Mars Target Encyclopedia: Text-Based Machine Learning for Planetary Science

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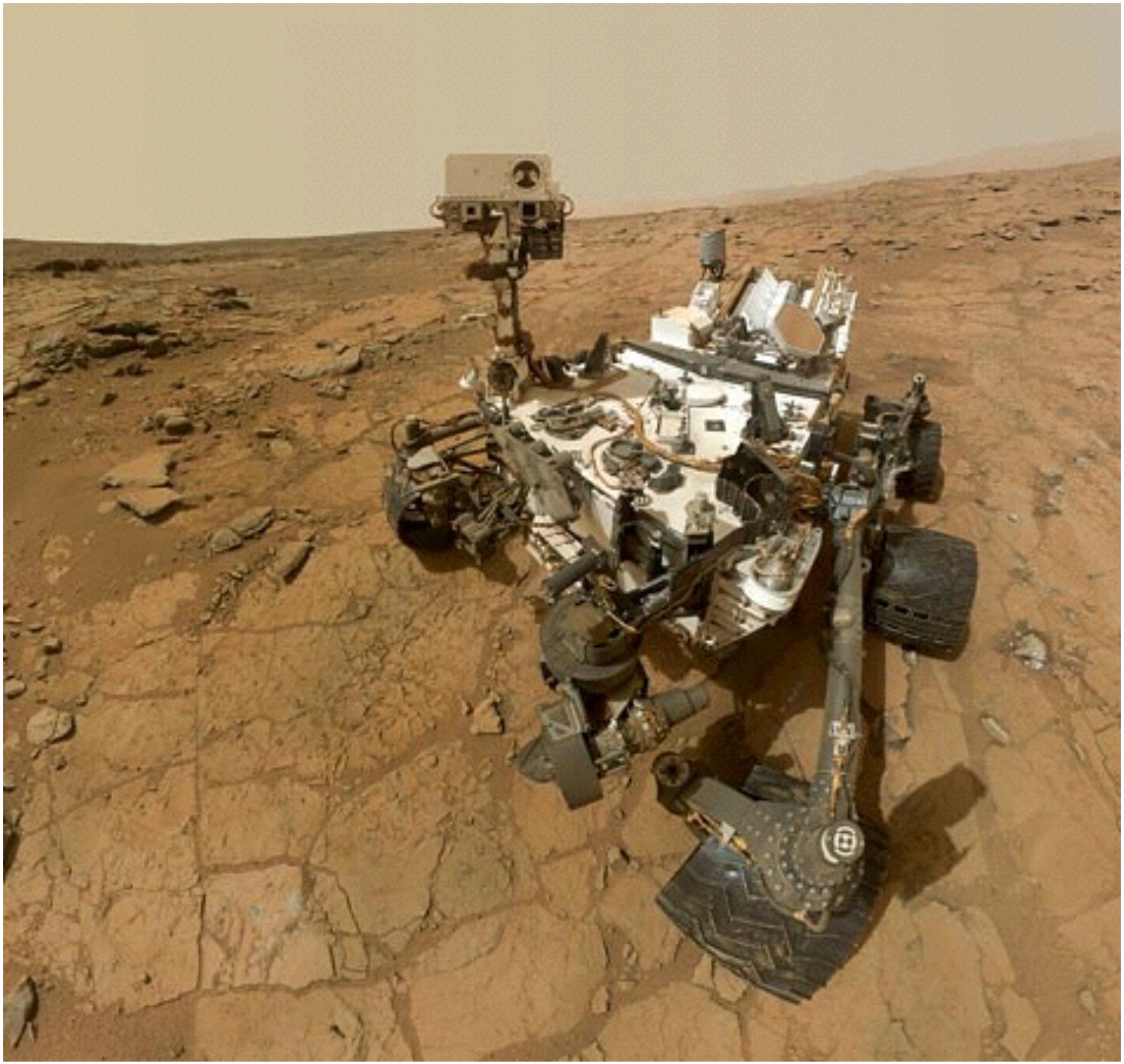
and Tom Stein (Washington University, St. Louis)

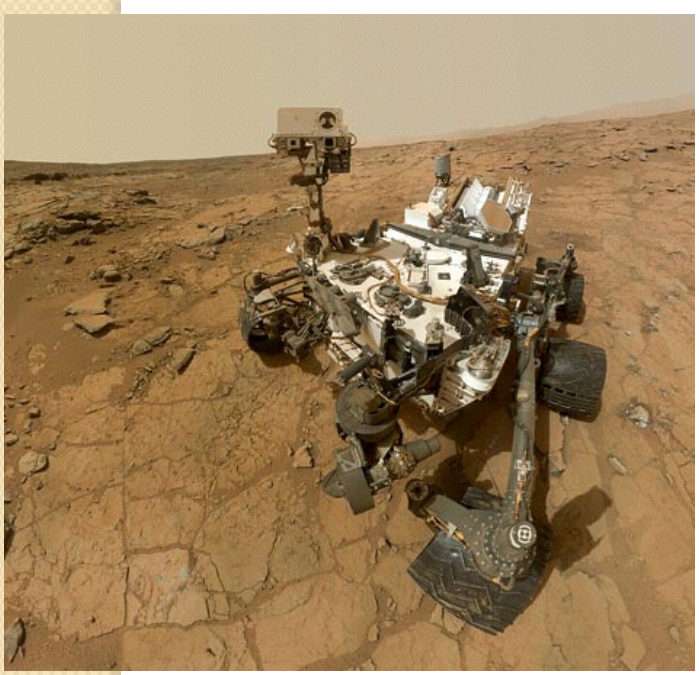
ASU SESE

November 1, 2018

Mastcam image from the Mars Science Laboratory rover

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.





Collect data

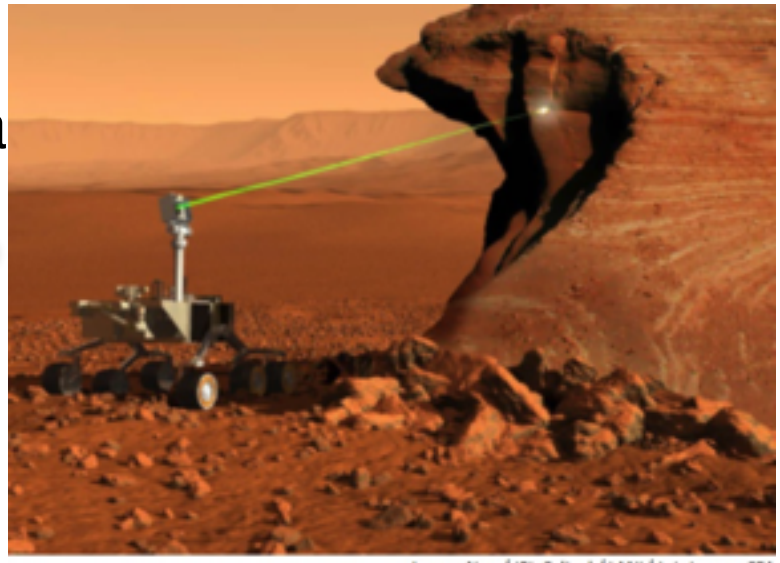


Image: Nasa/ JPL-Caltech/ LANL/ J.-L. Lacour, CEA

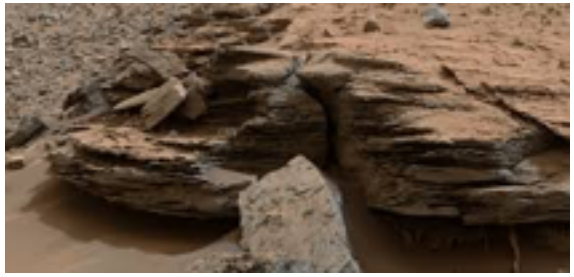
Uplink commands

Downlink data

MSL Data Archive

Drill hole

Rock



Rover wheel

...

Planetary Image Atlas

MSL: 905K Mastcam, 1.7M Hazcam, 8.2M Navcam

MSL Curiosity Analyst's Notebook

Home | Mission | Sol | Search | Map

2000+ per-sol summaries of data collected

What have we learned?

IRON METEORITE CANDIDATES WITHIN GALE CRATER, MARS, FROM MSL/MASTCAM MULTISPECTRAL OBSERVATIONS. D. F. Wellington (dfwellin@asu.edu)[1], J. R. Johnson[2], P.-Y. Meslin[3], J. F. Bell III[1], [1]Arizona State Univ., [2]Johns Hopkins Univ., APL, [3]IRAP, UPS-CNRS, Univ. Toulouse

Introduction: The Mastcam instruments on the MSL *Curiosity* rover each include an 8-position filter wheel that allows r
length range of 400
tures broad electro
primarily, from the
contained in constitu
phases of Gale Crat
servation commonl
may have weathere
transported from el
case that the float r
underlying or near
stances of spectral "
tral dataset can be
smooth, red-sloped

without chemistry, not definitive) evidence for a meteorite interpretation. For dark-toned materials imaged in

NEW ANALYSIS OF HYDROGEN ABUNDANCE IN THE SHEEPBED MEMBER OF YELLOWKNIFE BAY USING *IN SITU* GEOCHEMICAL DATA. S. Czarnecki[1], C. Hardgrove[1], T. S. J. Gabriel[1], M. Litvak[2], I. Mitrofanov[2], D. Lisov[2], S. F. Nowicki[3], W. Rapin[4,5], [1]Arizona State University, Tempe, AZ, sczarnec1@asu.edu, [2]Space Research Institute, RAS, Moscow, Russia, [3]Los Alamos National Laboratory, Los Alamos, NM, [4]Universite de Toulouse, UPS-OMP, Toulouse, France, [5]Institut de Recherche en Astrophysique et Planetologie, CNRS, UMR 5277, Toulouse, France.

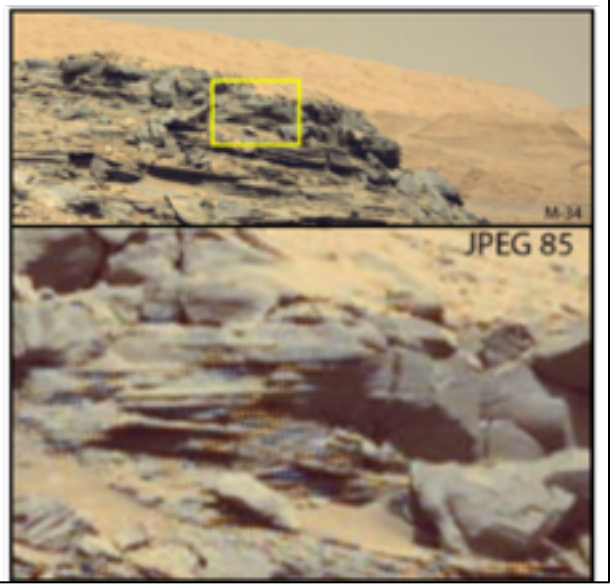
Introduction: The Mars Science Laboratory (MSL) rover, Curiosity, entered a fluvio-lacustrine depression named Yellowknife Bay (YKB) in December 2012. Curiosity completed a detailed observational campaign as it traversed across several geologic units of the YKB formation, inc
(SB) member [1,2]. Along
were acquired with the Dy
(DAN) instrument, a neutr
measuring the hydrogen (H)
cm of the subsurface. To
compare DAN data to mod
tian subsurface with user-s
geochemical data can be a
geochemistry [1,2,3] or ca
ments [4,5].

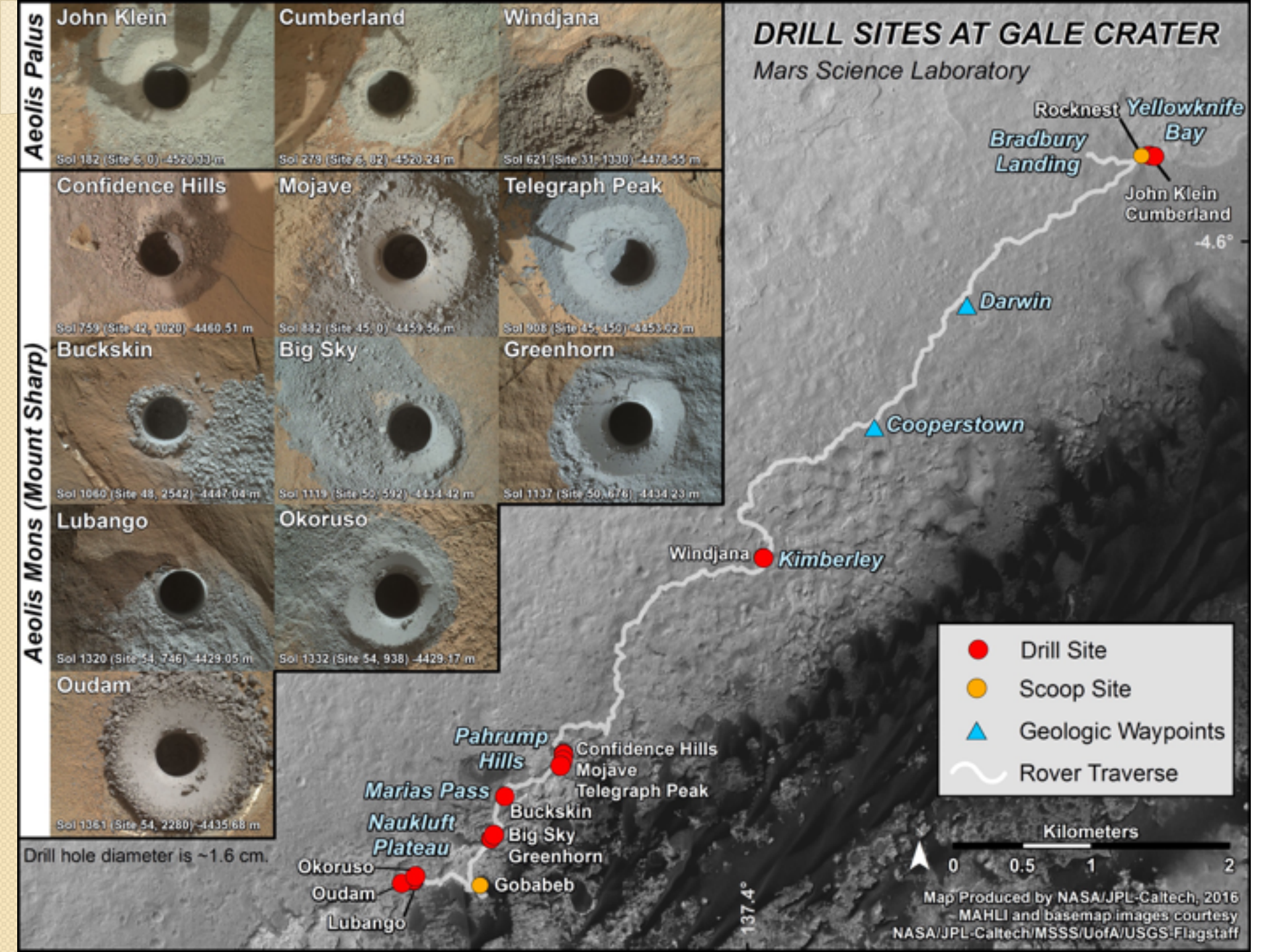
For this study, we first
published, best-fit DAN
abundance and depth [1] of
updated *in situ* geochemica
used a similar analysis rout
the H content and depth di

Previous studies have reported H abundances as wt. % Water-Equivalent-Hydrogen (WEH), assuming all H is bound in water, a convention we follow here. Litvak et al. (2014) reported WEH based on 2-layer DAN active modeling using variable Cl and top layer depth.

DETECTING AND CHARACTERIZING COMPRESSION-RELATED ARTIFACTS IN MARS SCIENCE LABORATORY MASTCAM IMAGES. H. R. Kerner[1], J. F. Bell III[1], H. Ben Amor[2] [1]Arizona State University School of Earth and Space Exploration, Tempe, AZ 85251 (hkerner@asu.edu); [2]Arizona State University School of Computing, Informatics, and Decision Systems Engineering, Tempe, AZ 85251.

Introduction: The Mastcam color imaging system on the Mars Science Laboratory Curiosity rover acquires images within Gale crater for a variety of geologic and atmospheric studies [1,2]. Images are often JPEG compressed onboard the rover before being downlinked to Earth. While critical for transmitting images on a low-bandwidth connection, this compression style can result in small image artifacts most noticeable as anomalous brightness or color changes within or near 8×8 JPEG compression block boundaries. In high-frequency detail regions of some images, for example in regions showing fine layering or lamination in sedimentary rocks, the image must be retransmitted losslessly to avoid introducing problems in the scientific interpretation of the data. The process of identifying which images have been adversely affected by such compression artifacts is performed manually by the Mastcam science team, costing significant ex-




DRILL SITES AT GALE CRATER
Mars Science Laboratory
Aeolis Palus
Aeolis Mons (Mount Sharp)
John Klein
Cumberland
Windjana
Confidence Hills
Mojave
Telegraph Peak
Buckskin
Big Sky
Greenhorn
Lubango
Okoruso
Oudam
Drill hole diameter is ~1.6 cm.
Rocknest
Yellowknife Bay
Bradbury Landing
John Klein
Cumberland
-4.6°
Darwin
Cooperstown
Windjana
Kimberley
Pahrump Hills
Confidence Hills
Mojave
Telegraph Peak
Marias Pass
Buckskin
Naukluft Plateau
Big Sky
Greenhorn
Okoruso
Oudam
Lubango
Gobabeb
137.4°
Drill Site
Scoop Site
Geologic Waypoints
Rover Traverse
Kilometers
0
0.5
1
2
Map Produced by NASA/JPL-Caltech, 2016
MAHLI and basemap images courtesy
NASA/JPL-Caltech/MSSS/UofA/USGS-Flagstaff

Google buckskin

Scholar About 23,800 results (0.02 sec) Any time 12

[PDF] Effect of disease assessment method on ranking potato cultivars for resistance to early blight [PDF] apsnet.org

C **Buckskin**, K Katahdin - Plant Disease, 1991 - apsnet.org

Significant differences among several potato cultivars (Solanum tuberosum) were observed for disease reaction to early blight, caused by Alternaria solani, in 1985, 1986, and 1988 field trials and in a greenhouse in 1986. Over the 3 yr, several assessment methods were ...

Cited by 58 Related articles All 3 versions Cite Save More

No

Mylonitization and detachment faulting in the Whipple-**Buckskin**-Rawhide Mountains terrane, southeastern California and western Arizona

GA Davis, JL Anderson, EG Frost... - Geological Society of ..., 1980 - memoirs.gsapubs.org

Abstract Field studies in the Whipple Mountains, southeastern California, and in the **Buckskin** and Rawhide Mountains, western Arizona, have defined the existence of an O1igocene (?) to middle Miocene gravity slide complex that is at least 100 km across in ...

Cited by 258 Related articles All 3 versions Cite Save More

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Tertiary structure and thermal history of the Harquahala and **Buckskin** Mountains, west central Arizona: Implications for denudation by a major detachment fault system

SM Richard, JE Fryxell, JF Sutter - Journal of Geophysical ..., 1990 - Wiley Online Library

Abstract The Harquahala and **Buckskin** mountains lie in the footwall of the Whipple-**Buckskin**-Bullard detachment system. In the Harquahala Mountains, Mesozoic fabric and structure are progressively more intensely overprinted by penetrative Tertiary deformation toward the ...

Cited by 59 Related articles All 5 versions Cite Save More

No

[BOOK] Cavalier in **Buckskin**: George Armstrong Custer and the Western Military Frontier

RM Utley - 2001 - books.google.com

George Armstrong Custer. The name evokes instant recognition in almost every American and in people around the world. No figure in the history of the American West has more powerfully moved the human imagination. When originally published in 1988, Cavalier in ...

Cited by 71 Related articles All 3 versions Cite Save More

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Scholar About 1,140 results (0.03 sec) Any time 12

High-Temperature, Perhaps Silicic, Volcanism on Mars Evidenced by Tridymite Detection in High-SiO2 Sedimentary Rock at Gale Crater, Mars [PDF] open.ac.uk
RV Morris, DT Vaniman, DF Blake, R Gellert... - 2016 - oro.open.ac.uk
... Curiosity at Gale Crater: The **Mars** Science La- boratory (MSL) rover, Curiosity, has been exploring sedimentary rocks within Gale crater since landing in ... of Aeolis Mons (aka Mount Sharp), drill powder was collected from a high-silica (74 wt% SiO2) outcrop named **Buckskin** (BK ...
All 3 versions Cite Save

Yes

Alteration Mineralogy and Geochemistry at Swansea, Arizona: A Potential Analog for Brine-Basalt Interaction on Mars
JR Michalski, SJ Reynolds, TG Sharp... - AGU Fall Meeting ..., 2002 - adsabs.harvard.edu
... has been documented in the Harcuvar Mountains to the east, where deep (~10 km) crustal brines that migrated along the Tertiary **Buckskin**-Rawhide detachment fault ... Future work will include the development of a model for alteration of basalt by brine on the Earth and **Mars**. ...
Cite Save

No

Silicic volcanism on Mars evidenced by tridymite in high-SiO2 sedimentary rock at Gale crater [HTML] pnas.org
Get-It @JPL Library
RV Morris, DT Vaniman, DF Blake... - Proceedings of the ..., 2016 - National Acad Sciences
... Tridymite, a low-pressure, high-temperature (>870 °C) SiO 2 polymorph, was detected in a drill sample of laminated mudstone (**Buckskin**) at Marias Pass in Gale crater, **Mars**, by the Chemistry and Mineralogy X-ray diffraction instrument onboard the **Mars** Science Laboratory ...
Cited by 2 Cite Save

Yes

Is Tridymite at Gale Crater Evidence for Silicic Volcanism on Mars?
RV Morris, DT Vaniman, DW Ming, TG Graff, RT Downs... - 2016 - ntrs.nasa.gov
... The X-ray diffraction (XRD) instrument (CheMin) onboard the MSL rover Curiosity detected 17 wt% of the SiO2 polymorph tridymite (relative to bulk sample) for the **Buckskin** drill sample (73 wt% SiO2) obtained from sedimentary rock in the Murray formation at Gale Crater, **Mars**. ...
Cite Save More

Yes

Google mars lubango

Scholar About 95 results (0.05 sec) Any time 12

Tip: Search for **English** results only. You can specify your search language in Scholar Settings.

[PDF] Cataloguing the **Lubango** Bird Skin Collection: towards an atlas of Angolan bird distributions [PDF] birdsangola.org

MSL Mills, U Franke, G Joseph, F Miato, S Milton… - Bull. ABC, 2010 - birdsangola.org

... Les spécimens du musée de **Lubango** proviennent d'une zone de contact des deux taxons et pourraient servir pour une étude ... haut) et femelle (en bas) du Tisserin à menton noir Ploceus nigrimentus, collectés à Huambo (auparavant Nova Lisboa) en **mars** 1966 probablement ...

Cited by 5 Related articles All 5 versions Cite Save More

No

Groupes nouveaux de Mimosacées et Caesalpiniacées

G Gilbert, R Boutique - Bulletin du Jardin botanique de l'Etat, Bruxelles/ …, 1952 - JSTOR

... 1914, Bequaert 2325; La Kulu, juin 1931, Vanden Brande 508; Nala, 1907, Seret 819; Buta, foret secondaire, fleurs blanc jaunatre, **mars** 1931; Lebrun 2472; entre Niangara et Wamba, anciennes cultures, juin 1931, Lebrun 3197 ... **Lubango**, chaine Ouest du lac tdouard, alt. ...

Cited by 3 Related articles All 2 versions Cite Save

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Observations critiques sur quelques Composées du Congo belge

H Humbert, P Staner - Bulletin du Jardin botanique de l'Etat a Bruxelles, 1936 - JSTOR

... 2,500 m. d'alt., arbuste de 2 m., fleurs centrales lilas, fleurs p6ripheriques blanchhtres, **mars** 1929, Humbert 7576; region S.-W. de Lemera, vall&e de la Ruzizi, vers 2,500 m. d'alt., buisson de 2 m., fleurs mauve clair, juill. 1927, Chapin 487; entre Kasindi et **Lubango**, chaine ' l ...

Cited by 1 Related articles Cite Save More

No

ACTIVITfiS EXTfiRIEURES

A sur le Planalto - Cambridge Univ Press

... Activites dans le sud de VAngola A l'occasion de sa mission en Angola, le delegue general du CICR pour l'Afrique, MJ-M. Bornet, s'est rendu a **Lubango** les 18 et 19 **mars** et s'est entretenu directement sur le terrain avec les autorites provinciates et militaires. ...

All 2 versions Cite Save

No

What if I want to know:

- Which targets contain fluorine?
- Which targets contain hematite?
- Is there consensus on target X's composition?

Mars Target Encyclopedia

- Collect all published knowledge about every target on Mars
- Provide search access
- Answer questions
- Inspire new investigations and hypotheses

Can computers do the reading?

From flickr user Atomic Taco (CC BY-SA)

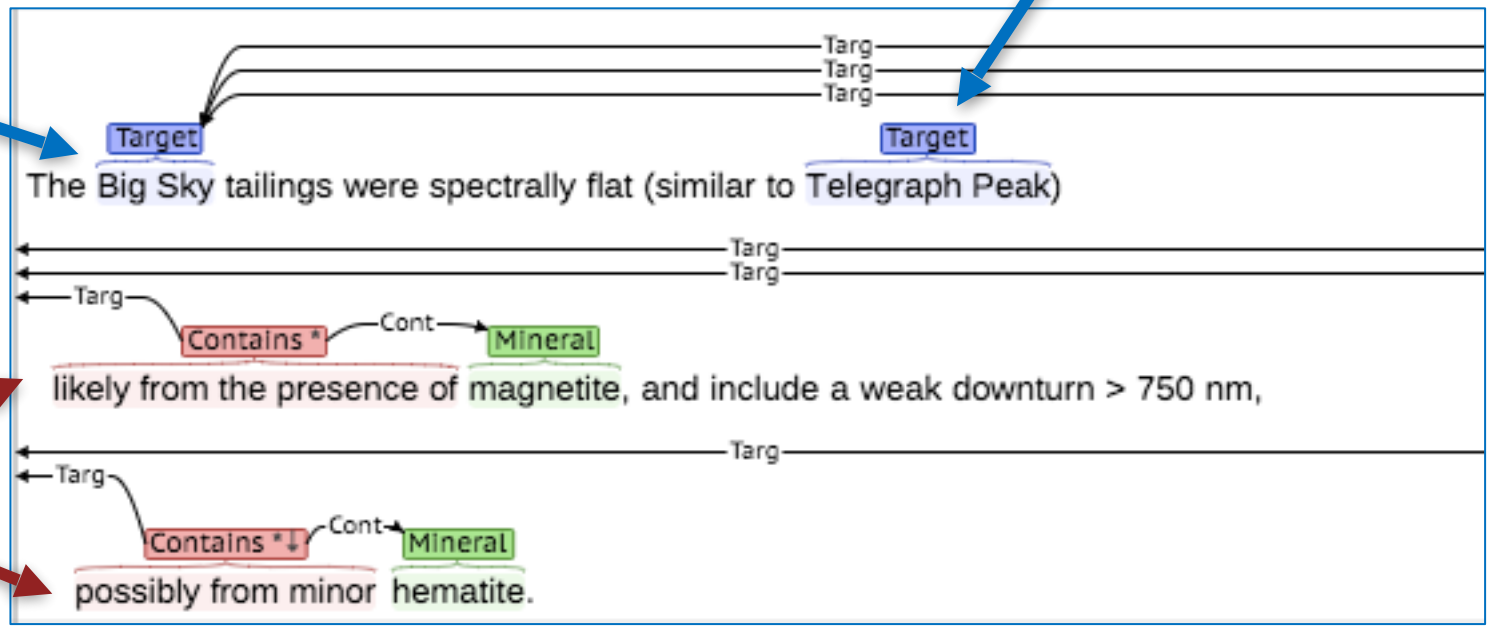
Can computers do the reading?

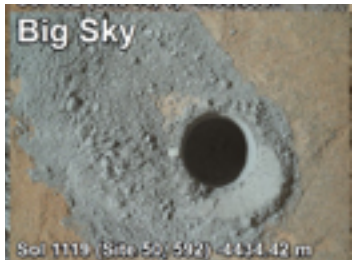
- How hard is it?

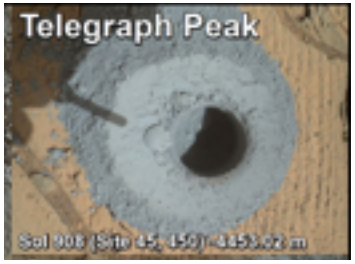
Mountain in CA

Resort in MT, 2015 movie

"Hedging"



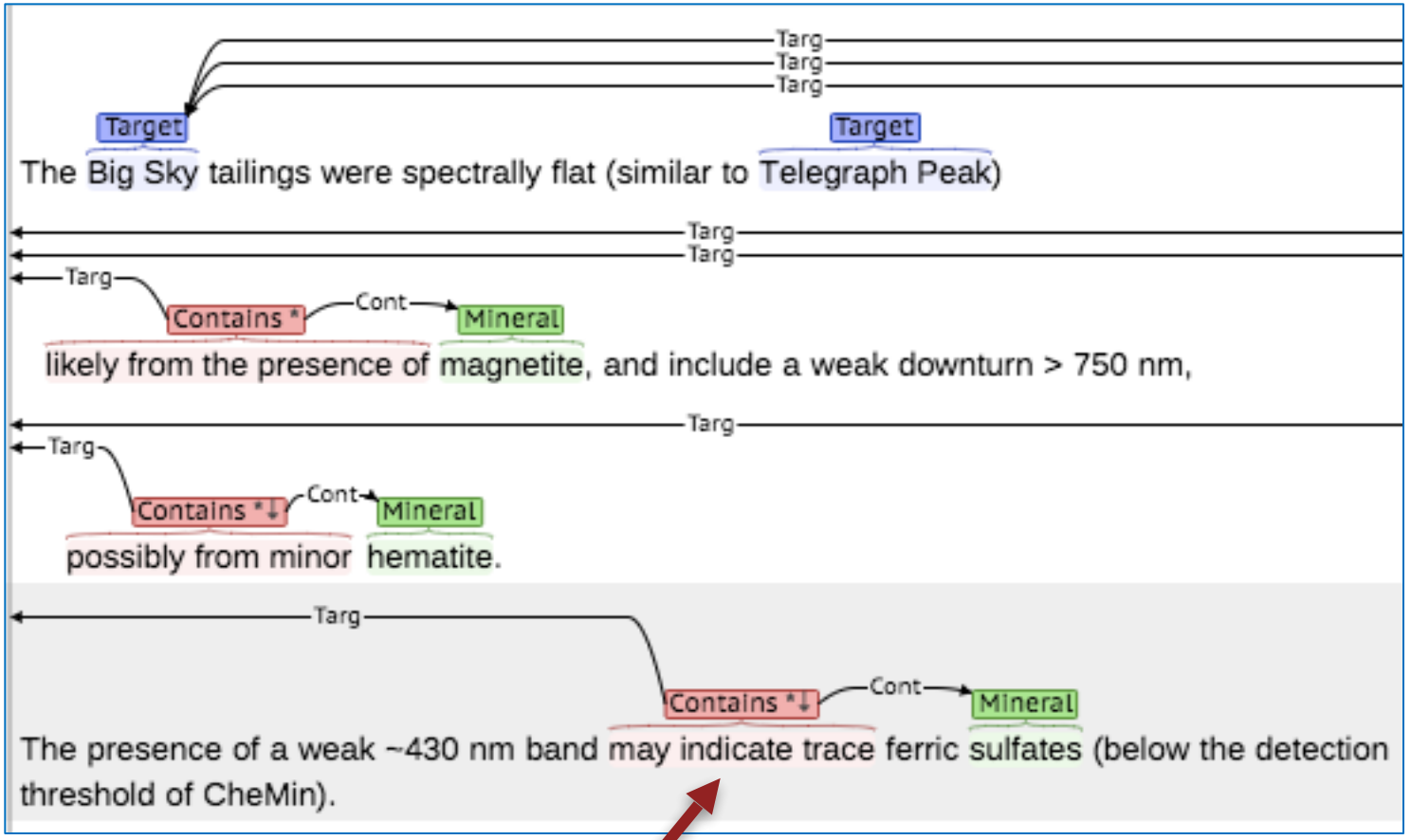




[Johnson et al., 2016]

Can computers do the reading?

- How hard is it?



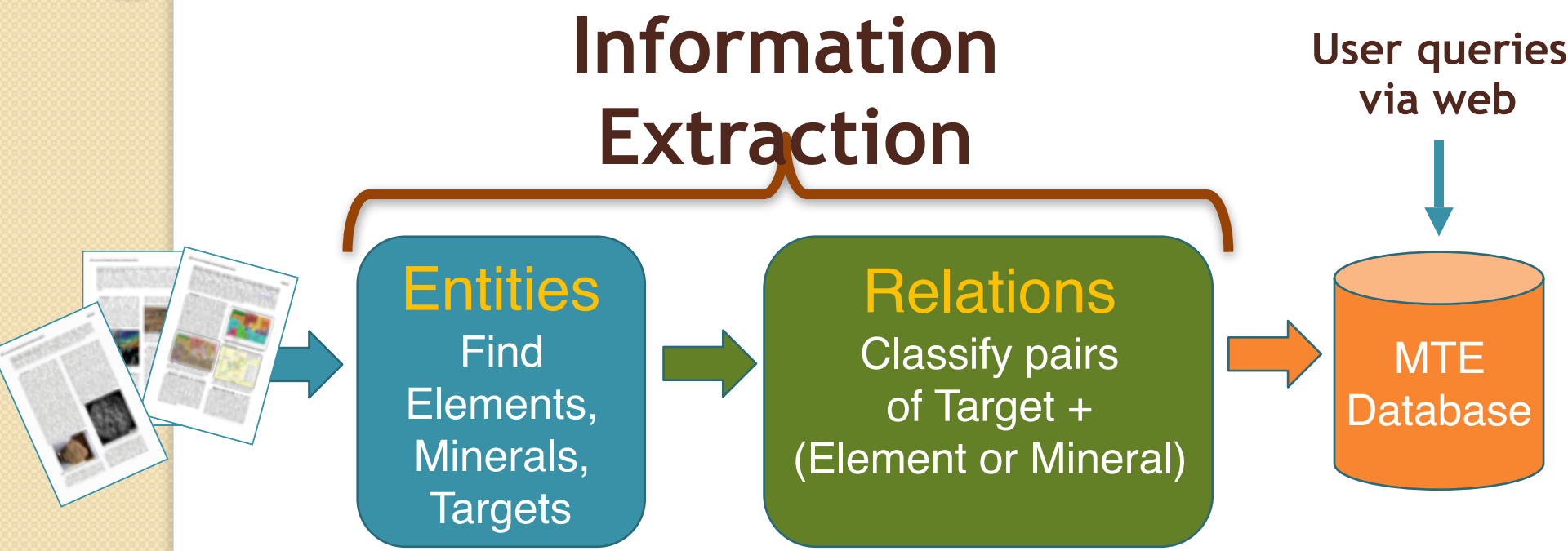
Not even in the same sentence!

[Johnson et al., 2016]

The documents

- Lunar and Planetary Science Conference
  - Three years
  - 5,920 documents
  - 2-page abstracts
  - 7.2M words

Mars Target Encyclopedia



Entities
Find Elements, Minerals, Targets

Relations
Classify pairs of Target + (Element or Mineral)

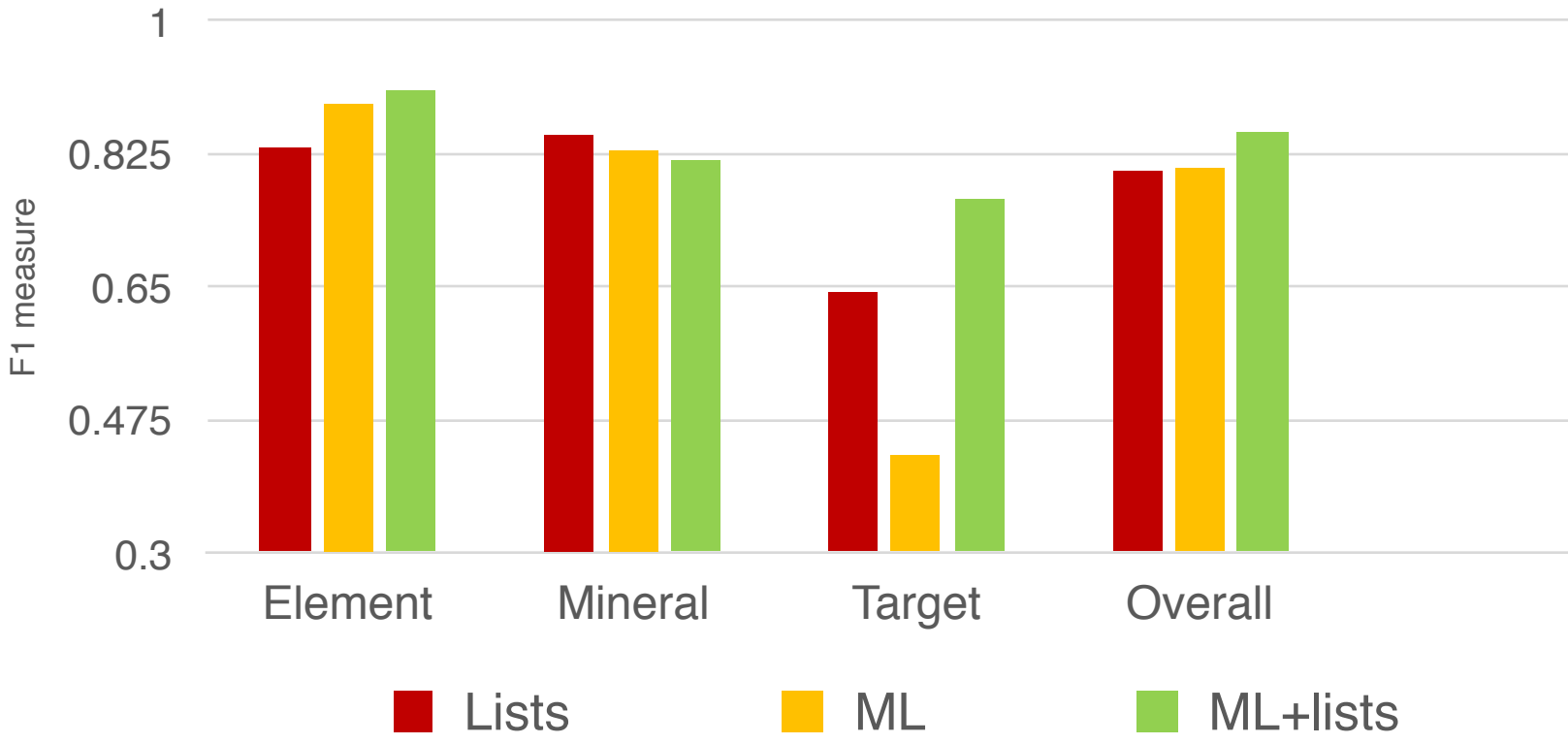
MTE Database

1. Find Targets, Elements, Minerals

- Use known lists
  - What about newly discovered targets?
- Machine learning
  - Given example texts, learn word patterns
    - "The Big Sky tailings were spectrally flat…"
  - Stanford CoreNLP system [Finkel et al., 2005]
    - Word sequences, parts of speech, word "shape"
    - ML: Conditional Random Field (CRF) model

Entity extraction performance

Train on 62 docs from 2015, test on 35 docs from 2016



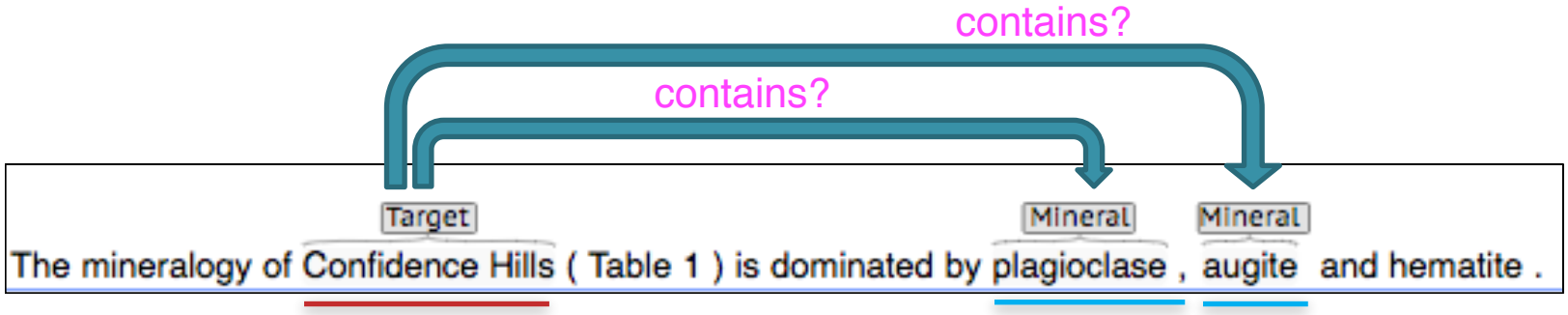
Entities
Find Elements, Minerals, Targets

Relations
Classify pairs of Target + (Element or Mineral)

MTE Database

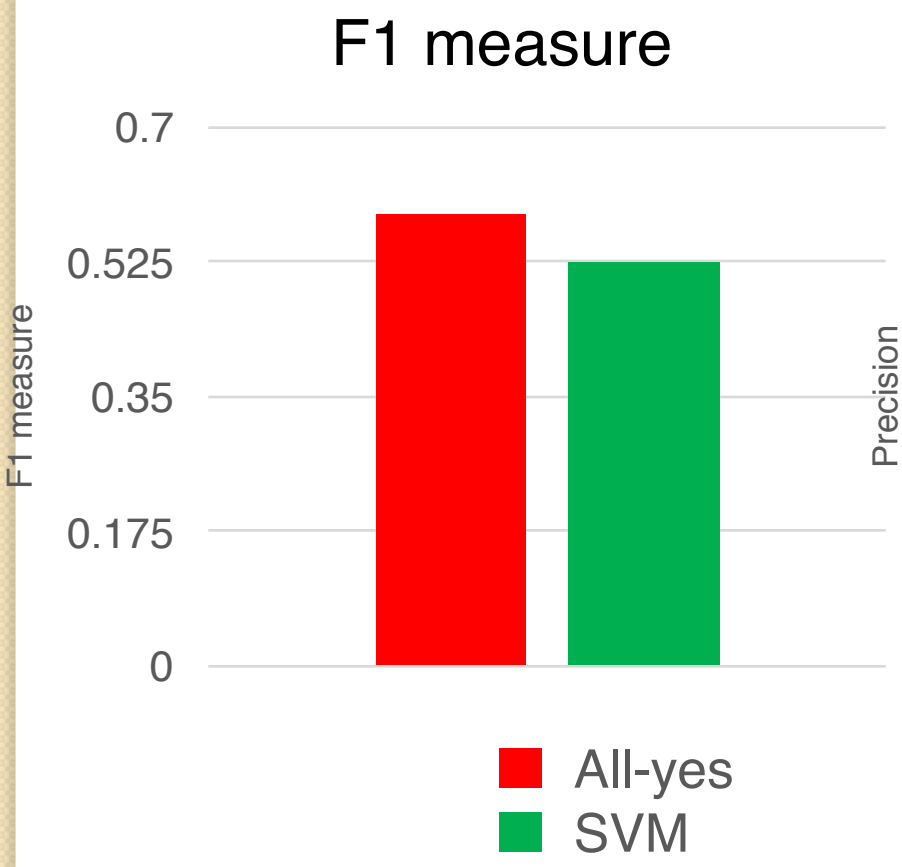
2. Find relationships

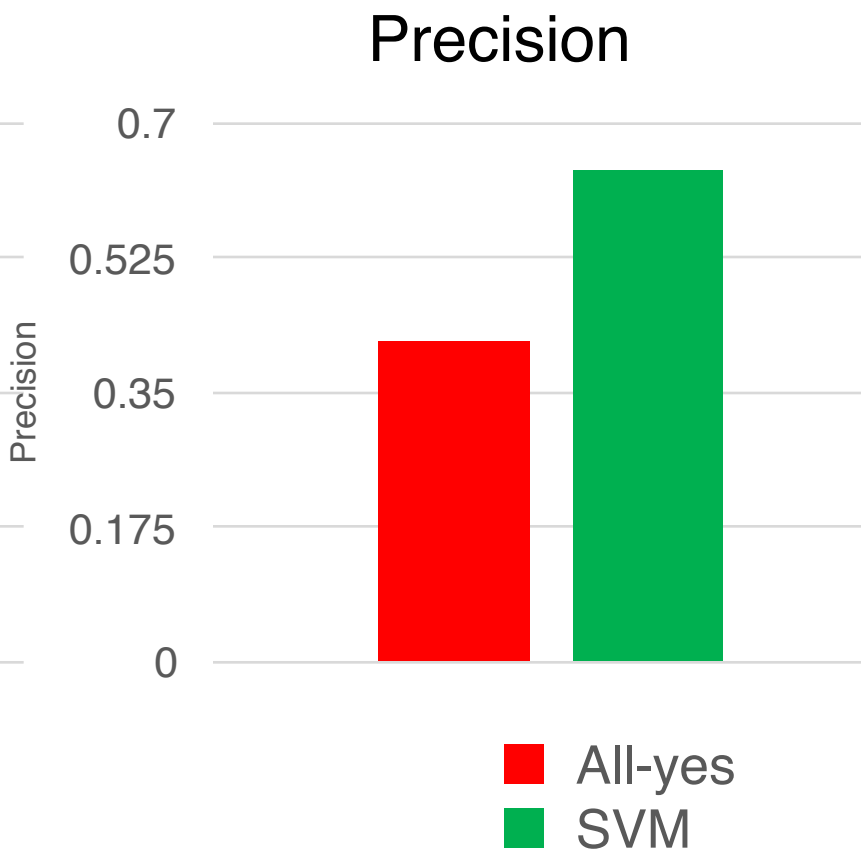
- Predict whether there is a "contains" relation for each [Target, Element] or [Target, Mineral] pair
- Machine learning: jSRE [Giuliano et al., 2006]
  - Words, positions, endings, parts of speech
  - ML: Support Vector Machine (SVM) model



Relation extraction performance

Train on 429 pairs from 2015, test on 173 pairs from 2016





Mars Target Database

Content type	Manual
Documents	118
Elements	2,224
Minerals	1,456
Targets	916
Relations	696

Mars Target Database

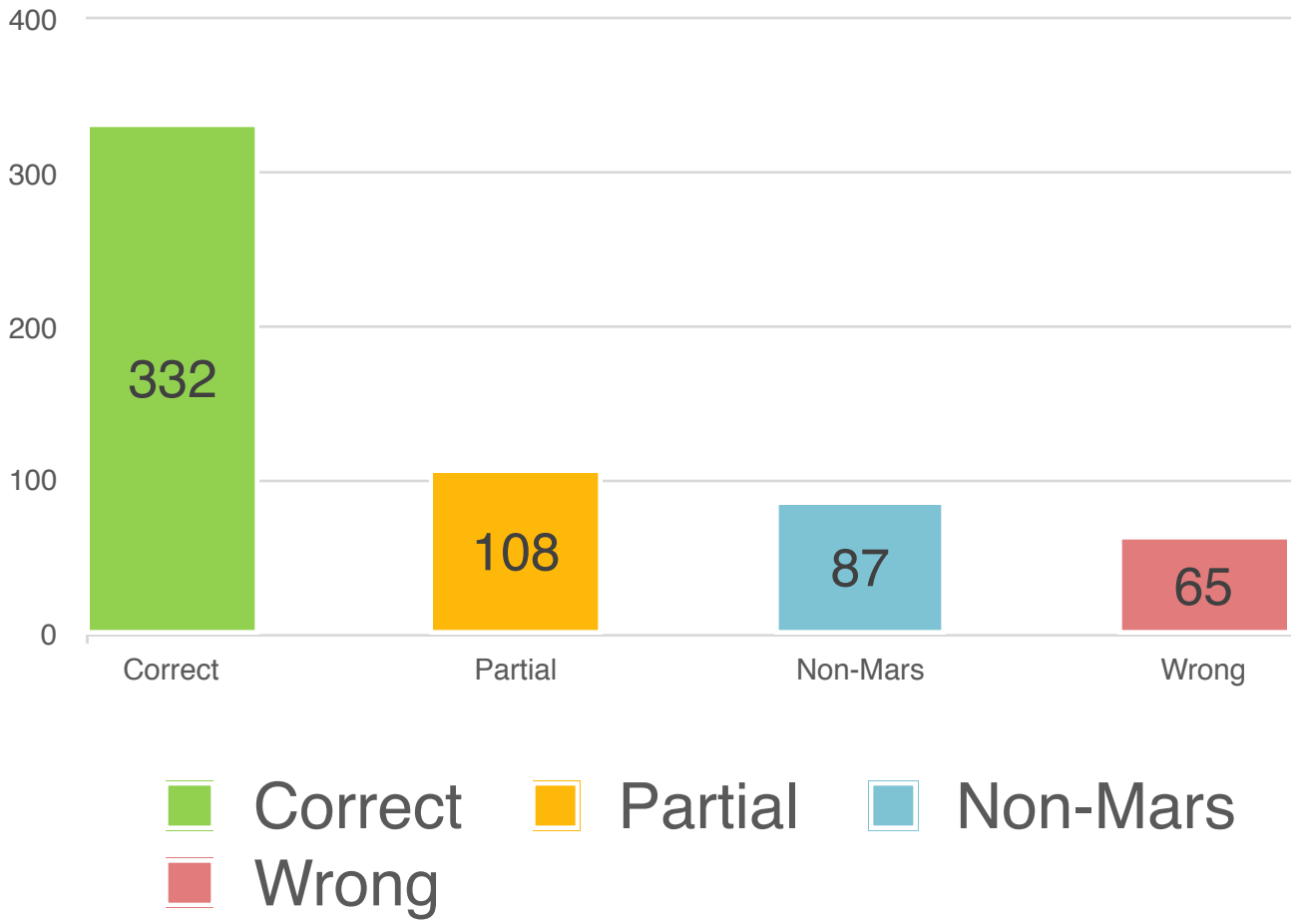
Content type	Manual	Automatic
Documents	118	5,920
Elements	2,224	48,614
Minerals	1,456	34,287
Targets	916	3,255
Relations	696	1,412

Mars Target Database

Content type	Manual	Automatic
Documents	118	5,920
Elements	2,224	48,614
Minerals	1,456	34,287
Targets	916	3,255
Relations	696	1,412
Time (per document)	~30 mins	~5 seconds

Manual review of relations

- Relations from non-training documents
- ~5 sec per document



Example extractions – correct

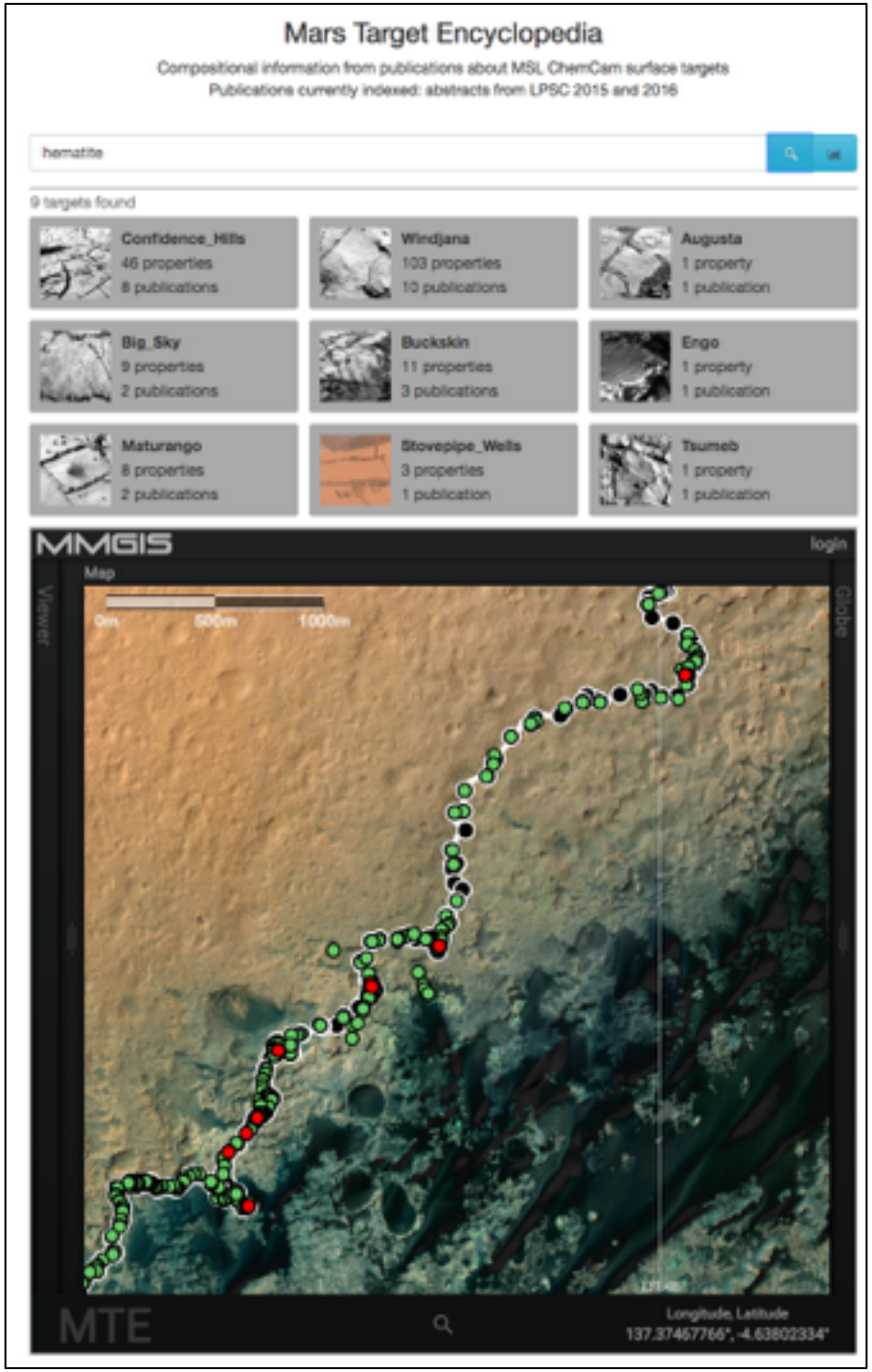
- Link contains potassium
  - "Link, which was one of the first K-rich conglomerate targets observed with ChemCam, whereas felsic group 5 shows a higher Na/K ratio."
- Link contains hydrogen
  - "Both of these are good candidates since, in Link at least, the hydrogen signature is relatively prominent."
- JK/CB and olivine/magnetite
  - "The RN crystalline component is depleted in MgO and FeO relative to JK and CB because of the absence of olivine and enrichment of magnetite in the latter."

Example extractions – incorrect

- Not a target (Mars region)
  - "While limited detections of phyllosilicates and hydrated silica are found in Acidalia and Utopia Planitia…"
- Not an element (Fm)
  - "The results indicate that the dip of the Shoemaker Fm impactite section…"
- Meteorite (not Mars, but same name as Mars target)
  - "Finally, the Bilanga diogenite has a model age that seems older but still similar within the error than basaltic and cumulative eucrites."

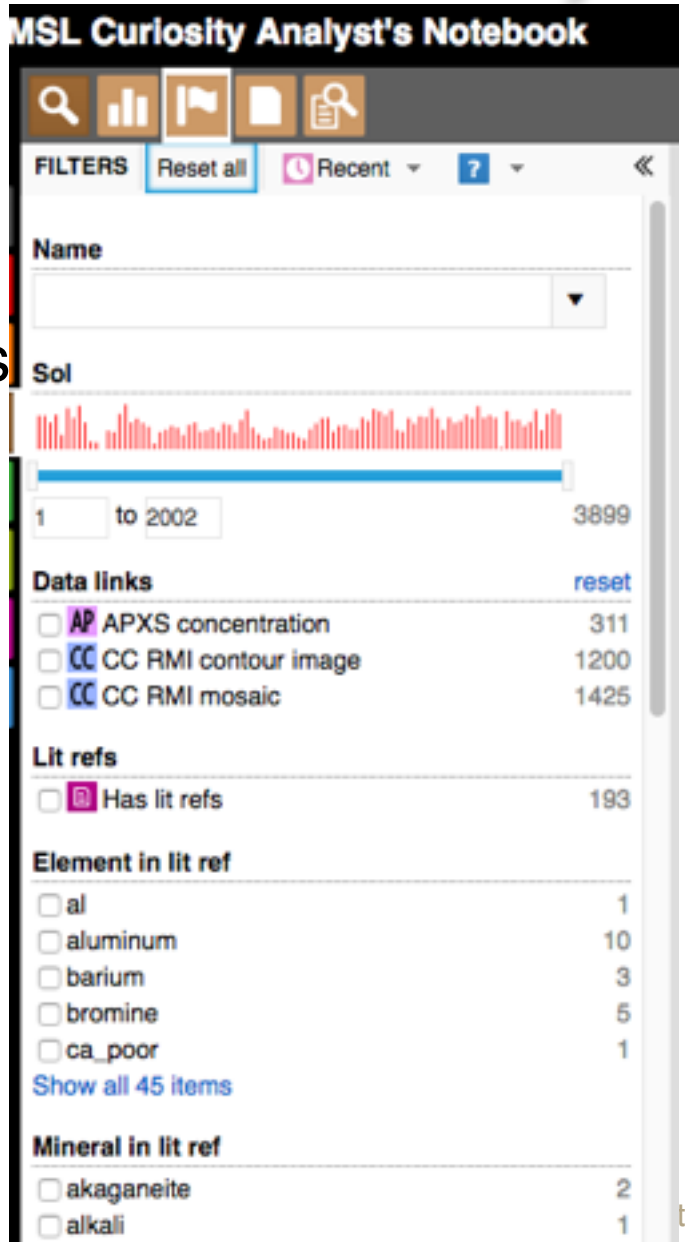
Map display of search results

Thanks: Fred Calef (MMGIS)

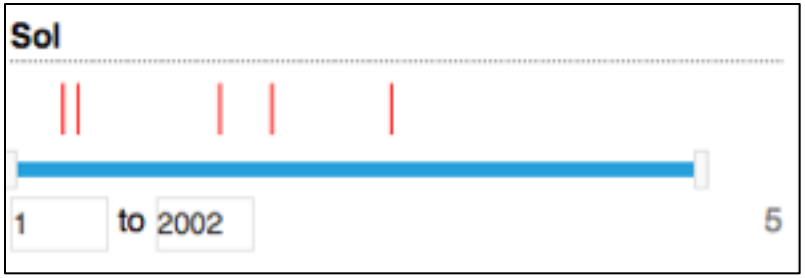


Integration with MSL Analyst's Notebook

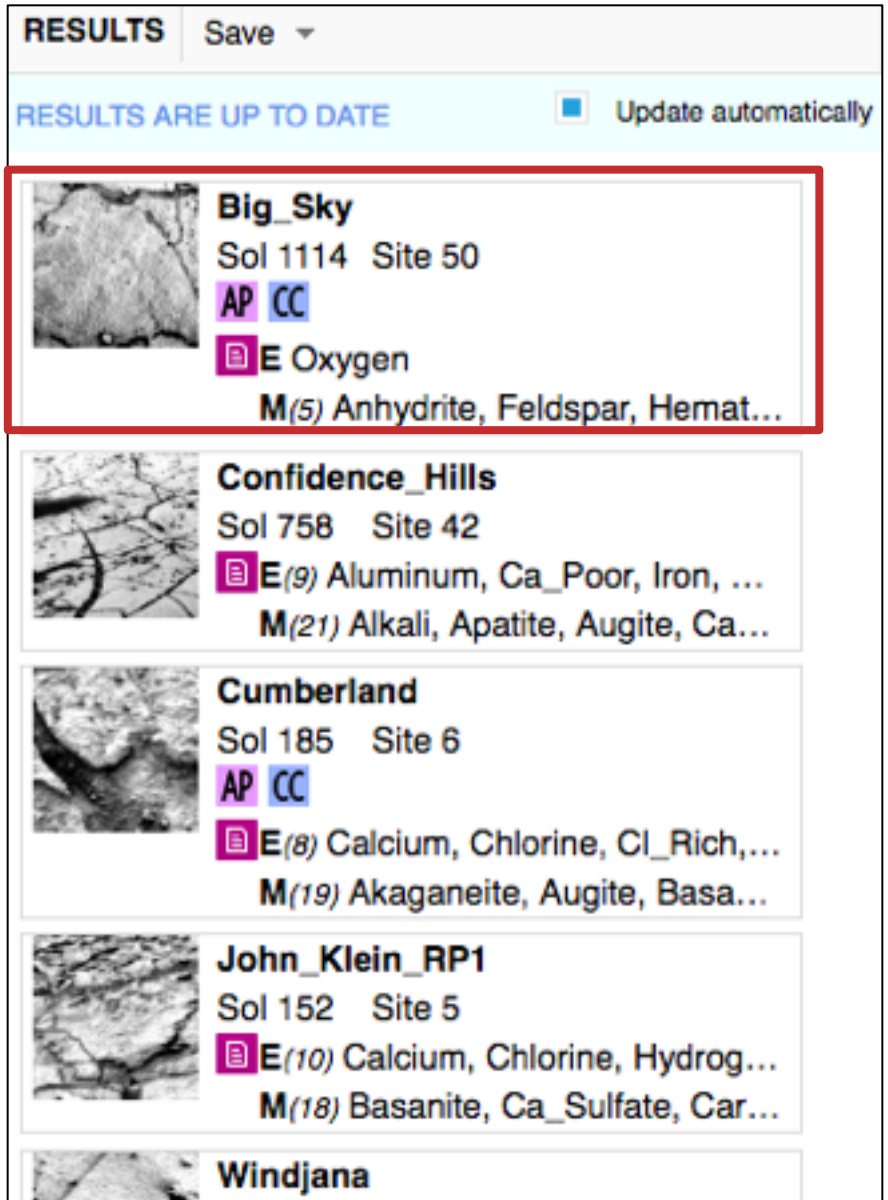
https://an.rsl.wustl.edu/ms



Integration with MSL Analyst's Notebook



Integration with MSL Analyst's Notebook



Integration with MSL Analyst's Notebook

https://an.rsl.wustl.edu/msl/

Target Big_Sky
Target defined on Sol 1114 Site 50 / 592

Compositional references

Element	References to elemental composition of this target, with relevant excerpts
	Oxygen
Mineral	References to mineral composition of this target, with relevant excerpts
	Anhydrite Feldspar Hematite Magnetite Pyroxene

Integration with MSL Analyst's Notebook

https://an.rsl.wustl.edu/msl/

Target Big_Sky
Target defined on Sol 1114 Site 50 / 592

Compositional references - Mineral

Anhydrite

Yen et al. (2016) "Cementation And Aqueous Alteration Of A Sandstone Unit Under Acidic Conditions In Gale Crater, Mars", Lunar and Planetary Science Conference, Abstract #1649.

"In comparison , the Big Sky sandstone has strikingly similar abundances of feldspar , pyroxene , amorphous constituents , anhydrite and other phases ."

Feldspar

Yen et al. (2016) "Cementation And Aqueous Alteration Of A Sandstone Unit Under Acidic Conditions In Gale Crater, Mars", Lunar and Planetary Science Conference, Abstract #1649.

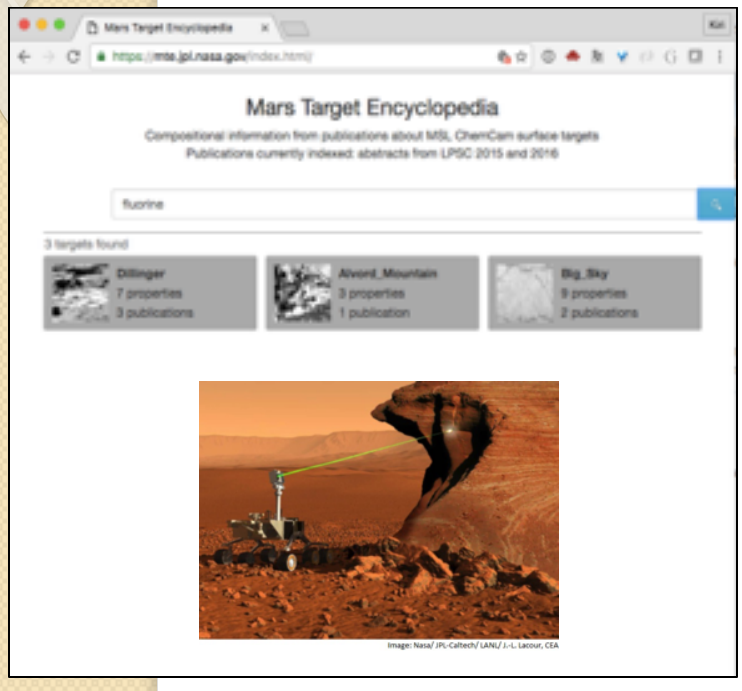
"In comparison , the Big Sky sandstone has strikingly similar abundances of feldspar , pyroxene , amorphous constituents , anhydrite and other phases ."

Hematite

Johnson et al. (2016) "ChemCam Passive Reflectance Spectroscopy Of Recent Drill Tailings, Hematite-Bearing Rocks, And Dune Sands", Lunar and Planetary Science Conference, Abstract #1155.

"The Big Sky tailings were spectrally flat (similar to Telegraph Peak) likely from the presence of magnetite , and include a weak downturn > 750 nm , possibly from minor hematite ."

Summary



- Information extraction for scientific publications
- Enable searches not previously possible
- Facilitate scientific progress and exploration using artificial intelligence methods
- Make discoveries accessible to everyone

https://an.rsl.wustl.edu/msl/

Thank you: JPL MGSS program, NASA Planetary Data System, and MSL project