Advances in satellite alteration mineral mapping for gold and silver deposits

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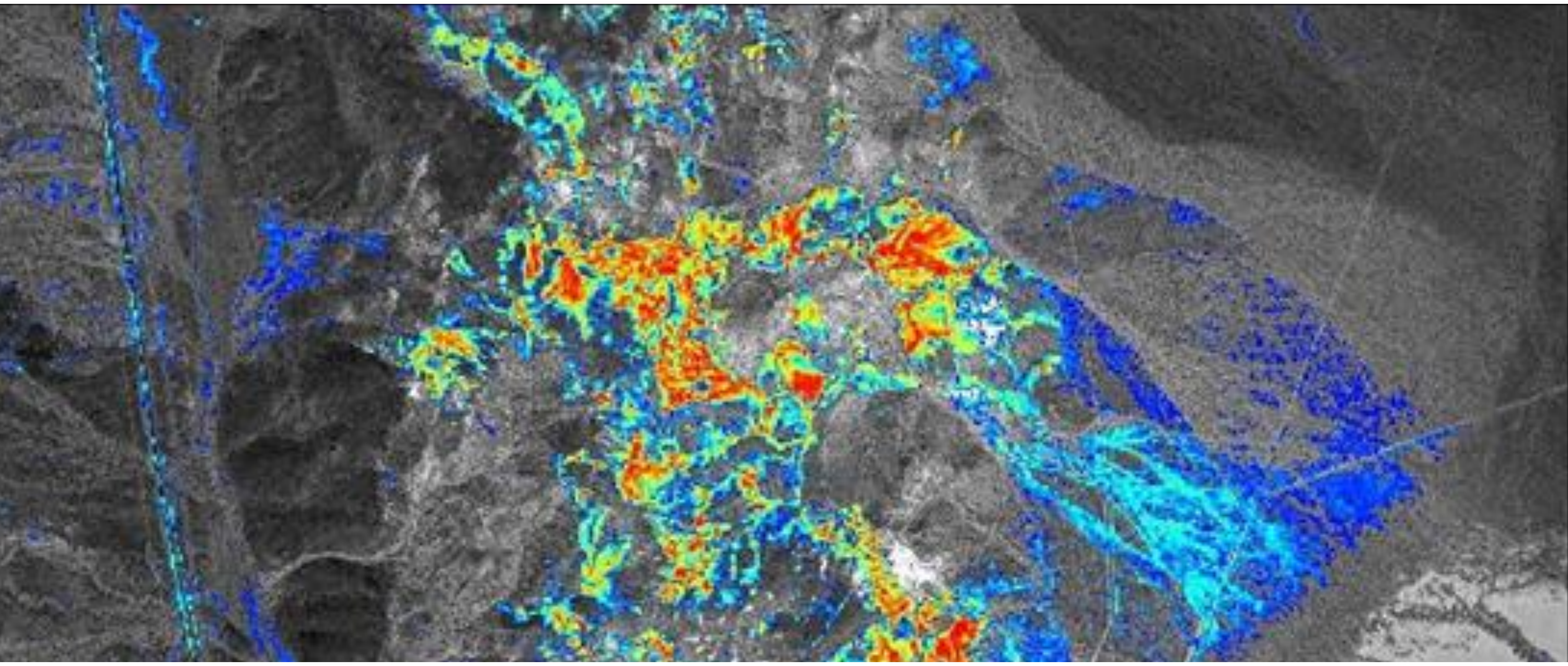

Zones of opal, chalcedony and other hydrous silica minerals at Cuprite, Nevada as detected by the short-wave infrared camera on the WorldView-3 satellite. These hydrous silica zones can be important indicators of underlying gold and silver deposits.

Higher spectral- and spatial-resolution data and better algorithms for increasingly detailed predictive mapping

Many new satellite exploration tools were developed since the last exploration cycle

New satellite alteration mineral mapping tools and capabilities have been developed since the last mining exploration cycle. The last cycle ended for most of us in 2012. Since then there has been very little funding for mining exploration. Most of these new capabilities are awaiting their first application in many promising exploration districts.

The new WorldView-3 (WV3) satellite photos became commercially available in 2015

The WorldView-3 (WV3) satellite was launched in September 2014. The WV3 photos became commercially available in early 2015. WV3 enables much better detection and mapping of alteration minerals associated with gold and silver deposits than did previous satellite systems (Figure 1).

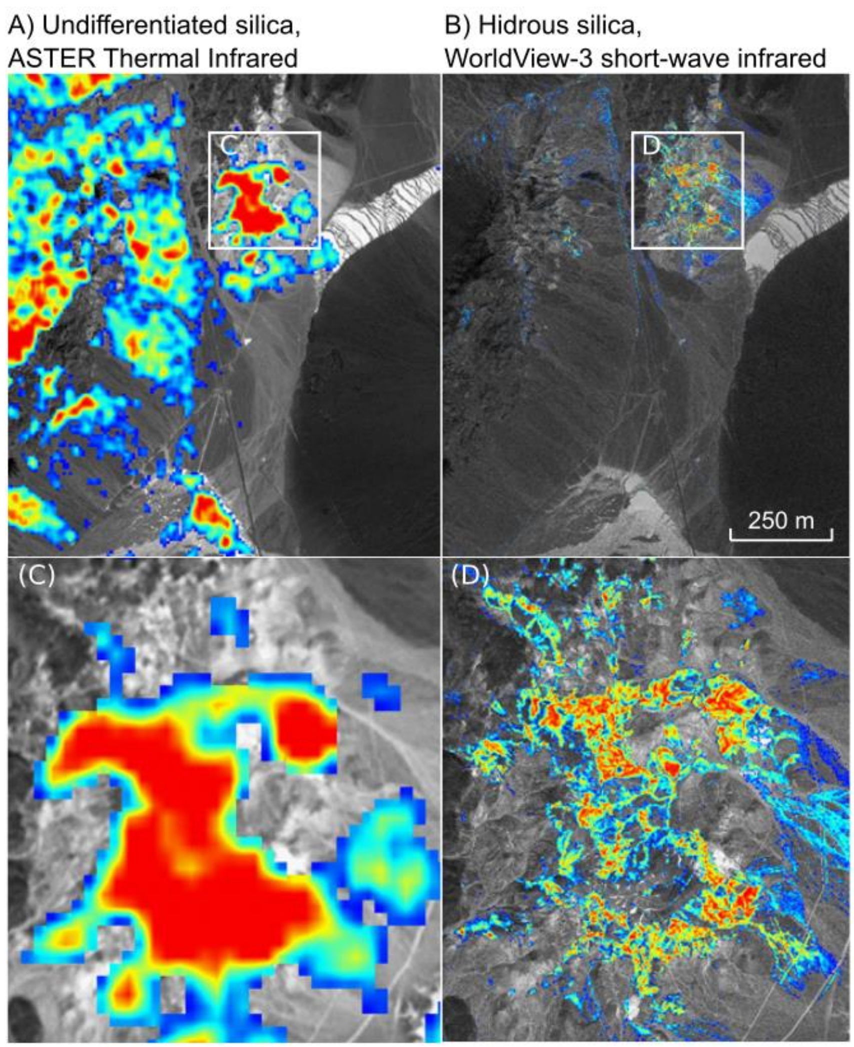

***Figure 1.** Silica mapping in the Cuprite, Nevada using ASTER and WorldView-3 satellite photos. The WorldView-3 clearly identifies only the opal and chalcedony in the Cuprite epithermal alteration zone while the ASTER shows all the areas of high silica.*

The WV3 short-wave infrared camera has over 15 times better spatial resolution than the ASTER SWIR camera

WordlView-3 can reliably detect much smaller zones of alteration minerals than any previous commercially available satellite system (Figures 1, 2). Prior to the WV3 short-wave infrared (SWIR) photos, the best satellite SWIR photos were those from the ASTER camera onboard the Terra satellite. The SWIR camera on the WV3 satellite has over 15 times the spatial resolution of the ASTER SWIR camera. WV3 SWIR pixels are 56 m^2 whereas ASTER SWIR pixels cover 900 m^2.

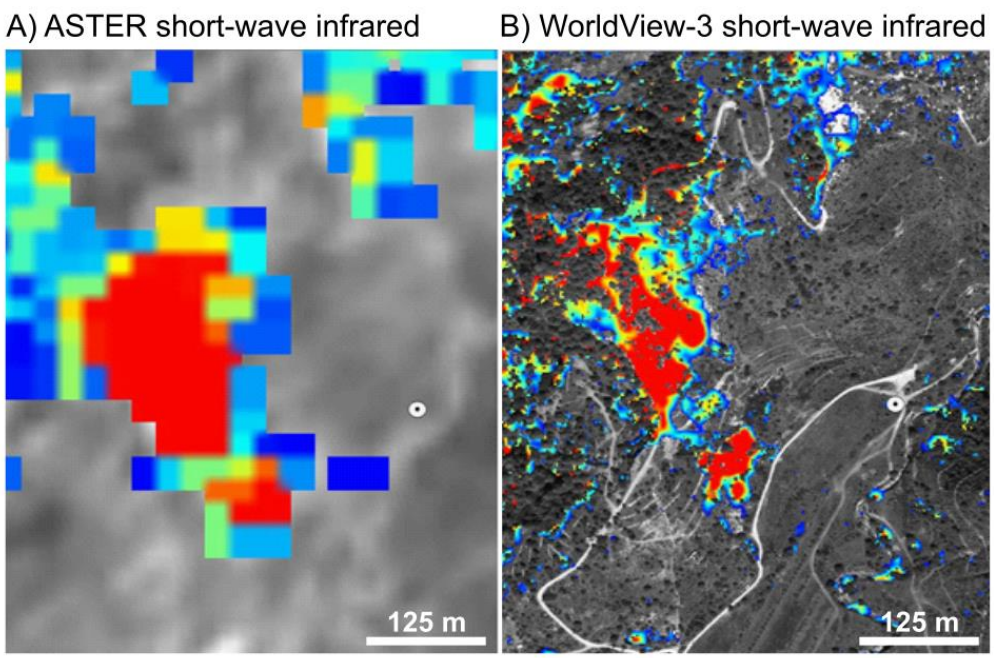

Figure 2. *Hydroxyl alteration minerals at the Ixtaca deposit in Puebla, Mexico. Due to differences in spatial resolution, the WorldView-3 short-wave infrared photos can detect smaller mineral alteration zones with greater certainty and show far more detail than ASTER photos.*

Worldview-3 maps "new" alteration minerals

WV3 satellite photos can reliably map minerals that we could not confidently identify with previous satellite systems. The most important of these for gold and silver exploration are probably the hydrous silica minerals opal and chalcedony. These minerals occur in the uppermost levels of epithermal gold and silver deposits (Figure 3).

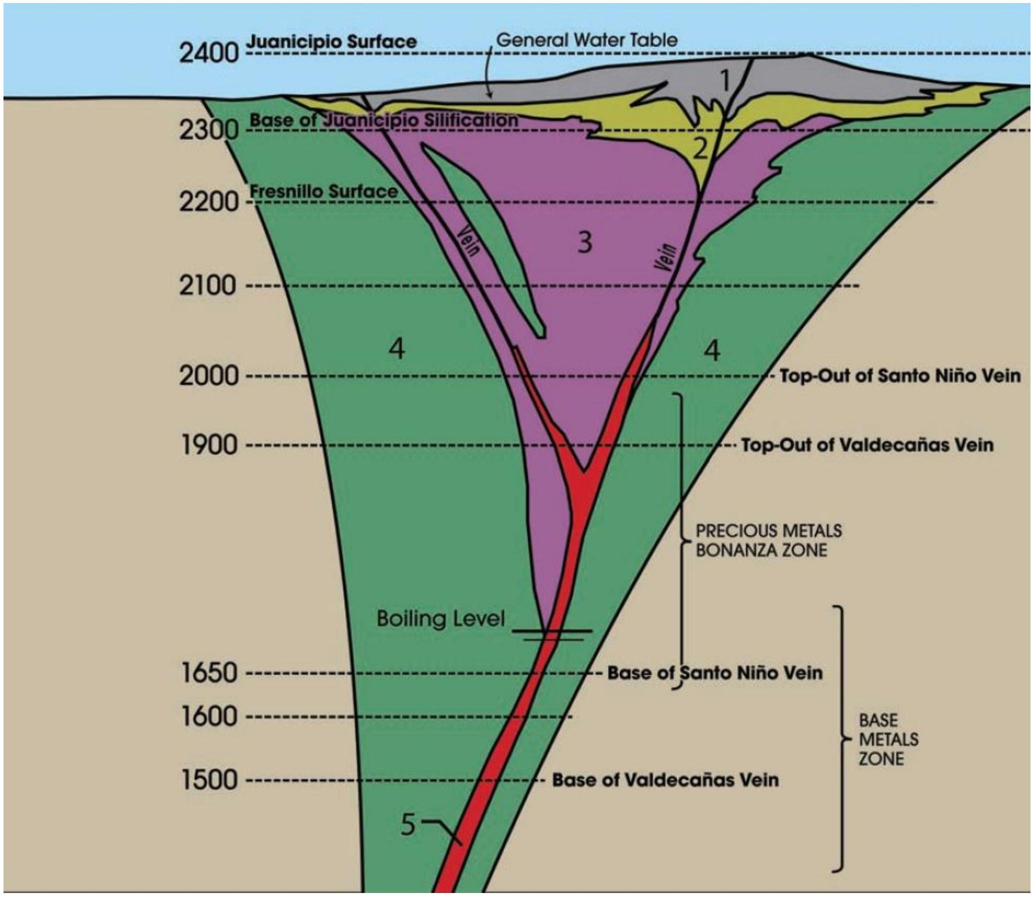

***Figure 3**. Geological model of mineral alteration zones for the epithermal silver deposit at Juanicipio, Zacatecas, Mexico. Model developed by Peter Megaw, modified from Buchanan (1981) and Simmons (1991). Peter Megaw and his team at Mag Silver used this model to make the amazing blind* discovery of the Juanicipio silver deposit discovery in 2003. Legend:*

(1) Siliceous residue: opal, chalcedony, cinnabar, pyrite, specularite.
(2) Advanced argillic alteration: ammonium alunite, kaolinite, buddingtonite.
(3) Silicification: usually with adularia.
(4) Propyllitic alteration: chlorite, epidote, calcite, pyrite, montmorillonite.
(5) Adularization: albite increases below the boiling level.

*There was absolutely no indication of gold or silver at surface above the Juanicipio deposit, making it a "blind" discovery. The ore zone is 450m below the ground surface. It was discovered through geological reasoning, interpretation, perseverance and courage.

The importance of being able to map the hydrous silica zones is shown in Figure 1. At Cuprite, Nevada the WV3 hydrous silica clearly shows the heart of the epithermal alteration zone. By comparison, ASTER shows all of the silica zones, not differentiating the epithermal hydrous silica zone from other areas of silica.

WV3 has better definition of the minerals associated with gold and silver deposits than ASTER

The WV3 SWIR camera produces much higher quality photos than the ASTER SWIR camera. This enables better discrimination of the clay, mica, hydrous iron oxide, and ammonium feldspar alteration minerals that are guides for exploration and development on many gold and silver projects.

Alteration minerals detectable with WV3 and/or ASTER

Table 1 lists alteration minerals for epithermal gold and silver deposits detectable with the WV3 and/or ASTER. The listed minerals are often used as prospecting guides. A conceptual model of an epithermal deposit showing the zones of different alteration minerals is shown in Figure 3.

Many opportunities to be first with WV3 alteration mineral mapping

Since the WV3 satellite photos first became available in 2015, international investment in mineral exploration has been at an historical low. Consequently, WV3 alteration mineral mapping has not yet been applied to many highly prospective epithermal gold and silver mineral belts.

Table 1. *Alteration minerals for epithermal gold and silver deposits detectable with WV3 and/or ASTER.*

Most of these minerals are best detected on photos from the short-wave infrared (SWIR) cameras. These cameras detect reflected light with wavelengths between 1,100 and 2,500 nanometers (Figure 7). Figure 7 shows the wavelength of WorldView-3 SWIR band 8, and ASTER SWIR band 6.

Clay	
Alunite	$(Na,K)Al_3(SO_4)_2(OH)_6$
Kaolinite	$Al_2Si_2O_5(OH)_4$
Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \bullet n(H_2O)$
Micas	
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
Paragonite	$NaAl_2(AlSi_3O_{10})(OH)_2$
Sericite	Sericite is not a specific mineral. It is a hydrothermal alteration of orthoclase or plagioclase feldspars. It may consist of each, or a combination of, Muscovite, Illite, and Paragonite.
Ammonium Feldspar	
Buddingtonite	NH4AlSi3O8
Silica	
Quartz	SiO2
Hydrous Silica	
Opal,	SiO2•n(H2O)
Chalcedony	SiO2•n(H2O)
Ferric Hydrous Iron Oxides	
Goethite	Fe3+O(OH)
Jarosite	KFe3+3(SO4)2(OH)6
Ferric Iron Oxide	
Hematite	Fe3+2O3

There are other alteration minerals that are important for gold and silver prospecting that are beyond the detection capacity of the ASTER and WV3 cameras.

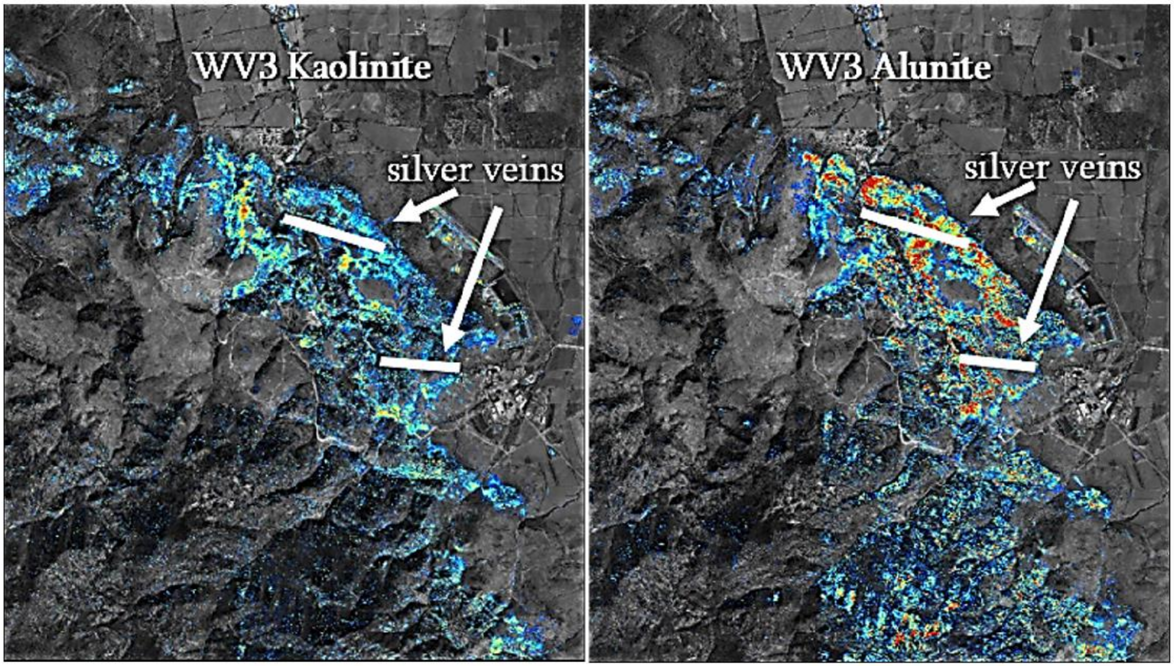

Figure 4. *WorldView-3 indications of kaolinite and alunite alteration at the Juanicipio silver deposit, Zacatecas, Mexico. Worldview-3 is much better at differentiating kaolinite and alunite than previous satellite systems. The silver veins are more than 400m below the current ground surface.*

USGS High Resolution Spectral Library

The reflectance spectra of mineral samples form the basis for much of the improvement in satellite mineral mapping. The US Geological Survey has an extensive publicly available library of mineral reflectance spectra: USGS Spectral Library.

Mineral reflectance spectra from this library is used to determine the expected spectral signatures of different minerals in multiband satellite photos. Figure 5 shows the expected spectral signatures of the clay alteration minerals Kaolinite and Alunite on WV3 visible and near-infrared and short-wave-infrared satellite photos. WV3 is much better at differentiating the reflectance responses of kaolinite and alunite than previous satellite systems.

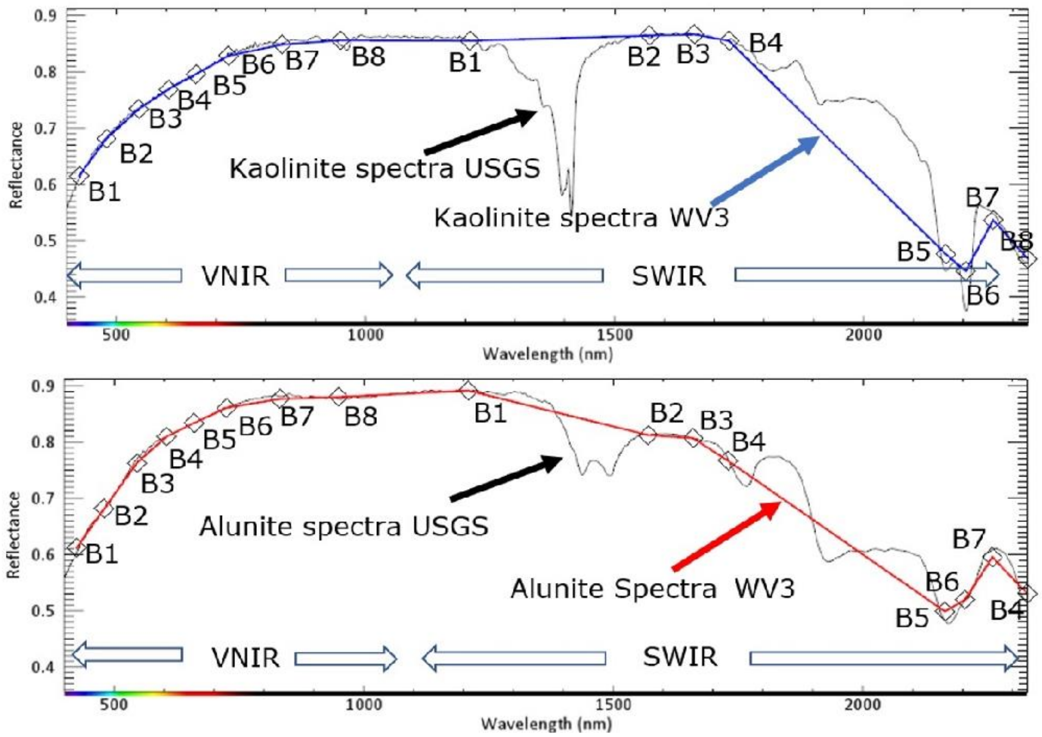

***Figure 5**. USGS laboratory and WorlView-3 reflectance spectra for Kaolinite and Alunite. Note the remarkable overlap between the two. Also note the very different spectral responses between Kaolinite and Alunite in WV3 SWIR bands B5, B6 and B7.*

Field portable reflectance spectrometers

Portable, field reflectance spectrometers can provide at-surface spectral signatures for the area of the satellite alteration mineral mapping. This enables adjustment of the data processing to improve the accuracy and reliability of alteration mineral mapping.

The Worldview-3 and ASTER satellite cameras

Almost all satellite-based alteration-mineral mapping is carried out using photos from the Worldview-3 and ASTER cameras. The Worldview-3 satellite became operational in 2015. The ASTER camera operated on the NASA Terra satellite. The ASTER camera collected a global database of multispectral satellite photos from February 2000 to April 2008.

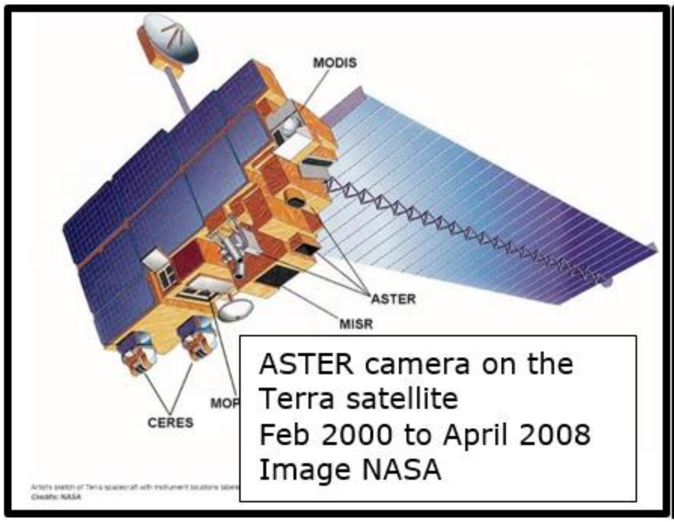

Figure 6*. ASTER camera on the Terra satellite on the left; Worldview-3 satellite on the right. The ASTER has 5 visible and near infrared bands (VNIR), 6 short-wave infrared bands (SWIR), and 5 thermal infrared bands (TIR). The Worldview-3 has 8 VNIR bands, 8 SWIR bands, and no TIR bands.*

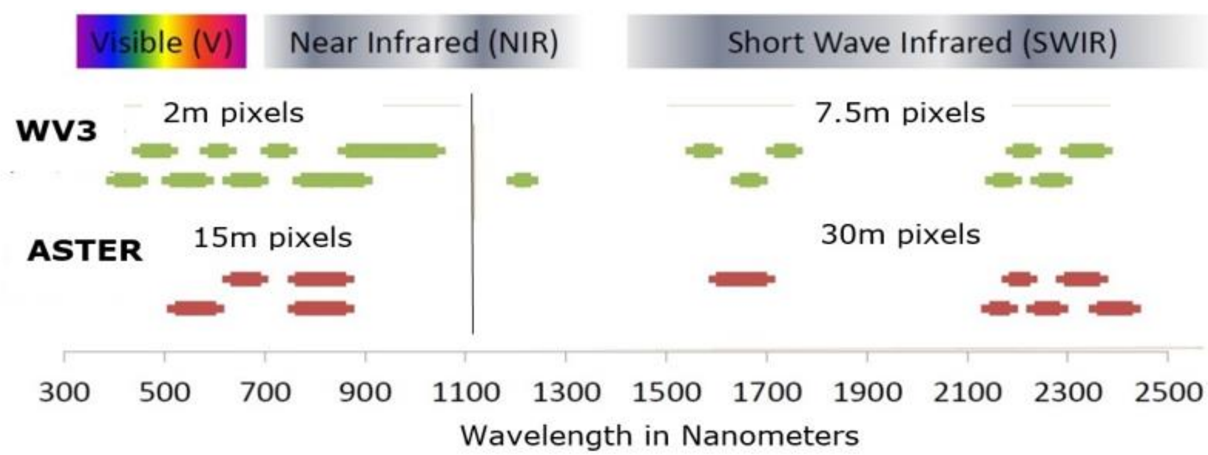

Figure 7*. Spectral and spatial characteristics of the WorldView-3 and ASTER satellite cameras.*

Worldview-3 is the only operating commercial satellite with a multiband SWIR camera

The 8-band, 7.5m ground-resolution WV3 SWIR camera is currently the only satellite camera in orbit with a multiband short-wave infrared (SWIR) spectral range. The WV3 SWIR satellite photos have better signal-to-noise ratio and a wider dynamic range than any previous commercially available SWIR satellite photos. The spectral and spatial characteristics of the WV3 satellite camera are shown in Figure 7.

ASTER alteration mineral mapping is still the best technology for regional prospecting of thousands of square kilometers

The global database of ASTER satellite photos collected by NASA and JAXA between 2000 and 2008 is still the best data for alteration mineral studies of thousands of square kilometers, covering large portions of mineral belts. Figures 8 and 9 show examples of gold deposits with distinctive alteration mineral anomalies on ASTER satellite photos that were collected before the discovery of the deposits.

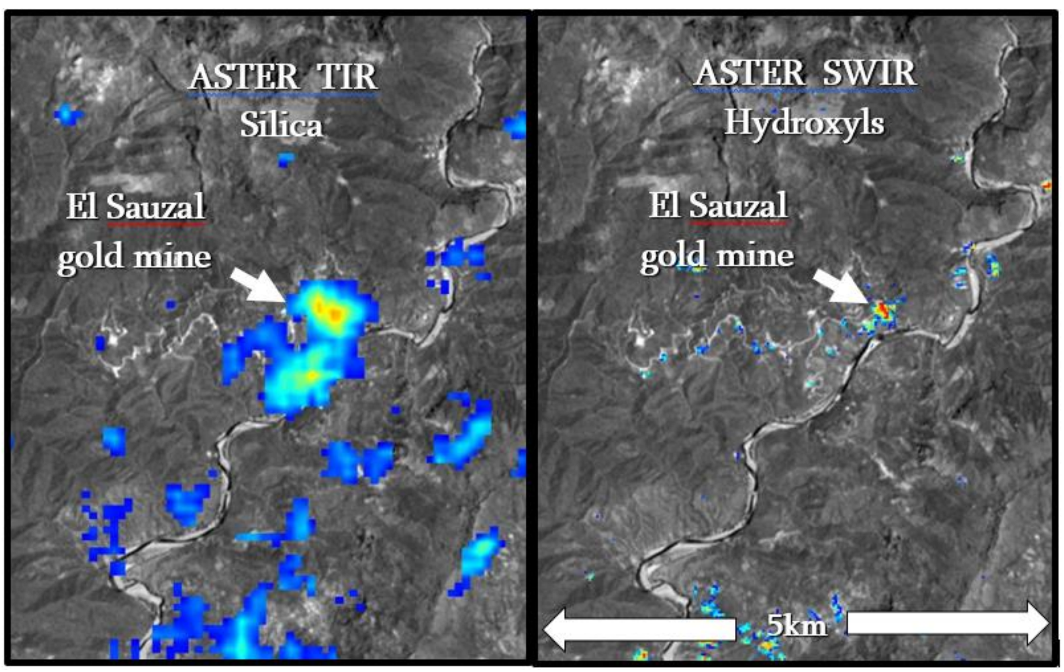

Figure 8*. ASTER silica and hydroxyl alteration over the El Sauzal gold mine in western Chihuahua, Mexico. This ASTER photo predates the discovery of the mine. Red represents strong, probable alteration. Blue represents weak, possible, alteration.*

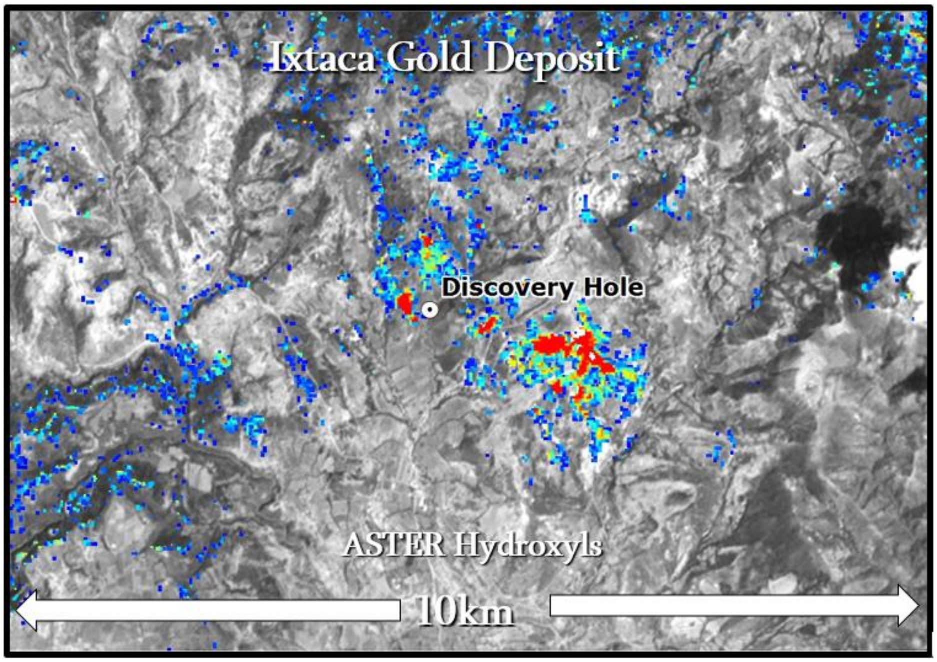

Figure 9*. Hydroxyl mineral alteration zones on an ASTER photo of the Ixtaca gold deposit, Puebla Mexico. Red represents strong, probable alteration. Blue represents weak, possible, alteration.*

Advances in satellite image processing knowledge and methods are improving WV3 and ASTER alteration mineral mapping

The continuing advances in computer processing capacity are significantly improving our ability to identify false-positive alteration-mineral responses on the WV3 and ASTER satellite photos. This enables us to identify more subtle alteration zones and map more effectively in partially vegetated areas. We expect to see significant advances in the near future from the application of Convolutional Neural Networks (a.k.a. Deep Learning).

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