PHOTOSAT

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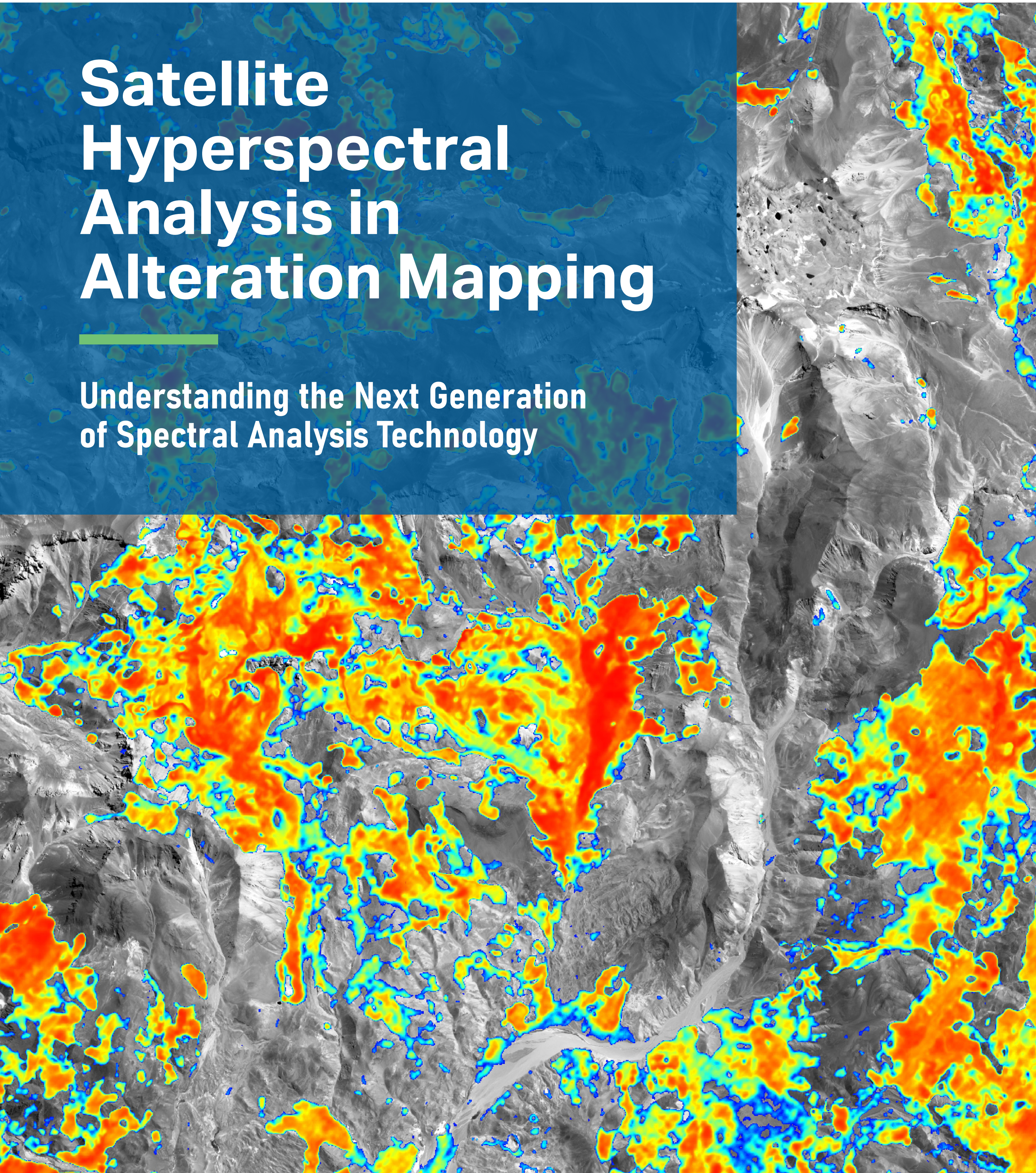
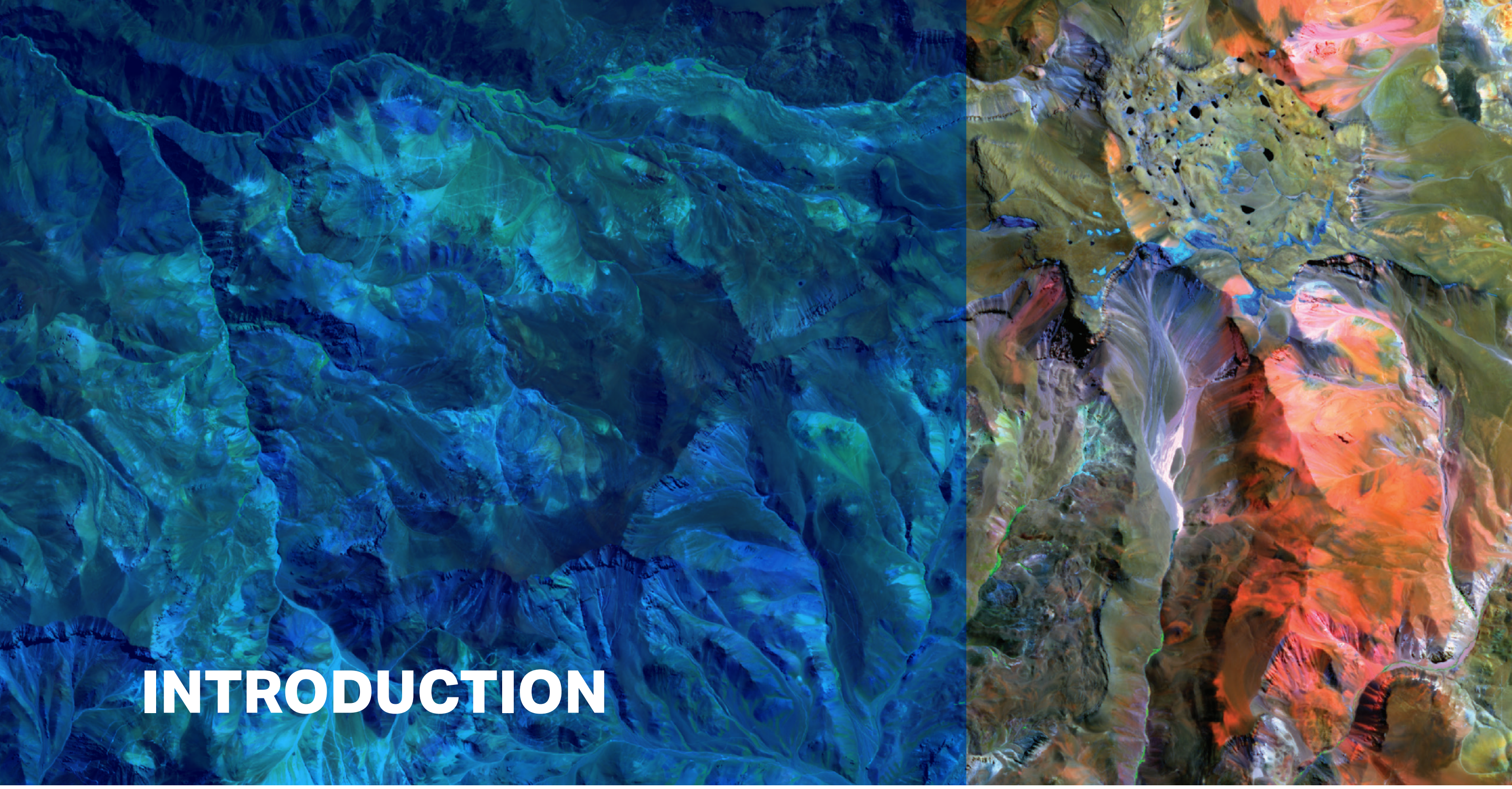
Satellite Hyperspectral Analysis in Alteration Mapping

Understanding the Next Generation of Spectral Analysis Technology





INTRODUCTION

Although hyperspectral analysis technology has existed for over thirty years, realizing the extent of its benefits has not been practical for many within the mineral exploration industry. Technical barriers, such as high costs and enormous processing demands for expansive datasets, have prevented broad adoption. With advancements in sensing technology, computing capabilities, and processing techniques, hyperspectral data has become more widely adopted across the industry. Handheld spectrometers, core scanning, and airborne hyperspectral sensors have become an industry standard when working in the right terrains and deposit types. With the next generation of satellites launched with high-quality hyperspectral sensors, exploration teams can now apply this technology from space.

Technology challenges remain. Hundreds more spectral bands mean much larger datasets, requiring specialized processing techniques that are often expensive. However, advancements in processing methods, such as deep learning algorithms, have helped improve results, reduce costs, and speed up processing times.

This ebook serves as a guide to hyperspectral satellite imaging for alteration mineral targeting and explores the differences between the well-established and widely adopted multispectral sensors, such as ASTER.

Understanding the Key Differences Between Multispectral and Hyperspectral Analysis

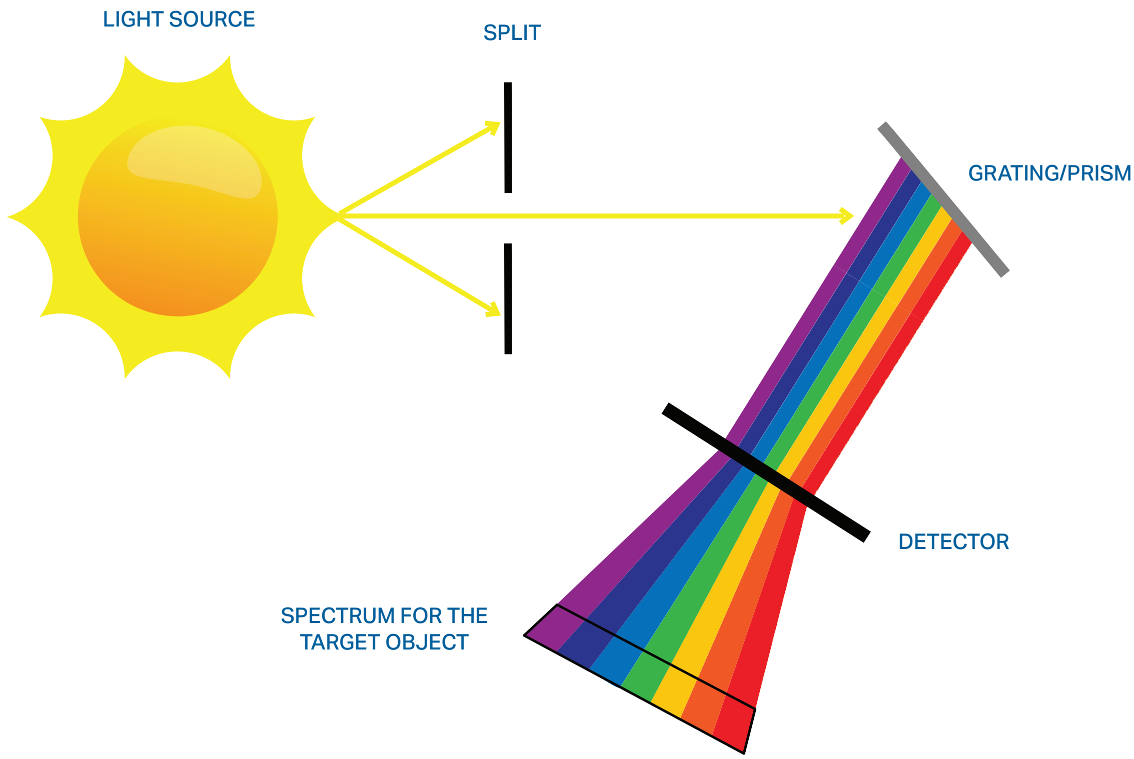
Spectral Analysis and the Rise of Multispectral Imaging

Although the human eye is a natural spectrometer, detecting various wavelengths within the visible range of the electromagnetic spectrum, it took many centuries to discover and apply the insights beyond visible light.

Spectral analysis detects different materials (in this case, minerals) by the amount of energy they absorb or reflect at specific wavelengths along the electromagnetic spectrum. Multispectral analysis is defined as anything more than three bands, but most multispectral satellites can detect between 8 and 16 spectral bands, depending on the satellite.

Over the past several decades, multispectral analysis has become a staple of alteration mineral mapping, primarily available through the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and WorldView-3 satellites.

Multispectral analysis employs specialized cameras equipped with multiple sensors to capture images across distinct wavelength ranges of the electromagnetic spectrum, often extending beyond visible light. Each sensor or filter isolates a specific band of light, which materials reflect or absorb differently. By combining these “layers” of information, analysts can detect patterns, identify hidden details about an object’s composition, and generate quantitative metrics like the Normalized Difference Vegetation Index (NDVI).



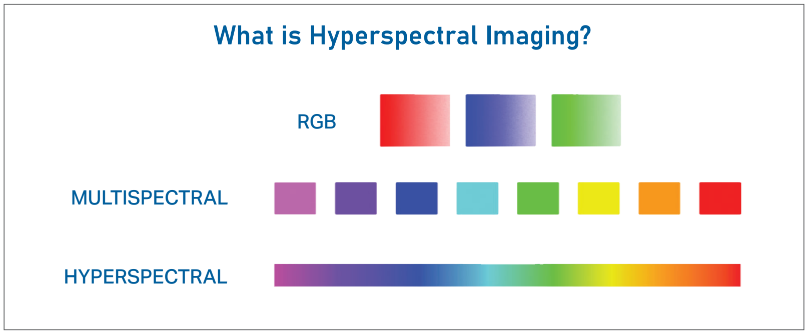
A Quick History of Spectral Analysis

- **17th Century:** Isaac Newton discovers that white light can be split into its component colours, marking the beginning of spectral analysis.
- **19th Century:**
  - Joseph von Fraunhofer catalogues dark lines in the solar spectrum.
  - Gustav Kirchhoff and Robert Bunsen demonstrated that each element has a unique spectral signature, leading to the discovery of helium in the sun.
- **Late 19th Century:** Joseph Fourier develops Fourier analysis.
- **Early 20th Century:** Spectral lines become crucial to Niels Bohr's atomic model and the development of quantum mechanics.
- **Mid 20th Century:** John von Neumann establishes a rigorous mathematical framework for spectral analysis.
- **Post-WWII Era:** Expansion of spectral analysis beyond optics, significantly influenced by the 1965 Fast Fourier Transform (FFT) algorithm.
- **Early to Mid-1980s:**
  - Multispectral remote sensing begins with aerial collections via aircraft.
  - The first experimental airborne hyperspectral imagers were developed, such as the Airborne Imaging Spectrometer (AIS) and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS).
- **Late 1980s:**
  - Commercial airborne hyperspectral instruments, like the Compact Airborne Spectrographic Imager (CASI), became available for researchers and commercial applications.
  - The development of field-portable instruments and their associated software made handheld hyperspectral sensors viable for alteration mapping.
- **1990s:**
  - The technology continued to develop, with instruments such as the DAIS and HYDICE entering use.
  - Portable ground sensors became more affordable.
  - Launch of the Terra satellite (ASTER), pushing multispectral remote sensing into space.
- **2000s to Present Day:**
  - Significant advancements in sensor and software technology have enabled the analysis of high-resolution hyperspectral data from aircraft, drones, handheld spectrometers, and core scanners.
  - Next-generation medium spatial resolution hyperspectral satellite sensors, such as EnMAP, PRISMA, and EMIT, have become available. These sensors offer much higher data quality than past hyperspectral satellites.
  - Launch of new high spatial resolution VNIR satellite hyperspectral sensors.

(Williams, n.d; Windham, 2023; Goetz, 2009)

Hyperspectral Imaging for Satellite Remote Sensing

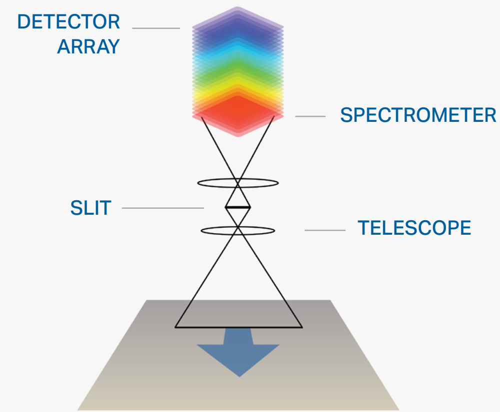
Spectral imaging employs specialized cameras or sensors, known as spectrometers, to detect wavelengths that fall outside the visible light spectrum. Hyperspectral imaging is a leap forward in spectroscopy. It captures hundreds of continuous and narrow wavelength bands, whereas multispectral imaging typically detects only a dozen or so bands.



A hyperspectral camera captures light from a scene by breaking it down into individual wavelengths, resulting in a two-dimensional image with spectral information for each pixel. Each pixel in a hyperspectral image corresponds to a unique spectrum, akin to fingerprints. Since materials interact with light differently, their spectral signatures vary. These spectra can be used to identify and quantify materials within the scene, such as minerals or vegetation.

Hyperspectral satellite imaging is an advanced remote sensing technology that can detect and analyze hundreds of continuous electromagnetic spectrum (EMS) bands across a wide range of wavelengths. Unlike traditional multispectral imaging systems, which typically operate in only a few broad spectral bands, hyperspectral sensors collect data in hundreds or even thousands of narrow, contiguous spectral bands. This detailed spectral information allows for a more precise characterization of materials on the Earth's surface, providing insights into chemical composition, mineralogy, vegetation, and more.

Hyperspectral analysis captures detailed spectral information by imaging objects or scenes across numerous narrow, continuous spectral bands. This data is then translated to surface reflectance to produce a "data cube" where each pixel contains a unique spectral "fingerprint" of the material. Specialized software then employs algorithms to analyze these spectral signatures, extracting specific information, identifying substances, and mapping properties. In other words, with hyperspectral imaging and analysis, we only need one pixel to determine the potential presence of alteration minerals, but with multispectral imaging, we would need to analyze many pixels to make the same determination.



Spatial Versus Spectral Resolution

Spatial resolution and **spectral resolution** are essential concepts in remote sensing.

Spatial resolution pertains to the level of detail in an image, determined by the size and number of pixels. Higher spatial resolution means that each pixel represents a smaller area on the ground, leading to more precise and detailed images.

Spectral resolution relates to a sensor's ability to differentiate between narrow wavelength intervals of electromagnetic radiation. A sensor with high spectral resolution can capture more bands within the electromagnetic spectrum, allowing it to detect subtle variations in materials based on their spectral signatures.

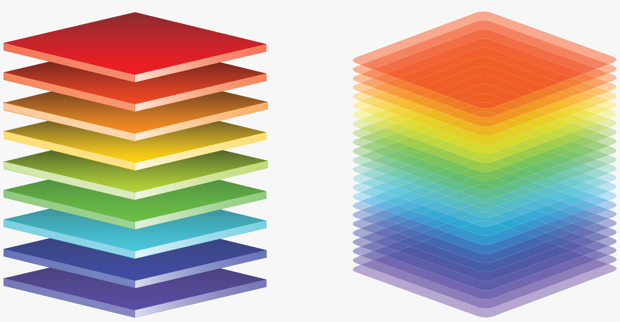
While multispectral sensors typically capture data in a limited number of broad bands, hyperspectral sensors gather information across hundreds of contiguous spectral bands.

Engineers must know the tradeoffs between spatial resolution, spectral resolution, signal-to-noise, swath size, and data size. Sometimes, hyperspectral satellites may have a lower or equal spatial resolution than multispectral satellites. However, the higher spectral resolution means that each pixel contains much more information, which means that minerals can be identified with much higher confidence.

SIDEBAR:

Data Cubes and Hyperspectral Data Processing

A hyperspectral data cube is a sophisticated three-dimensional dataset that integrates spatial (x,y) and spectral (z) information, providing a comprehensive view of the sampled environment. Each pixel within a scene captures a continuous spectrum of light intensities across a wide range of wavelengths, often numbering in the hundreds. This rich spectral information serves as a unique fingerprint for identifying various materials. In exploration geology, many more alteration minerals can be accurately discerned, leading to more informed decisions regarding mineral exploration.



Processing hyperspectral imaging data for alteration mineral mapping is a multi-step workflow designed to transform raw spectral data into detailed geological information, significantly advancing over traditional, labour-intensive fieldwork. The process begins with crucial preprocessing, including radiometric calibration to convert sensor readings into standardized radiance units and top of atmosphere reflectance, followed by atmospheric corrections that remove interference from water vapour and aerosols.

Geometric corrections are then applied to align the data precisely with real-world geographic coordinates and topographic elevation models. With the clean data in the form of a data cube, dimensionality reduction is often performed to manage the immense data volume, with techniques like Principal Component Analysis (PCA) or Minimum Noise Fraction (MNF) used to isolate the most informative spectral bands, focusing on the short-wave infrared (SWIR) region where many alteration minerals exhibit unique spectral features (Living Optics, 2025).

However, the most critical step for mineral mapping is spectral or pixel unmixing, an advanced analytical technique used because individual pixels in a hyperspectral image often represent a mix of multiple minerals, especially in complex geological environments. Pixel unmixing mathematically decomposes the spectrum of a mixed pixel into its constituent “endmembers”—the pure spectral signatures of individual minerals—and calculates the fractional abundance of each endmember within that pixel (Amigo, 2020). Geologists can identify and map the alteration zones that indicate potential ore deposits by determining the proportion and distribution of key alteration minerals like clays, sulphates, and carbonates.

The final stage involves converting these fractional abundance maps into actionable information through classification and visualization. This process provides geologists with a spatially accurate and quantitative assessment of mineralogy, which helps identify promising targets and optimize exploration programs.

The Possibilities of Hyperspectral Satellite Imaging in Alteration Mapping

What exactly are the benefits of hyperspectral satellite imaging when applied to alteration mapping? In short, the next generation of spectral satellite sensors can be used to extrapolate far more relevant geological information with much greater accuracy, which leads to better data-driven exploration decision-making compared to past multispectral solutions.

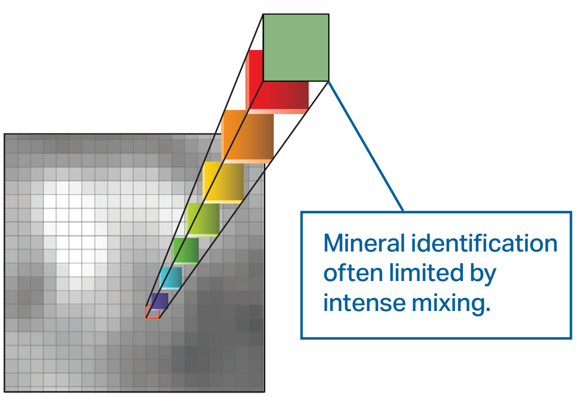
PhotoSat's multispectral alteration mapping product using the ASTER sensor can identify eight distinct minerals. In contrast, our new Hyperspectral Exploration Targeting (more on this below) can currently identify more than twice the number of minerals with much greater accuracy and reliability.

While multispectral satellite imaging offers an excellent overview suitable for basic alteration mapping, hyperspectral imaging allows for extracting much more geological information to identify exploration targets that others have overlooked.

Importantly, with hyperspectral data multiple minerals within the same pixel can be identified, and minerals can be identified even when the pixel is majority vegetation (mixed vegetation and mineral signature), which is not the case with multispectral data where nearly bare ground is necessary for positive identification.

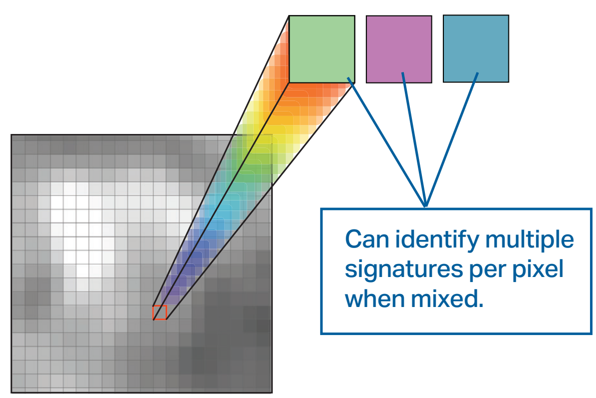
MULTISPECTRAL

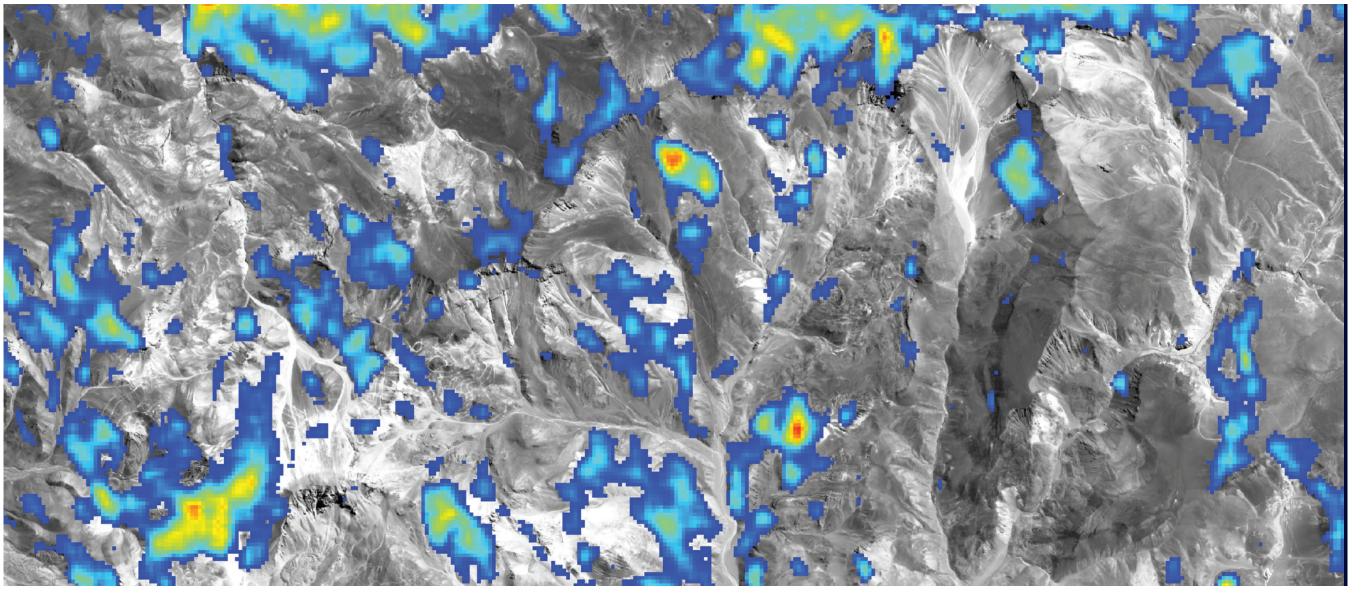
Cannot confidently identify minerals when signatures are intensely mixed.



HYPERSPECTRAL

High spectral resolution means minerals can be identified with confidence even when signatures are intensely mixed.





PhotoSat's New Hyperspectral Alteration Mineral Targeting (HET) Solutions

PhotoSat has developed new proprietary deep-learning alteration mineral mapping products that use true hyperspectral satellite data. These products will combine the benefits of various multispectral and hyperspectral satellite sensors with PhotoSat's extensive experience producing deep-learning alteration mineral mapping solutions.

Hyperspectral datasets processed with PhotoSat's proprietary deep learning models support exploration projects by mapping more minerals, relative abundances, and changes in mineral compositions/crystallinities to identify alteration patterns overlooked with traditional multispectral datasets.

Key benefits of the hyperspectral alteration products include:

- Mapping more key alteration minerals such as pyrophyllite, muscovite, and illite
- Differentiating compositions and crystallinities of minerals such as K-alunite vs Na-alunite or high-Al Muscovite vs low-Al muscovite
- Detecting subtle subpixel alteration signatures using advanced deep learning models, which improve accuracy and reduce false positives
- The ability to map relative abundances of minerals allowing for the development of better exploration targets
- Compelling visuals that aid in building a complete ore deposit model story for investors, executives, and other stakeholders

These new products are the "next generation" of satellite alteration mapping, which improves on the capabilities of our current Regional-Scale (ASTER) and Property-Scale (WorldView-3) Alteration Mapping products.

Target Minerals and Deposit Types

Minerals	Additional Minerals	More Deposit Types
High Al - Muscovite	Med-Al Muscovite	Topaz
Low Al - Muscovite	Fe-Rich Muscovite	Prehnite
Illite	Paragonitic Muscovite	Serpentine
Montmorillonite	Low-Al Illite	Tourmaline
K-Alunite	Kaolinite Well Crystalline	Albite
Na-Alunite	Kaolinite Poorly Crystalline	Amphibole
Kaolinite	Dolomite	Pyroxene
Dickite	Chamosite	Rare Earth Minerals
Pyrophyllite	Ammonium-Illite	Other Carbonates
Calcite	K-feldspar	Other Smectities
Mg-Chlorite	Biotite	Goethite Grain Sizes
Fe-Chlorite		Hermatite Grain Sizes
Epidote		
Opal		
Buddingtonite		
Jarosite		
Hematite		
Goethite		

Regional Hyperspectral Exploration Targeting

Hyperspectral satellite analysis is entirely remote and can cover vast areas, making it a cost-effective solution for regional targeting in exploration project generation. This first new offering from PhotoSat is a regional hyperspectral exploration targeting tool incorporating datasets from any hyperspectral satellite into our proprietary deep-learning models for high quality project generation. PhotoSat's Regional HET is the evolution of the traditional ASTER regional alteration solution.

Property Hyperspectral Exploration Targeting

Expected to launch in 2026, PhotoSat is also developing a property-scale hyperspectral offering utilizing PhotoSat's new hyperspectral deep-learning models to provide the same benefits as the regional product but at much higher spatial resolutions, for application in smaller-scale areas (exploration properties). Using high-spatial resolution will allow for finer features to be identified, facilitating better use in the field to identify minerals in outcroppings. This data will help geologists on the ground generate targets for field work and drilling. All functionalities associated with the regional product should also apply to the property-scale product.

Revolutionizing Mineral Exploration with Hyperspectral Imaging

With the ability to capture and analyze hundreds of spectral bands, hyperspectral imaging offers unprecedented geological insights not possible with multispectral data, enabling geologists to make more informed exploration decisions. As the mining industry embraces these technological advancements, the potential for discovering new deposits and optimizing exploration strategies becomes significantly more promising.

PhotoSat is a trusted partner supporting safe and responsible mining projects worldwide. With over 70 years of combined engineering and geology expertise, we offer innovative solutions to real-world challenges. From exploration to operation to maintenance and closure, PhotoSat is the leading expert in satellite solutions produced using proprietary software and deep-learning models designed and tested for optical satellite data.

Request quote.

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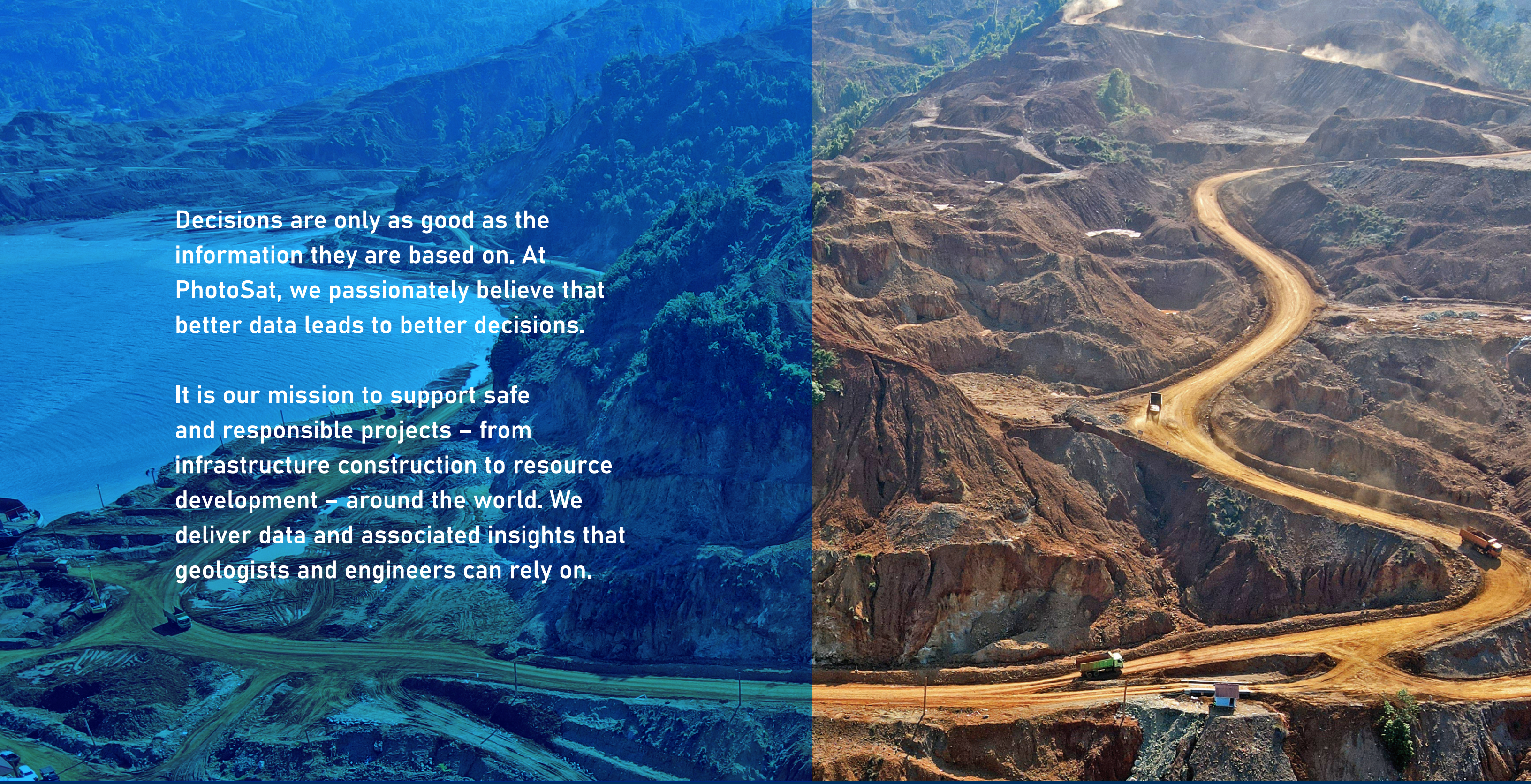

Decisions are only as good as the information they are based on. At PhotoSat, we passionately believe that better data leads to better decisions.

It is our mission to support safe and responsible projects – from infrastructure construction to resource development – around the world. We deliver data and associated insights that geologists and engineers can rely on.

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