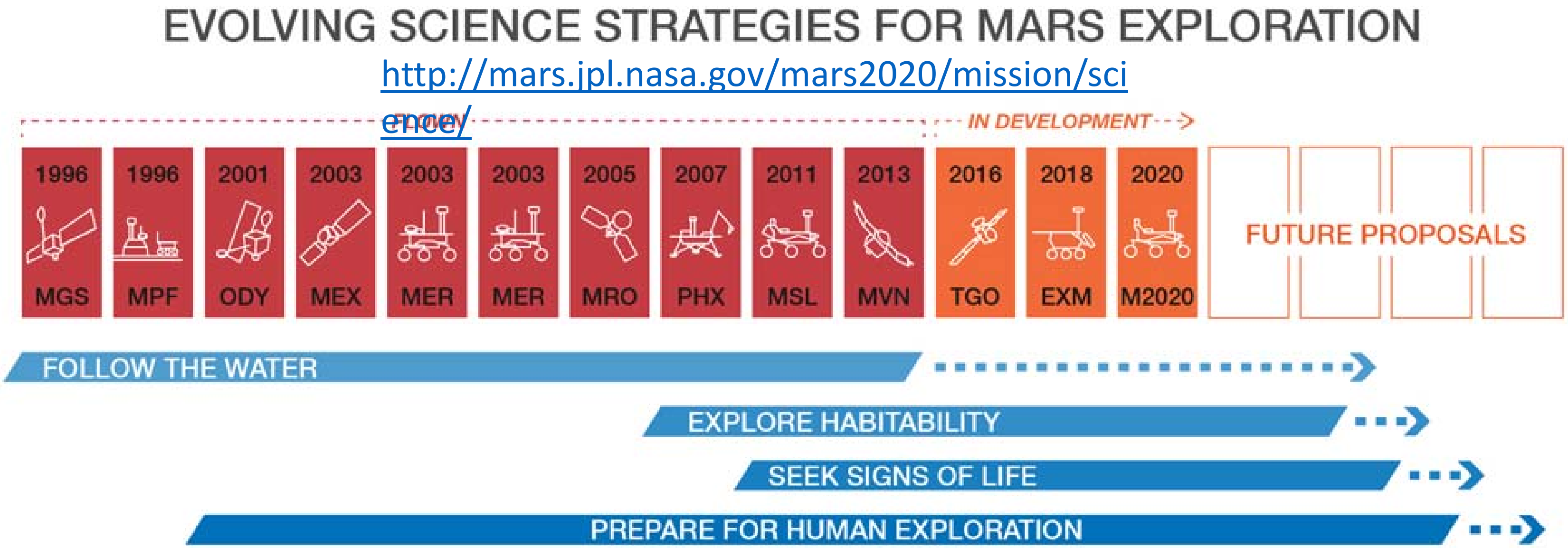
L. Pan[1], B. L. Ehlmann[2,3], P. D. Asimow[2], J. Hu[2], R. N. Greenberger[2]. [1]Laboratoire de Géologie de Lyon, Université Claude Bernard Lyon 1 (2 rue Raphaël Dubois, Bâtiment GEODE, Villeurbanne, 69622. lu.pan@univ-lyon1.fr), [2]Division of Geological and Planetary Sciences, California Institute of Technology, [3]Jet Propulsion Laboratory, California Institute of Technology.



Compact Reconnaissance Imaging Spectrometer for Mars

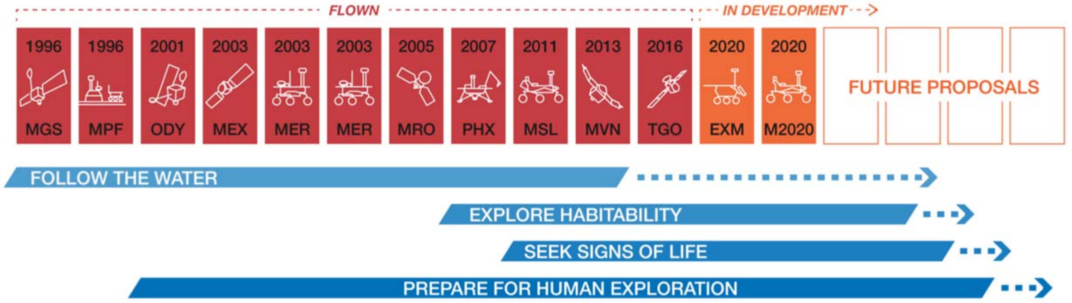
Instrumentación: técnicas de diagnóstico, análisis y simulación (espacio)





http://mars.jpl.nasa.gov/mars2020/mission/science/

Instrumentación: técnicas de diagnóstico, análisis y simulación (espacio)



FLOWN — IN DEVELOPMENT

1996	1996	2001	2003	2003	2003	2005	2007	2011	2013	2016	2020	2020
MGS	MPF	ODY	MEX	MER	MER	MRO	PHX	MSL	MVN	TGO	EXM	M2020

FUTURE PROPOSALS

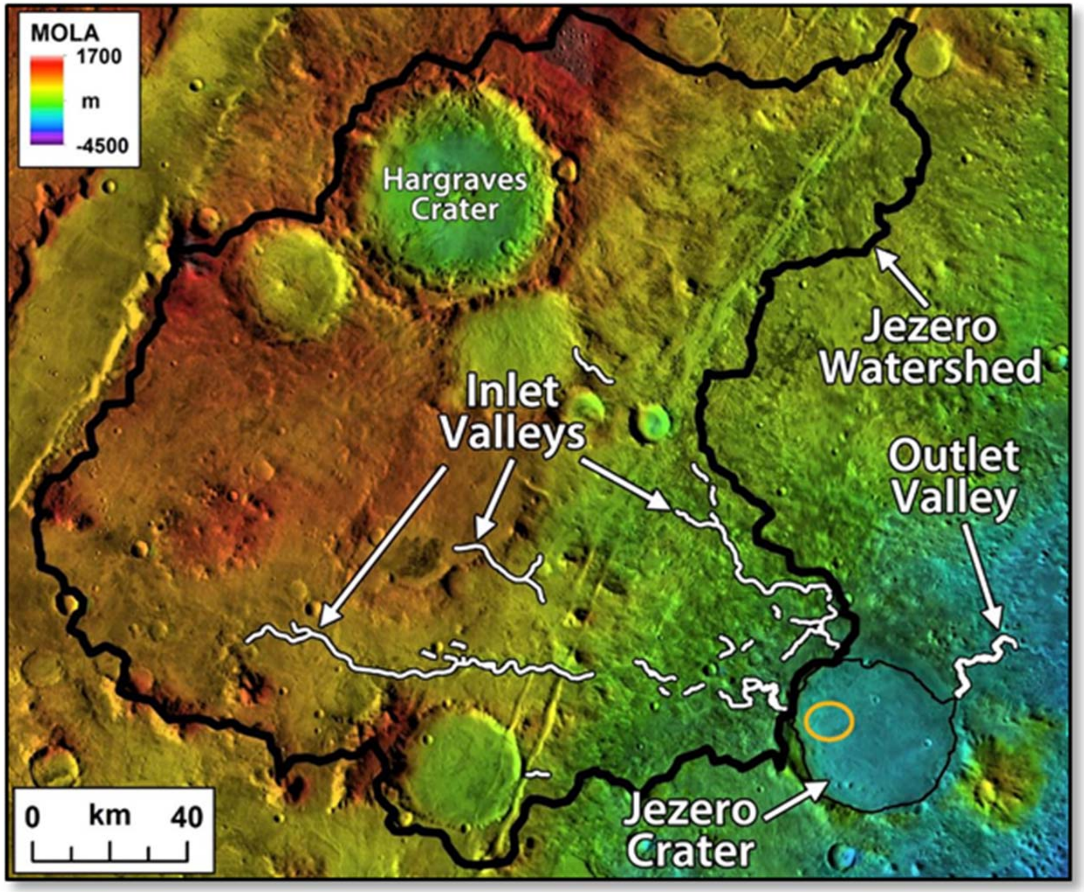
FOLLOW THE WATER

EXPLORE HABITABILITY

SEEK SIGNS OF LIFE

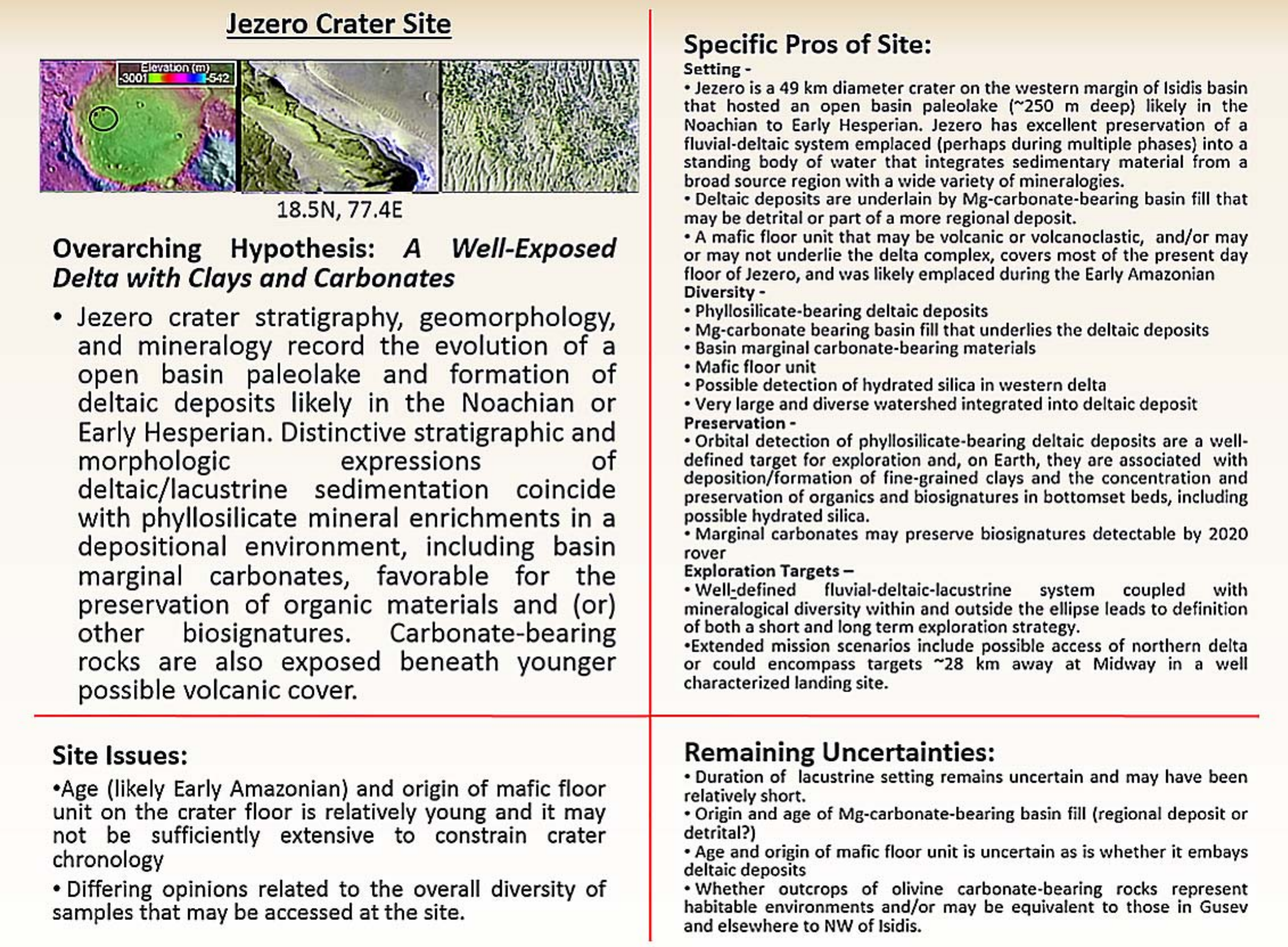
PREPARE FOR HUMAN EXPLORATION

Jezero Crater – MARS 2020



Instrumentación: técnicas de diagnóstico, análisis y simulación (es espacio)

Jezero Crater: the Mars 2020 Landing Site



Jezero Crater Site

18.5N, 77.4E

Overarching Hypothesis: *A Well-Exposed Delta with Clays and Carbonates*

- Jezero crater stratigraphy, geomorphology, and mineralogy record the evolution of a open basin paleolake and formation of deltaic deposits likely in the Noachian or Early Hesperian. Distinctive stratigraphic and morphologic expressions of deltaic/lacustrine sedimentation coincide with phyllosilicate mineral enrichments in a depositional environment, including basin marginal carbonates, favorable for the preservation of organic materials and (or) other biosignatures. Carbonate-bearing rocks are also exposed beneath younger possible volcanic cover.

Specific Pros of Site:

Setting -

- Jezero is a 49 km diameter crater on the western margin of Isidis basin that hosted an open basin paleolake (~250 m deep) likely in the Noachian to Early Hesperian. Jezero has excellent preservation of a fluvial-deltaic system emplaced (perhaps during multiple phases) into a standing body of water that integrates sedimentary material from a broad source region with a wide variety of mineralogies.
- Deltaic deposits are underlain by Mg-carbonate-bearing basin fill that may be detrital or part of a more regional deposit.
- A mafic floor unit that may be volcanic or volcanoclastic, and/or may or may not underlie the delta complex, covers most of the present day floor of Jezero, and was likely emplaced during the Early Amazonian

Diversity -

- Phyllosilicate-bearing deltaic deposits
- Mg-carbonate bearing basin fill that underlies the deltaic deposits
- Basin marginal carbonate-bearing materials
- Mafic floor unit
- Possible detection of hydrated silica in western delta
- Very large and diverse watershed integrated into deltaic deposit

Preservation -

- Orbital detection of phyllosilicate-bearing deltaic deposits are a well-defined target for exploration and, on Earth, they are associated with deposition/formation of fine-grained clays and the concentration and preservation of organics and biosignatures in bottomset beds, including possible hydrated silica.
- Marginal carbonates may preserve biosignatures detectable by 2020 rover

Exploration Targets –

- Well-defined fluvial-deltaic-lacustrine system coupled with mineralogical diversity within and outside the ellipse leads to definition of both a short and long term exploration strategy.
- Extended mission scenarios include possible access of northern delta or could encompass targets ~28 km away at Midway in a well characterized landing site.

Site Issues:

- Age (likely Early Amazonian) and origin of mafic floor unit on the crater floor is relatively young and it may not be sufficiently extensive to constrain crater chronology
- Differing opinions related to the overall diversity of samples that may be accessed at the site.

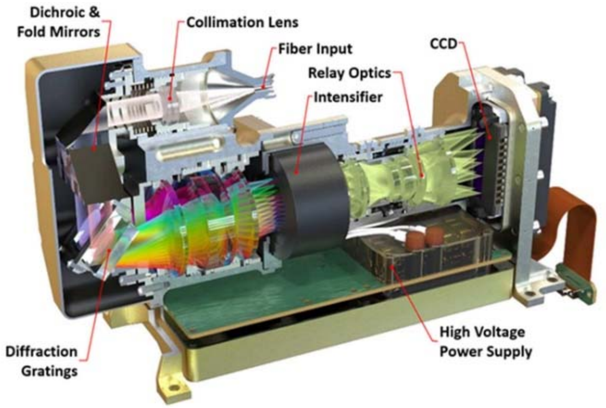
Remaining Uncertainties:

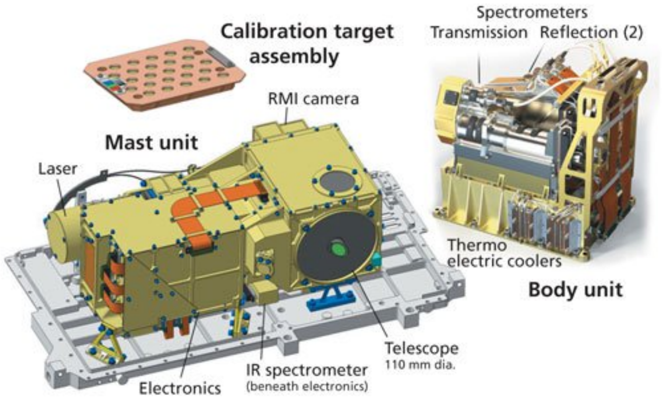
- Duration of lacustrine setting remains uncertain and may have been relatively short.
- Origin and age of Mg-carbonate-bearing basin fill (regional deposit or detrital?)
- Age and origin of mafic floor unit is uncertain as is whether it embays deltaic deposits
- Whether outcrops of olivine carbonate-bearing rocks represent habitable environments and/or may be equivalent to those in Gusev and elsewhere to NW of Isidis.

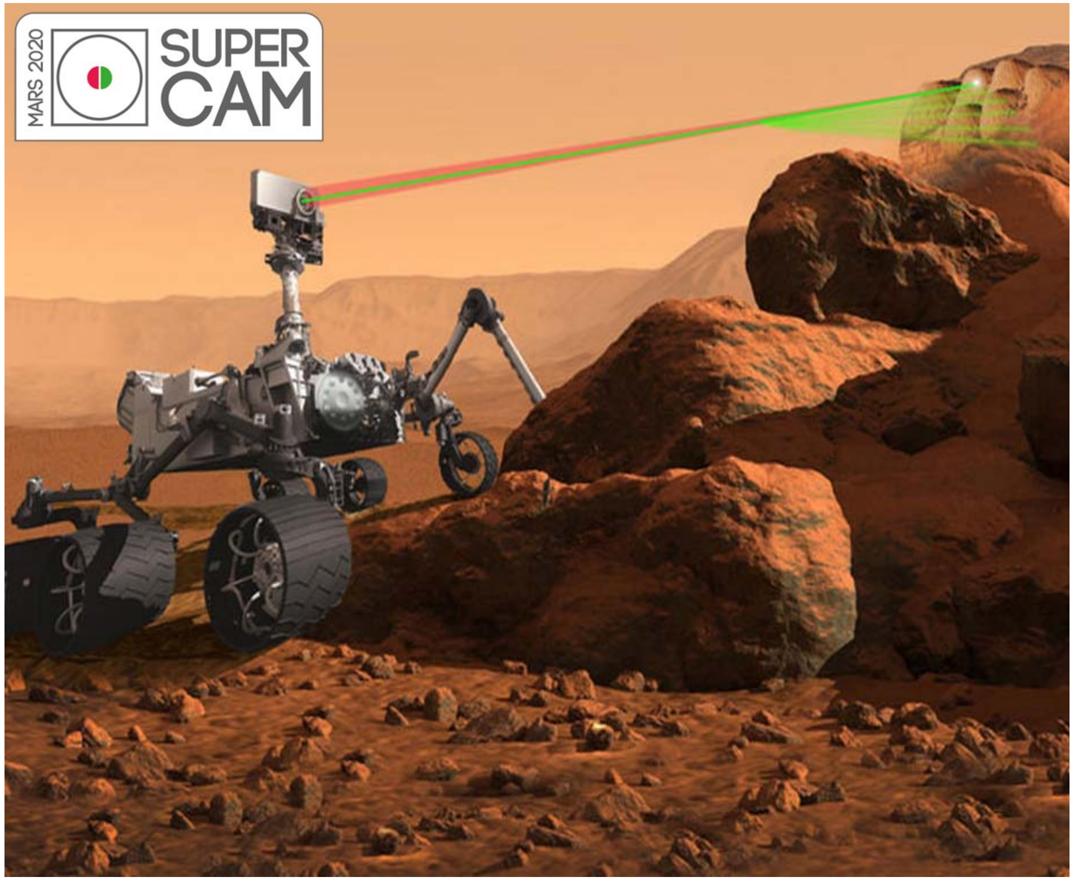
Instrumentación: técnicas de diagnóstico, análisis y simulación (es espacio)

SuperCAM Raman spectrometer.- Light enters (top) from an optical fiber bundle over which an aperture slit is mounted. The dichroic (left) splits light into two traces. The transition between blue and purple traces occurs at 598-618 nm (2100-2600 cm^{-1}). The second Raman region extends to 4900 cm^{-1}. The red trace (upper right), to 853 nm, is used exclusively for fluorescence, LIBS, and passive reflectance spectroscopy.

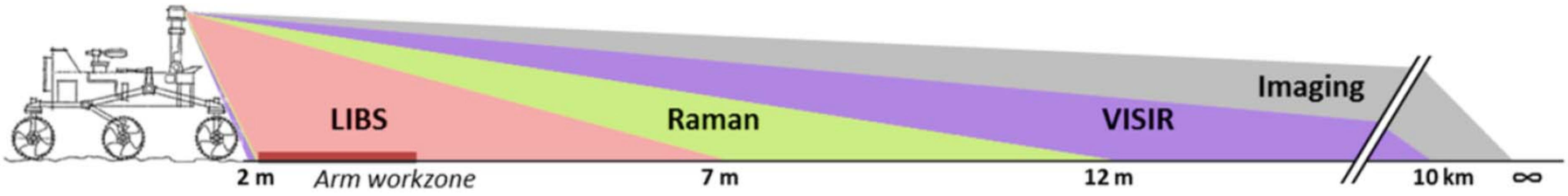
(THE SUPERCAM REMOTE RAMAN SPECTROMETER FOR MARS 2020, R.C. Wiens et al. Lunar and Planetary Science XLVIII, 2017).

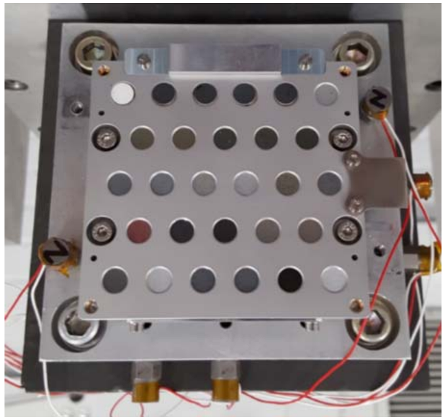


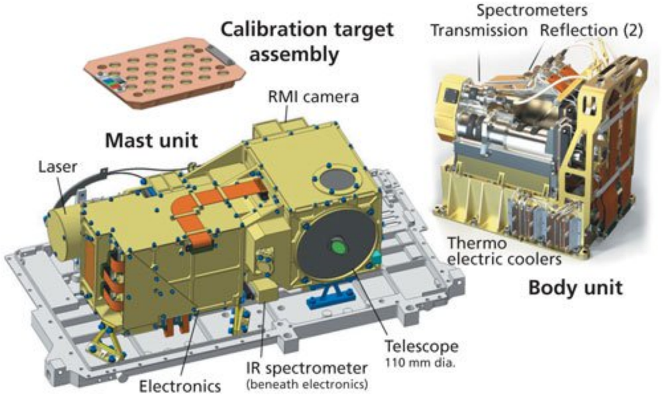


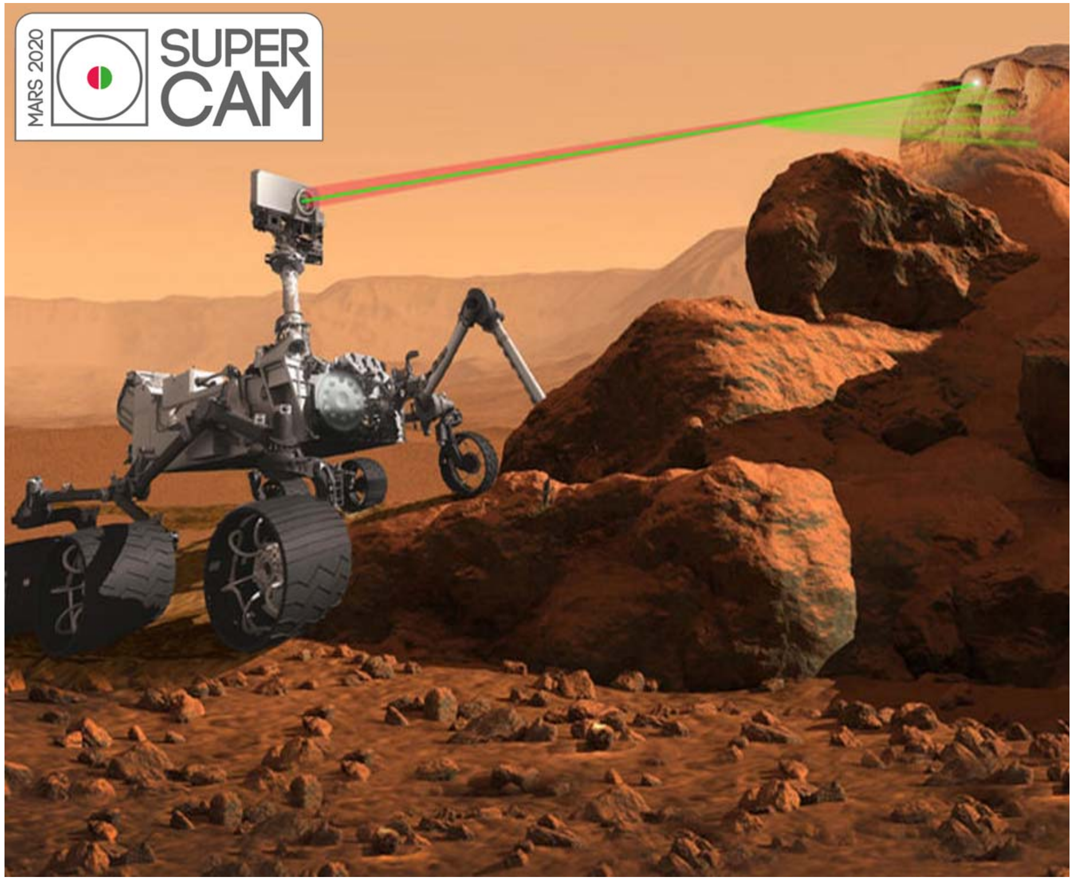


Instrumentación: técnicas de diagnóstico, análisis y simulación (es espacio)









INTRODUCCIÓN A LA EXPLORACIÓN ESPACIAL Y SU UTILIZACIÓN

Lección 12. Meteoritos, Luna y minería espacial – Valentín García Baonza

PROGRAMA:

Parte I: Contexto general

- Recursos minerales en el espacio.
- Meteoritos y cráteres de impacto.
- Ejemplos de fenómenos de impacto.

Parte II: Instrumentación: diagnóstico, análisis y simulación

- Estudios en tierra
- Misiones espaciales

Parte III: Debate y perspectivas