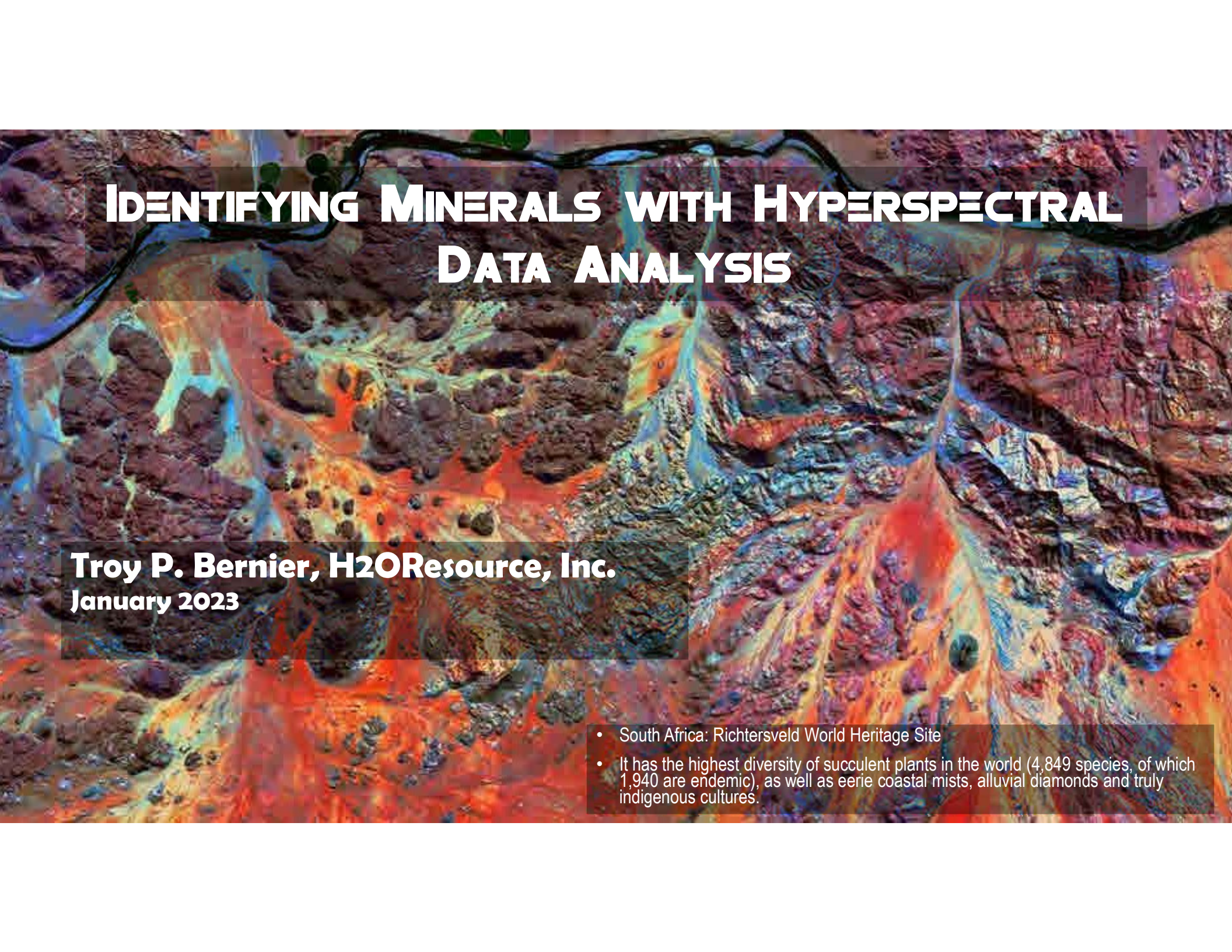


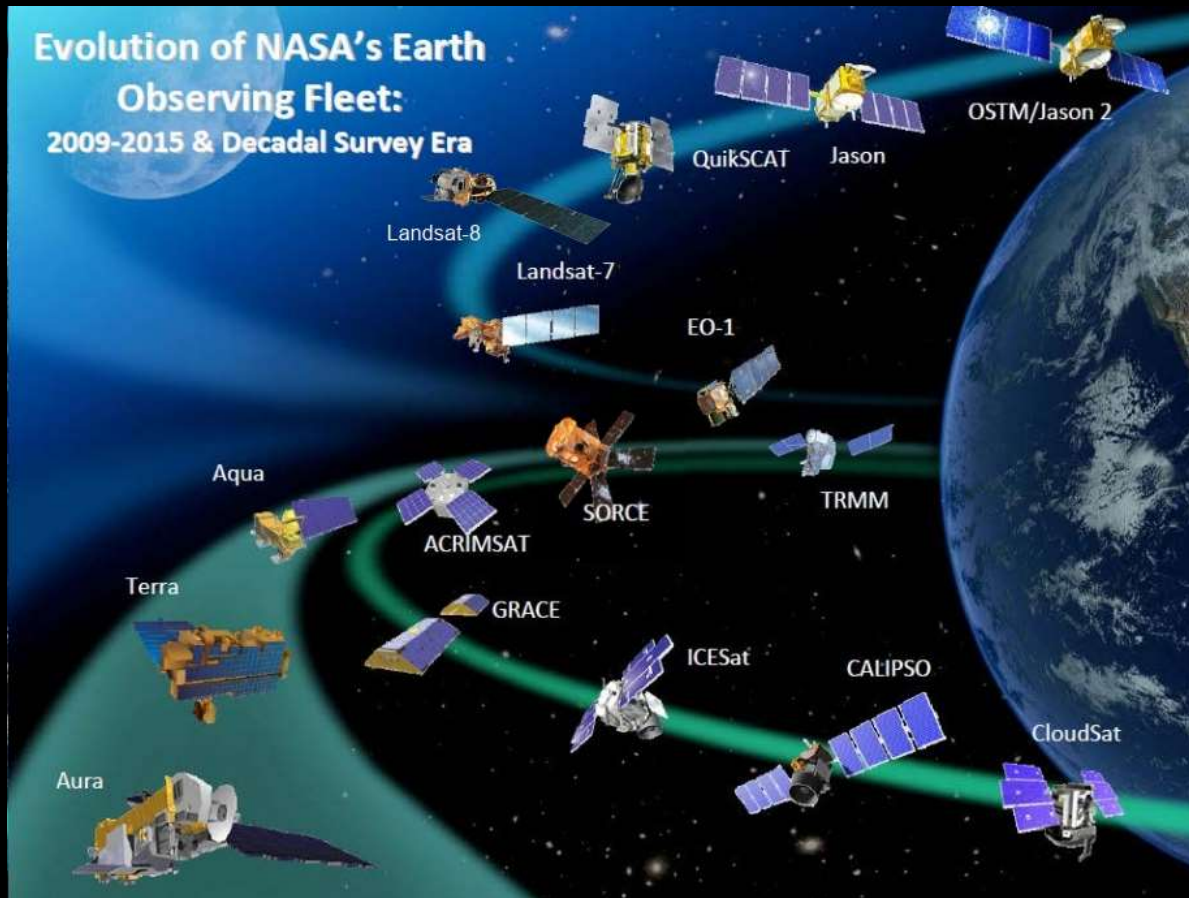


IDENTIFYING MINERALS WITH HYPERSPECTRAL DATA ANALYSIS

Troy P. Bernier, H2OResource, Inc.
January 2023

- South Africa: Richtersveld World Heritage Site
- It has the highest diversity of succulent plants in the world (4,849 species, of which 1,940 are endemic), as well as eerie coastal mists, alluvial diamonds and truly indigenous cultures.

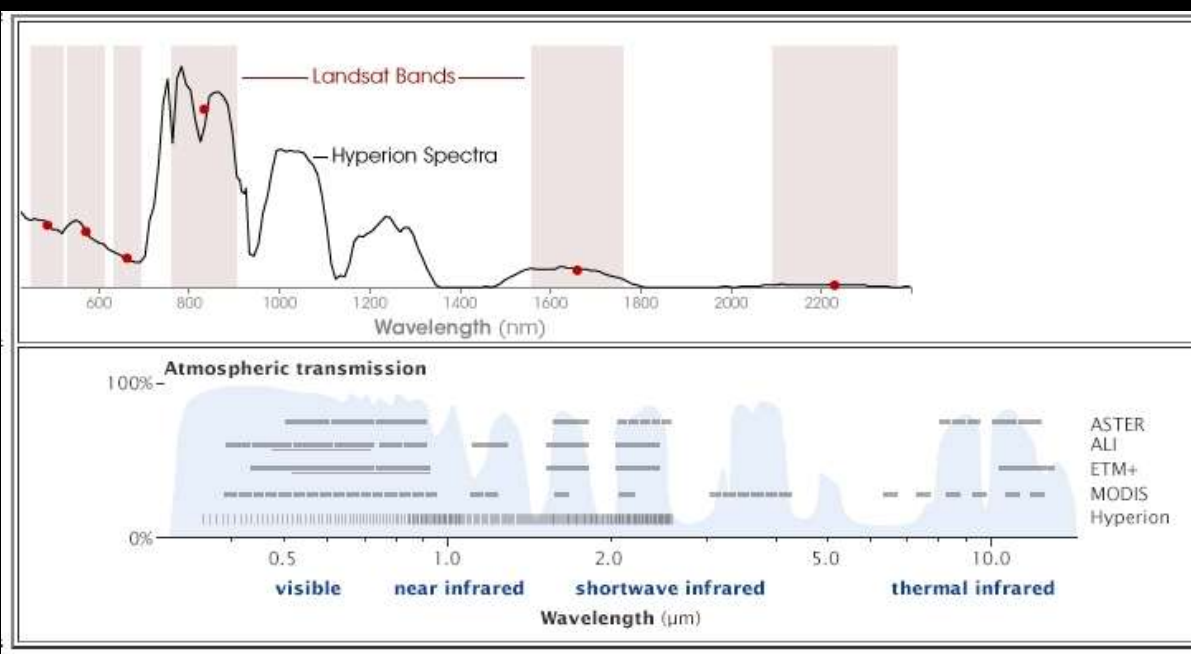
Hyperspectral technology has been around for a few decades.



Starting with Landsat 8,
Pushbroom methodology was applied
See video

Major Disadvantage,
The multidimensional datasets can be massive,
where the map of a county would be in the
hundreds of terabytes. Therefore,
improvements in hyperspectral resolution
improve the storage requirements and price
increases.

Troy P. Bernier, H2OResource, Inc.
January 2023



Initially developed for mining and geology, today, there's a wide range of hardware sizes and applications;

Agriculture

Waste Sorting and recycling

Eye Care

Food Processing

Surveillance

Astronomy

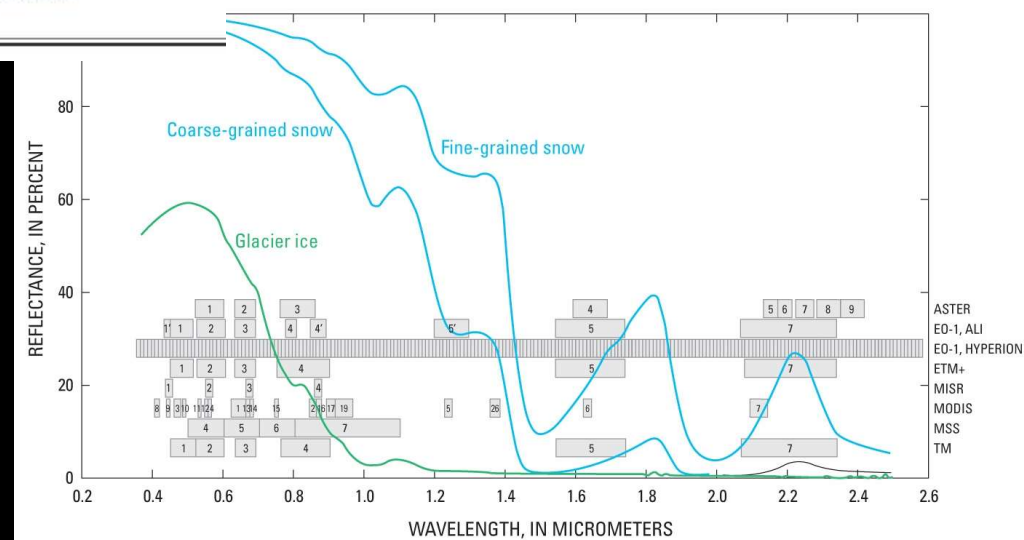
Environmental Monitoring

Biomedical Imaging

and more

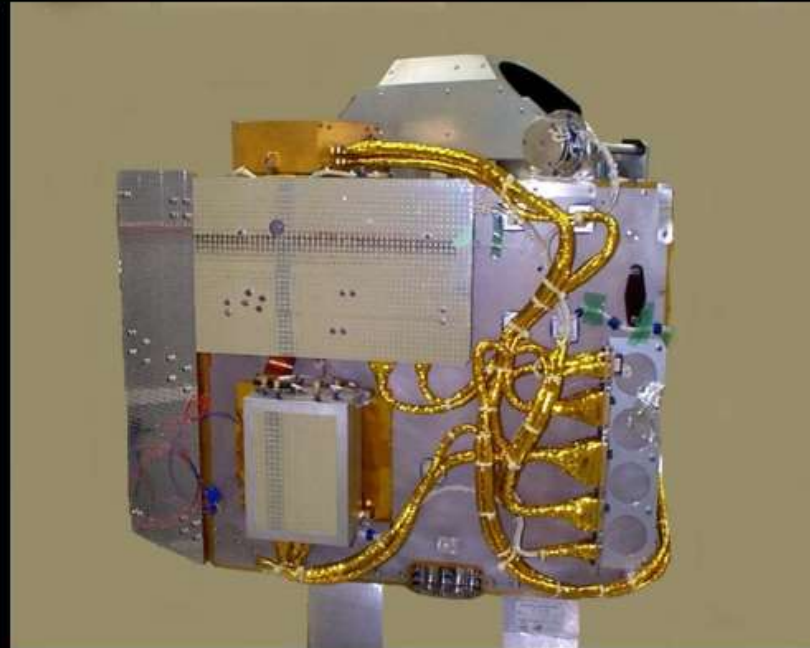
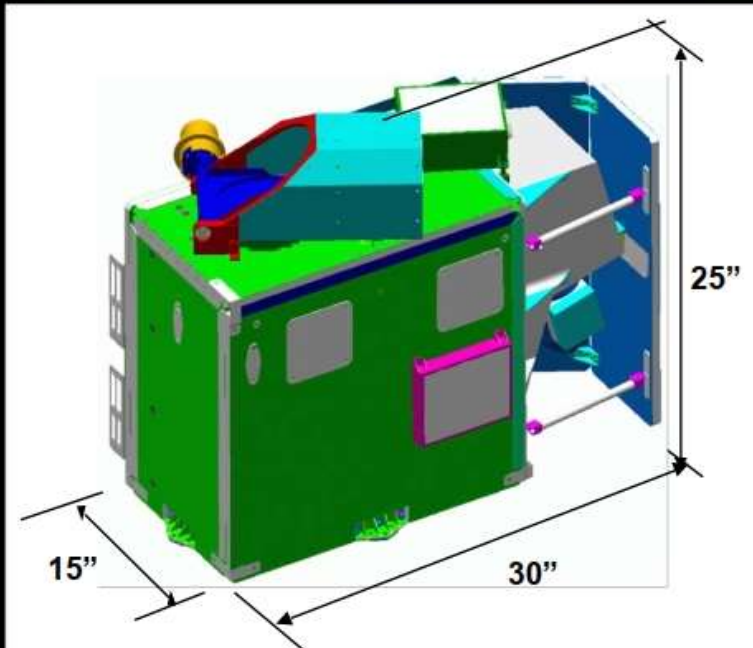
From a segmented set of wavelets such as with Landsat to a continuous spectra with hyperspectral

Troy P. Bernier, H2OResource, Inc.
January 2023





Hyperion Imaging Spectrometer



Hyperion is a push-broom imager

- 220 10nm bands covering 400nm - 2500nm
 - 6% absolute rad. accuracy
 - Swath width of 7.5 km
 - IFOV of 42.4 μ radian
 - GSD of 30 m
 - 12-bit image data
 - Orbit is 705km alt (16 day repeat)
- Convex Grating spectrometers with CCD VNIR and HgCdTe SWIR detectors (60 μ m pixels)
 - 30m spatial and 10nm spectral resolutions over 7.5km swath and 400-2500nm spectral range
 - Multiple calibration options: lamps, lunar, solar, ground imaging and laboratory
 - Hyperspectral Imaging Capability to address Earth Observation applications



A wide range of cameras have
be produced for the numerous
applications



SWIR Hyperspectral Camera 13.00°W x 32.00°D x 13.00°H ATH1015-17	Hyperspectral Camera VNIR 400-1000nm 90.80°W x 90.80°D x 121.00°H ATH1010 ★★★★★ Add To Cart Buy Now Add To Wishlist Compare	VIS-NIR Hyperspectral Camera 66.00°W x 132.00°D x 66.00°H ATH1500	300nm	Handheld Hyperspectral Camera VNIR 400-1700nm 90.80°W x 90.80°D x 121.00°H ATH2000-4-17	Hyperspectral Imaging Microscope 0.00°W x 0.00°D x 0.00°H ATH6500-17
VIS-NIR Hyperspectral Camera 66.00°W x 132.00°D x 66.00°H	Hyperspectral Imager VNIR 400-1000nm And Wider FOV 90.80°W x 90.80°D x 121.00°H	1000-1700nm Short-Wave Infrared Hyperspectral Imager 66.00°W x 132.00°D x 66.00°H	nm)	Portable Ground Imaging System-ATH6500 0.00°W x 0.00°D x 0.00°H ATH6500 Add To Cart Buy Now	Portable Ground Imaging System-ATH6500-17 0.00°W x 0.00°D x 0.00°H ATH6500-17

Troy P. Bernier,
H2OResource, Inc.
January 2023

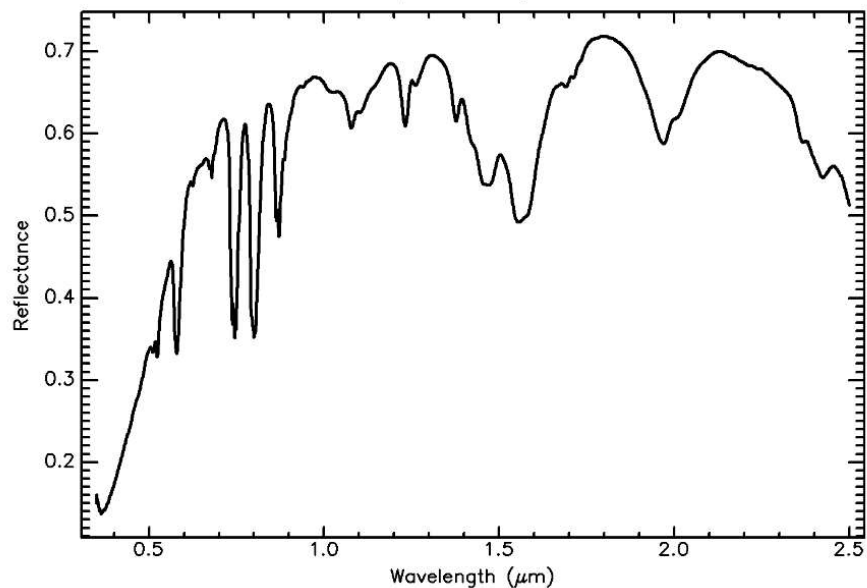


Sources/Usage: Public Domain.

Raymond Kokaly (USGS research geophysicist) conducting ground-based hyperspectral imaging of hydrothermally-altered rock at Cuprite, NV.

Monazite_REE GDS947 Calif ASDFRb AREF (splib07a rec=7102)

Formula=(Ce,La,Nd,Th)PO₄
Mineral=Monazite Type=Phosphate
Spectral Purity=b

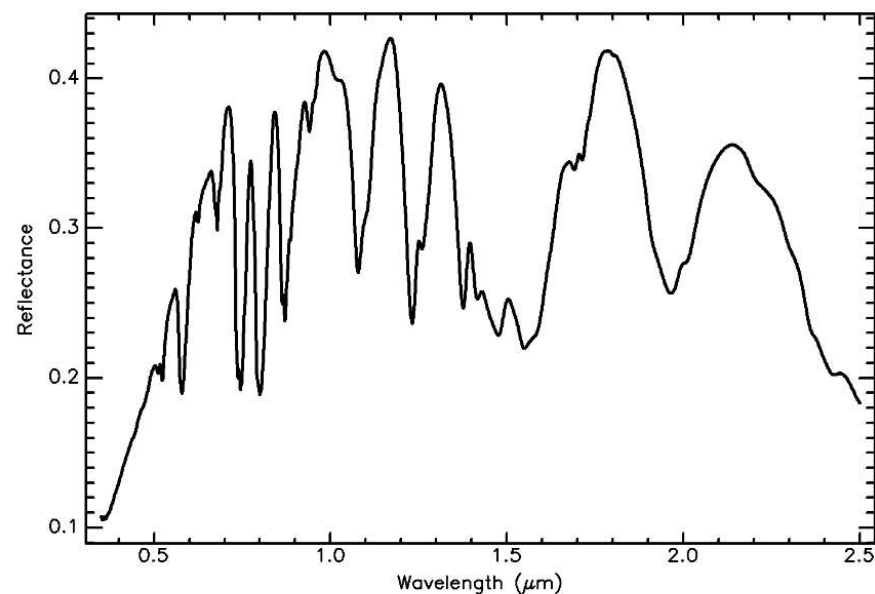


Citation: Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Lowers, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., <https://doi.org/10.3133/ds1035>

ASCII data=splib07a_Monazite_REE_GDS947_Calif_ASDFRb_AREF.txt HTML metadata=Monazite_REE_GDS947_Calif_ASDFRb_AREF.html

Monazite_REE GDS955 Iveland ASDFRb AREF (splib07a rec=7111)

Formula=(Ce,La,Nd,Th)PO₄
Mineral=Monazite Type=Phosphate
Spectral Purity=b



Citation: Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Lowers, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., <https://doi.org/10.3133/ds1035>

ASCII data=splib07a_Monazite_REE_GDS955_Iveland_ASDFRb_AREF.txt HTML metadata=Monazite_REE_GDS955_Iveland_ASDFRb_AREF.html

TITLE: Monazite_REE GDS947 Calif DESCRIPT

DOCUMENTATION_FORMAT: MINERAL

SAMPLE_ID: GDS947

MINERAL_TYPE: Phosphate

MINERAL: Monazite

FORMULA: (Ce,Lu,Nd,Th)PO₄

FORMULA_HTML: (Ce,Lu,Nd,Th)PO₄

COLLECTION_LOCALITY: near Ione, CA

ORIGINAL_DONOR: James Post

CURRENT_SAMPLE_LOCATION: USGS Denver Spectroscopy Laboratory

ULTIMATE_SAMPLE_LOCATION: USGS Denver Spectroscopy Laboratory

SAMPLE_DESCRIPTION: Fine brown powder.

IMAGE_OF_SAMPLE:

END_SAMPLE_DESCRIPTION:

XRD_ANALYSIS:

Near-monomineralic monazite. Ce-bearing monazite is a best fit. There is a trace unidentified phase present in this sample, possibly a clay or mica phase indicated by low angle peaks. (R. Driscoll)

END_XRD_ANALYSIS:

COMPOSITIONAL_ANALYSIS_TYPE: None # XRF, EPMA, ICP(Trace), WChem

COMPOSITION_TRACE:

COMPOSITION_DISCUSSION:

END_COMPOSITION_DISCUSSION:

MICROSCOPIC_EXAMINATION:

END_MICROSCOPIC_EXAMINATION:

SPECTROSCOPIC_DISCUSSION:

The spectrum of this sample was measured on what resembles a single monazite crystal. There are numerous intense sharp absorptions (f-f orbital electronic transitions) throughout the 0.35 to 1.35 micron region presumably due to variable proportions of lanthanide series rare earth elements (i.e., Nd, Sm, and others). (G. Swayze)

END_SPECTROSCOPIC_DISCUSSION:

SPECTRAL_PURITY: 1b2_3_4_ # GDS947 # 1= 0.2-3, 2= 1.5-6, 3= 6-25, 4= 20-150 microns

TITLE: Monazite_REE GDS955 Iveland DESCRIPT

DOCUMENTATION_FORMAT: MINERAL

SAMPLE_ID: GDS955

MINERAL_TYPE: Phosphate

MINERAL: Monazite

FORMULA: (Ce,Lu,Nd,Th)PO₄

FORMULA_HTML: (Ce,Lu,Nd,Th)PO₄

COLLECTION_LOCALITY: Iveland, Setesdal, Norway

ORIGINAL_DONOR: Minerals Unlimited

CURRENT_SAMPLE_LOCATION: USGS Denver Spectroscopy Laboratory

ULTIMATE_SAMPLE_LOCATION: USGS Denver Spectroscopy Laboratory

SAMPLE_DESCRIPTION: Large single mottled reddish-brown crystal.

IMAGE_OF_SAMPLE:

END_SAMPLE_DESCRIPTION:

XRD_ANALYSIS:

Measurements are compatible with either a Ce-bearing or Pr-bearing monazite. Minor muscovite was also detected. (R. Driscoll)

END_XRD_ANALYSIS:

COMPOSITIONAL_ANALYSIS_TYPE: None # XRF, EPMA, ICP(Trace), WChem

COMPOSITION_TRACE:

COMPOSITION_DISCUSSION:

END_COMPOSITION_DISCUSSION:

MICROSCOPIC_EXAMINATION:

END_MICROSCOPIC_EXAMINATION:

SPECTROSCOPIC_DISCUSSION:

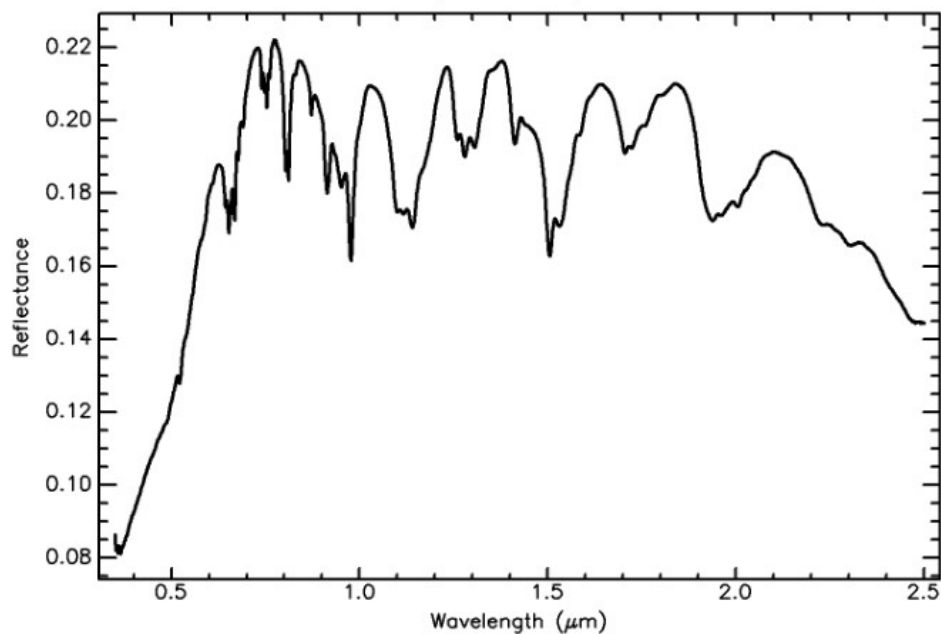
The spectrum of this sample was measured on what resembles a single monazite crystal. There are numerous intense sharp absorptions (f-f orbital electronic transitions) throughout the 0.35 to 1.35 micron region presumably due to variable proportions of lanthanide series rare earth elements (i.e., Nd, Sm, and others). (G. Swayze)

END_SPECTROSCOPIC_DISCUSSION:

SPECTRAL_PURITY: 1b2_3_4_ # GDS955 # 1= 0.2-3, 2= 1.5-6, 3= 6-25, 4= 20-150 microns

Xenotime GDS966 Iveland REE ASDFRa AREF (splib07a rec=11525)

Formula=Y(PO₄)
Mineral=Xenotime Type=Phosphate
Spectral Purity=a

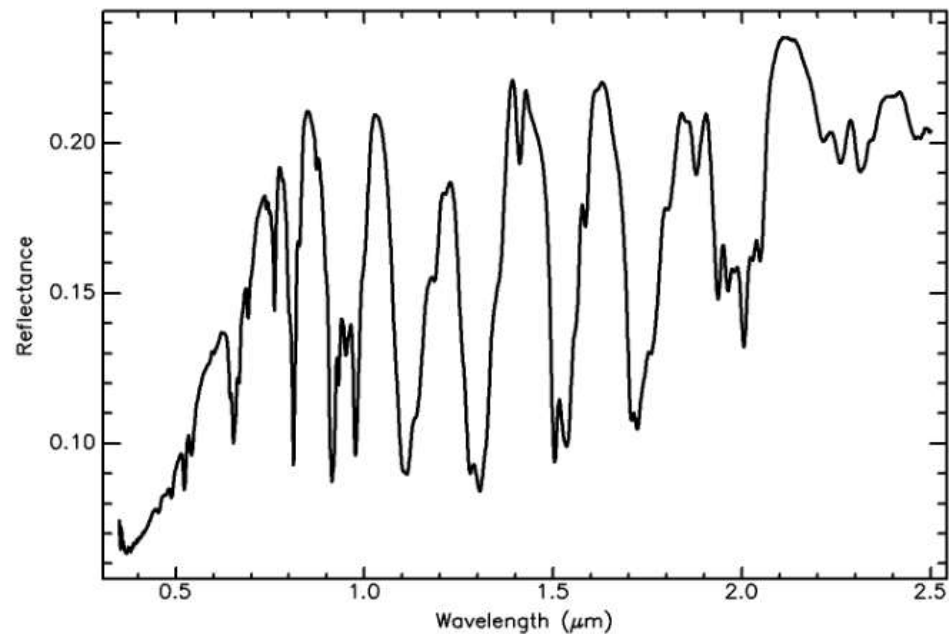


Citation: Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Leners, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., <https://doi.org/10.3133/ds1035>

ASCII data=splib07a_Xenotime_GDS966_Iveland_REE_ASDFRa_AREF.txt HTML metadata=Xenotime_GDS966_Iveland_REE_ASDFRa_AREF.html

Xenotime+Monazite_REE WS384 ASDFRa AREF (splib07a rec=13367)

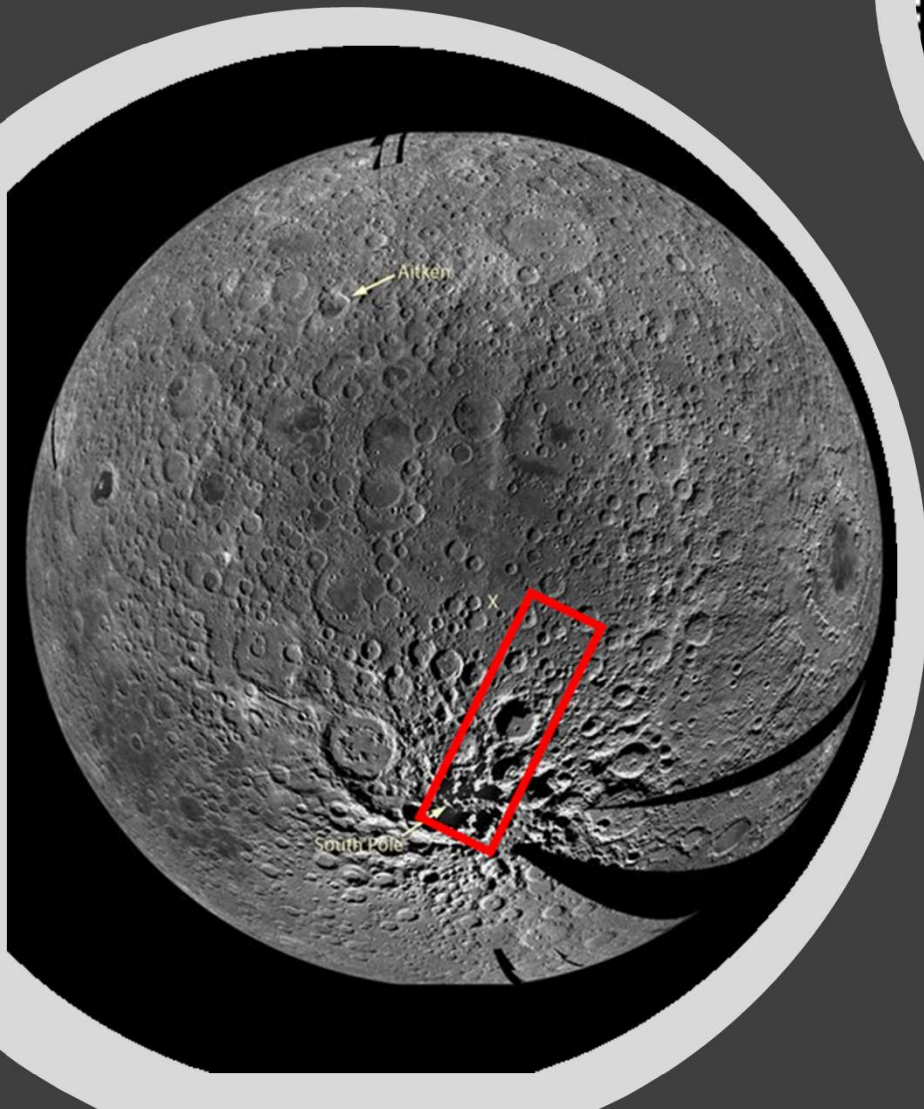
Formula=Y(PO₄)
Mineral=Xenotime (Hussakite) Type=Phosphate
Spectral Purity=a



Citation: Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Leners, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., <https://doi.org/10.3133/ds1035>

ASCII data=splib07a_Xenotime+Monazite_REE_WS384_ASDFRa_AREF.txt HTML metadata=Xenotime+Monazite_REE_WS384_ASDFRa_AREF.html

Troy P. Bernier,
H2OResource, Inc.
January 2023



Lunar Features



<https://www.enchantedlearning.com/subjects/astronomy/moon/>

Description of the moon

- Average distance to earth: 238, 900 mile (384, 000 km)
- Closest approach: 221, 460 miles
- Farthest approach: 252, 700 miles
- Diameter: 2169 miles (27% of earth's)
- Synchronous rotation
- Density: 3340 kg/m^3 (3/5 of earth's)
- Gravitational force=17% of the earth's
- Surface temperature range: -170C to +140C

A Selection of Previous Works

Troy P. Bernier,
H2OResource, Inc.
January 2023

Isaacson, P. J., Pieters, C. M., Besse, S., Clark, R. N., Head, J. W., Klima, R. L., ... & Taylor, L. A. (2011). Remote compositional analysis of lunar olivine-rich lithologies with Moon Mineralogy Mapper (M3) spectra. *Journal of Geophysical Research: Planets*, 116(E6).

Prettyman, T. H., Hagerty, J. J., Elphic, R. C., Feldman, W. C., Lawrence, D. J., McKinney, G. W., & Vaniman, D. T. (2006). Elemental composition of the lunar surface: Analysis of gamma ray spectroscopy data from Lunar Prospector. *Journal of Geophysical Research: Planets*, 111(E12).

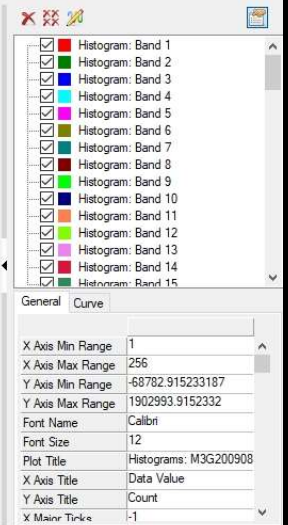
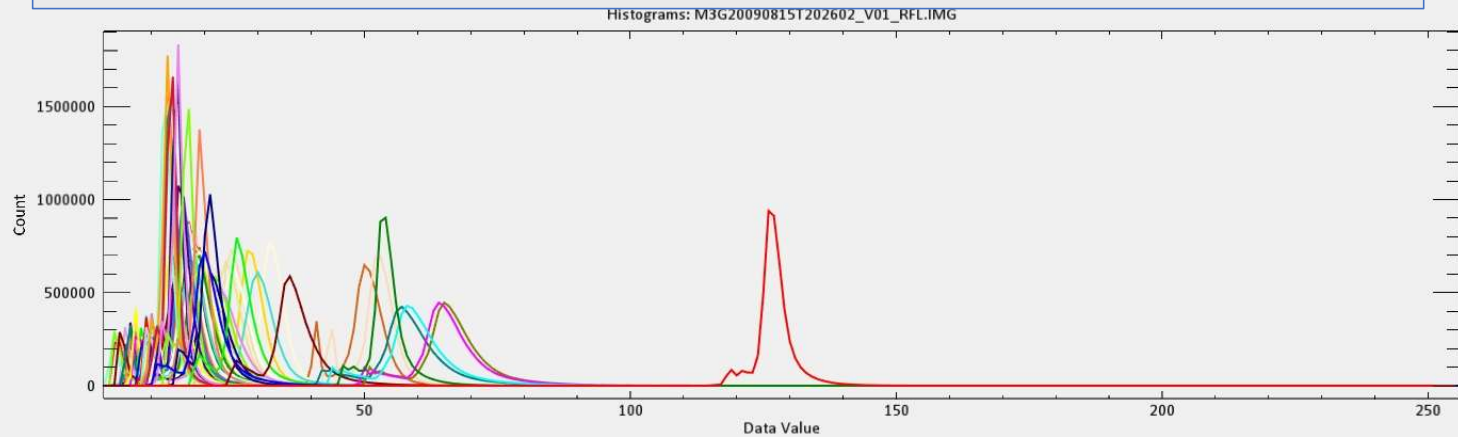
Lucey, P. G., Blewett, D. T., & Hawke, B. R. (1998). Mapping the FeO and TiO₂ content of the lunar surface with multispectral imagery. *Journal of Geophysical Research: Planets*, 103(E2), 3679-3699.

Crown, D. A., & Pieters, C. M. (1987). Spectral properties of plagioclase and pyroxene mixtures and the interpretation of lunar soil spectra. *Icarus*, 72(3), 492-506.

Bielefeld, M. J., Reedy, R. C., Metzger, A. E., Trombka, J. I., & Arnold, J. R. (1976, April). Surface chemistry of selected lunar regions. In *Lunar and Planetary Science Conference Proceedings* (Vol. 7, pp. 2661-2676).

Lyon, R. J. P. (1963). Evaluation of infrared spectrophotometry for compositional analysis of lunar and planetary soils.

Hyperspectral methods reveal a multitude of minerals



Band 7	-0.136890	0.701925	0.054067	0.026969
Band 8	-0.119523	1.108500	0.055452	0.027809
Band 9	-0.117264	1.564003	0.056348	0.028008
Band 10	-0.128045	2.143814	0.057206	0.028335
Band 11	-0.164052	2.846033	0.058723	0.028607
Band 12	-0.175912	3.482827	0.059451	0.028947
Band 13	-0.188103	4.160017	0.060025	0.029445
Band 14	-0.170428	4.258111	0.060472	0.029725
Band 15	-0.173173	4.352674	0.060905	0.030074
Band 16	-0.184034	4.183251	0.060851	0.030382
Band 17	-0.148322	4.087753	0.060738	0.030397
Band 18	-0.146083	4.181935	0.060898	0.030698
Band 19	-0.148887	3.981006	0.061459	0.031122
Band 20	-0.123829	3.615960	0.062093	0.031389
Band 21	-0.110750	3.239197	0.062782	0.032088
Band 22	-0.108652	2.794058	0.063829	0.032679
Band 23	-0.099893	2.592756	0.065378	0.033576
Band 24	-0.087969	2.405460	0.066579	0.034415
Band 25	-0.080603	2.400486	0.068116	0.035029
Band 26	-0.076352	2.162722	0.069534	0.035895
Band 27	-0.076736	2.112823	0.070701	0.036487
Band 28	-0.074692	2.039603	0.071997	0.037324

- To assess the abundance and distribution of lunar resources for the feasibility of a permanent lunar base

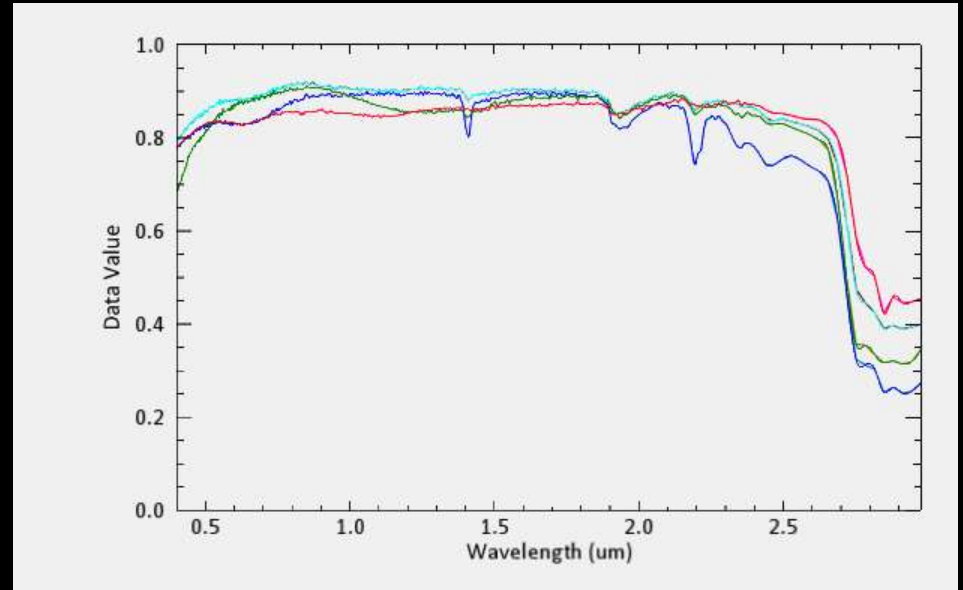
Lunar Minerals

- Numerous minerals species have been validated in the moon
- Moon surface rocks is made up mainly of a Anorthite $\text{CaAl}_2\text{Si}_2\text{O}_8$
- Anorthite is found in mafic igneous rocks
- Anorthite is a plagioclase feldspar
- Anorthite has about 20 % of Aluminum and will be the main ore for Aluminum and Calcium in the moon
- Other minerals are Bytownite and Labradorite

Papike, J., Taylor, L., & Simon, S. (1991). Lunar minerals. *Lunar sourcebook: A user's guide to the Moon*, 121-181.

Spectra Analysis - Anorthite

- Mineral identification
Plagioclase/Albite/Anorthite
- Green Pigment Possibly
Regolith Fines
- Red Pigment Possibly
Plagioclase, Albite, Anorthite
- Tools Used
ENVI/ERDAS



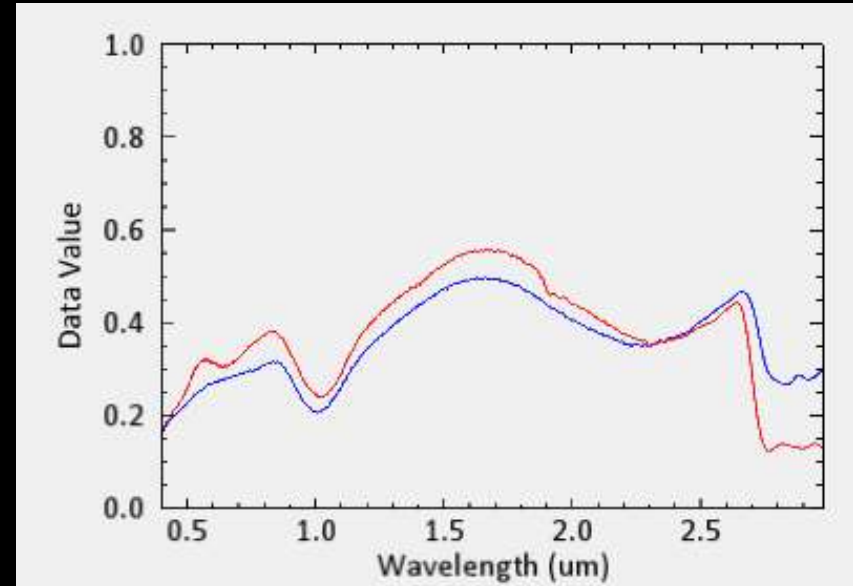
Albite ($\text{NaAlSi}_3\text{O}_8$)

High chemical variability occur between Albite and Anorthite
Lunar plagioclase have less sodium compared to terrestrial plagioclase

Source: Papike, J., Taylor, L., & Simon, S. (1991). Lunar minerals. *Lunar sourcebook: A user's guide to the Moon*, 121-181.

Spectra Analysis - Augite

- Mineral identification
Augite
- Dk Green Pigment Possibly
Augite
- Tools Used
ENVI/ERDAS

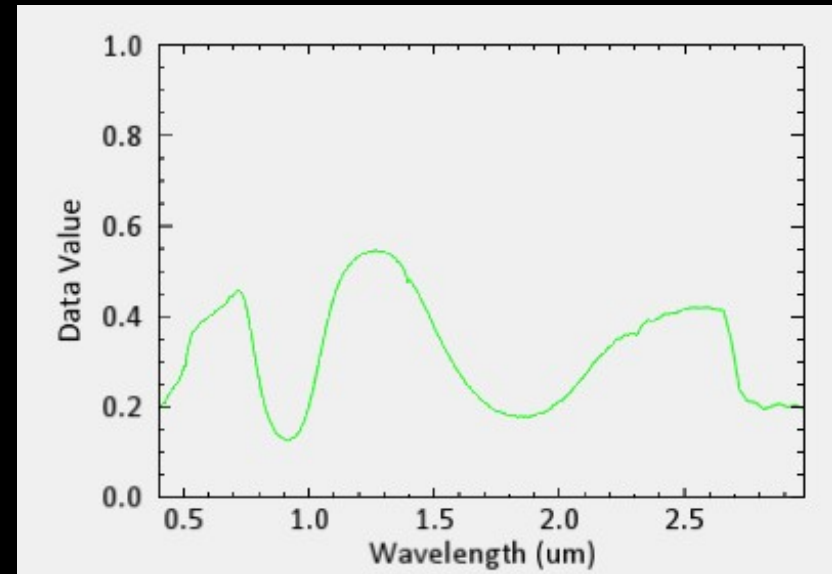
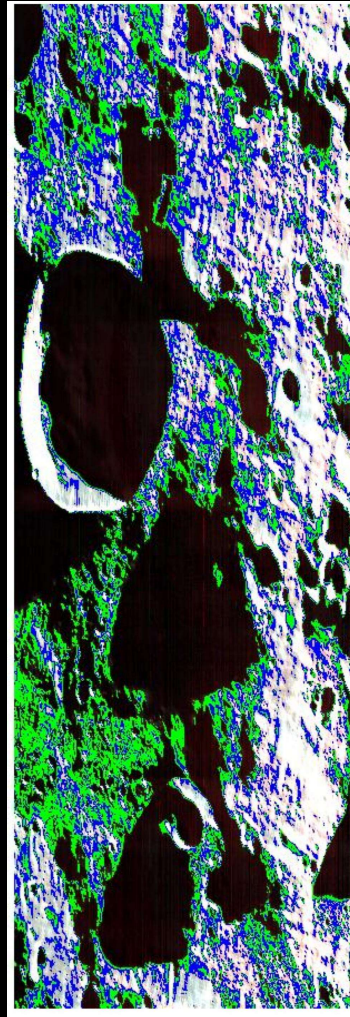


Augite - $(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}, \text{Al}, \text{Ti})(\text{Si}, \text{Al})_2\text{O}_6$
Pyroxenes and Pigeonites are expected

Source: Isaacson, P. J., Sarbadhikari, A. B., Pieters, C. M., Klima, R. L., Hiroi, T., Liu, Y., & Taylor, L. A. (2011). The lunar rock and mineral characterization consortium: Deconstruction and integrated mineralogical, petrologic, and spectroscopic analyses of mare basalts. *Meteoritics & Planetary Science*, 46(2), 228-251.

Spectra Analysis - Diopside

- Mineral identification
Diopside
- Blue and Green Pigment
Possibly Diopside with Ortho-
Clino-Pyroxene Mixtures
- Tools Used
ENVI/ERDAS

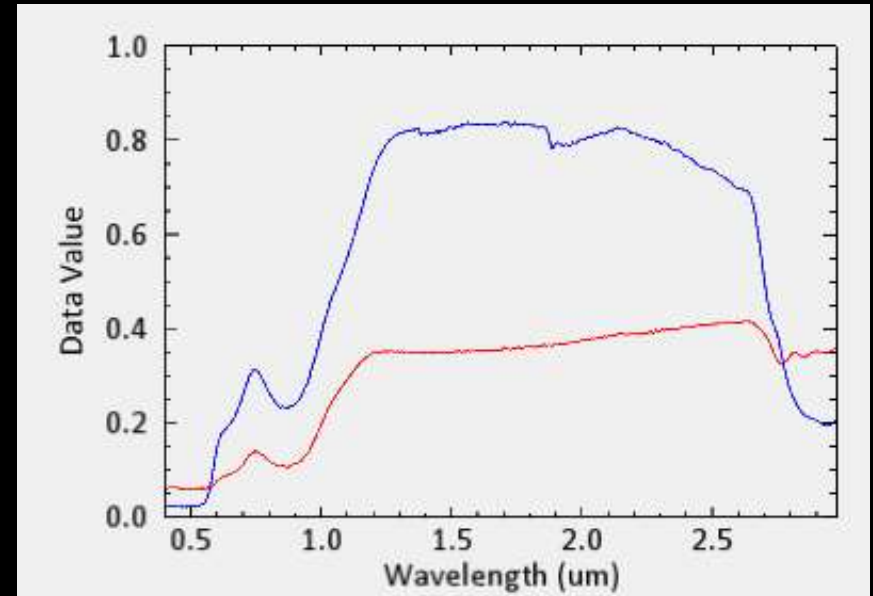
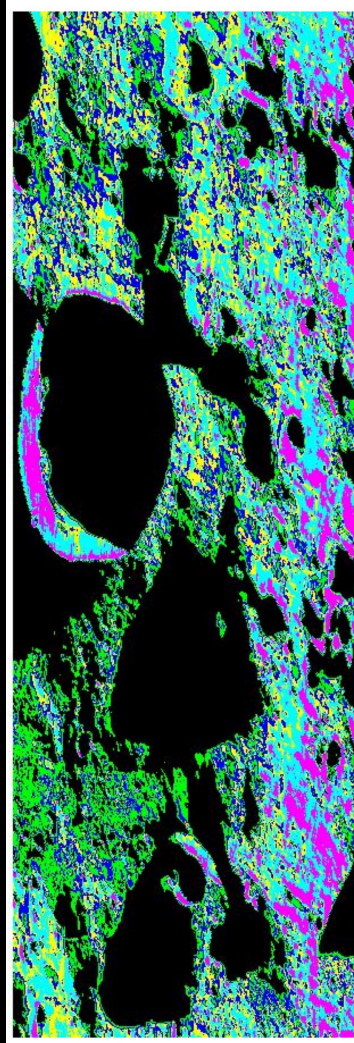


Diopside - $\text{MgCaSi}_2\text{O}_6$

Orthopyroxenes and Clinopyroxenes are expected

Spectra Analysis - Hematite

- Mineral identification Hematite
- Aqua Pigment Possibly reflects the broad spectral Hematite response between wavelength 1372 & 2576 nm
- Tools Used ENVI/ERDAS



Hematite - Fe_2O_3

While the moon is rich in iron bearing rocks, it does not have liquid water and oxygen.

The oxygen is thought to have been moved from the earth's upper atmosphere on the earth's magnetotail to the moon and reacted with moon's surface rocks to form hematite.

Future Work

- Image Processing is a complex task that requires numerous iterations.
- We desire to fine-tune our results to identify more minerals.
- Mineral quantification



Troy P. Bernier,
H2OResource, Inc.
January 2023

Conclusion

- There is an abundance of minerals on the moon.
- The exploration of these minerals will support the establishment of a human colony and manufacturing facilities.
- Further analysis will be done to quantify the minerals.
- Based on the current assessments, lunar settlements seem feasible.

Thank You