HYPERSPECTRAL:
IMPROVING ORE BODY KNOWLEDGE

An introduction to hyperspectral

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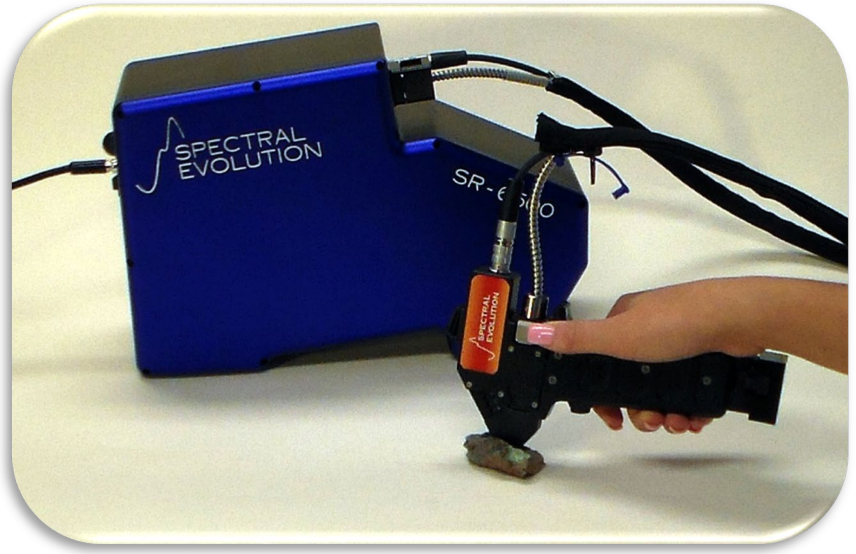
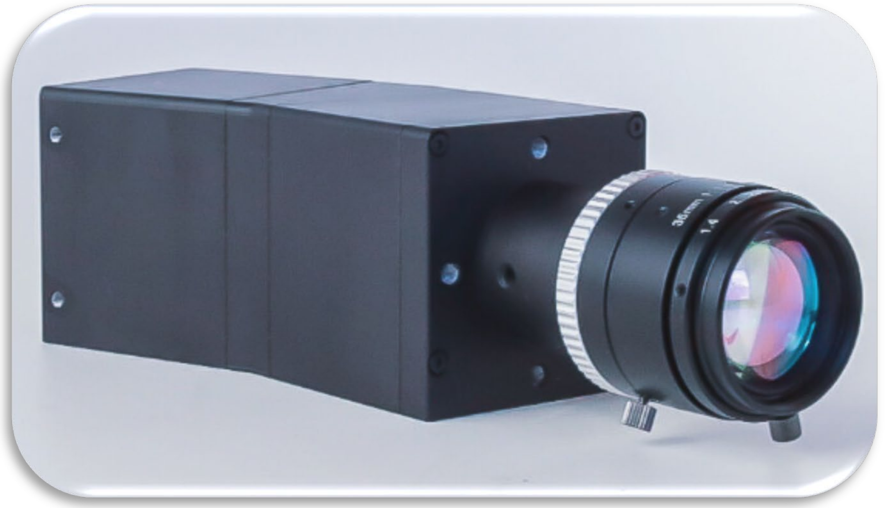
What does a hyperspectral instrument look like?





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Optical spectrometers

- Optical spectrometers measure the properties of light, usually near the optical region of the EM spectrum, i.e., UV, visible and IR light.
- The change in the absorption and emission of the light intensity with wavelength allows for the identification of materials.
- The process simplified:
  - Photons reach the detector (at specific wavelength) and are converted to electrons via the photoelectric effect.
  - These electrons at-detector are converted to a voltage
  - The voltage is digitized (turned into a number) by an Analog to Digital Converter (Digital Number – DN).
  - Each DN value is tallied and summed into a final spectral signature.
  - Radiance is derived by applying gain and offset values (inherent to sensor) to the DN values, resulting in a radiance signature.

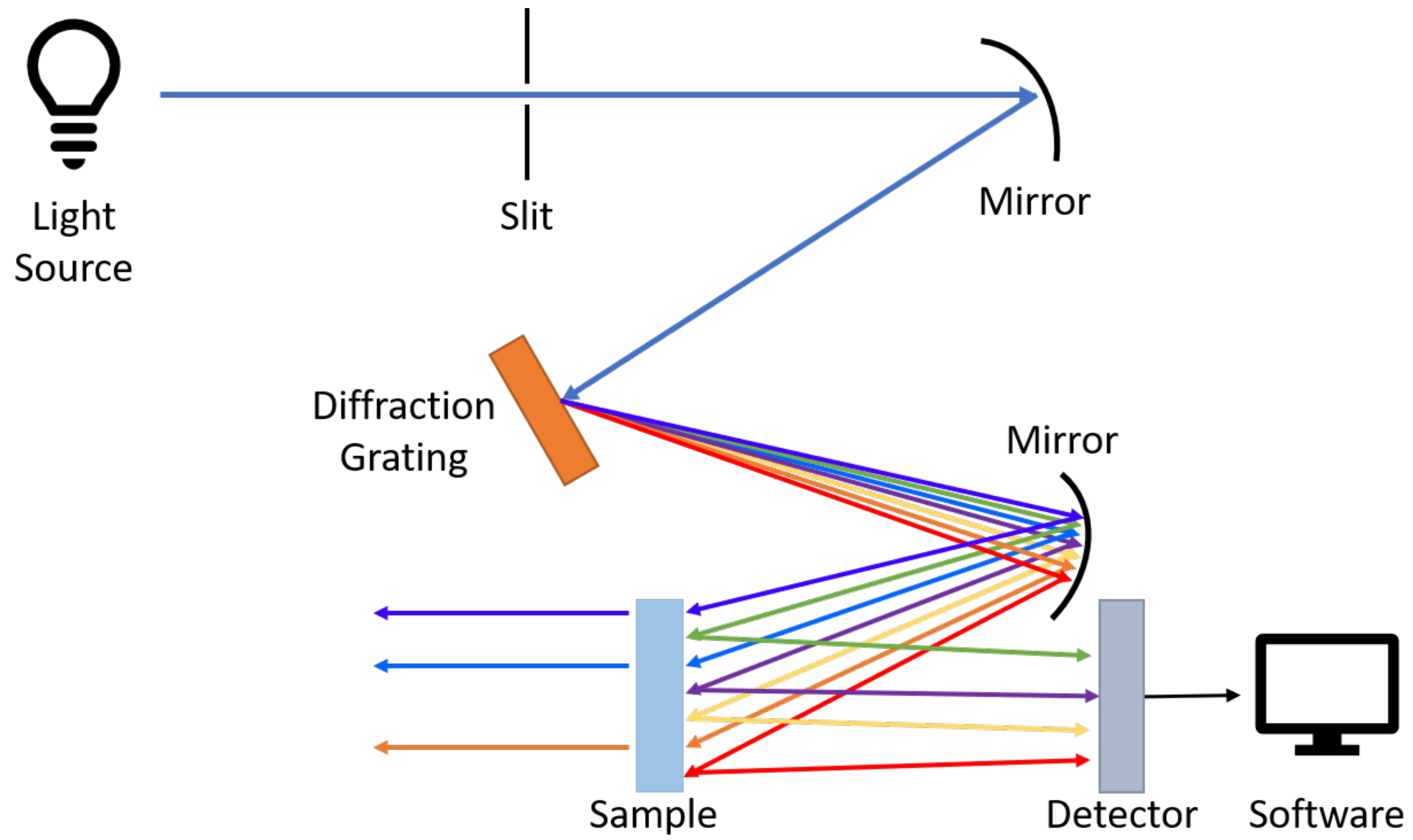

Image Credit: Wavelength Opto-Electronic

Spectroscopy is physics, a brief history:

1. **Sir Frederick William Herschell**
2. **James Clerk Maxwell**
3. **Max Planck**
4. **Albert Einstein**

1. Discovered the **visible light spectrum** and invisible light using a prism and thermometers.
2. Responsible for the classical theory of **EM radiation**, the first theory to describe electricity, magnetism and light as different manifestations of the same phenomenon. He demonstrated that electric and magnetic fields travel through space as waves moving at the speed of light. He also invented color photography…
3. The originator of **quantum theory**, describes light as more than wave energy, but also as discrete packets, or quanta, that can be both emitted and absorbed. Later these particles were named **photons**. Each photon has a very specific amount of energy, which corresponds to its wavelength – this allows geoscientists to identify everything from planets to minerals.
4. The **photoelectric effect** led to important steps in understand the quantum nature of light and electrons and influenced the formation of the concept of wave-particle duality. Light energy interacts with surface atoms, liberating electrons which we measure with detectors mounted on planes, spacecraft, imaging systems, etc.

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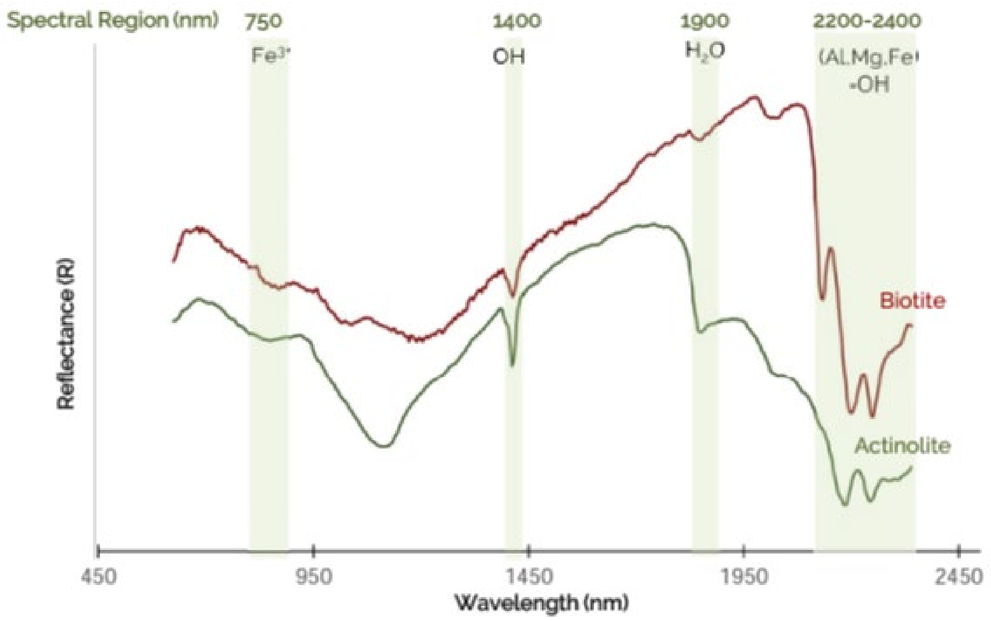
The physics of spectroscopy

- In order to understand basic spectral properties, we must understand the elementary physics of the interaction of electromagnetic (EM) energy with our targets (i.e., rocks).
- Namely, what IS light, how does it travel from point A to point B and what it does once it gets to point B (the basic interaction of light with other matter).



Spectra from Corescan skarn presentation (link).

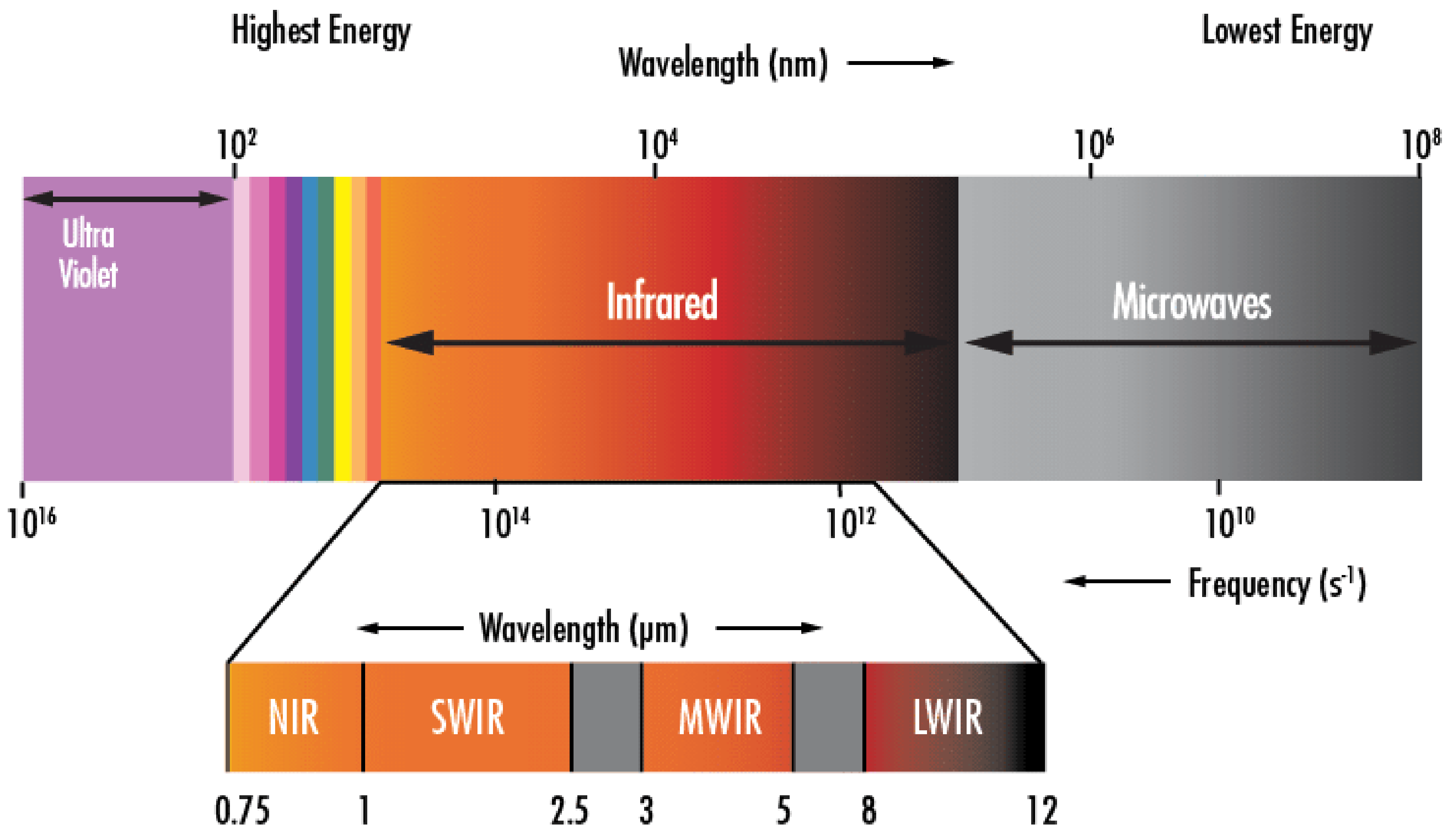
Electromagnetic energy (EM)

EM radiation refers to all energy that moves with the velocity of light in a harmonic wave pattern.

EM radiation spans an enormous range of wavelengths and frequencies and this range is known as the EM spectrum.

The EM spectrum is generally divided into seven regions, in order of decreasing wavelength and increasing energy and frequency with the wavelength is divided into discrete ranges (at right).

Spectral geology is the measurement and analysis of portions of the electromagnetic spectrum to identify spectrally distinct and physically significant features of different rock types and surface materials, their mineralogy and their alteration signatures.



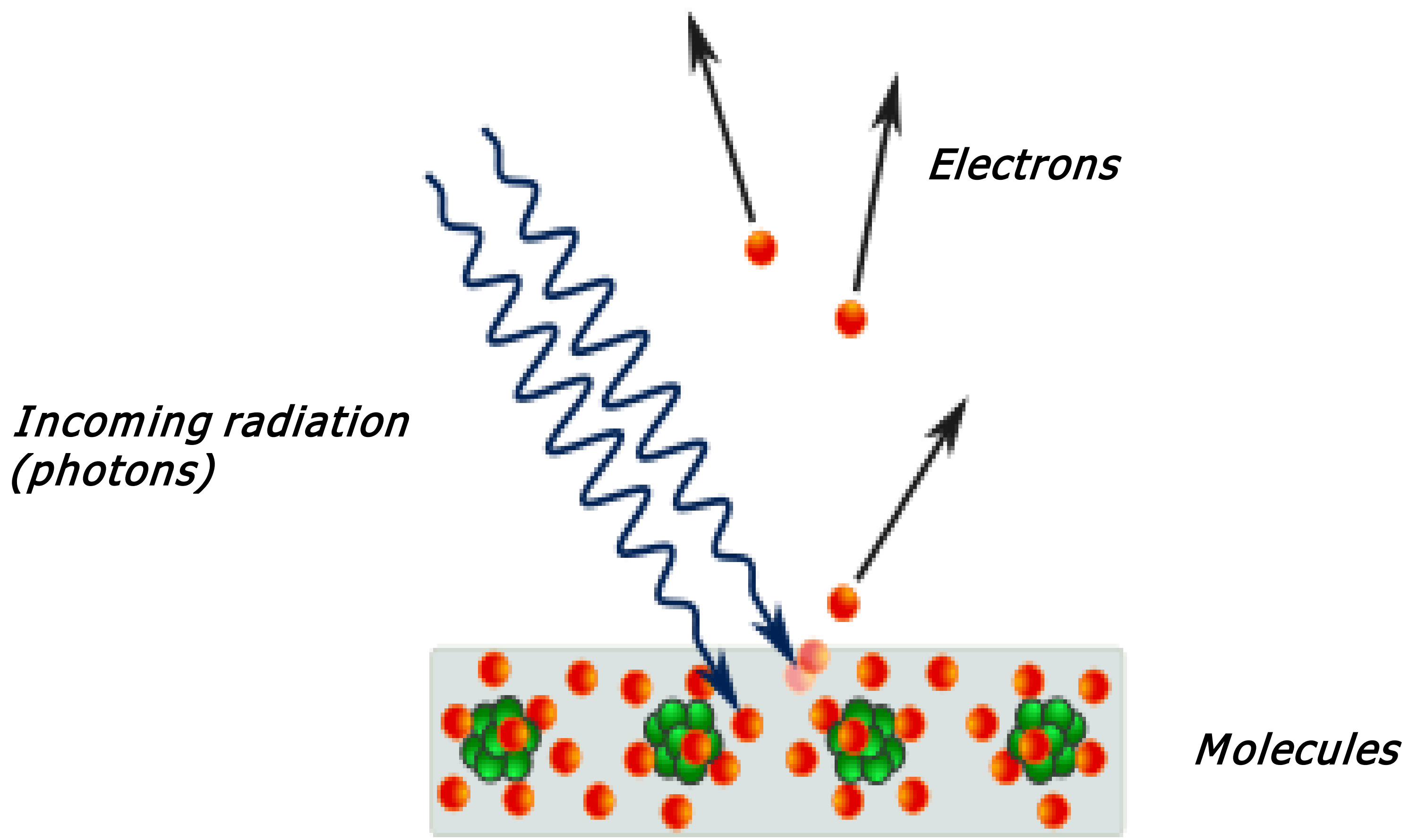
Mouahid, 2018

IR spectroscopy: absorption

This absorbed energy affects fundamental molecular dynamics and energy state.

Total energy contained within one molecule is the sum of:

- **Electronic Energy**
- **Vibrational Energy**
- Rotational Energy



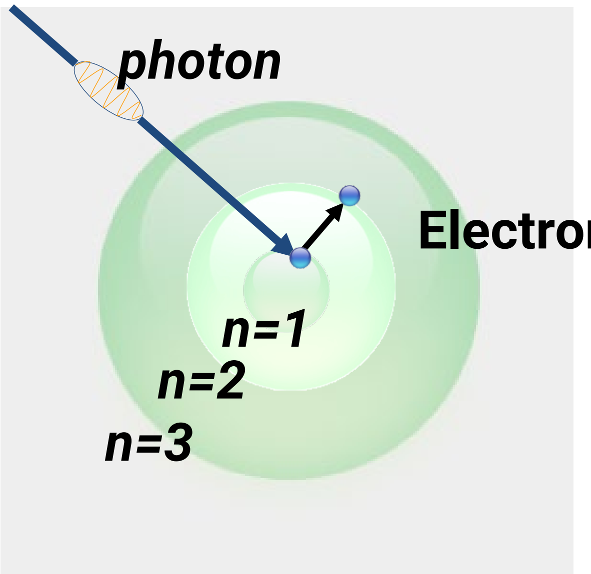
The emission of electrons from a metal plate caused by light quanta – photons (link).

Absorption: electronic energy

Absorbing energy initiates a reaction whereby electrons within target molecules may be ‘excited’ to other energy levels/orbits/shells.

This jump to another energy level leaves a fingerprint that is recorded in a spectral absorption feature.

These electronic transitions are high-energy and create broad absorption features.



In this diagram, a photon is absorbed into an atom and its electron is able to jump to a new level (i.e., excitation). Once the electron is in the higher orbit it possesses potential energy and when it falls back to the atom’s lowest empty energy level / orbit it gives off radiation. The wavelength of radiation given off is a function of the amount of work done on the atom, or the quantum of energy it absorbed to cause the electron to move to the higher orbit (McBride, 2018).

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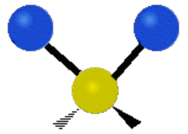
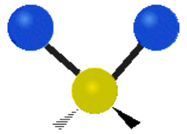
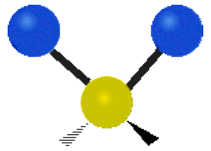
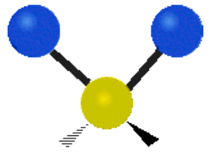
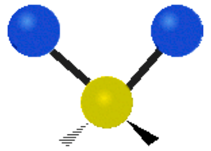
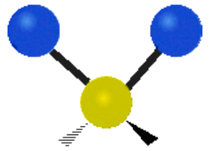
Absorption: vibrational energy

Incoming radiation also causes molecules to ‘vibrate’; the bonds between atoms bend and stretch in predictable geometries.

These bonds relate directly to the chemical makeup, nature, and geometry of molecules in the material that is being analyzed.

The vibrations (and accompanying combinations and overtones) result in specific absorption features.

Symmetry / Direction	Symmetric	Antisymmetric
Radial	 Symmetric stretching (v_s)	 Antisymmetric Stretching (v_{as})
Latitudinal	 Scissoring (δ)	 Rocking (ρ)
Longitudinal	 Wagging (ω)	 Twisting (τ)

Examples of different types of molecular vibrations seen in the atoms of the CH_2X_2 group (source: Wikipedia).

Diagnostic features in the VNIR-SWIR

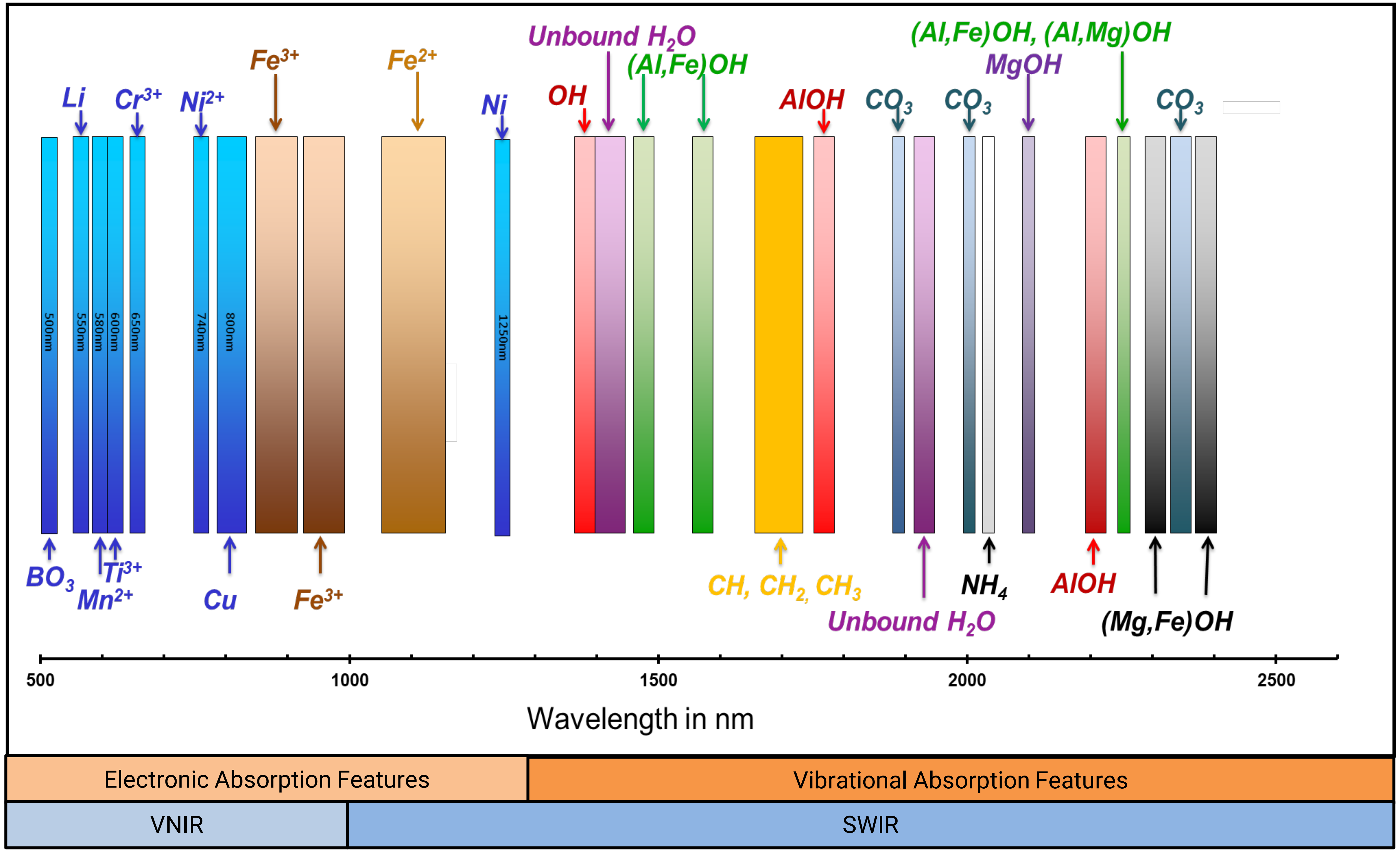
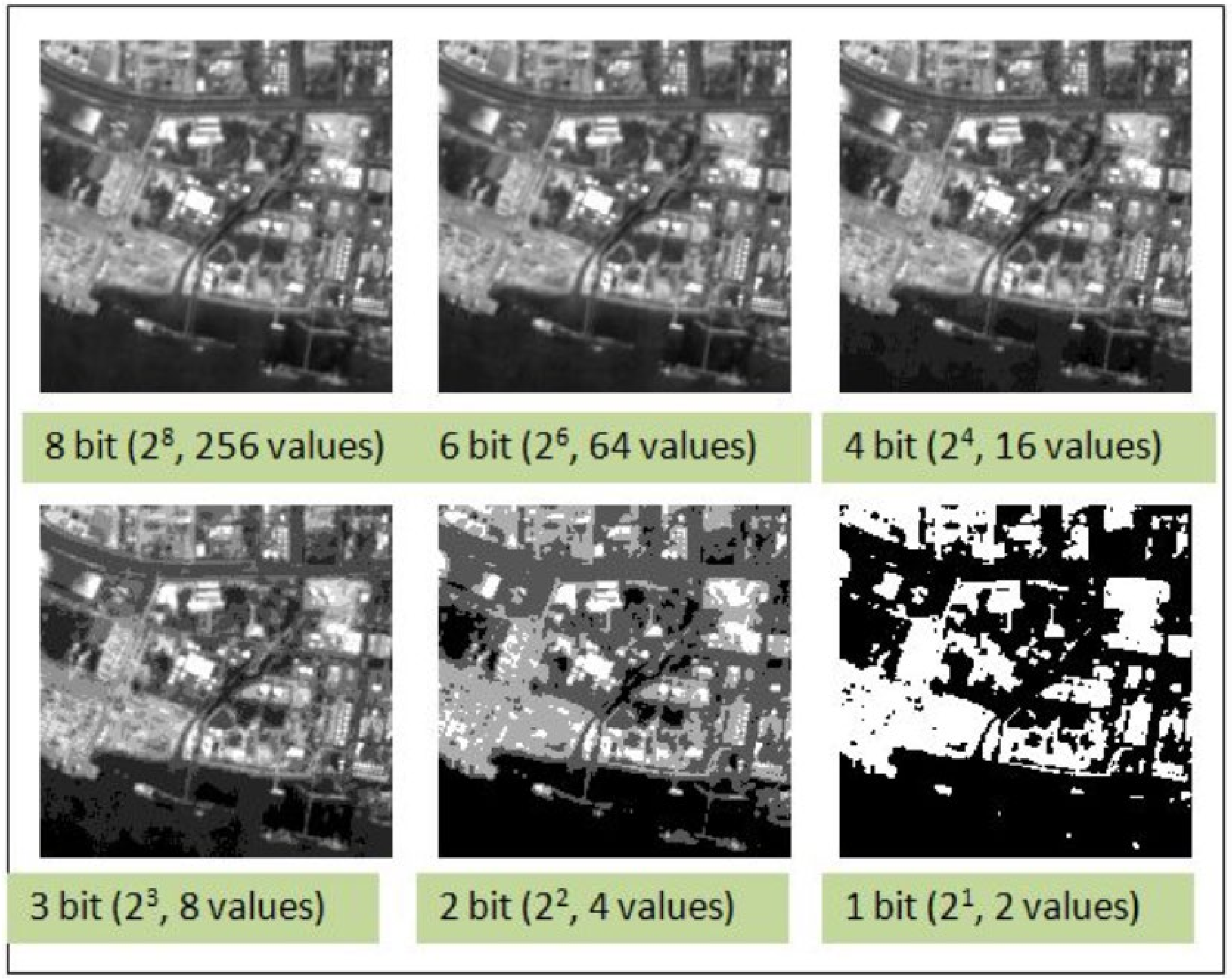


Image Credit: Corescan

Key terminology

Spatial resolution
Spectral resolution

Still important, but I'll get to later…
Spectral range
Spectral bands
Band configuration
Signal to Noise Ratio (SNR)
Field of View (FOV)
Swath width
Data interpretation methods



SNR and its importance towards interpreting mineralogical information from measured spectra (Image Credit: Descartes Labs)

Spatial resolution

Spatial resolution is generally reported as the dimension of the pixel or sample area that is measured by the spectrometer: the ‘pixel size’ or ‘spot size’.

Defined as the smallest object clearly imaged with distinct boundaries.

Images with large pixel sizes are considered to be of coarse scale or low resolution (low spatial resolution).

Fine scale or high-resolution images have small pixel sizes (high spatial resolution).

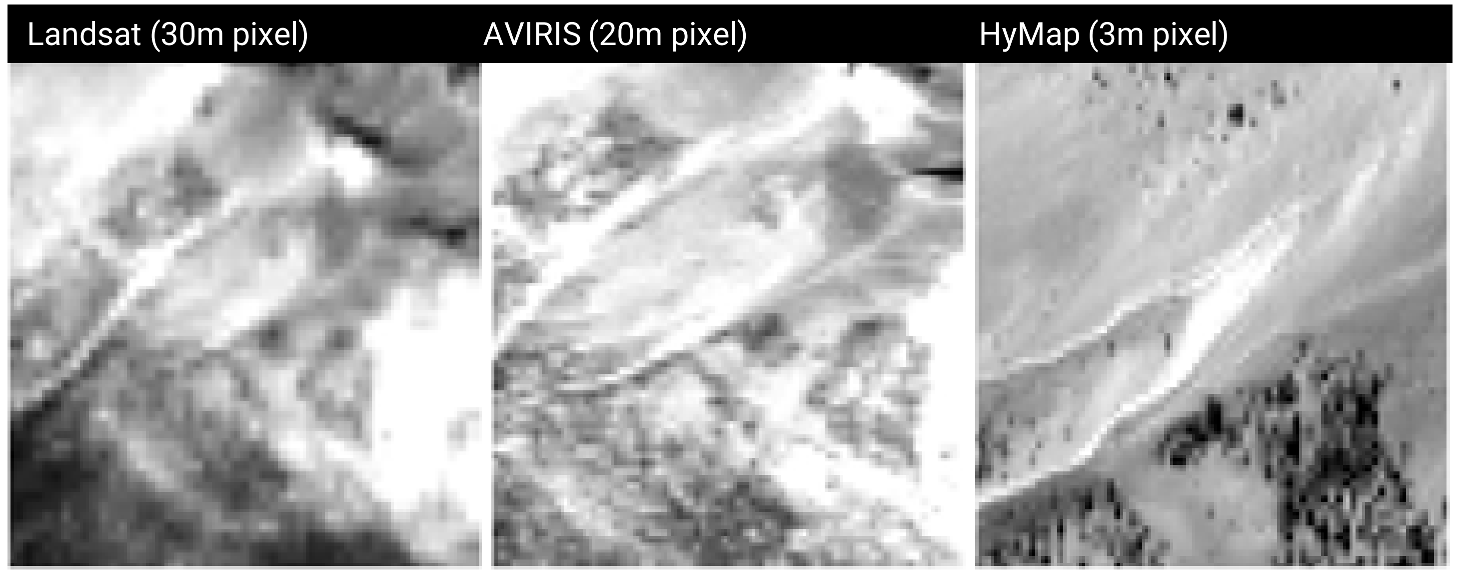
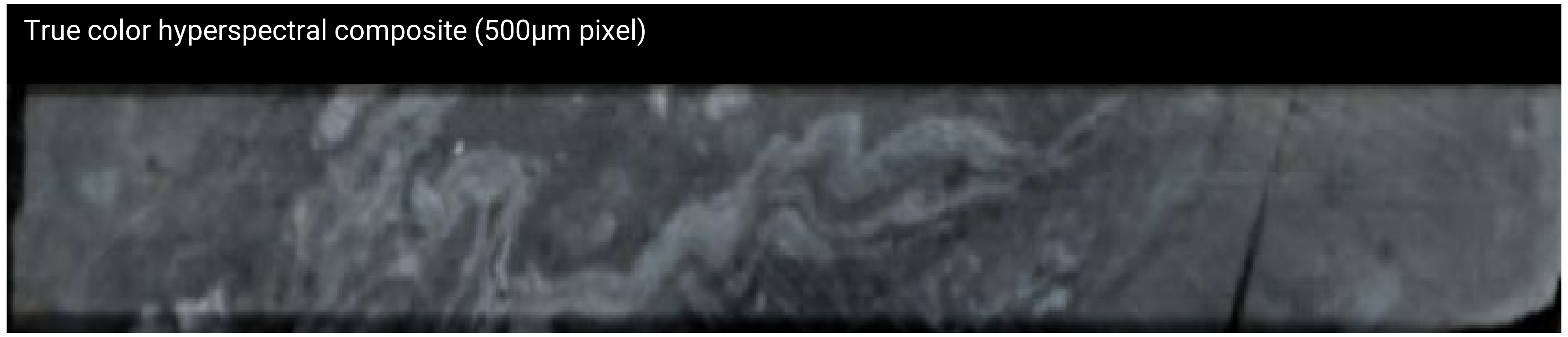


Image credit: Martini et al., 2001.



Hyperspectral core imaging data at 500µm. Image credit: Minnesota Department of Natural Resources.

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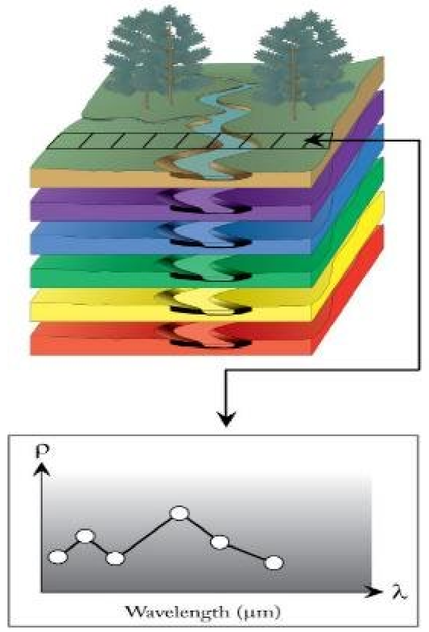
Spectral resolution

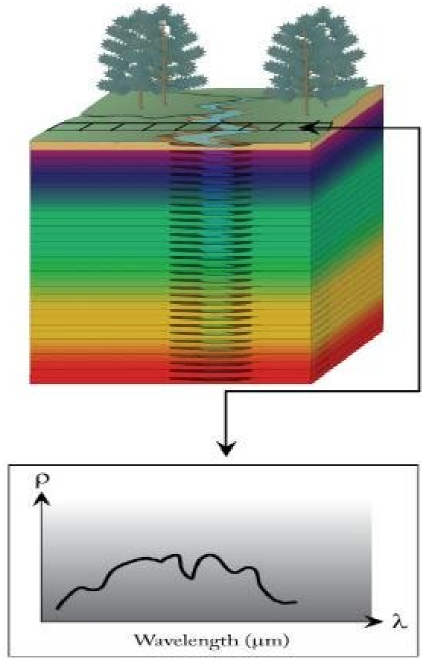
Spectral resolution describes the wavelength intervals over which each spectral band’s measurement is made, and which determines the ability to discriminate fine spectral features.

It typically refers to how “wide” each band is, or the range of wavelengths covered by a single measurement band.

Important to consider for determining if you can identify the minerals / mineral groups of interest.

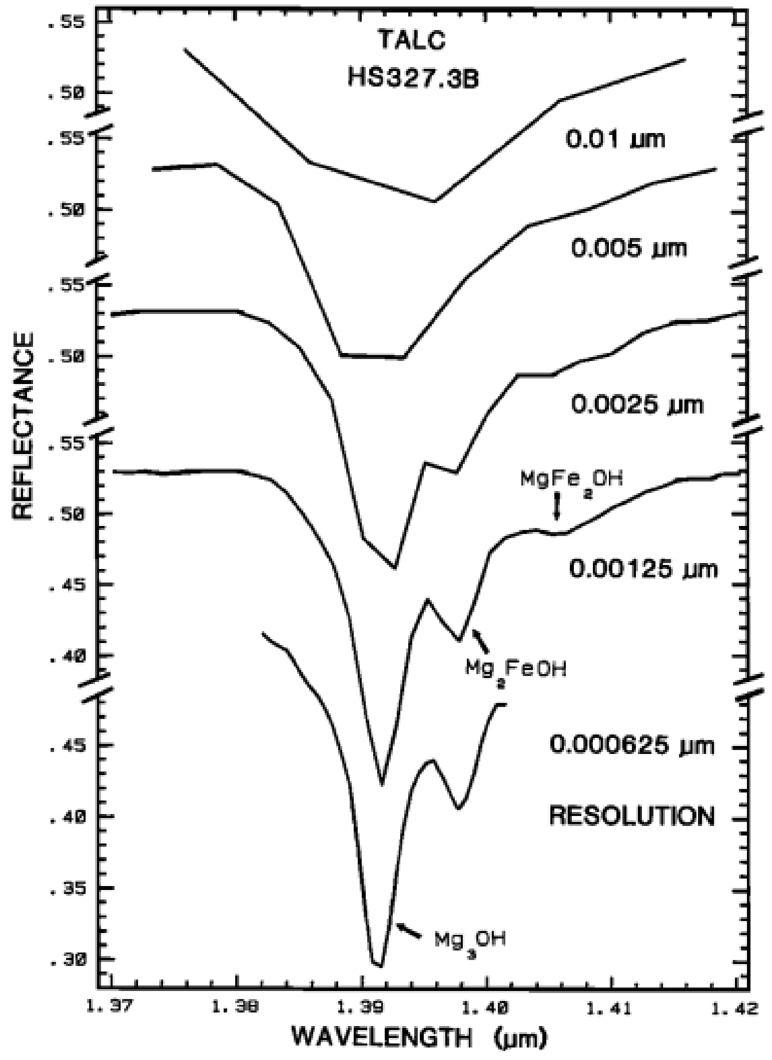


Example multi-band: 0.5μm or 500nm



Example hyperspectral: 0.004μm or 4nm

Reflectance spectra of talc ~1400nm



(from Clark et al.,1990)

Increasing spectral resolution = more detailed spectral features

Higher spectral resolution = increased ability to resolve subtle differences in spectral signatures!

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Schedule

10:00 - 10:15	**Introduction of Hyperspectral by Sam Scher.**

HYPERSPECTRAL TECHNOLOGY PROVIDERS

Each supplier will briefly present its technology:

10:15 - 10:45	**Cari Deyell**, Veracio **Cristal Palofox**, Corescan **Jessica Andrew**, GeologicAI **Dave Browning**, Terracore **Questions**
10:45 - 11:10	COFFEE

FROM SPECTRA TO IMPLEMENTATION

11:10 – 13:00	**Cari Deyell**, Veracio: "From spectra to smectite – understanding how to derive mineralogy from hyperspectral data." **Jorge Beltran**, Terracore; "Hyperespectral Imaging: Longwave and Shortwave infrared imagery, a versatile tool across the entire project pipeline." **Cristal Palafox**, Corescan: "Hyperspectral Imaging as an Exploration Tool: Hydrothermal Deposits." **Sam Scher**, LKI Consulting: "How to construct meaningful hyperspectral studies and implement programs with actionable deliverables." **Questions**
13:00 – 14:30	LUNCH

BUILDING OREBODY KNOWLEDGE

14:30 – 15:40	**Carlos Saenz**, Newmont: "Alteration Zonation Patterns Characterized by Hyperspectral Data within Orogenic Gold Deposits of the Ahafo South Camp, Sefwi Granite-Greenstone Belt, Ghana." **David Portocarrero**,Regulus Resources: "Applications of Hyperspectal scanning images technology: The case of AntaKori, Cu-Au-Ag, North of Perú." **Cristian Jara**, Outlier: "Interpretation of chemometric hardness model for Esperanza using reflectance spectroscopy and PLSR algorithm." **Questions**

DEVELOPING TECHNOLOGY

15:40 – 16:30	**Alejandro Ehrenfeld**, Laboratorio ALGES: "Stochastic Hyper-Spectroscopy: a disruptive technique for estimation rapid analysis of geometallurgical variables, on diverse mineral samples." **David Henderson**, GeologicAI: "The application of artificial intelligence and multi-sensor data for enhanced resource modeling." **Questions**
16:30 – 16:45	COFFEE

PANEL DISCUSSION

16:45 – 17:45	The current state of hyperspectral technology in mining and mineral exploration and its outlook in the near future. Modulated by **Sam Scher**. Panelists: **1. David Henderson** **2. Cari Deyell** **3. Cristal Palafox** **4. Jorge Beltran**

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