DEFENCE AND SPACE

Musmer Area, Sudan Remote Sensing Study

AP68270

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Introduction and Objectives

- Contained within this report are the results from a remote sensing study of an area in Sudan ‘Musmer Area’.
- The aim of the study is to provide satellite imagery and derived analysis and interpretation to support mineral exploration, encompassing the following three main objectives:
  - Task and process 16-band World View-3 satellite imagery
  - Provide a geological interpretation study encompassing mineral mapping and structural interpretation
  - Satellite imagery and interpretation layers associated with this study are provided within an associated ArcGIS project, allowing the further exploration of the results

Summary

- WorldView-3 (WV-3) Very High Resolution (VHR) Satellite Imagery has been acquired, processed and interpreted over the Musmer area in Eastern Sudan. WV-3 has “super-spectral” resolution in the VNIR and SWIR ranges of the EM spectrum and enables Spectral Mapping at VHR scales that has previously only been possible on Regional Scales using LANDSAT and ASTER satellite data.

- WV3 Clay-Iron and WV3 Mineral Map Topo Images have been constructed using techniques transferred from processing of regional datasets; LANDSAT and ASTER. These are primarily designed for detection of hydrothermal mineral deposits but they have not been very useful in geological environments like the project area before because of insufficient spatial resolution.

- The central part of the exploration area is occupied by a large near-isoclinal fold structure with a SW-NE trending fold axis and a fold closure in the NE. The fold is interpreted to be bounded and truncated on its NW side by a large fault structure. The folded rocks are dominated by CPS Mineral Mapping signatures. These are probably mainly chlorite bearing metavolcanics. Some felsic metavolcanics with argillic signatures are probably also present. There are also a number of E-W trending felsic dykes intruded into the folded meta-volcanics – these also have argillic signatures. The areas to the NW and SE of this structure are largely covered by recent deposits with very little bedrock exposure. There appears to be no significant spectral information on the nature of the underlying basement rocks in these areas.

- Mineral Mapping of dolomite has revealed a “marker horizon” bearing dolomite-like spectral profiles and can be seen in both limbs of the fold structure as well as around the fold nose in the NE. If these rocks are dolomite then they may well be exhalative sediments associated with base-metal mineralisation. This signals the possibility of VMS style mineralisation. Re-distribution of metal sulphides during deformation also raises the possibility of the development of saddle reefs in the region of the fold nose in the NW. There are other possibilities for mineralogy to produce these spectral profiles – an iron rich chlorite for example. Field checking of these spectral features should provide answers.

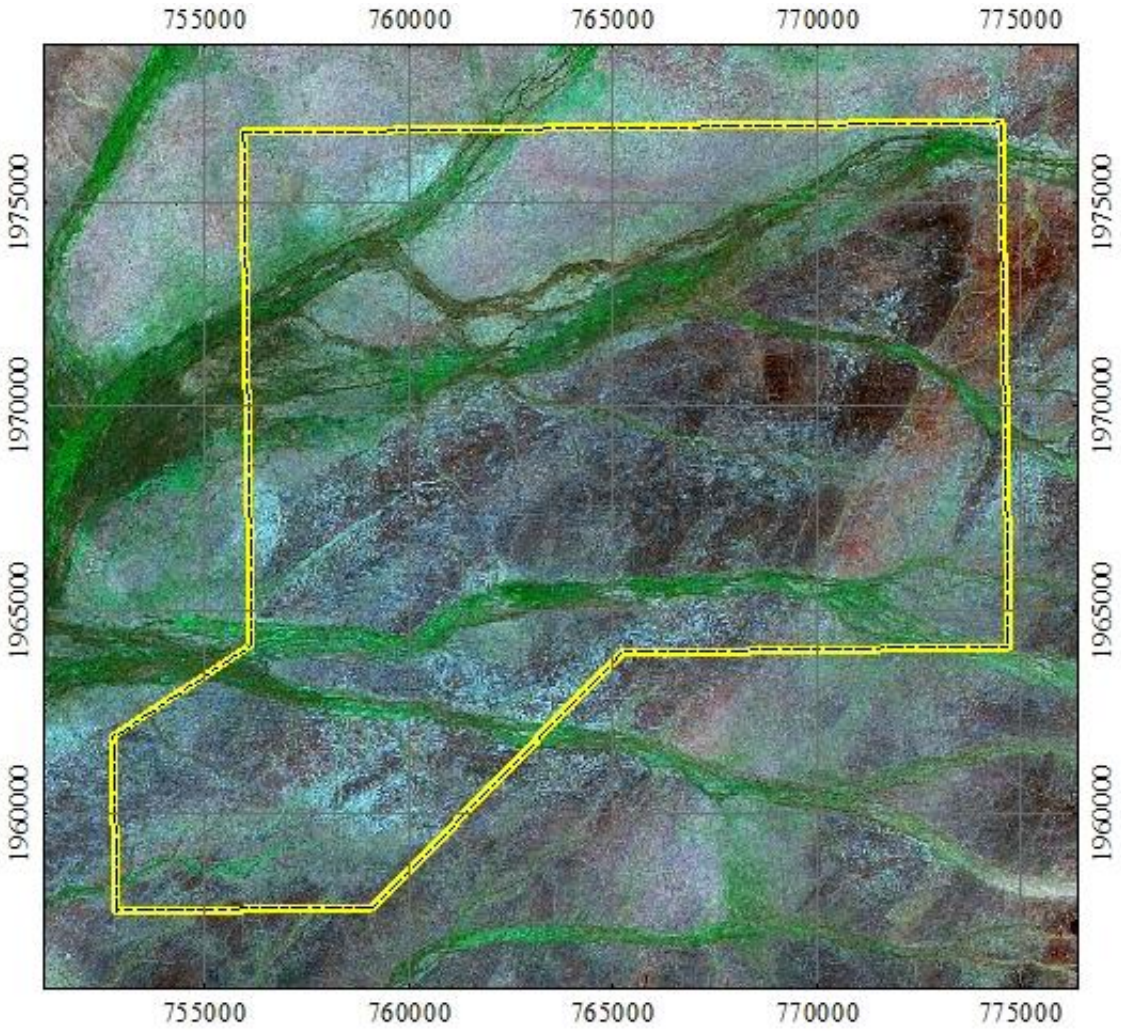
Summary (continued)

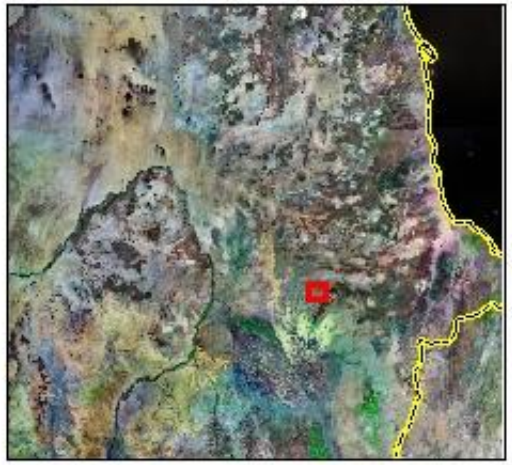
- Mineral Mapping of iron oxide rich rocks that include gossans has been carried out using just the VNIR at 1.2m pixel. The areas defined by this are dominantly iron-oxide rich sediments in the wadis but a few small areas of possible gossan have been defined in the bedrock. If bedrock gossans are undisturbed then they will not be mappable using this technique as a thick black desert coating obscures the underlying spectral features.

- A total of 22 exploration targets have been identified. The criteria that have been used are (1) intense Clay/Iron anomalies that may indicate intense alteration (2) presence of mixed WV3 Mineral Mapping profiles that may be indicative of hydrothermal alteration minerals (3) presence of dolomite that may be associated with exhalative processes (4) the presence of Iron Oxide anomalies that may indicate the presence of gossans. There are three type (1) targets with significant size and both Clay/Iron and Mineral Mapping anomalies. There are seven type (2) target – these include smaller anomalies with both Clay/Iron and Mineral Mapping anomalies or structures associated with dolomite bodies. The nine type (3) targets have only one spectral anomaly type – Clay/Iron or Mineral Mapping. The three type (4) targets show interesting spectral geological features but are not necessarily associated with mineralisation. It is recommended that the 22 spectral targets are visited in the field, in order of grading from 1-4, with detailed geological observations and geochemical sampling.

- There are some artefacts present that may have produced false spectral anomalies. The problem appears to be mainly in the short wavelength bands – possibly due to haze - and has produced over-mapping of goethitic type iron hydroxides. Most of the Mineral Mapping profile types rely on data from longer wavelength bands and these appear to be unaffected.

- Users of this report are asked to bear in mind that the results and conclusions arrived at herein are solely based on spectral analysis of WV3 Imagery and field knowledge of other similar areas in the Arabian-Nubian Shield. No information from the ground has been taken into account.





Location Map

The project area for this Remote Sensing Super-Spectral survey lies in the Eastern Desert of Sudan around 100km east of the Nile and 150km south-west from the Sudan Red Sea coast. Topographically it lies on the desert peneplain near to the western edge of the Red Sea Hills

WV3 Project Location Map

Main map and regional map is LANDSAT ETM+ Millennium Tiles © NASA. Coordinates in metres UTM36N WGS84.

Country map is World Topographic and Bathymetric Image © ESRI.

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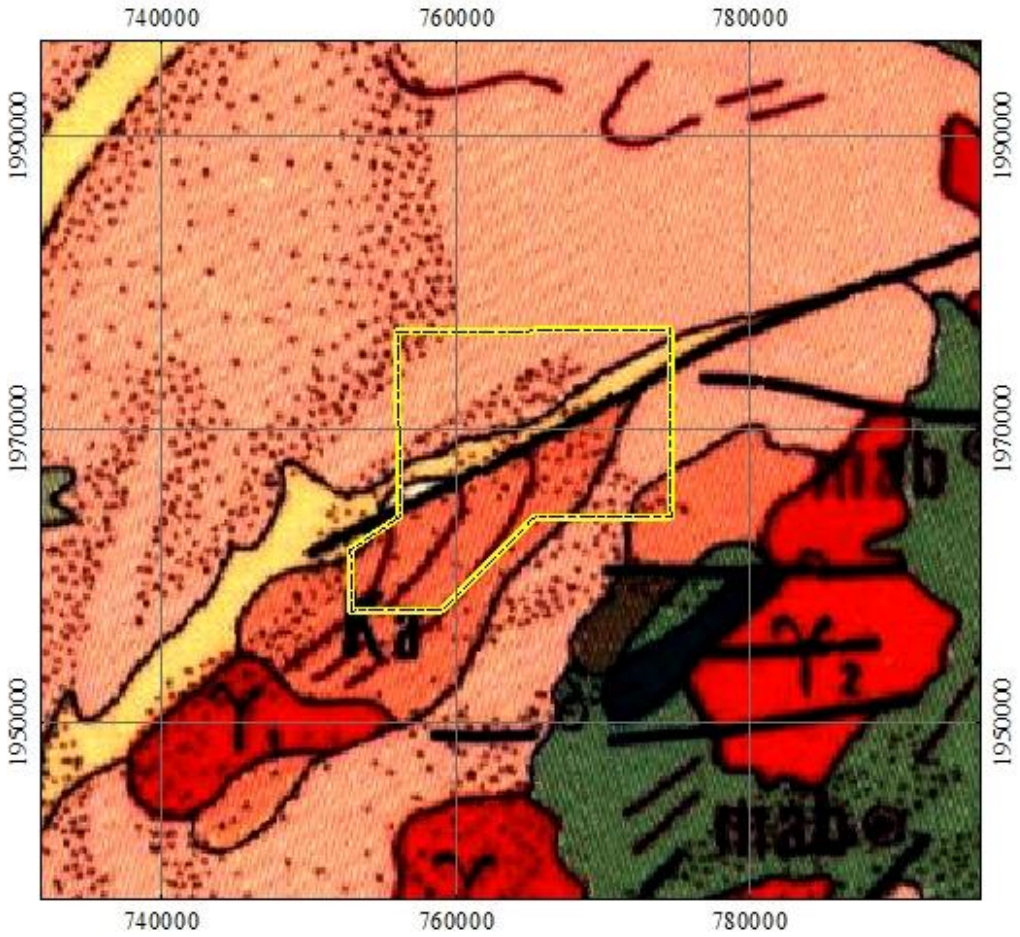

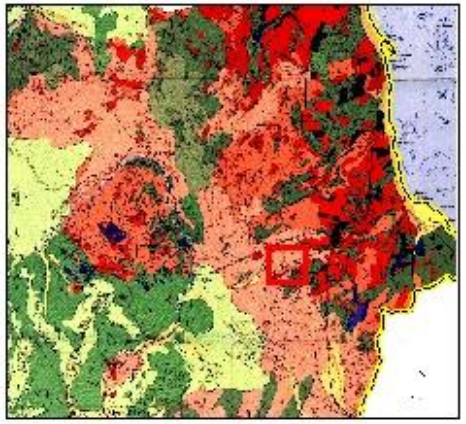

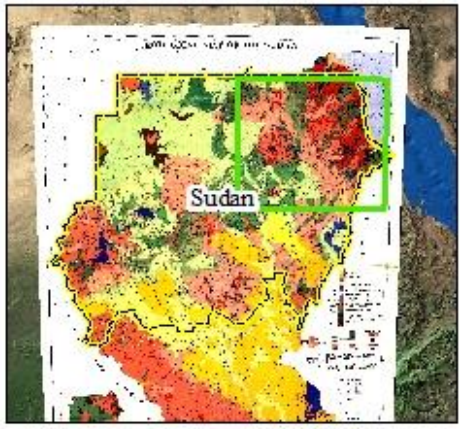

A	Alluvium
Y_2	Younger granite
Y_d	Granodiorite
Y_1	Older granite
Px	Obscured basement
Nf	Metaseds/volcs
Ps	Undiff schists
Ka	Basement Gneiss

WV3 Project Regional Geological Map

Main map and regional map is Geological Map of Sudan at 1:2m scale [1]. Coordinates in metres UTM36N WGS84.

Country map is World Topographic and Bathymetric Image © ESRI.

Regional Geology

The project area is underlain by basement rocks of the Arabian Nubian Shield. This is an accreted assemblage of metasediments and metavolcanics from island arc and back-arc settings with associated intrusive rocks dating from Pan-African times at 800-600 ma.

In the north of the area - because of the partial coverage of recent aeolian deposits - the basement rocks are not mapped on the regional map but rather the area is included in a partially covered undifferentiated basement unit (Px).

In the southern part of the area the regional map shows basement gneisses with a fold structure truncated by a large regional fault at its northern limb. The WV-3 Mineral Mapping provides detailed information that allows us to redefine the geological mapping much more accurately.

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Oblique View

Oblique view of the Study Area in Google Earth – Imagery from 2019. This simulated true colour (STC) imagery shows subtle colour and tonal differences. You can just about make out a fold closure in the darker rocks in the NE of the AOI. There is very little spectral information in a 3-band FCC.

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Remote Sensing Data Summary

- Remote sensing datasets primarily consist of WorldView-3 and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data. An outline of the basic specifications are described below. More detailed information on the WorldView-3 data is provided later in this report relating to its significance for mineral mapping.

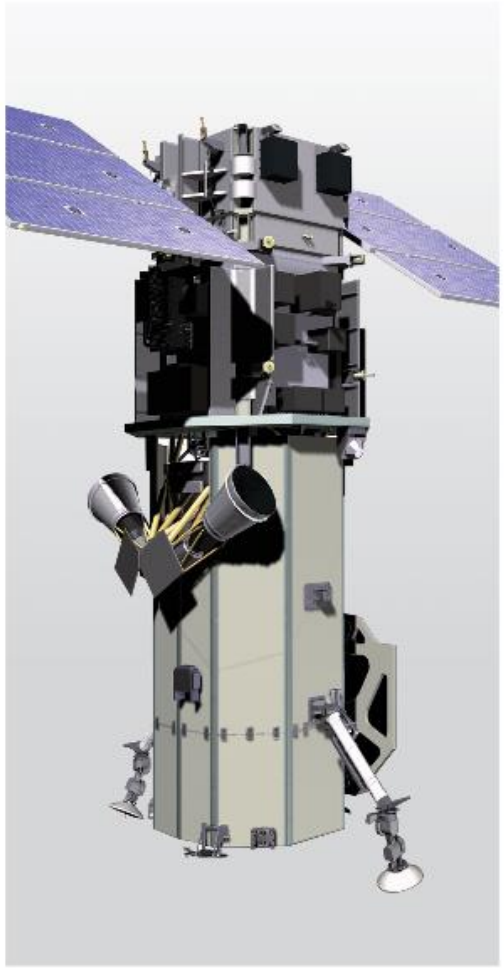
- WorldView-3 imagery (WV-3)
  - 16 band data (8 Visible and Near Infra-Red {VNIR}, 8 Short Wave Infra-Red {SWIR}) plus panchromatic band
  - Acquired 19/04/2019 in three strips
  - Pre-marked GCP points were used for the orthorectification of the WV3 imagery in conjunction with the SRTM DEM
  - Image mosaics were produced at 0.3m resolution
  - In addition specific image mosaics were produced, optimised for the mineral mapping.

- SRTM DEM
  - 30m grid spacing

WorldView-3 Imagery

- The purpose of using WV3 Imagery is to be able to carry out Spectral Mapping at high spatial resolution.
- WV-3 collects 3 separate sets of data at different spectral and spatial resolutions:
    - Panchromatic – single band image at 30cm pixel
    - VNIR – 8 bands of spectral data at 120cm pixel
    - SWIR – 8 bands of spectral data at 370cm pixel *

  * the SWIR is currently only available at 750cm pixel due to US Government regulations so has to be supplied sub-sampled.
- The 8 bands of VNIR and 8 bands of SWIR data can be combined into a “super-spectral” 16 band image which allows Spectral Mapping of rocks and soils in the High Resolution realm. Before WV-3 we had ASTER 9-band spectral data and LANDSAT-8 7-band data which allowed Spectral Mapping on a regional scale.
- WV-3 data allows us to perform Spectral Mapping in high spatial resolution. VNIR-SWIR data are analysed at 750cm pixel. The results of Spectral Mapping are presented in colour on a topographic base derived from the Panchromatic data at 300cm pixel.



WorldView-3 artist rendering

wwww.digitalglobe.com

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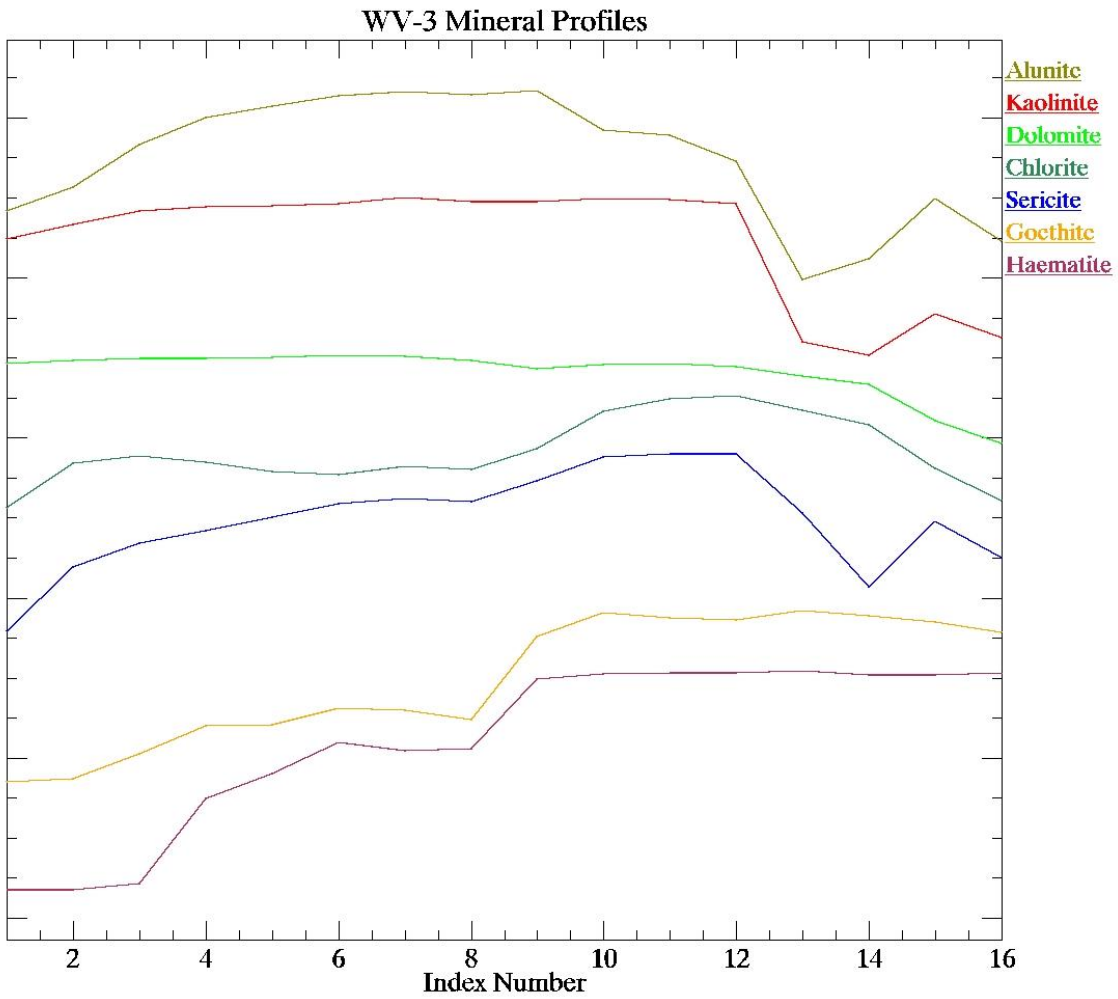
WorldView-3 Imagery – Spectral Profiles of Geological Materials - 1

- WV-3 collects 3 sets of co-registrable data at different spatial and spectral resolutions:
  - Panchromatic.
    - A single band (visible to near infra red) at 30cm pixel. This provides superb detail and can be used to “Pan-sharpen” colour imagery.
  - Visible and Near Infra-Red (VNIR)
    - Bands 1 - 8 from UV to NIR at 1.2m pixel. Provides simulated true colour (STC) in great detail and maps vegetation, water and iron minerals.
  - Short Wave Infra-Red (SWIR).
    - Bands 9-16 at 3.6m pixel but currently sub-sampled to 7.5m pixel due to US regulations. Combines with VNIR to produce false colour composites (FCCs) and enables WV-3 Clay/Iron and WV-3 Mineral Mapping processing at unprecedented spatial resolution.

WorldView-3 Imagery – Spectral Profiles of Geological Materials - 2



Mineral Mapping & WV-3

The Super-Spectral resolution of WV-3 enables us to map and distinguish 4 mineral groups – Iron oxides/Hydroxides (Hae & Goe), Argillic minerals (Arg), Carbonates, Propylites and Serpentinites (CPS) and Phyllites (Phyll).

Hae & Goe

Haematite and Goethite. These are characterised by an absorption feature at B8 and also by an absorption at B2. To distinguish between them we use the slope of the profile between B5 and B3 which is shallower for Goethite and Steeper for Haematite.

Argillic

Minerals like alunite and kaolinite that have characteristic absorption features at B13 and B14.

CPS (Carbonate, Propylites, Serpentines)

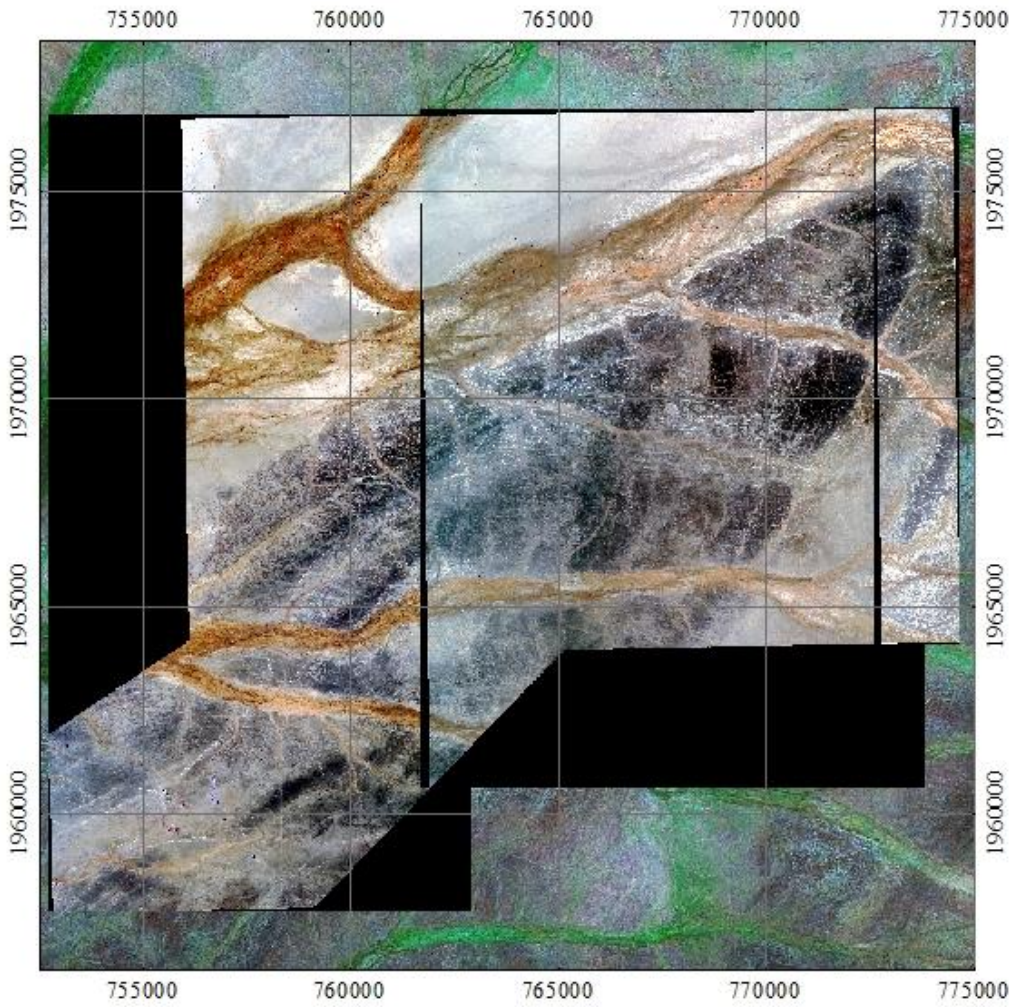
Minerals including calcite and dolomite, epidote and chlorite and serpentines that have a characteristic absorption feature at B16.

Phyllic

Minerals such as sericites and smectite clays that have a characteristic absorption feature at B14.

Selected mineral spectra from the USGS Spectral Library re-sampled to the bands of WV-3. The mineral profiles are shown in "band-space" rather than wavelength on the x-axis where the Index Number is the WV-3 Band Number.

WorldView-3 Data



Coordinates in metres UTM36N WGS84. Grid spacing is 5km.
Background imagery is LANDSAT ETM+ Millennium Tiles © NASA.

Visible and Near Infra-Red (VNIR) at 120 cm pixel

The VNIR from WV3 is collected at very high resolution (VHR) in the spatial domain with a 120 cm pixel. This allows simulated true colour (STC) false colour composites (FCCs) to be made as well as the classic False Colour Infra Red familiar from the days of Colour Infra Red aerial photography and early Remote Sensing satellite imagery such as the LANDSAT Multi Spectral Scanner (MSS).

Overviews of the WV-3 VNIR data are shown here as FCC753 in RGB – equivalent to the Infra-Red False Colour imagery from MSS and Aerial Photography. Note the orange-brown colours in the wadi drainage. These are areas of scrubby desert vegetation that are confined to the wadis where the roots can access water in the substrate.

The rocks in the central fold structure are represented in various subtle shades of blue-grey. The surrounding partially sand covered desert surface shows in a lighter blue-grey. Note the lighter colours over the western side of the central strip. It looks like this part of the imagery may have been collected when there was minor haze cover.

WV3 VNIR data presented as FCC753 Image over the project area. Note that the full area coverage consists of 3 separate images. This is because the survey area is wider than 2x the maximum swath width of WV-3. The swaths were collected on the same date - 19th April 2019.

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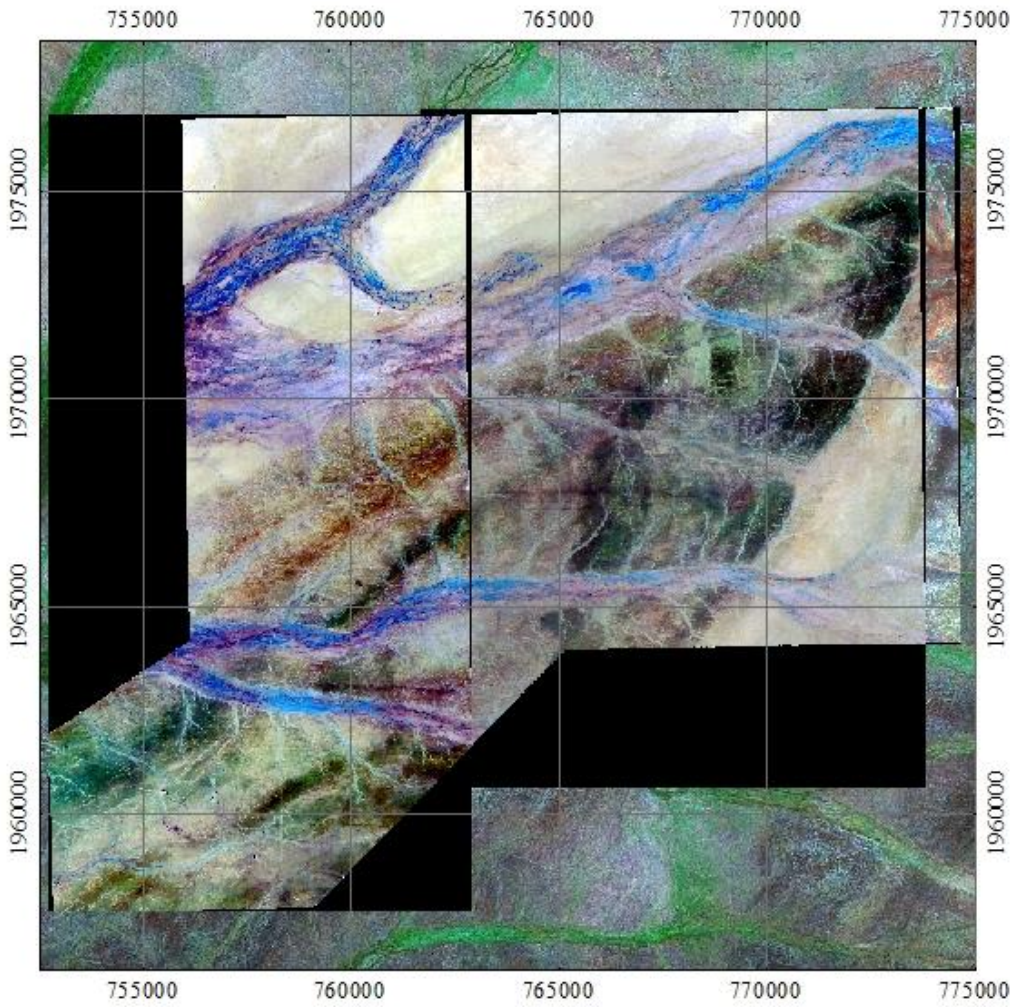
WorldView-3 Data



Coordinates in metres UTM36N WGS84. Grid spacing is 5km.
Background imagery is LANDSAT ETM+ Millennium Tiles © NASA.

Short Wave Infra-Red (SWIR) at 750 cm pixel

The SWIR data of WV-3 is collected at 370cm pixel but it is not currently available at this resolution because of US regulations and is delivered to users at 750cm. The 8 bands of WV3 SWIR cover regions of the spectrum where diagnostic absorption features of major mineral groups occur. Combination of the SWIR data with co-registered VNIR data (sub-sampled to 750m pixel) constitutes a “Super-Spectral” array and enables Spectral Mapping of these major mineral groups to provide mineralogical information way beyond the scope of any of the 3 band combinations we normally see.

The overviews of the WV-3 SWIR data are shown here as FCC16 12 9 in RGB. This is just an arbitrary 3 band display. We get some different colours to the other combinations we have seen so far but the significance of the colours is difficult to interpret when you just choose 3 bands from a 16 band array. This is the reason for using many of the available bands to characterise our mineral profiles in the data and to give each spectral type a standard colour so that we have a much clearer idea of the type of rocks that are present.

Note that the central haze affected strip is still present but less pronounced in the longer wavelength data.

WV3 SWIR data presented as FCC16 12 9 Image over the project area. Note that the full area coverage consists of 3 separate images. This is because the survey area is slightly wider than 2x the swath width of WV-3. The 3 swaths were collected on the same date - 19th April 2019.

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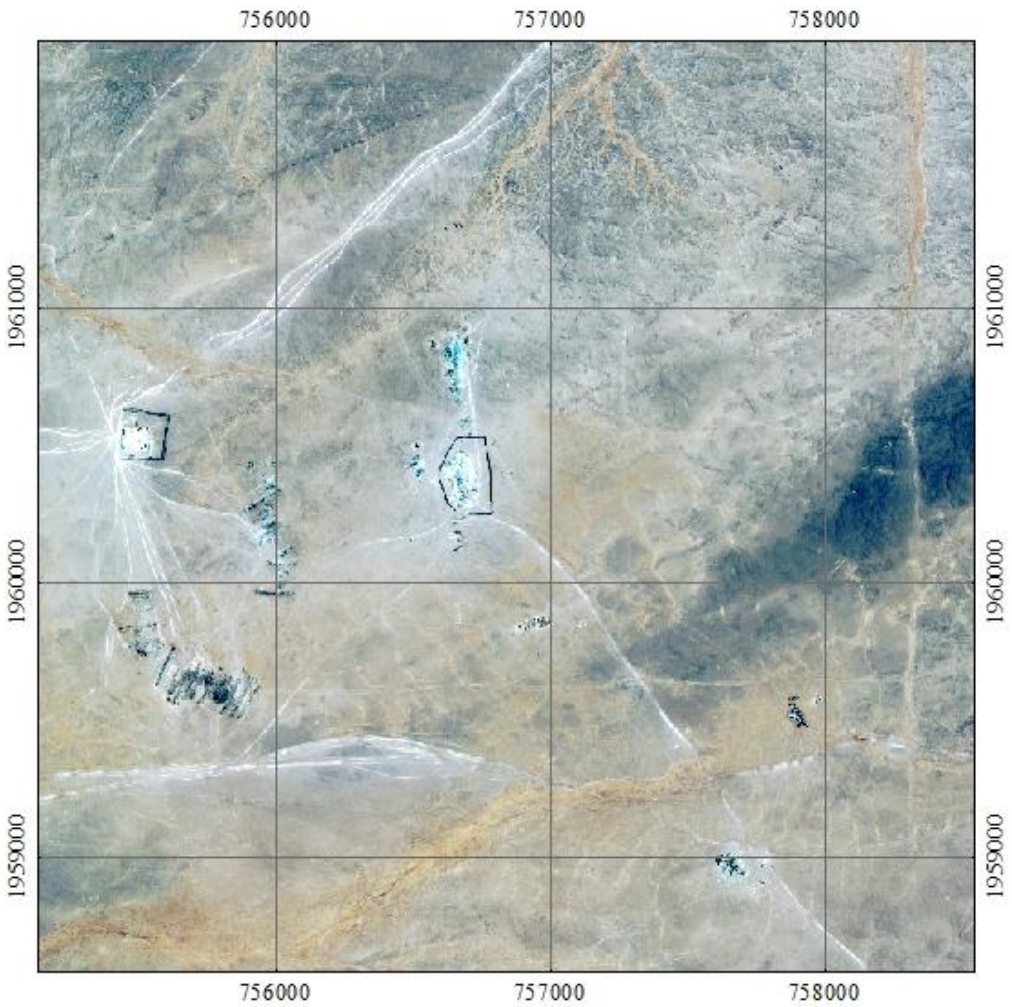
SW Area – WV3 532



WV-3 Simulated True Colour

This is the WV-3 SimulatedTrue Colour (STC) equivalent of the imagery we see on Google Earth. The quality of the WV-3 data with a 1.2m pixel is apparent, even in this zoomed out image. We can see some excavation and trenching along linear zones.

The desert surface is represented in various shades of grey in this STC image. There is a darker grey-green zone trending SW-NE on the eastern side. Desert tracks are very high reflectance in all 3 bands and appear white. Drainage channels appear as light orange or browns. The orange-brown colour could be due to iron oxides / hydroxides but, it is likely this is the visible colour of the scrubby vegetation that is restricted to the wadis where there is sub-surface water closer to the surface.

In the excavations and trenching we see grey to white to cyan colours – these could be due to the presence of hydrothermally altered rocks related to the metalliferous mineralisation that appears to be being explored for. However – it is difficult to distinguish these areas from other man-made surface disturbances using an STC image

SW Area WV3 FCC 532 Simulated True Colour.
Coordinates in metres UTM36N WGS84. Grid spacing 1000m.

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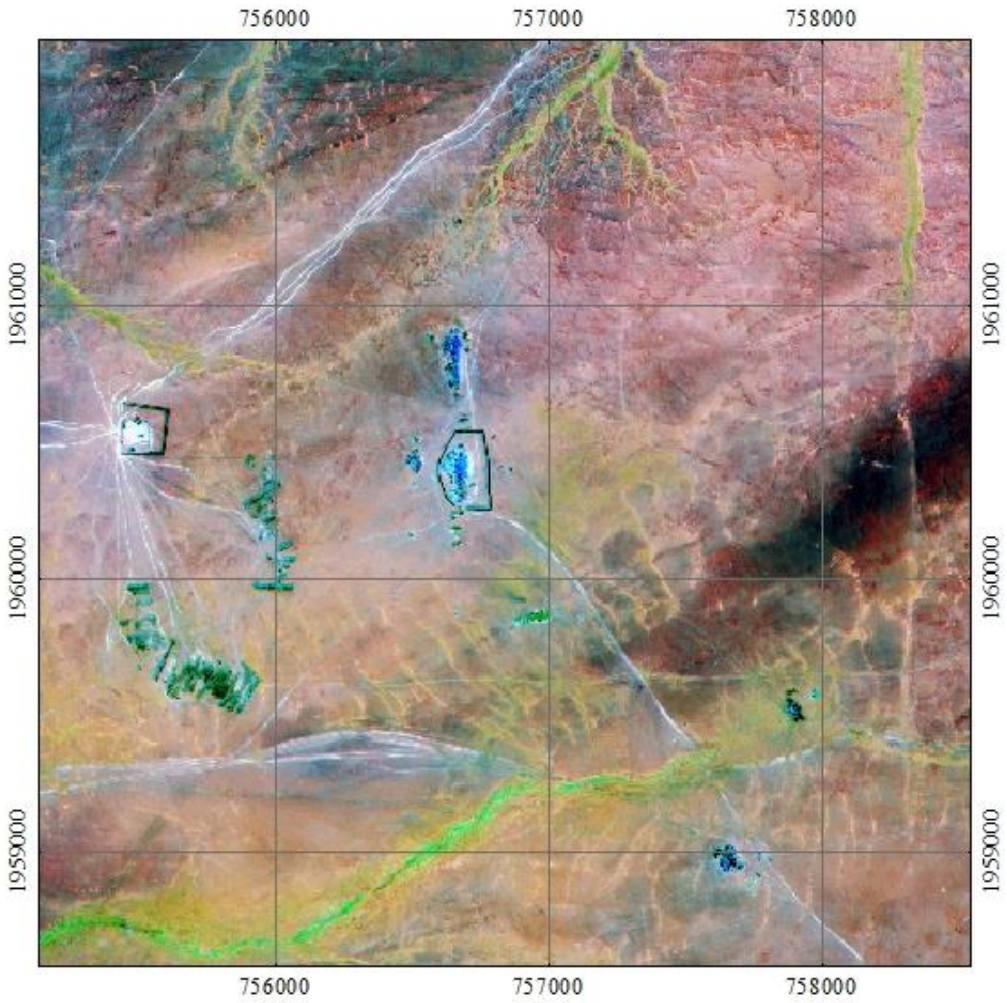
SW Area – FCC 14-7-2



FCC 14-7-2

This is a new innovation in the realm of very high resolution (VHR) imagery with LANDSAT – like spectral properties at VHR scales. For the mineral mapping and interpretation PAN sharpening was undertaken at 3m pixel using a sub-sampled product of the 30cm panchromatic data, as using a 30cm product for pan-sharpening of 750cm data can produce artefacts. A separate 30cm pan-sharpened SWIR mosaic image has also been provided as part of the study for general interpretation.

In this FCC14-7-2 image, in the SW of the project area, the main geological features visible are:

- Pale orange alluvial material in the wadis
- Pale orange yellow surface sand
- Pale Red-brown basement subcrop
- Dark red-brown basement unit
- Green vegetation in the wadis and in the trenches
- Cyan coloured altered rocks in the excavations

SW Area. WV3 FCC 14-7-2. This is equivalent to the standard LANDSAT-8 FCC752. This produces "intuitive" False Colour where rocks range in colour from red to brown to blue-green, vegetation is bright green. Coordinates in metres UTM36N WGS84. Grid spacing 1000m

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WV3 Mineral Profiles - 1

- Mineral Mapping is a technique developed on ASTER imagery. ASTER is a “Super-spectral” regional satellite system that allows Spectral Mapping of rocks on a regional scale with a 30m pixel.

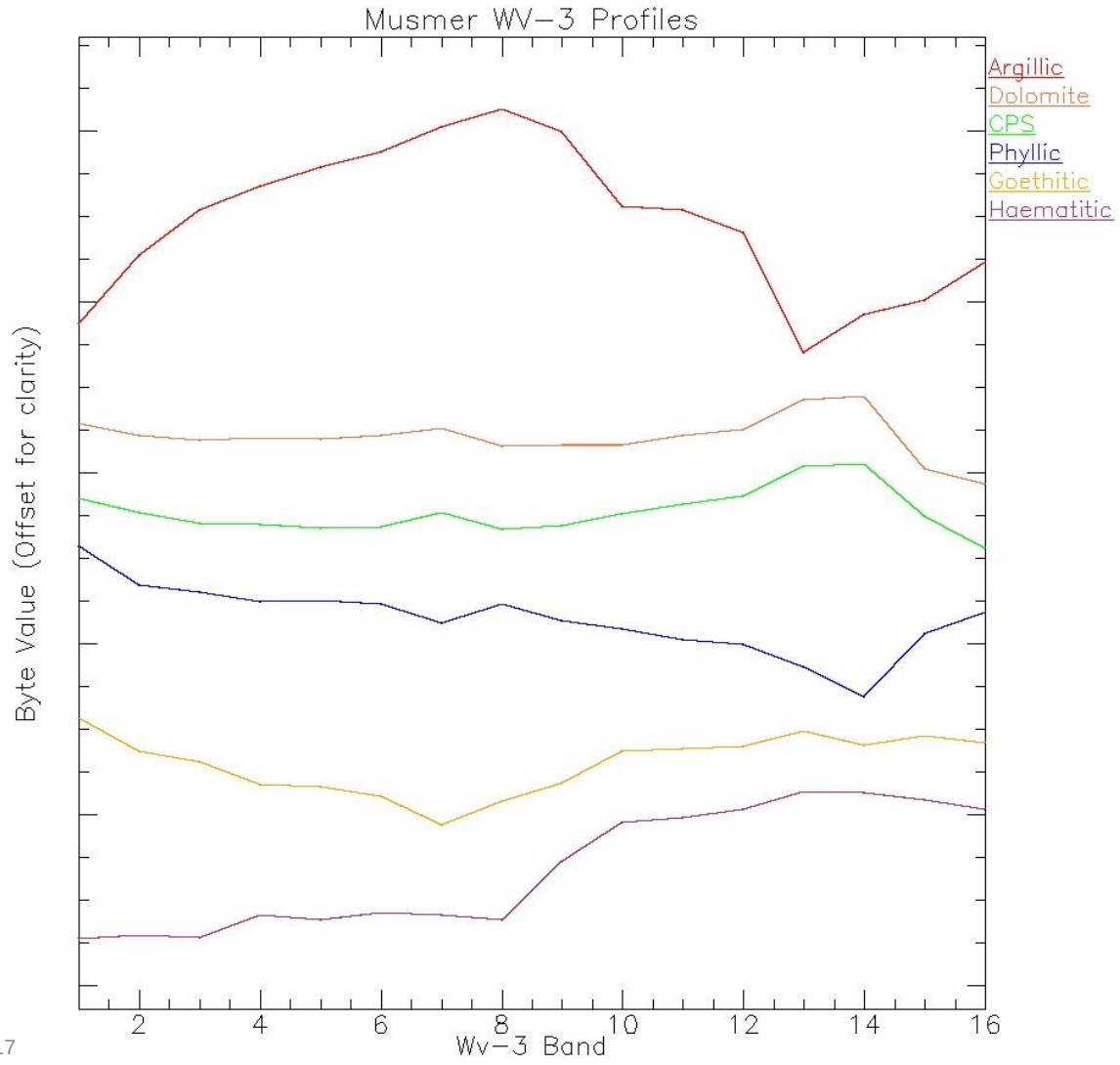
- The Mineral Mapping of ASTER is directly translatable to WV-3 which brings Mineral Mapping into the high resolution realm with 16x the spatial resolution of the regional system.

- To make the Mineral Mapping imagery we use Logical Operator expressions to characterise the band profiles in multi-band space. The outputs are bitmaps that can be constructed into a colour image using a selected standard colour palette.

- Note that we cannot usually identify individual mineral species with 16 band “super-spectral” resolution. To achieve this we would need hyperspectral (typically 100+ bands over the VNIR-SWIR range).

- Division into these 6 mineral groups enables us to achieve a significant amount of lithological and alteration mapping. For our standard Mineral Mapping image we normally do not include Dolomite as this is usually not present. It has been included in the mapping here as there ARE significant bodies of dolomite along a possibly mineralised trend. The dolomite mapping is delivered as a vectorised shapefile separate from the WV3 MM11 standard image.

WV3 Mineral Profiles - 2



- Mean spectral profiles for WV-3 Mineral Mapping.
- Super-spectral resolution has enabled mapping of 6 spectral types:

Argillic, CPS*, Dolomite, Goethite, Haematite & Phyllic

* Carbonate, Propylite, Serpentine minerals all main absorption at B16

X-axis of plot = WV-3 VNIR-SWIR Band Numbers 1 to 16

Y-axis of plot = DN number in Byte range – stacked values

Argillic – main absorption feature at Band 13 with also absorption in B14.

Dolomite – main absorption at B16 with also absorption in B15.

CPS* - main absorption feature at B16

Phyllic – main absorption feature at B14

Goethite – main absorption feature at B7 with –ve slope B5 to B 1

Haematite – main absorption feature at B8 with +ve slope B5 to B1

Mixed Mineral Profiles - 1

- Hydrothermal alteration zones typically contain intensely altered lithologies that combine the lithic types argillic and phyllic – and maybe CPS in skarns – with goethitic or haematitic iron hydroxide / oxide profiles. Therefore to further subdivide our spectral types we can map the coincidence of our 3 lithic types – Arg CPS and Phyll with our two Iron types Goe and Hae to get 6 mixed spectral types.

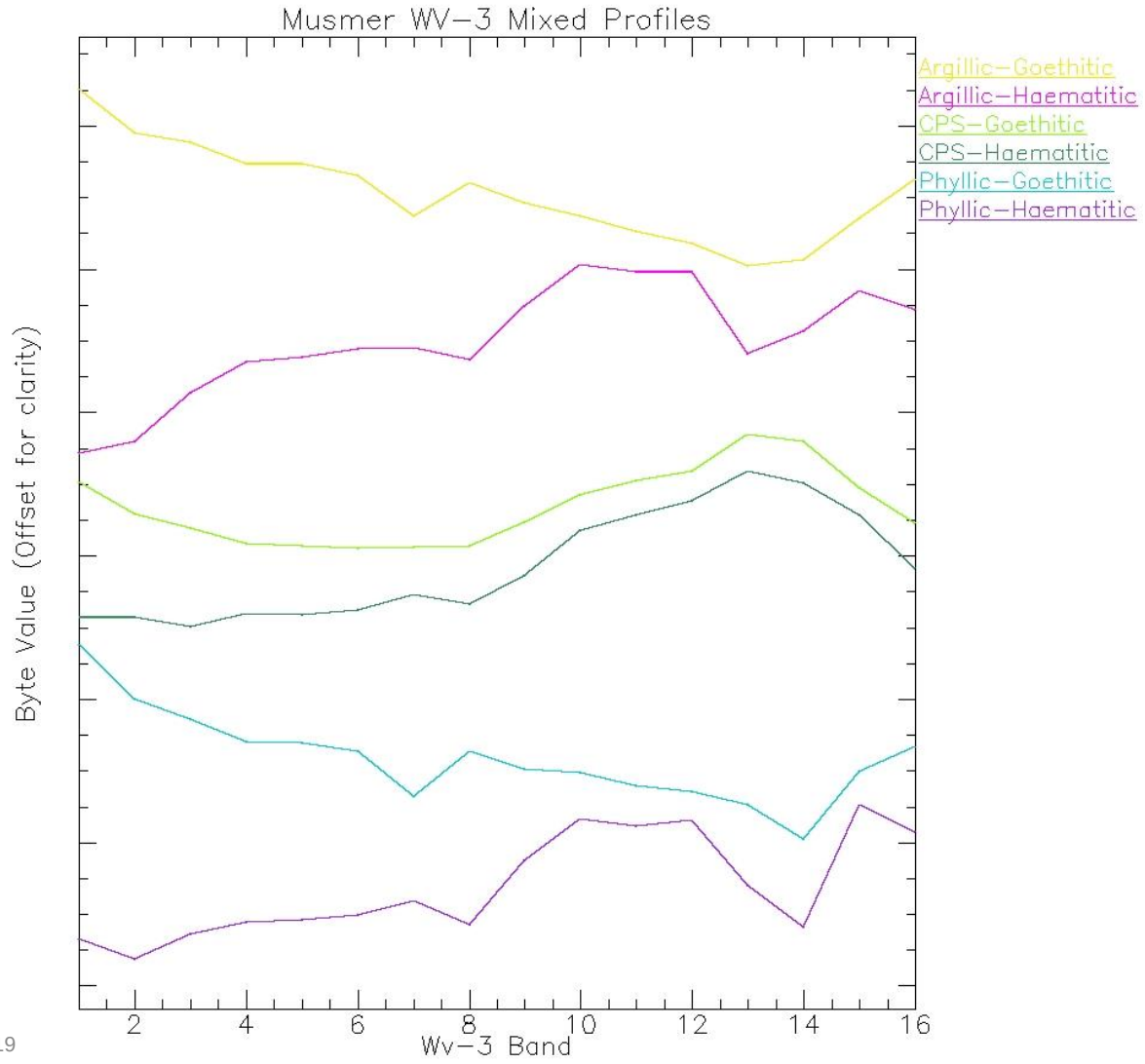
- From previous experience in volcanic terranes the mixed spectral types that are mostly indicative of hydrothermal alteration are argillic - goethitic and phyllic - goethitic. These two alteration types can occur in high-sulphidation and low-sulphidation epithermal deposits respectively. These type of hydrothermal alteration systems are normally large and intense enough to be readily detectable using the regional low-cost datasets LANDSAT and ASTER.

- In the Arabian Nubian Shield the VMS type mineralised systems are also associated with hydrothermal alteration but these tend to be much smaller and less intense areas of alteration that are usually not detectable using the regional data.

- This is where WorldView-3 imagery becomes uniquely useful as it is the only system delivering the “super-spectral” spectral resolution of ASTER at Very High (Spatial) Resolution (VHR) scales.

- The 5 main Mineral Mapping units plus the 6 mixed units seen here are combined in a standard colour scheme to compose the WV-3 Mineral Mapping 11 spectral unit image. This colour image is then combined with a Pan topo image at 3m pixel to create the WV3 MM11 Topo Image.

Mixed Mineral Profiles - 2



- Mean mixed spectral profiles from the WV-3 Mineral Mapping
- We can map areas where pixels have both a lithic type profile (arg, CPS* or phyll) combined with an iron type profile (goe or hae).

* Carbonate, Propylite, Serpentine minerals all main abs at B16

X-axis of plot = WV-3 VNIR-SWIR Band Numbers 1 to 16

Y-axis of plot = DN number in Byte range – stacked values

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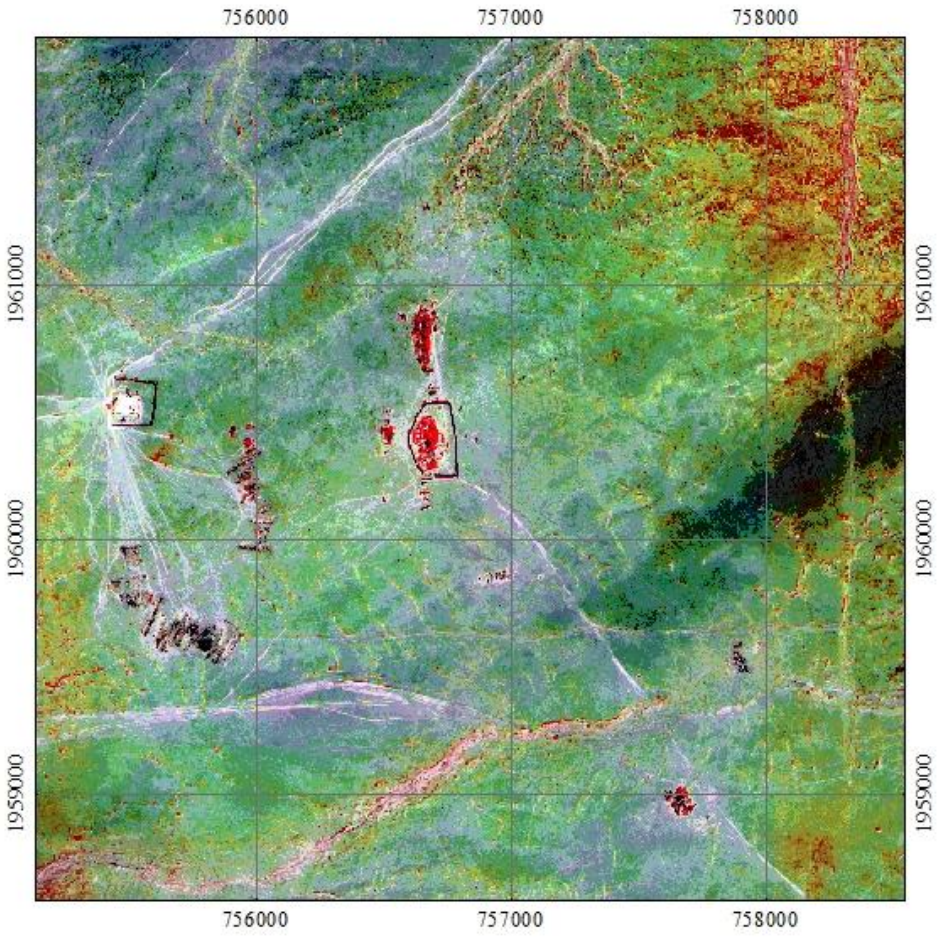
SW Area - WV3 Clay-Iron Imagery - 1



Coordinates in metres UTM36N WGS84. Grid spacing 1000m.

The Clay-Iron image was first developed on LANDSAT4-5 data in 1987 and further modified in 1995[(2)]. It is still being used on LANDSAT-8 imagery today, 32 years on from its first use.

Inclusion of the SWIR bands in WV3 data – for the first time in VHR satellite data – now enables the use of Clay-Iron processing at unprecedented scales allowing detection of much smaller areas of intense hydrothermal alteration than was previously possible. In the Arabian-Nubian shield, where intense hydrothermal alteration associated with VMS style mineralisation can be very localised, WV3 can bring Clay-Iron processing into play.

In a Clay-Iron image the target zones of intense hydrothermal alteration are bright red. None of the other colours really matter for targeting purposes although they can be useful for geological mapping in some cases. Here “clay” is used *sensu lato* meaning any minerals that produce a strong absorption feature at Band 7 of LANDSAT and Band 14 of WV3 centred on 2200nm. These can be clays such as kaolinites or smectites but also includes micas/sericites alunite and pyrophyllite. Some of these ONLY occur in hydrothermally altered rocks but others can be present in unaltered rocks or in low temperature weathering. Therefore it is important to recognise that all that is bright red is not necessarily hydrothermal alteration. On the other hand, if there is sufficient extent of intense hydrothermally altered rocks they WILL be a strong red colour on the WV3 Clay-Iron Image.

This is demonstrated here in the SW area where bright red zones in the excavations and around the trenching indicate the possible presence of intense hydrothermal alteration.

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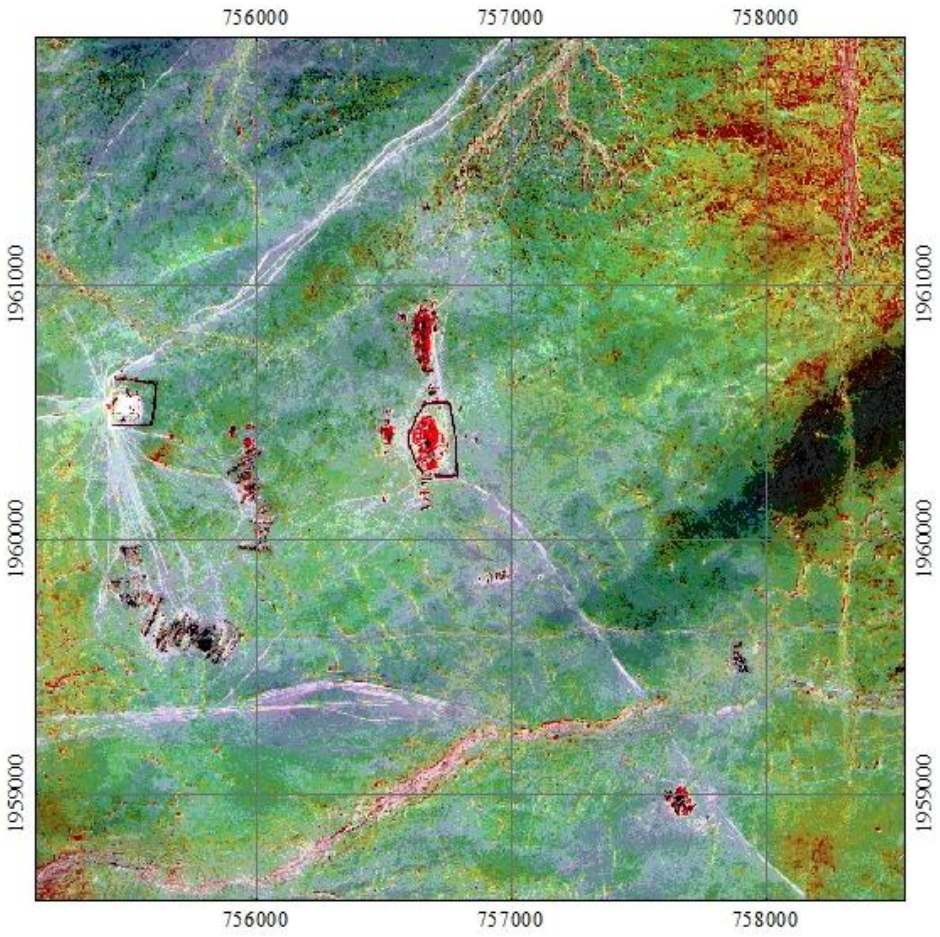
SW Area - WV3 Clay-Iron Imagery - 2



Coordinates in metres UTM36N WGS84. Grid spacing 1000m.

WV3 Clay-Iron Image. This image is constructed using an Intensity-Hue-Saturation (IHS) construction. A topographic image is used in the Intensity (I), a "clay" image in the Hue (H) and an "iron" image in the Saturation (S). The end result is that "Clay" and "Iron" rich rocks – typically present in hydrothermal alteration zones – are presented in bright red. All other shades can be interpreted in terms of their Hue (colour) and Saturation (strength of colour) but it is the red "anomalies" that we are targeting. The WV-3 Pan data subsampled to 3m has been used here as (I).

Note that there is some vertical striping in this image – presumably due to the different image acquisitions used to cover the whole scene. The central vertical portion in the Clay/Iron image is more green/blue than the sides that are more yellow to orange. This is not easily avoided. It is visually unappealing, but it is important to note that it does not affect the strong Clay-Iron anomalous areas.

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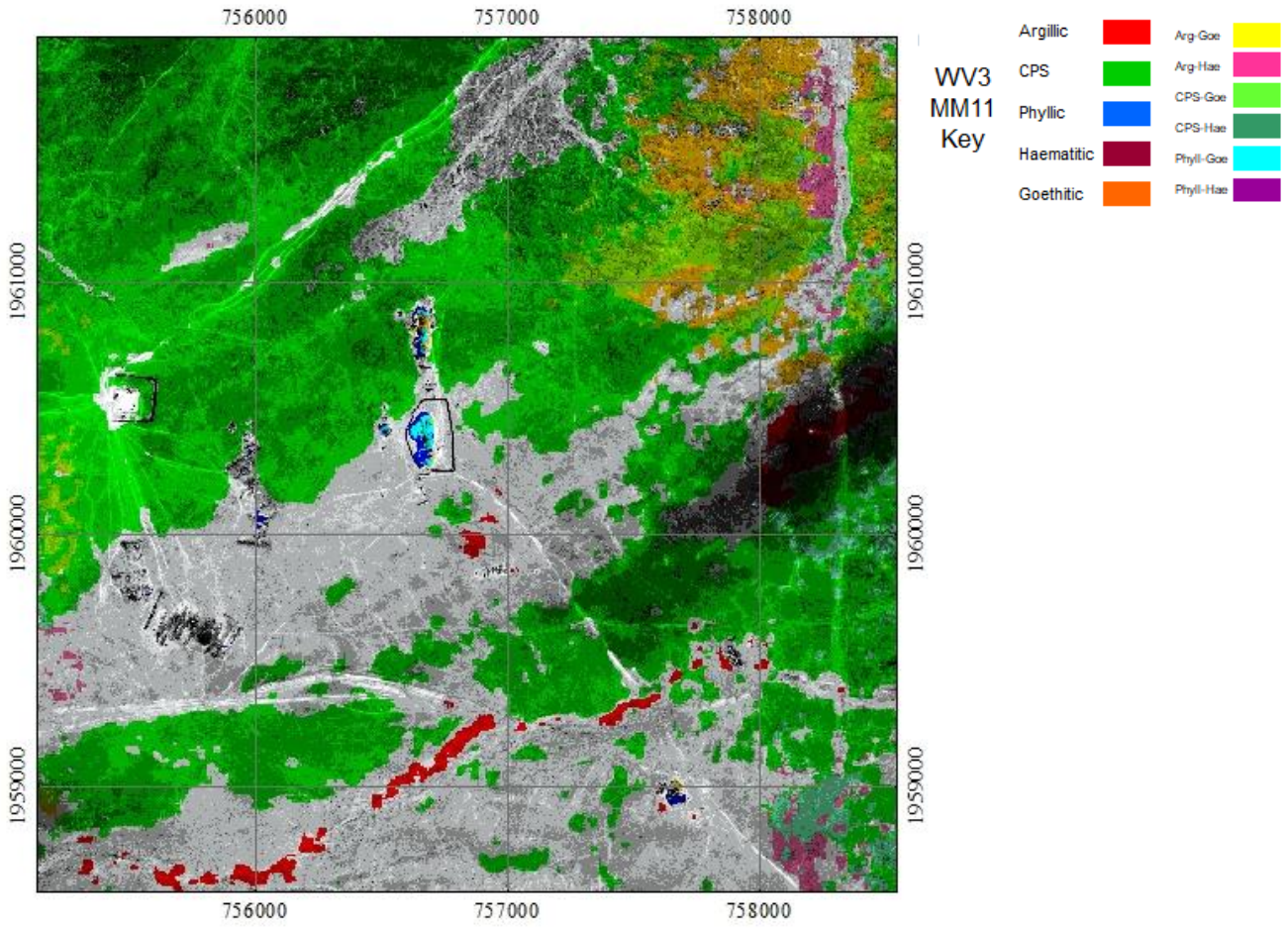
SW Area - WV-3 MinMap 11 Topo Image



WV3 Mineral Mapping 11 Topo Image. A colour image is constructed from the 11 Mineral Mapping units and this is then draped over a single band Topographic image at 3m pixel constructed by sub-sampling the WV-3 30cm pixel Panchromatic Image.
Coordinates in metres UTM36N WGS84. Grid spacing 1000m.

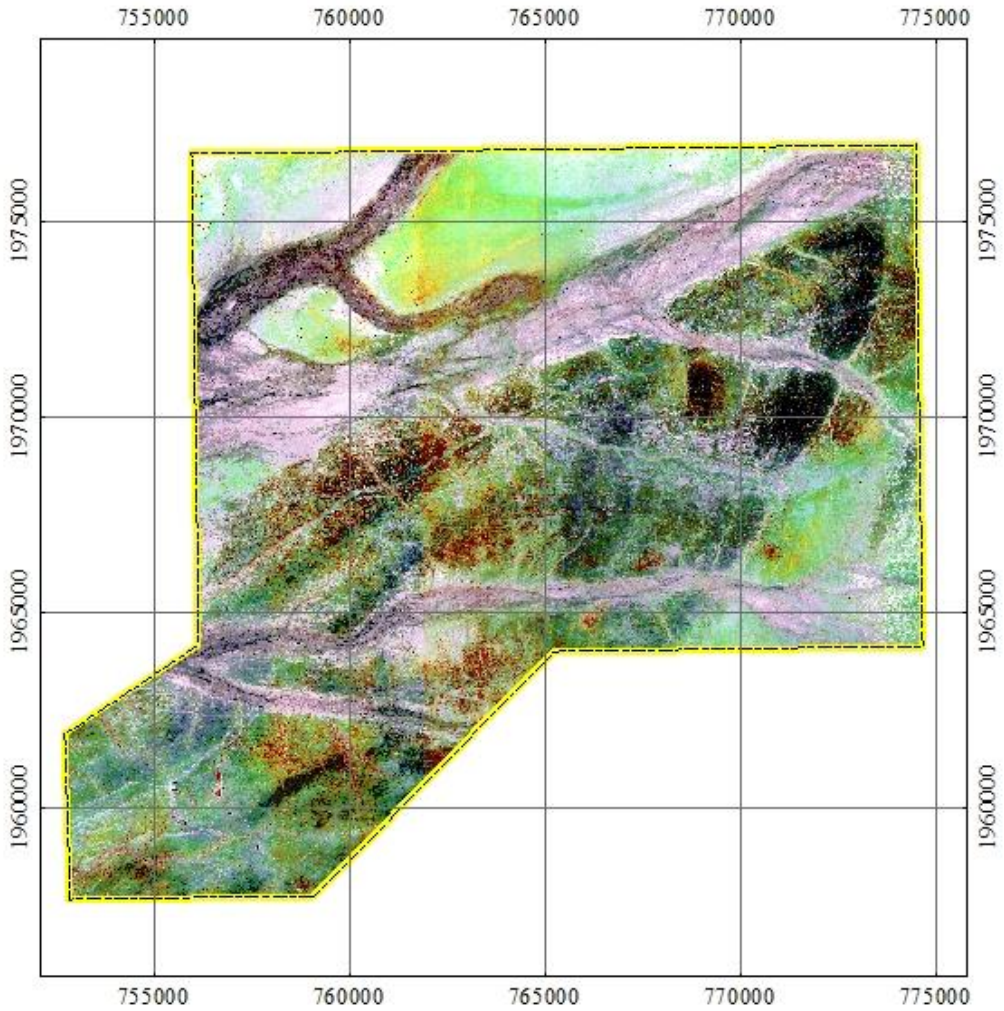
Construction of this image relies on characterisation of the spectral profile present in each pixel across the 16 WV-3 bands in a VNIR-SWIR composite image at 7.5m pixel – the sub-sampled resolution of the WV-3 SWIR data. The method uses a combination of simple measurements to detect characteristic spectral features of the 3 lithic and 2 iron spectral types. Where both iron and lithic features are present we get one of the 6 mixed spectra types.

This technique was developed on ASTER imagery in 2006[(2)]. It is primarily designed to map hydrothermal alteration systems in geologically recent volcanic terranes but it has also proved to be useful in other geological terranes for geological mapping as well as hydrothermal anomaly detection.

The exposed desert surface in this area is dominated by CPS (green), CPS-goethitic (yellow-green) and CPS-haematitic (sea-green) type profiles. These rocks are likely to be chlorite bearing metasediments or metavolcanics. This seems to be at odds with the 1:2m scale mapping that has this area mapped as gneissic basement. There are argillic (red) signatures in the sinuous wadi in the south but also some argillic areas in the desert rock surface – notably along the SW-NE trending dark unit on the east side of the area. Possible hydrothermal alteration is seen in the central excavated areas where phyllic (blue), goethitic (orange) and mixed phyllic-goethitic (cyan) can be seen. It is these mixed spectral types that we home in on when looking for mineral exploration targets when they coincide with intense alteration indicated by red zones on the WV-3 Clay/Iron imagery.

AIRBUS

WV3 Clay-Iron Image - Area overview



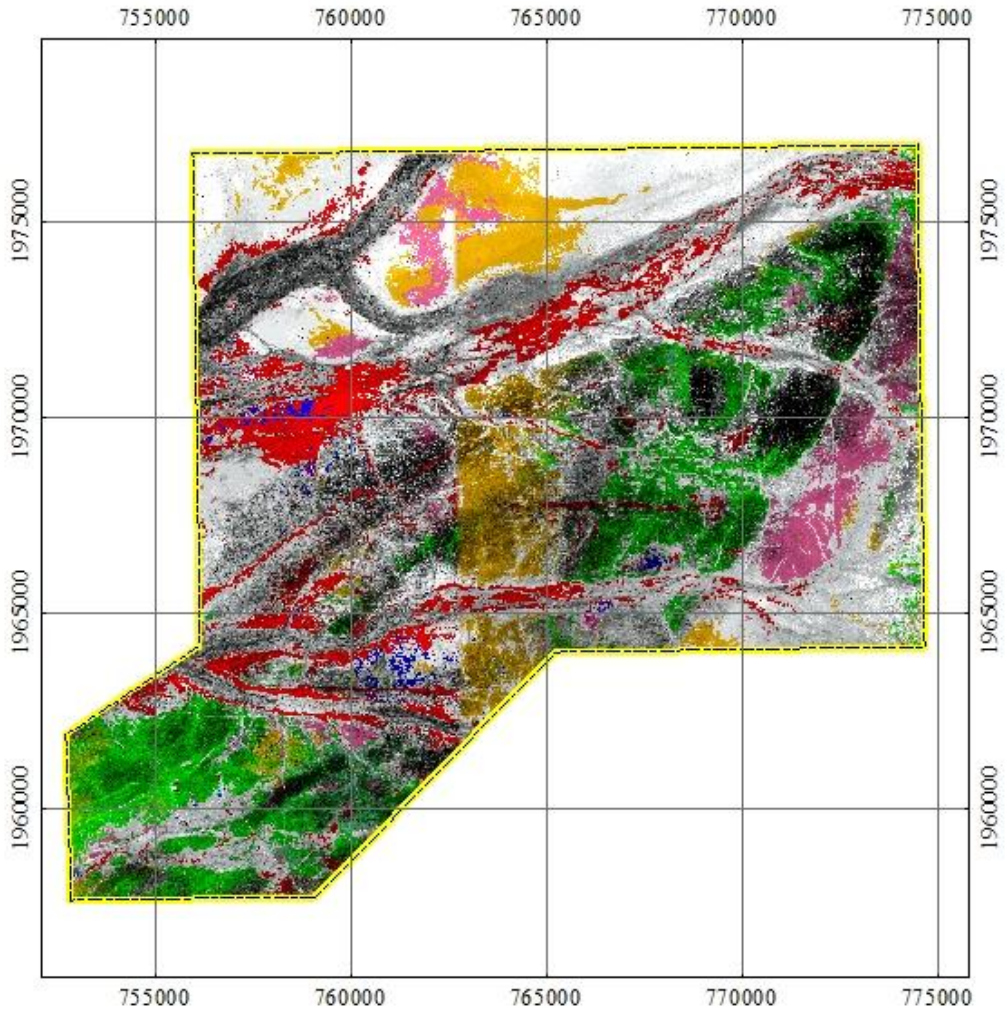
Clay-Iron Image. Mosaic of 3 WV-3 Images.
Coordinates in metres UTM36N WGS84. Grid spacing 5000m.

The Clay-Iron images from each of the 3 component images for the project area have been joined digitally in a mosaic to create a single image for GIS display purposes. When we look at an overview the vertical banding is immediately apparent, but it does not prevent the stronger anomalies being picked up unhindered. The example from the SW area given on P15, for instance, is in a vertical band of generally lower Clay/Iron values – the blue-green strip between the yellow orange strips in the SW of the area shown here. Despite this – the strong Clay/Iron anomalies that are present there are picked out just as strongly as any other anomalies elsewhere.

The detailed imagery shown over selected anomalies on later pages of this report shows that this WV-3 Clay/Iron imagery is still fully functional for spectral anomaly detection.

AIRBUS

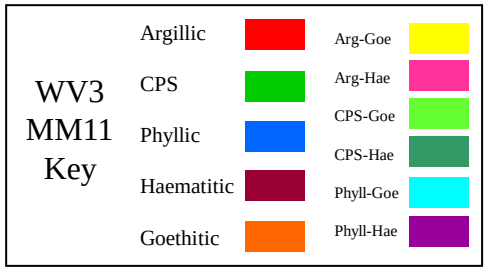
WV3 MinMap 11 Topo Image - Area Overview



WV3 Mineral Mapping 11 Topo Image. - Mosaic of 3 WV-3 Images
Coordinates in metres UTM36N WGS84. Grid spacing 5000m.

The vertical banding is also apparent in the WV-3 Minmap11 Imagery. The banding in the SW described in the Clay-Iron imagery is not apparent but the central band manifests itself as an orange strip due to over-mapping of goethitic signatures. It is likely that the haze boosts the reflectance in the shorter wavelengths more than in longer wavelengths. This would explain the goethitic – rather than haematitic – mineral mapping.

Base colours of Mineral Mapping Topo Image shown in the key below. Note that the colours on the image can be a lot darker than on this key depending on the brightness of the rock surface.



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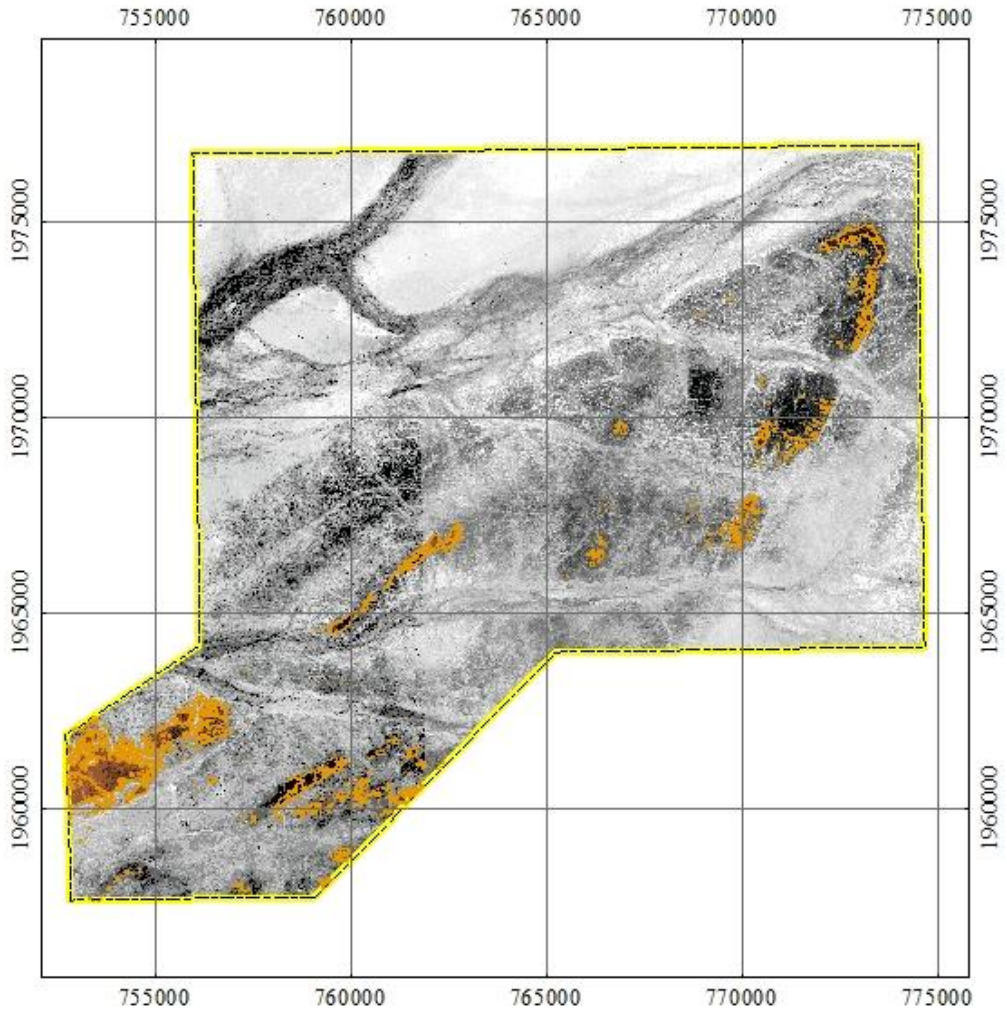
Dolomite Vectors



WV3 Dolomite Mineral Mapping vectors overlaid in pale orange outlines on WV3 Pan Topo image at 3m pixel.
Coordinates in metres UTM36 WGS84. Grid spacing 5000m.

Experience from elsewhere in the Arabian Nubian Shield has shown that dolomitic bodies are commonly associated with VMS style mineralisation. These are interpreted to be exhalative or replacement style volcanogenic-hydrothermal carbonates. As the “super-spectral” resolution of WV-3 allows mapping of dolomite then these small discrete bodies have also been mapped and converted to vector data:

Dolomitic bodies (pale orange):

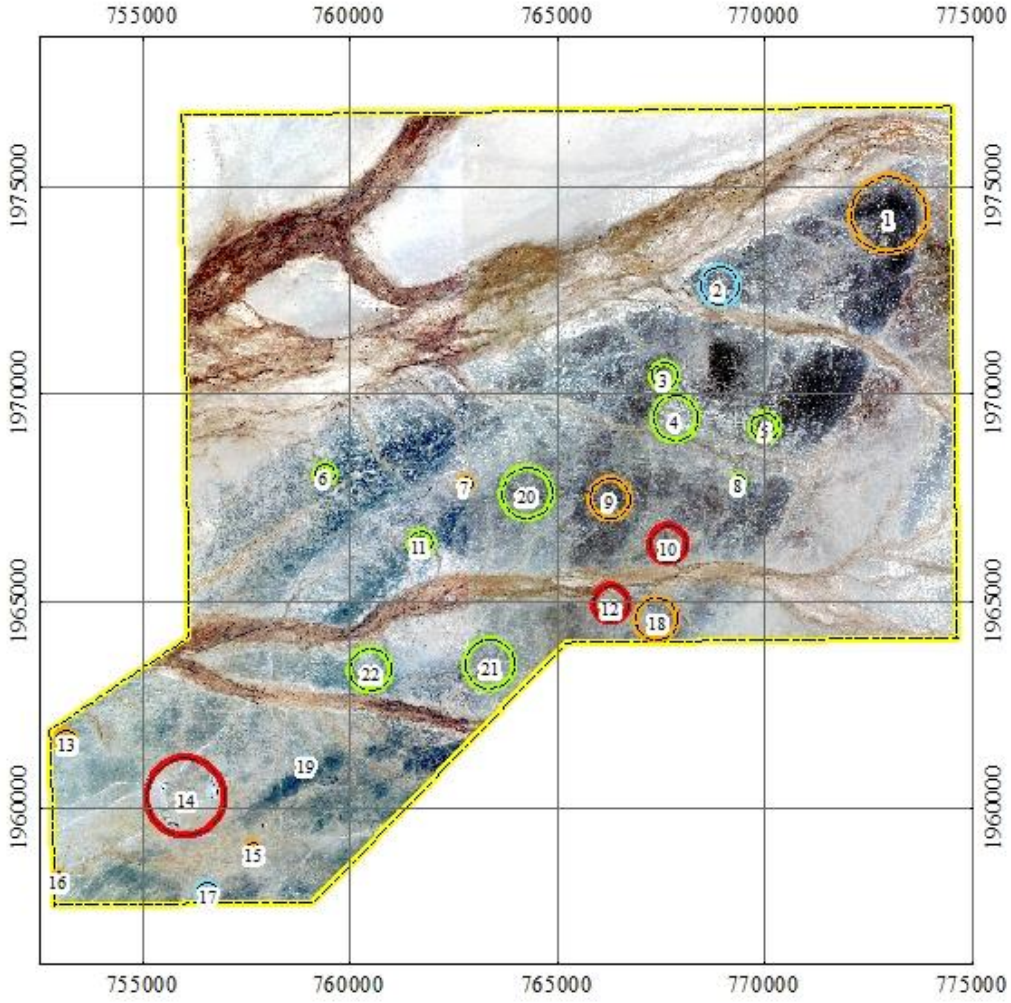
We can see that there appear to be linear dolomitic units with a dominant SW-NE trend. Most significantly we see that there is a dolomitic unit that clearly maps a fold nose in the north eastern part of the project area. The dolomite is acting as a marker unit around the fold surface.

This is a significant result as the regional mapping suggests that this fold is truncated by a major fault structure on its NW side. The WV-3 data shows that the fold nose is preserved and this raises prospects of possible “saddle-reef” development in extensional fractures in the fold axis area.

Whilst the spectral profile that has been extracted for these rocks fits dolomite very well it could possibly be due to a few other minerals – perhaps an iron rich chlorite? Field checking of this spectral mapping is recommended.

AIRBUS

Target Areas



WV3 FCC532 Image with 22 Target Areas.
Target areas have been selected on the basis of their WV-3 spectral properties and Graded 1-4 based on size and spectral parameters. Grades: 1 = Red, 2 = Orange, 3 = Green and 4 = Cyan.
Coordinates in metres UTM36N WGS84. Grid spacing 5000m.

A total of 22 field targets have been identified.

These are graded 1 – 4 in terms of size and priority based on their spectral characteristics and a perceived likelihood that they might be related to mineralisation

The criteria that have been used to pick these areas as possible sites of mineralisation are:

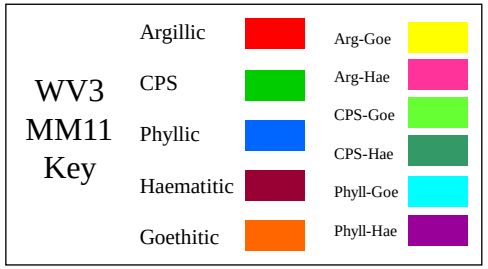
1. Significant size and intensity – anomalies seen on both WV-3 Clay/Iron and WV-3 MM11 Topo image.

2. Smaller areas where anomalies seen on both WV-3 Clay/Iron and WV-3 MM11 Topo image and / or dolomite zones are associated with structure and/or WV-3 VNIR Iron Oxide anomalies indicate possible gossans.

3. Smaller areas where anomalies occur in WV-3 Clay/Iron or WV-3 MM11 Topo but not both.

4. Areas where interesting features occur that may be of geological interest but not necessarily of exploration interest.

There are 3 Grade 1, 7 Grade 2, 9 Grade 3 and 3 Grade 4 Targets



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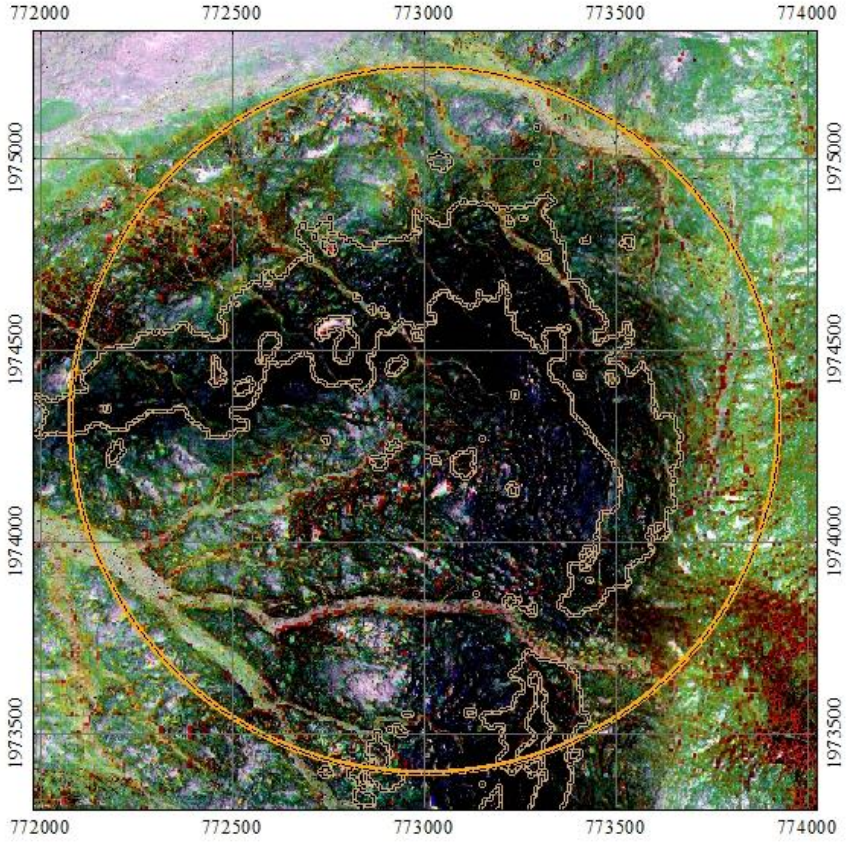
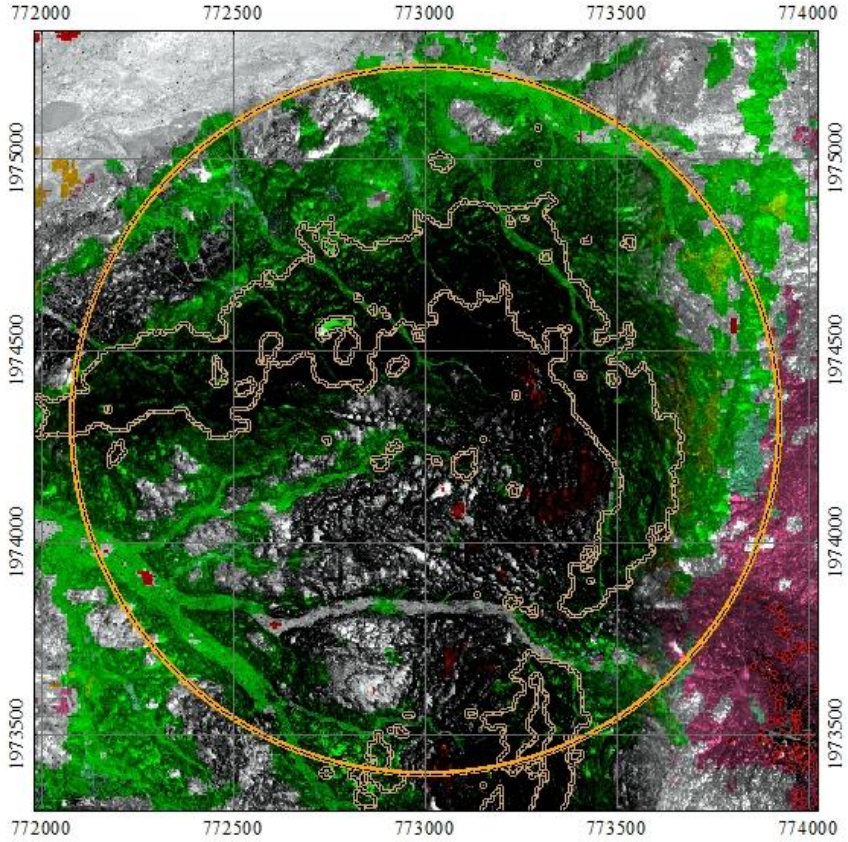
Target 1 – Grade 2

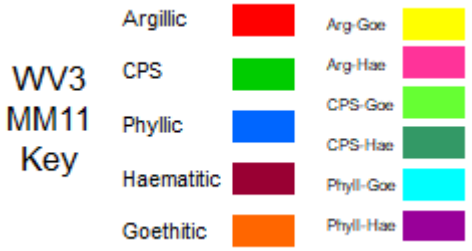
Here we can see the dolomite unit is a subset of the CPS unit – shown in green on the MM11Topo Image. This is consistent with the observation from the extracted profiles that the dolomites have a dominant B16 absorption, in common with the other candidates for CPS (carbonates , propylites and serpentinites). Dolomite is, of course, a carbonate itself, except that it also has a Band15 feature (see WV-3 profiles). The dolomite marker horizon picks out a fold nose in the CPS unit which is probably dominantly chlorite bearing metavolcanics into which the exhalative dolomite bodies have been introduced. If there was base metal VMS type mineralisation accompanying this then re-mobilisation during tectonism may have produced saddle reefs in this area?



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 500m .



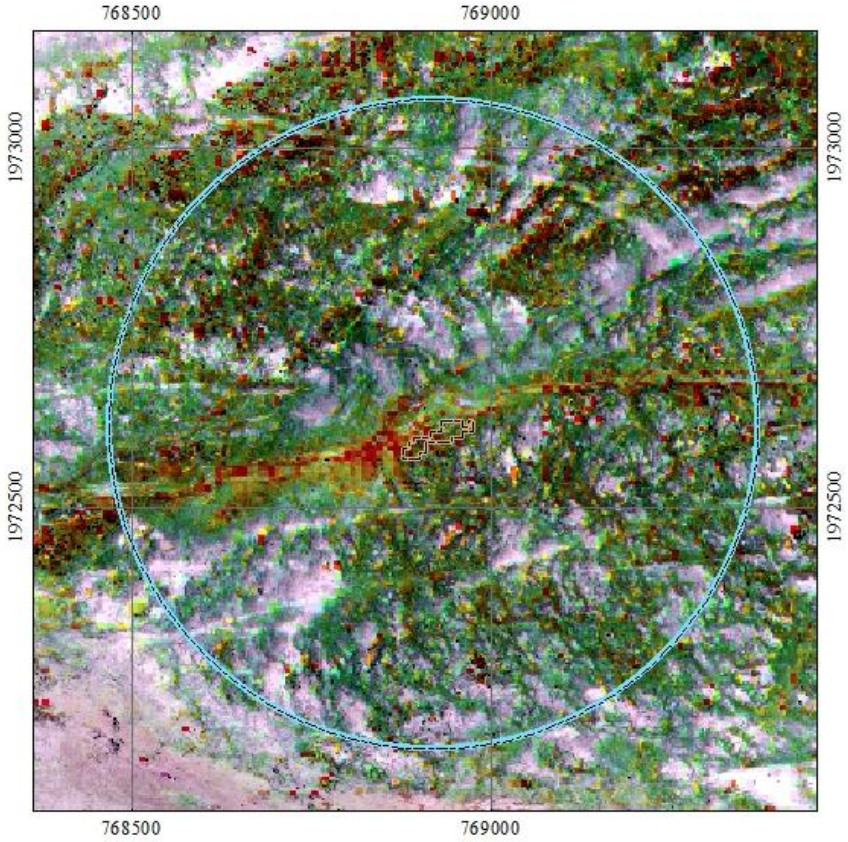
WV3 Minmap11-Topo Image. Dolomite areas displayed in beige coloured outlines.
Coordinates in metres UTM36N WGS84 with grid spacing 500m .



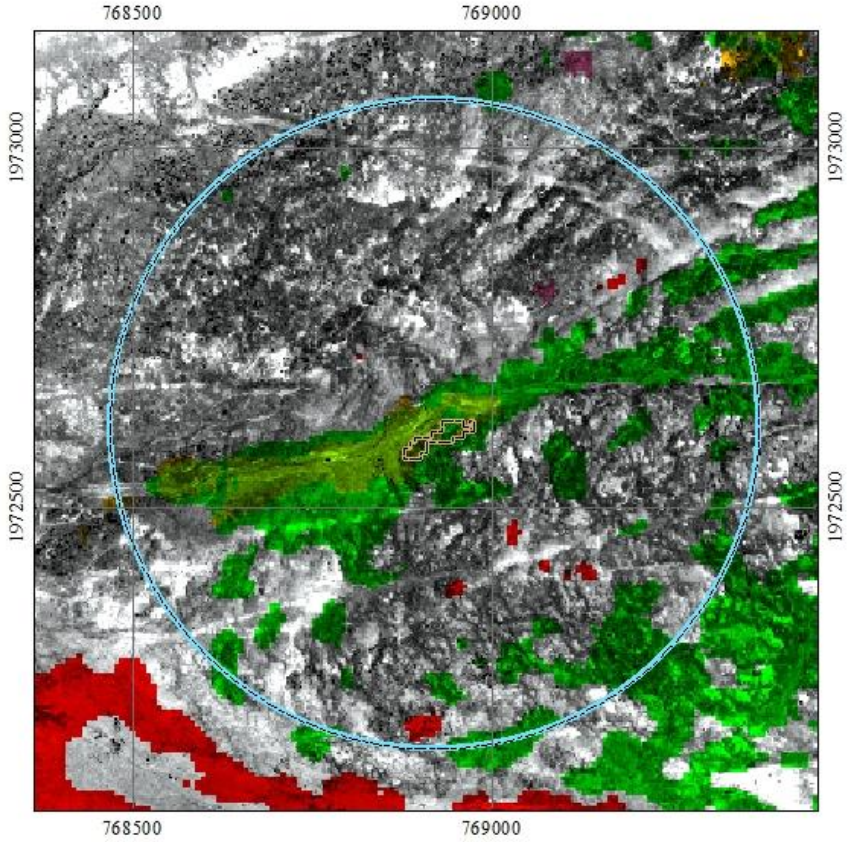
AIRBUS

Target 2 – Grade 4

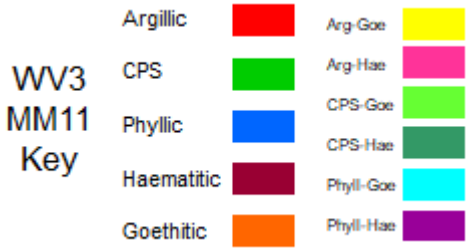
Here we see a linear feature in the basement rocks with a sinuous S-shaped bend. There are Clay-Iron anomalies along the structure and there is a small dolomite body on the southern side of the structure at the bend. If there was a component of sinistral strike-slip movement along this structure during a mineralising phase then this could have been a releasing bend resulting in deposition of metallic minerals in the low pressure zone. This is very speculative, therefore this is a low grade field target.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration.
Coordinates in metres UTM36N WGS84 with grid spacing 500m .



WV3 Minmap11-Topo Image. Dolomite areas displayed in beige coloured outlines.
Coordinates in metres UTM36N WGS84 with grid spacing 500m .



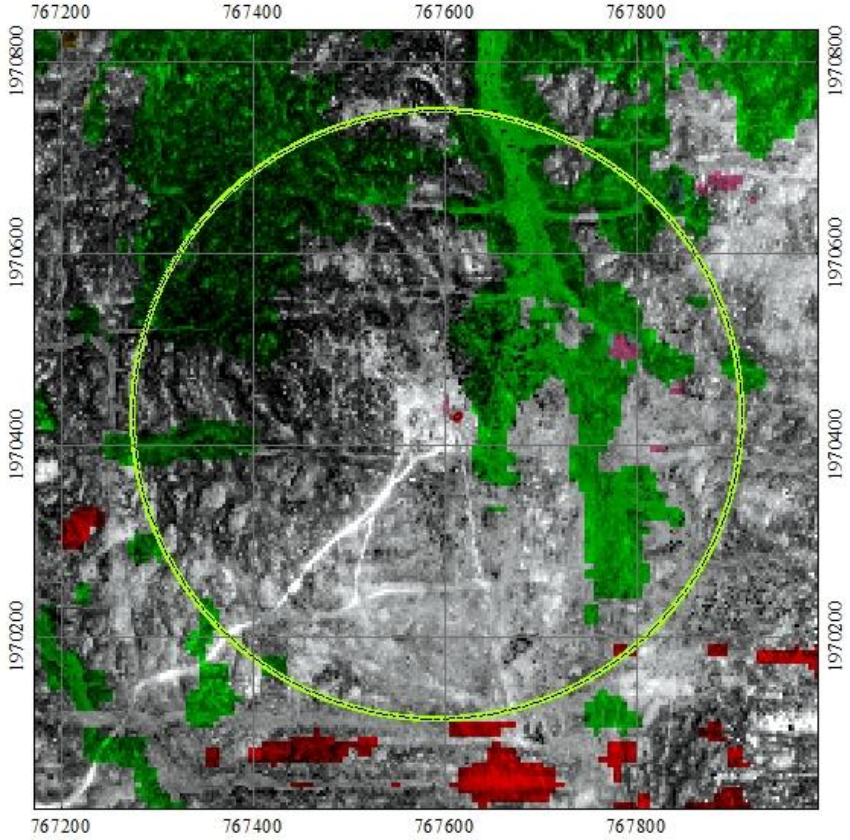
AIRBUS

Target 3 – Grade 3

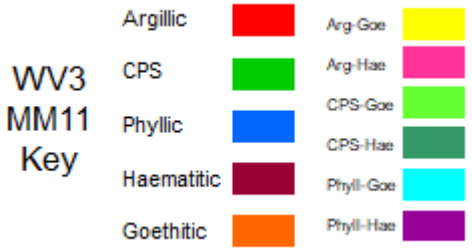
A well used track leads to this intense Clay-Iron anomaly. It is perhaps a quarry or open pit extraction site? There are no hydrothermal alteration type minerals mapped on the WV-3 Mineral Mapping image therefore this site is down-graded to Grade 3.

This site should be visited to see what is causing the strong Clay-Iron anomaly.

WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



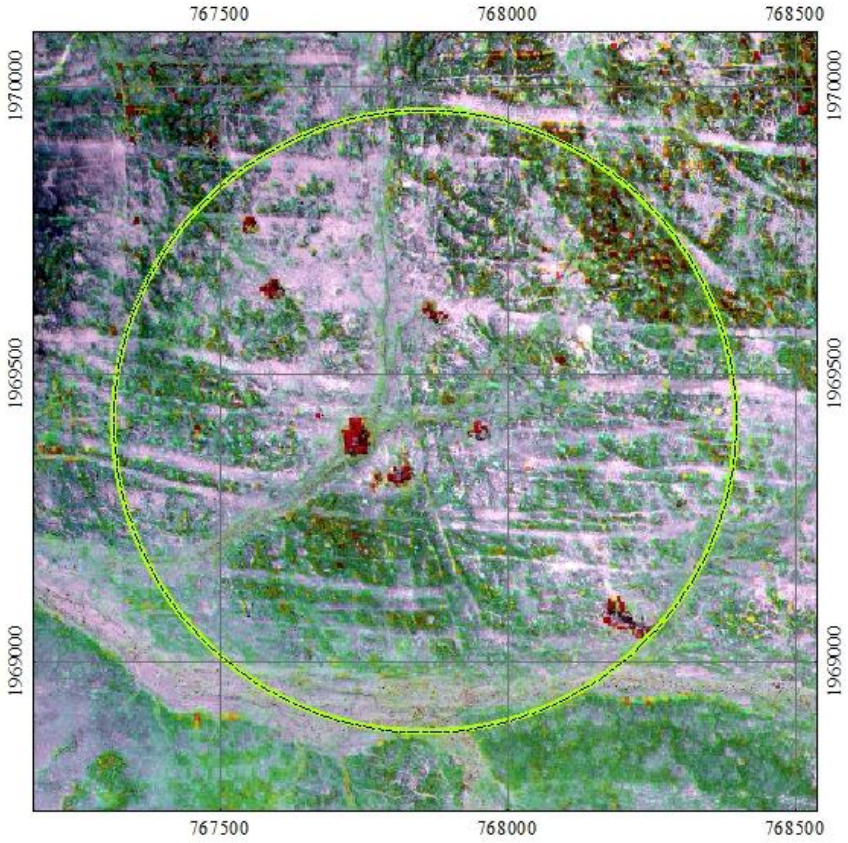
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



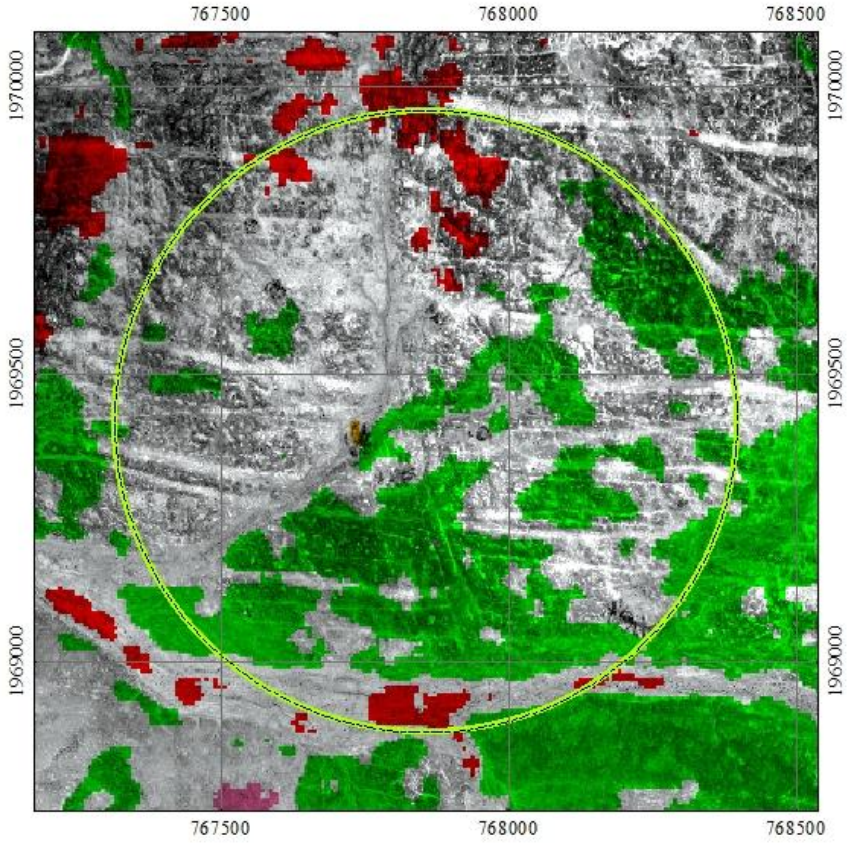
AIRBUS

Target 4 – Grade 3

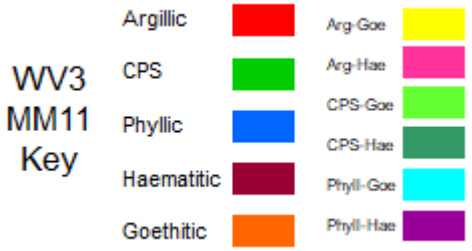
This target area contains 8 very small but intense Clay-Iron anomalies. Two of these have associated Mineral Mapping signatures. These two sites at least should be visited and sampled if signs of mineralisation are discovered.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 500m .



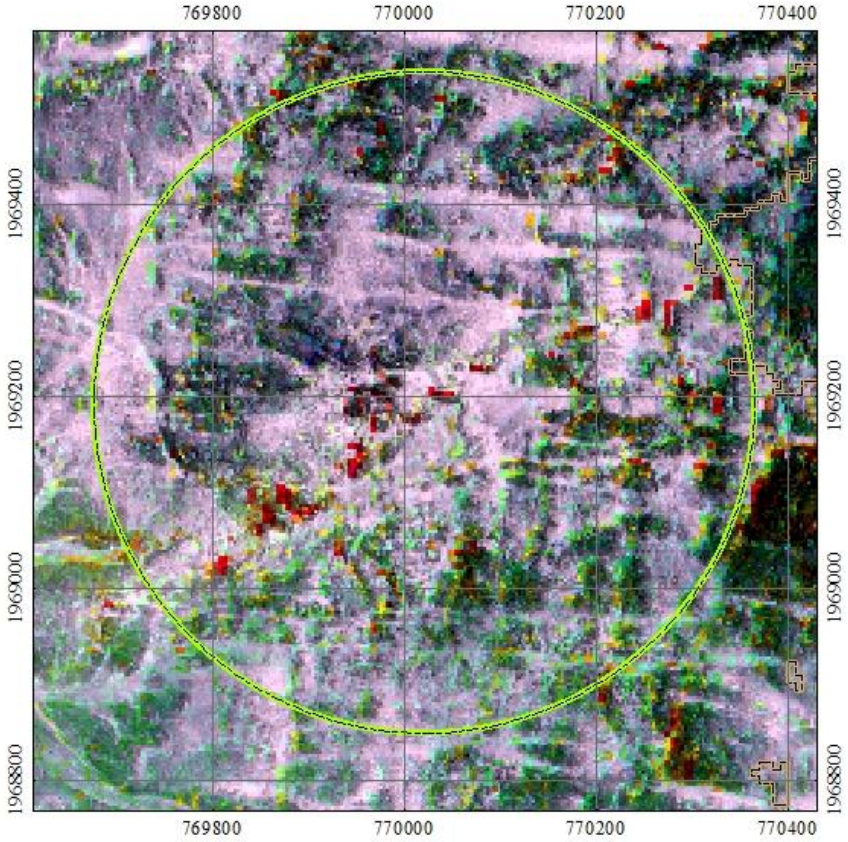
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 500m .



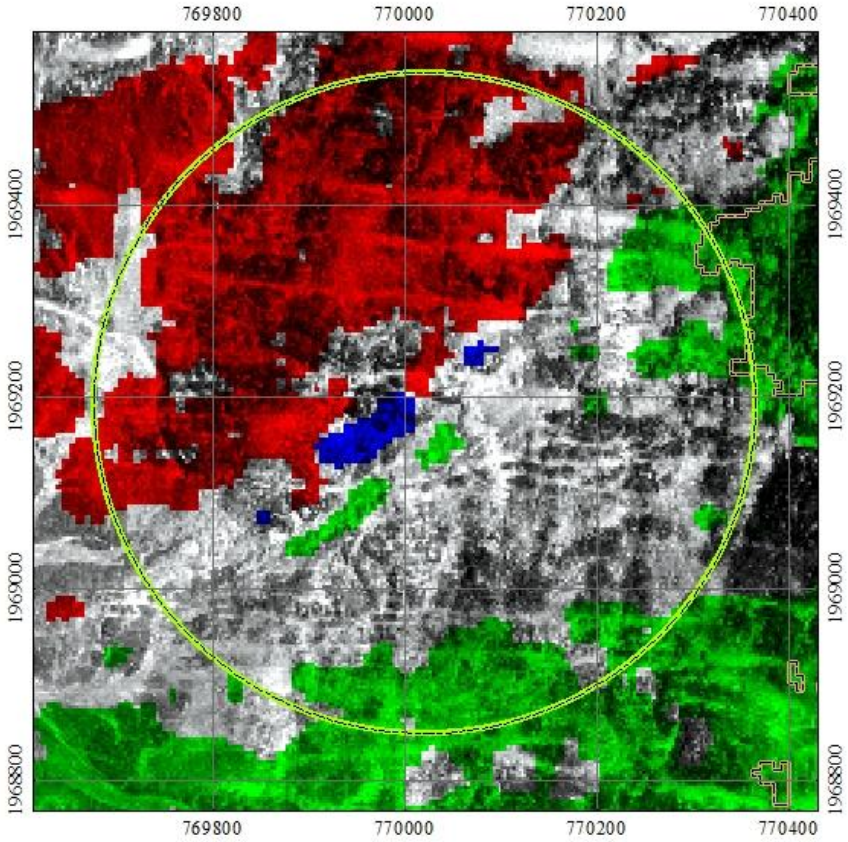
AIRBUS

Target 5 – Grade 3

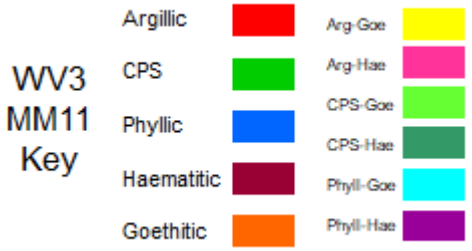
This target area contains a row of small Clay/Iron anomalies along a sinuous linear structure. The structure appears to be at a geological boundary between rocks with an argillic signature to the NW – possibly felsites – and a CPS signature to the SE – possibly chlorite bearing meta-volcanics? There is a linear phyllic unit along the boundary but no apparent link between the Mineral Mapping units and the Clay/Iron anomalies. This is an interesting arrangement of spectral features that should be checked out in the field.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



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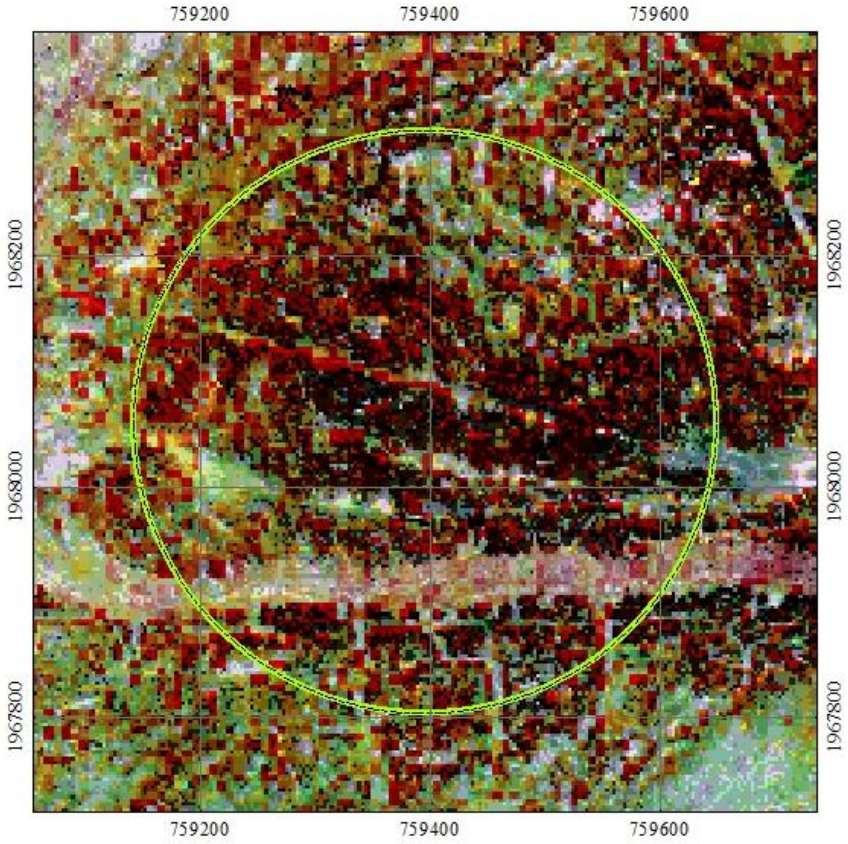
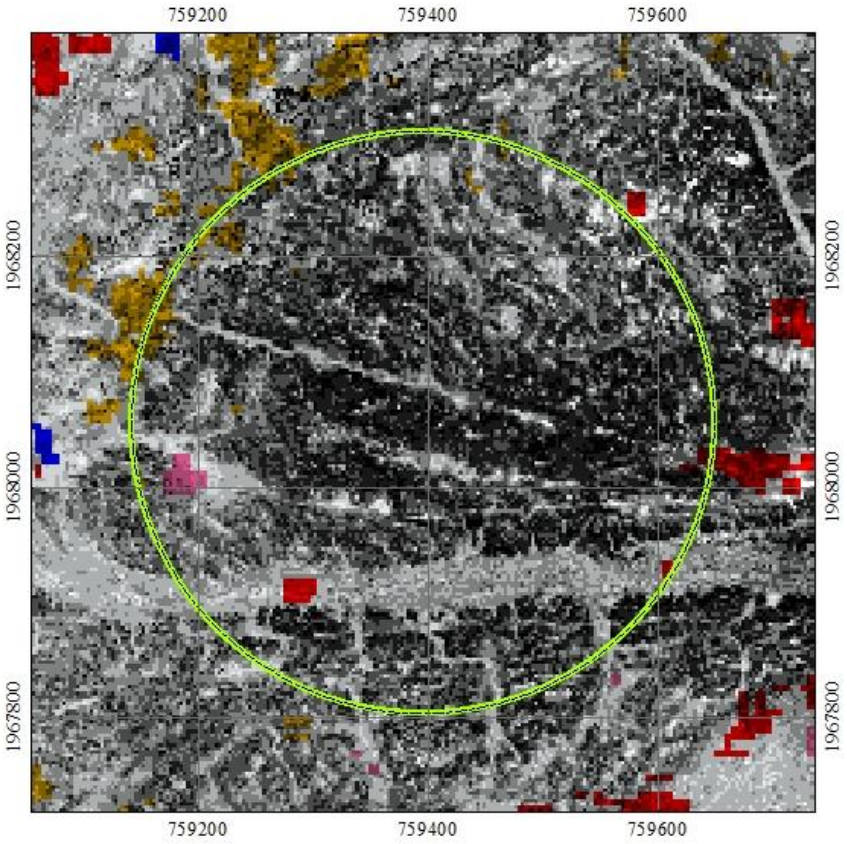
Target 6 – Grade 3

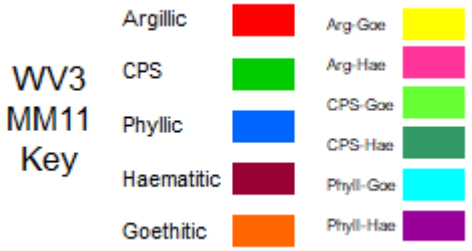
Here we see two parallel linear structure with possible Clay-Iron signatures along them. I say possible as this might be an artefact of the Pan-sharpening of the Clay-Iron image at 7.5m pixel to 3m pixel using a sub-sampled Panchromatic image. There is practically no mineral information on the WV-3 Mineral Map Image in this area. These are linear features though so they might be of interest related to shear-zone hosted gold? They should be field-checked.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



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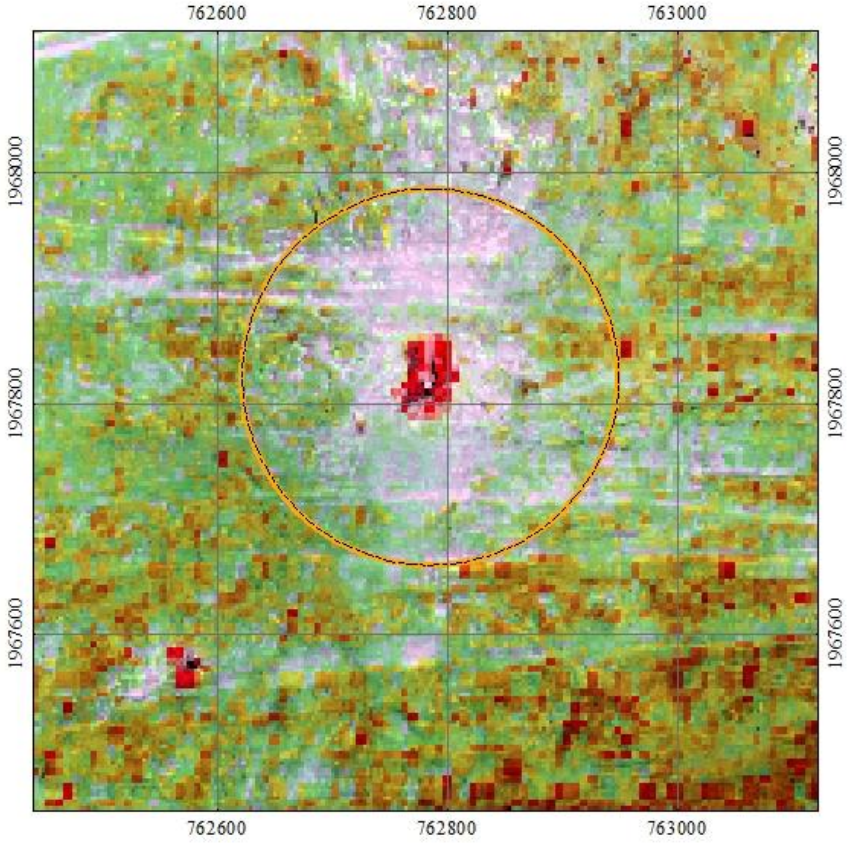
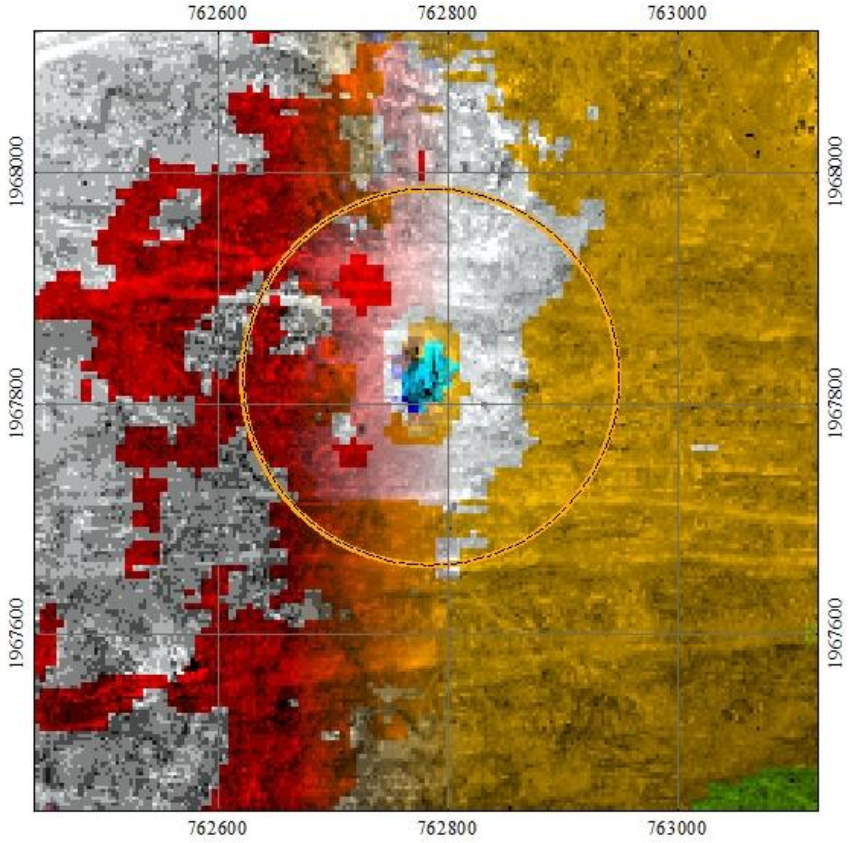
Target 7 – Grade 2

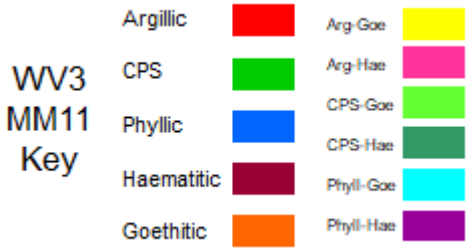
This is an oval shaped Clay-Iron anomaly that has corresponding Phyllic-Goethitic signatures in the WV-3 Mineral Map image. This looks like a favourable site for hydrothermal alteration and possible metalliferous mineralisation. A word of caution though as this is at the edge of the central vertical band of artefact goethitic signatures. This may mean that the seemingly favourable WV-3 Mineral Mapping signatures are an artefact too. Despite this – the site merits a field visit to check for signs of mineralisation.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



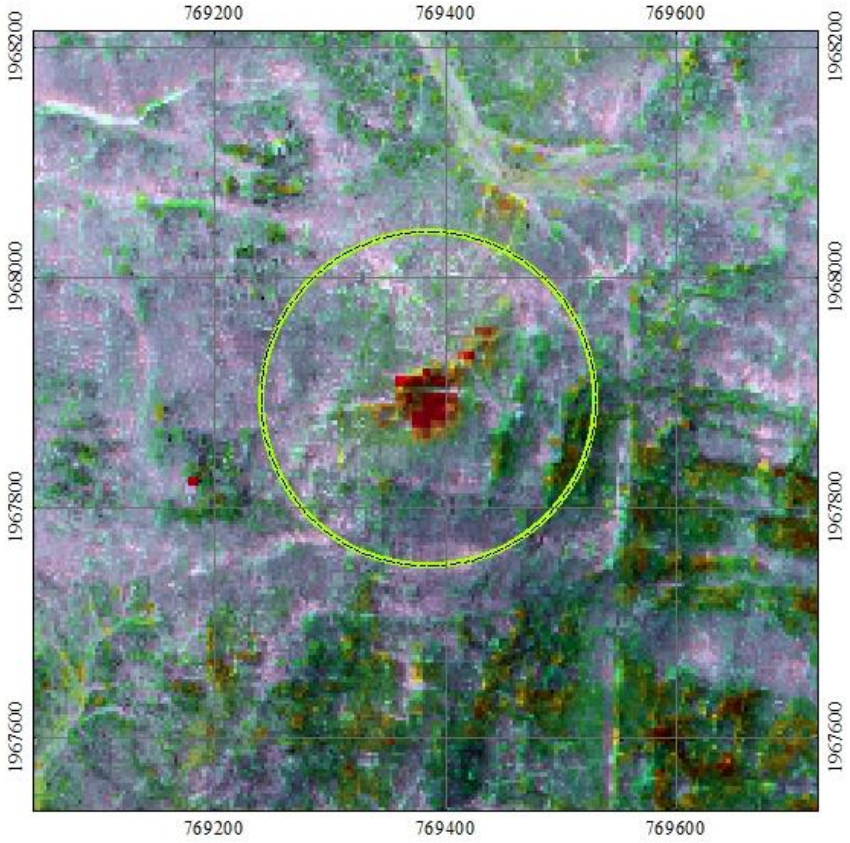
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



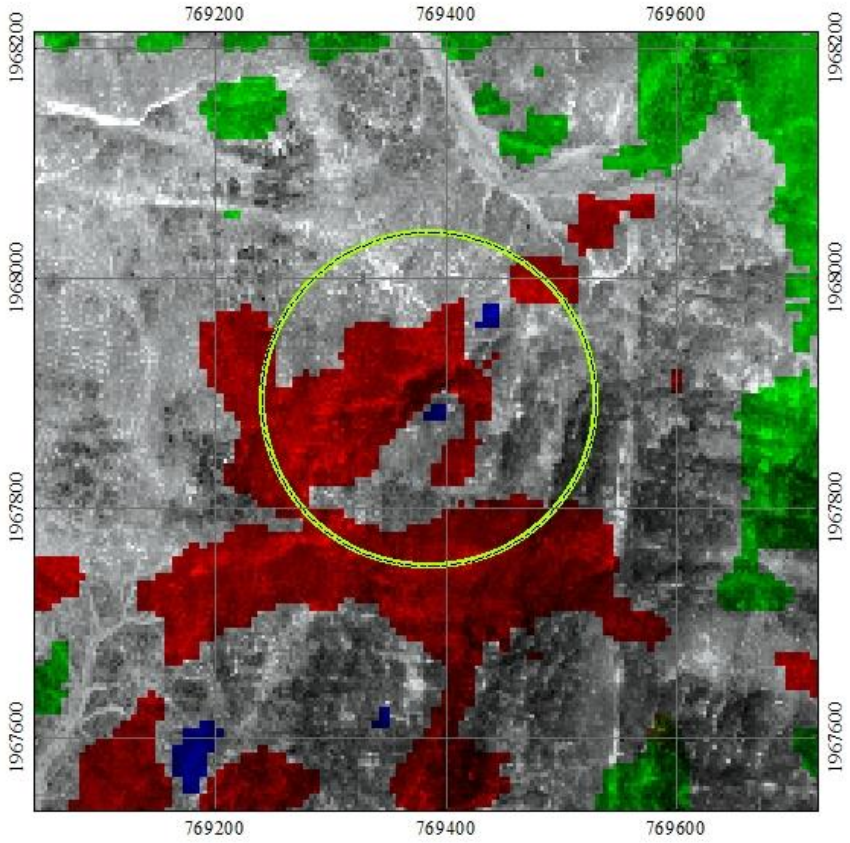
AIRBUS

Target 8 – Grade 3

This is a moderate sized intense Clay-Iron anomaly. The WV-3 Mineral Map image shows that the area lies in an area of dominantly argillic signatures – possibly felsites – but there are no Mineral Map anomalies associated with the Clay-Iron feature. The feature appears to be in a relative topographic high on a watershed with drainage channels leading off to the north, north west and south. Based on experience, sites of mineralisation often form high points and watersheds – possibly due to being more resistant due to silicification associated with mineralisation? This site should be visited and possibly sampled in the field.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

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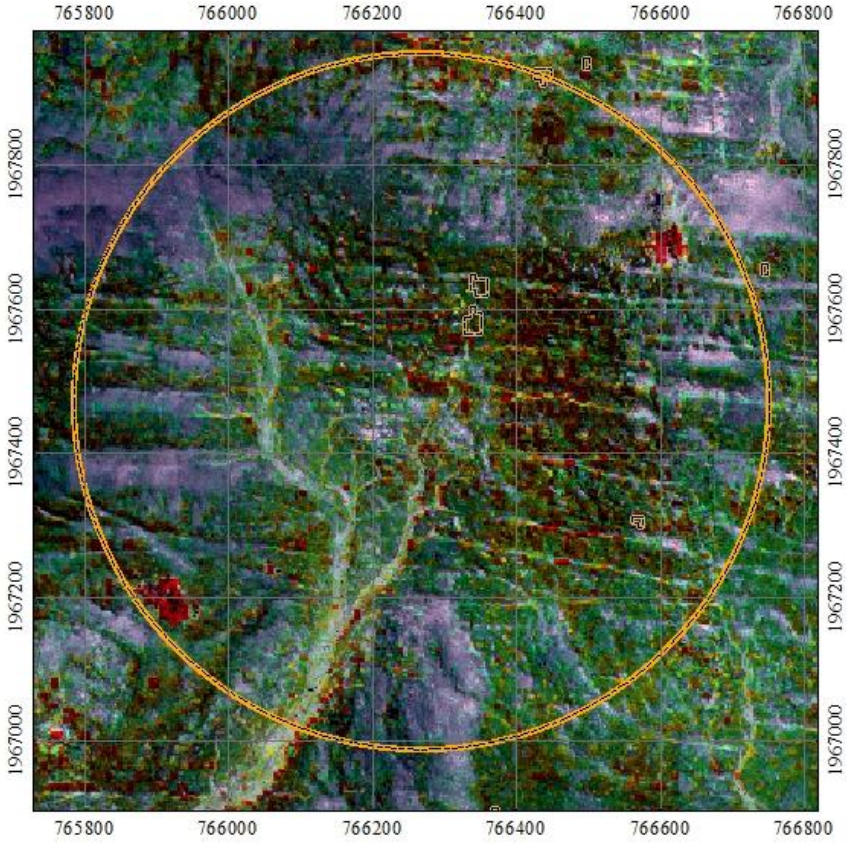
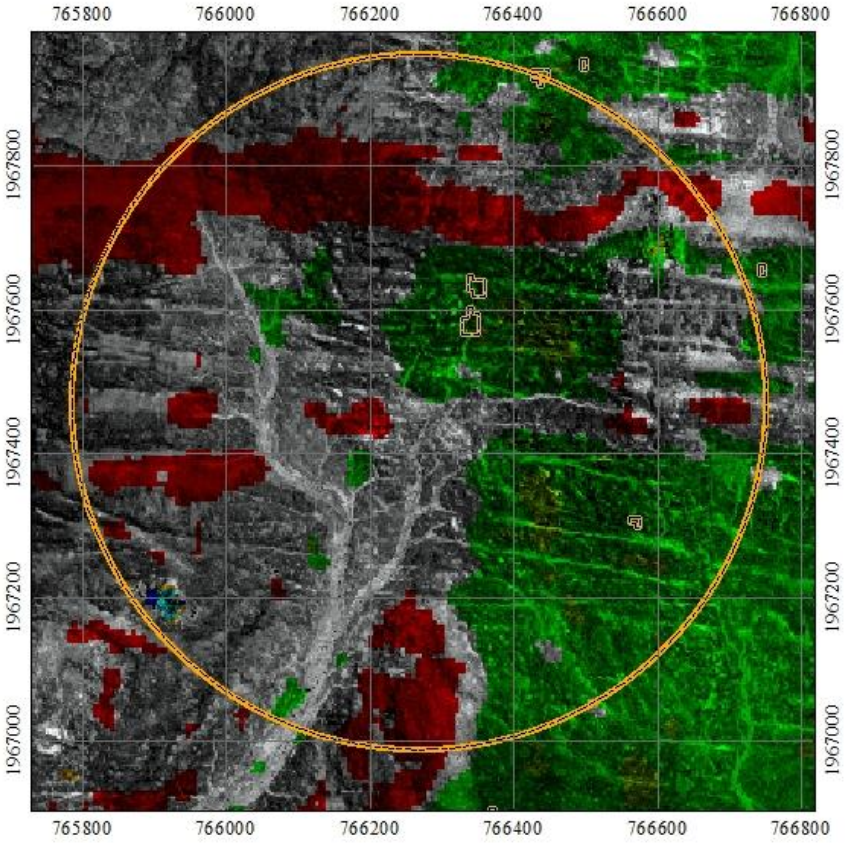
Target 9 – Grade 2

This target area contains 2 small intense Clay-Iron anomalies in the NE and SW of the circle. They look identical on the Clay-Iron image but the Mineral Map image shows that the SW feature is associated with Phyllic-Goethitic type minerals and the NE feature has CPS-goethitic minerals. These two anomalies should be visited in the field as mineralisation targets. It will also be interesting to see the contrast in the mineralogy producing the very different Mineral Map profiles.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m

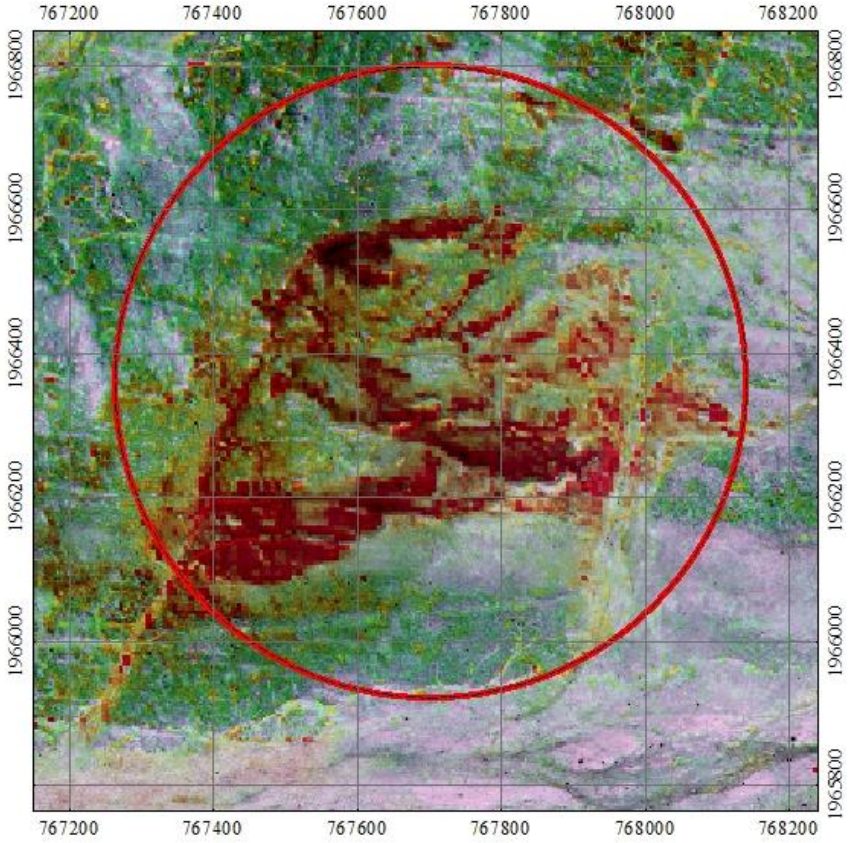


WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

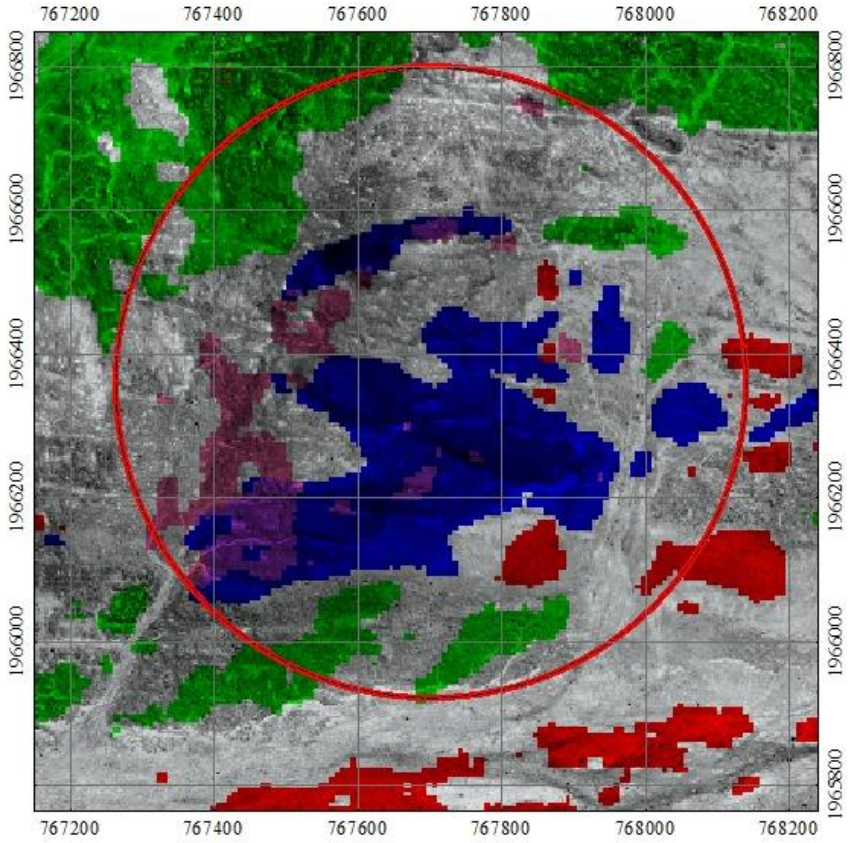
AIRBUS

Target 10 – Grade 1

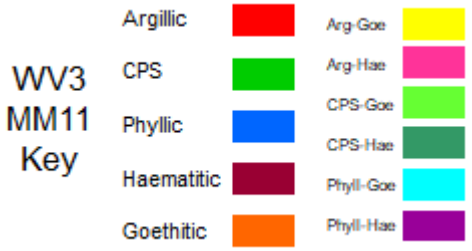
This is a large Clay-Iron anomaly associated with Phyllic, Haematitic and Phyllic-Haematitic signatures in the Mineral Map image.
This combination of haematitic and phyllic signatures has been seen elsewhere in the Arabian-Nubian shield where gossans are associated with underlying VMS mineralisation. No gossans have been detected here. This may be due to masking by dark surface crusts if the gossans have not been disturbed. The size of the feature and combination of Clay-Iron and mixed signatures in the Mineral Map qualify this as a Grade 1 anomaly. This area should be visited in the field as a priority with field observations and geochemical sampling if favourable signs of mineralisation are encountered.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



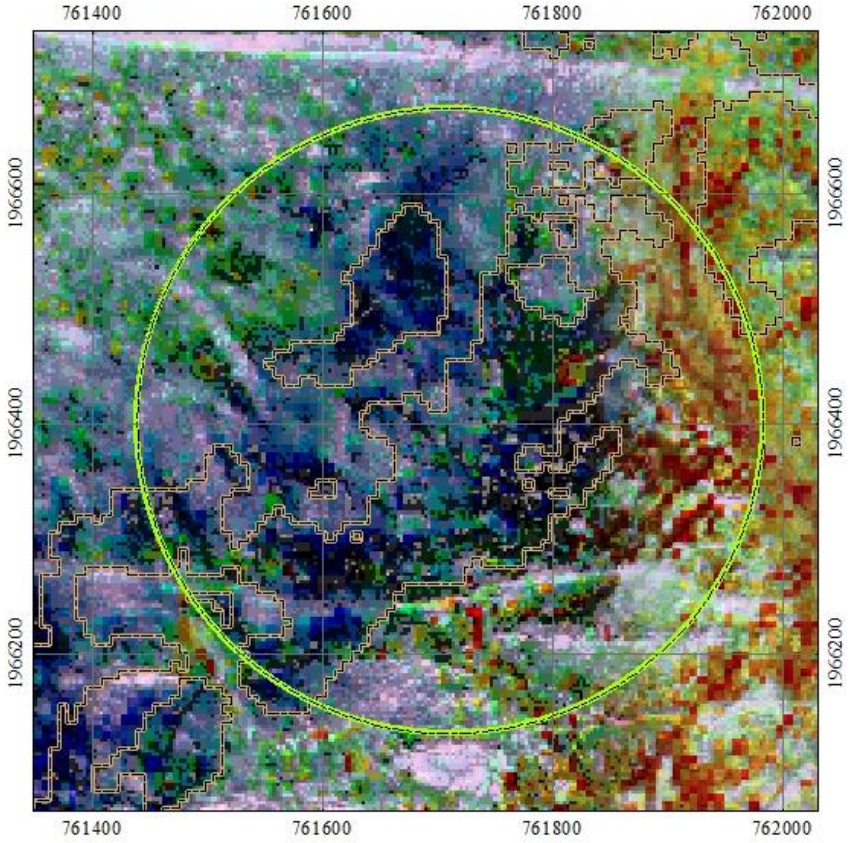
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



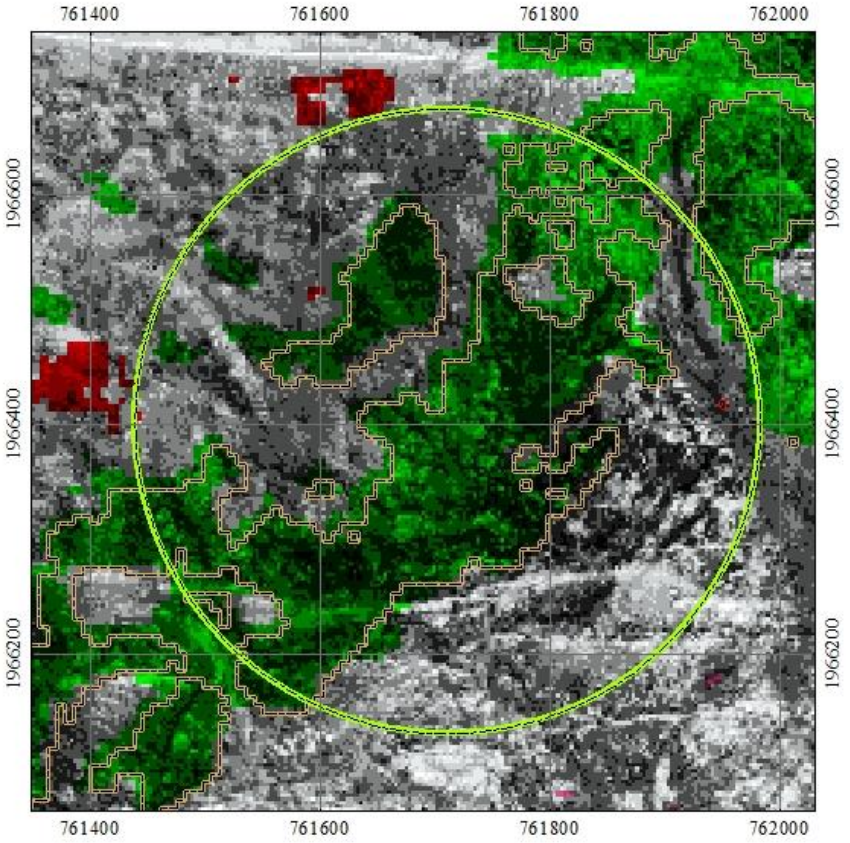
AIRBUS

Target 11 – Grade 3

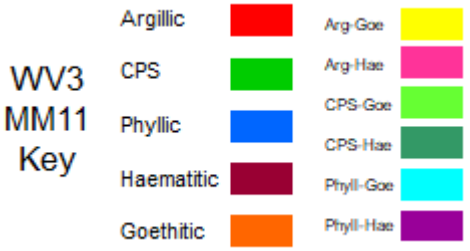
Here we have a large dolomite unit associated with two small Clay-Iron anomalies. The dolomites are mapped in the Mineral Mapping and also coincide with CPS signatures – naturally enough as they are Carbonates. The small Clay-Iron anomalies do not have corresponding anomalous signatures on the Mineral Mapping, however, so this area is down-graded to Grade 3. These should be field checked if possible but not as a priority.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



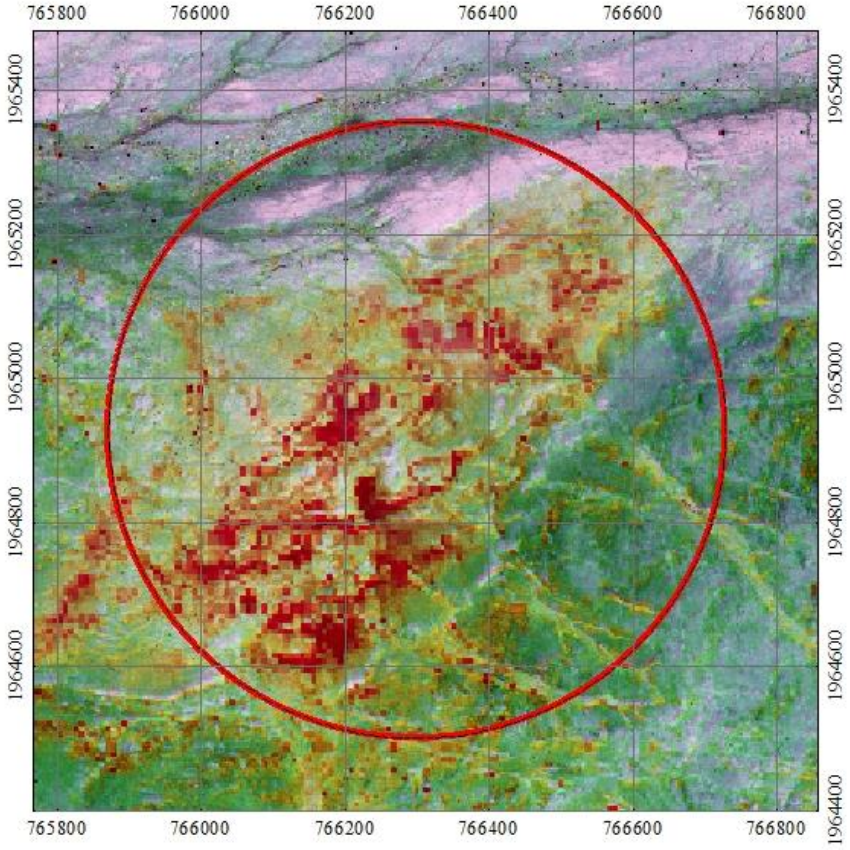
WV3 Minmap11-Topo Image. Code in key above. Dolomite areas displayed in beige coloured outlines. Coordinates in metres UTM36N WGS84 with grid spacing 200m.



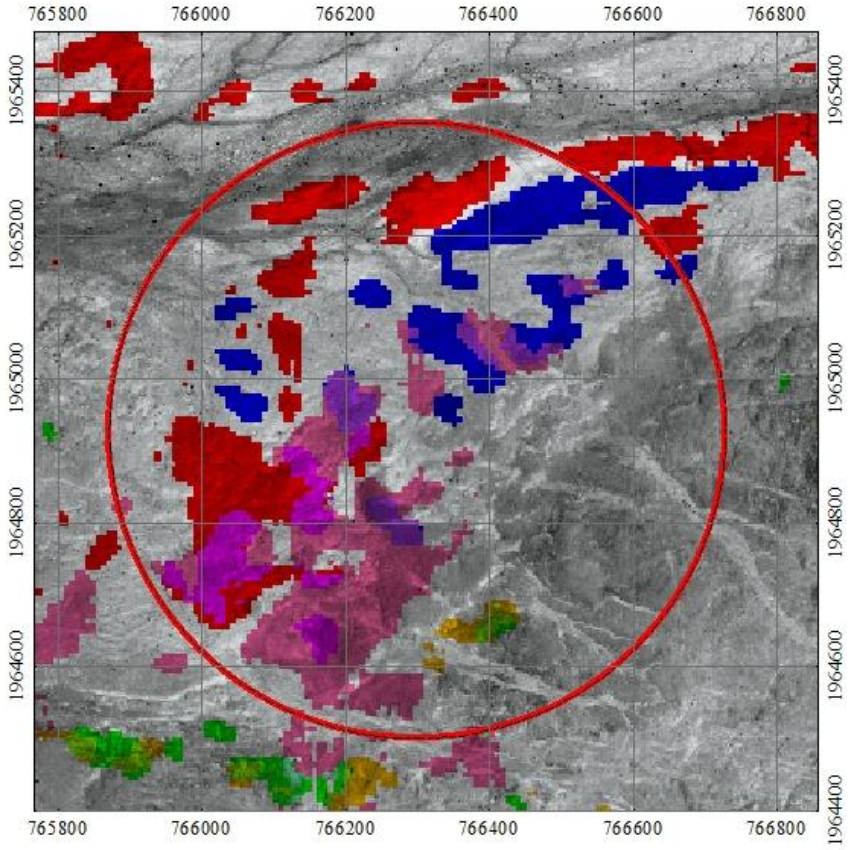
AIRBUS

Target 12 – Grade 1

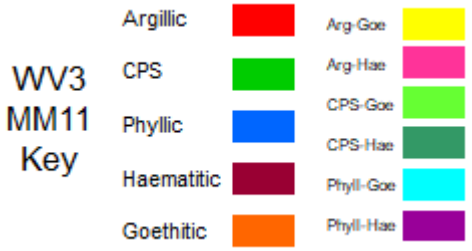
A large rectangular area containing Clay-Iron anomalies associated with Haematitic, Phyllic and mixed Phyllic-Haematitic signatures. This is very similar to the feature seen at Target 10 and these two may be part of the same feature lying on a SW-NE trend separated by a large East to West flowing wadi. This area should be visited as a priority in conjunction with Target 10.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



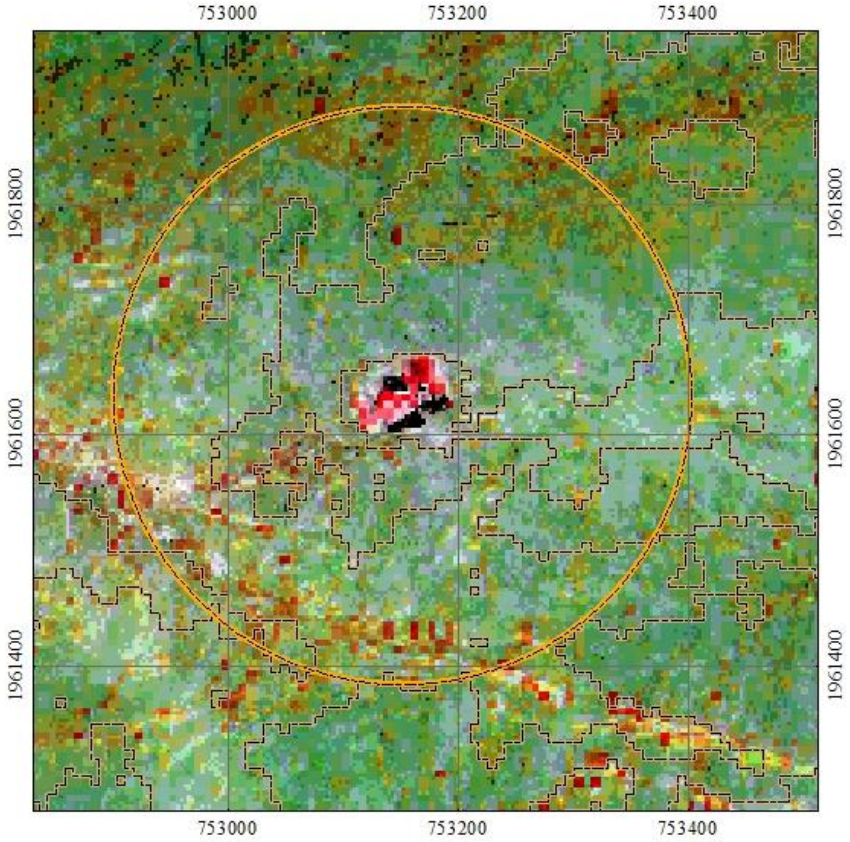
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



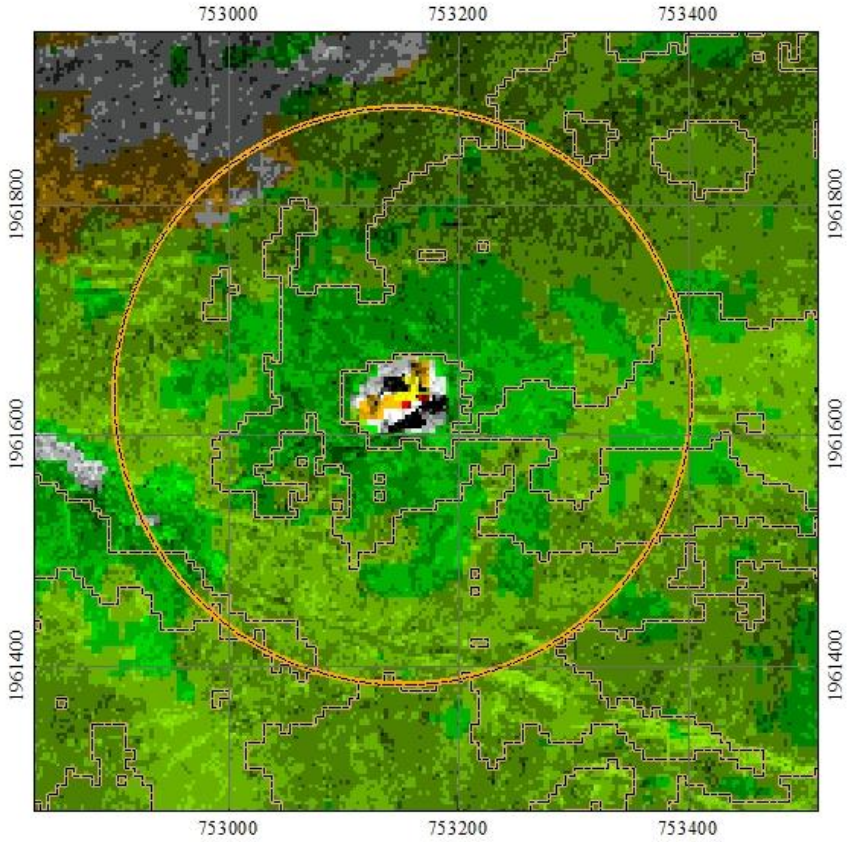
AIRBUS

Target 13 – Grade 2

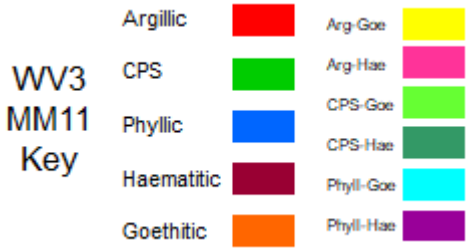
Here we see a Clay-Iron anomaly within an area of dolomites associated with argillic-goethitic Mineral Mapping profiles. This is an unusual combination. This area definitely warrants field investigation for observations and possible sampling.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



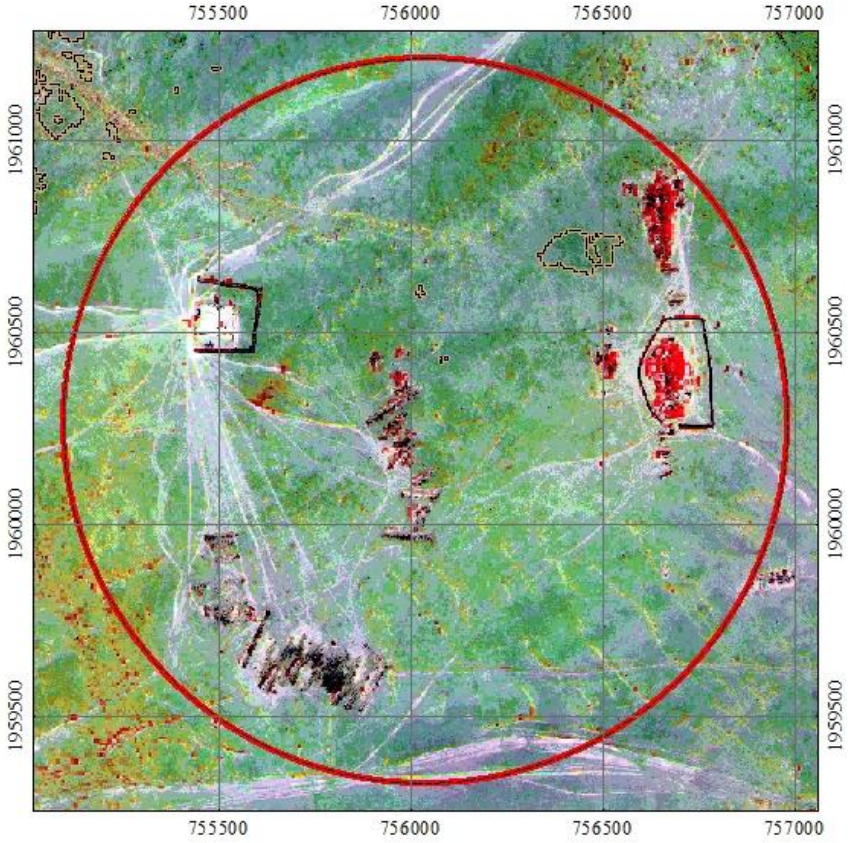
WV3 Minmap11-Topo Image. Dolomite areas displayed in beige coloured outlines. Coordinates in metres UTM36N WGS84 with grid spacing 200m.



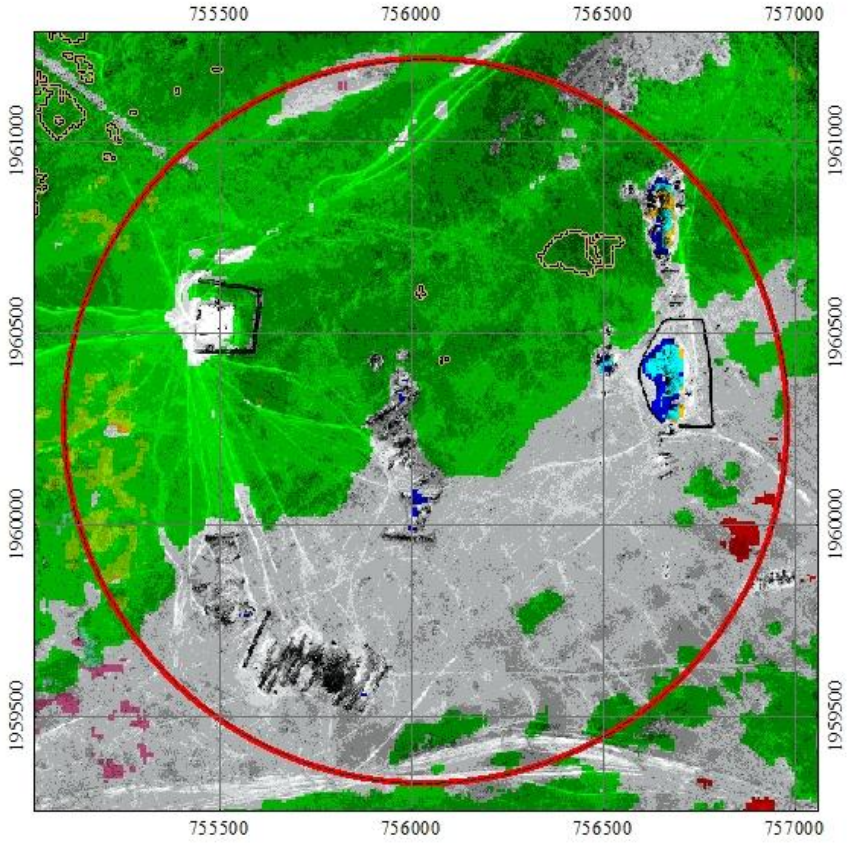
AIRBUS

Target 14 – Grade 1

This is the area in the SW of the exploration area where we see evidence of mineral exploration. There are two large features on a north south trend in the NE of the circle where some extraction may have been carried out. These features produce intense Clay-Iron anomalies with accompanying goethitic, phyllic and phyllic-goethitic mixed signatures. Where we see similar features in targets elsewhere in the exploration area we may be dealing with similar alteration minerals and also styles of mineralisation. There are 2 other sub-parallel features in the centre and SW of the circle that appear to have been trenched. These have small amounts of Clay-Iron signatures but not much evidence of the strong phyllic-goethitic signatures seen in the main features.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m

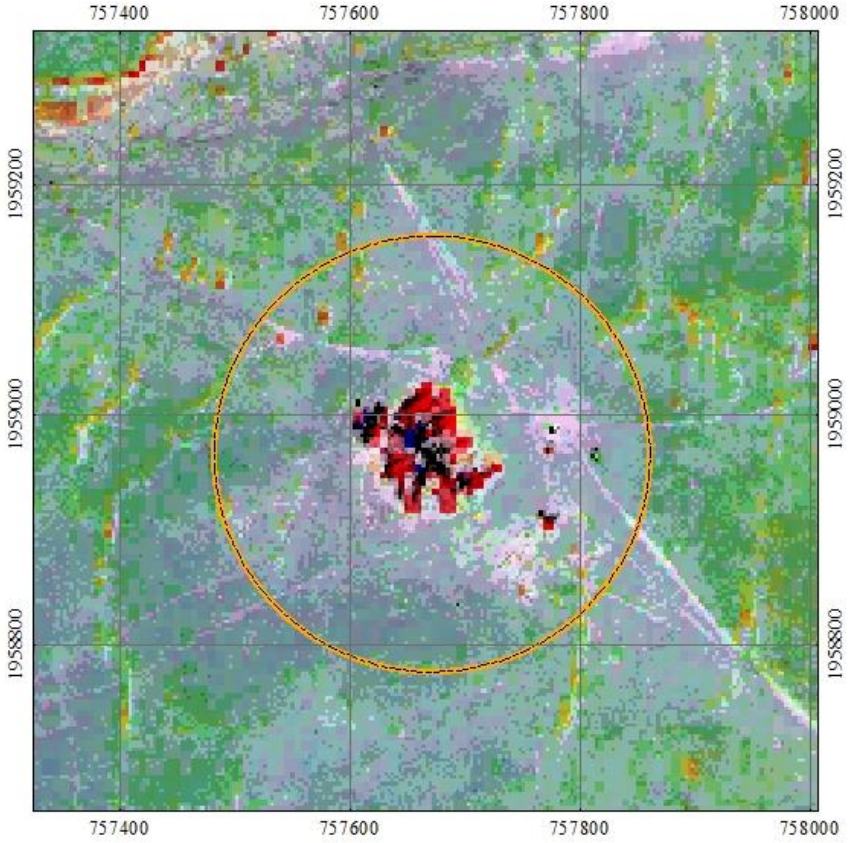


WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

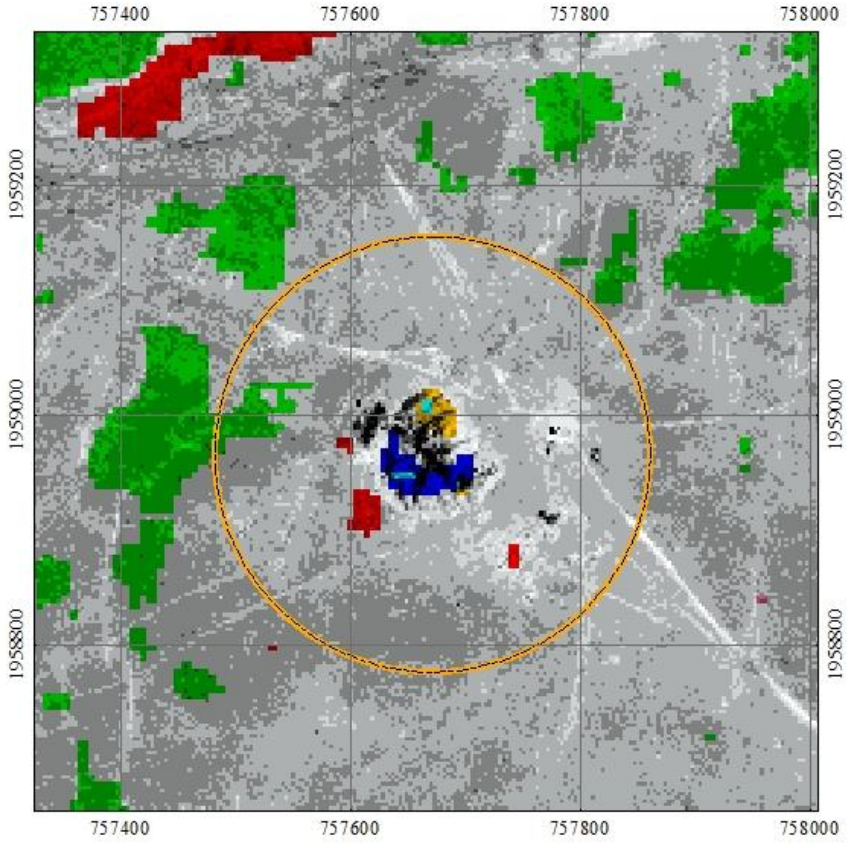
AIRBUS

Target 15 – Grade 2

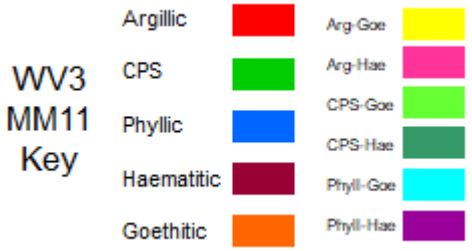
In this area we see a moderate sized roughly circular Clay-Iron anomaly associated with Phyllic, Goethitic and mixed Phyllic-Goethitic Mineral Mapping signatures. This is the same association as seen at the presumed known mineralised area at target 14. This target should therefore be visited for field observations and possible sampling.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



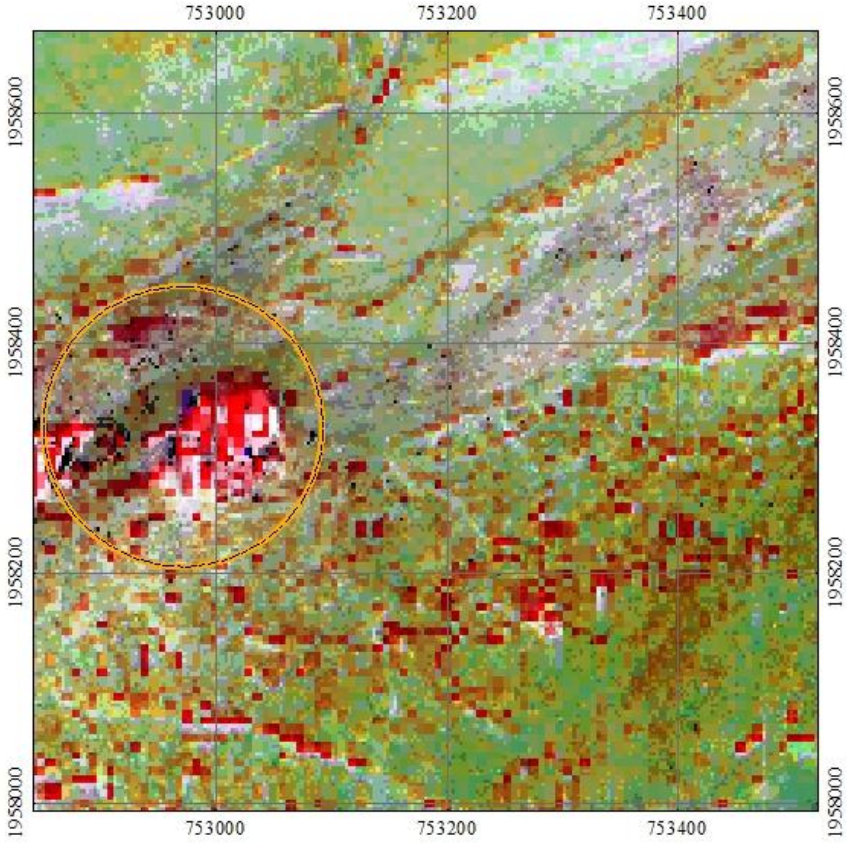
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



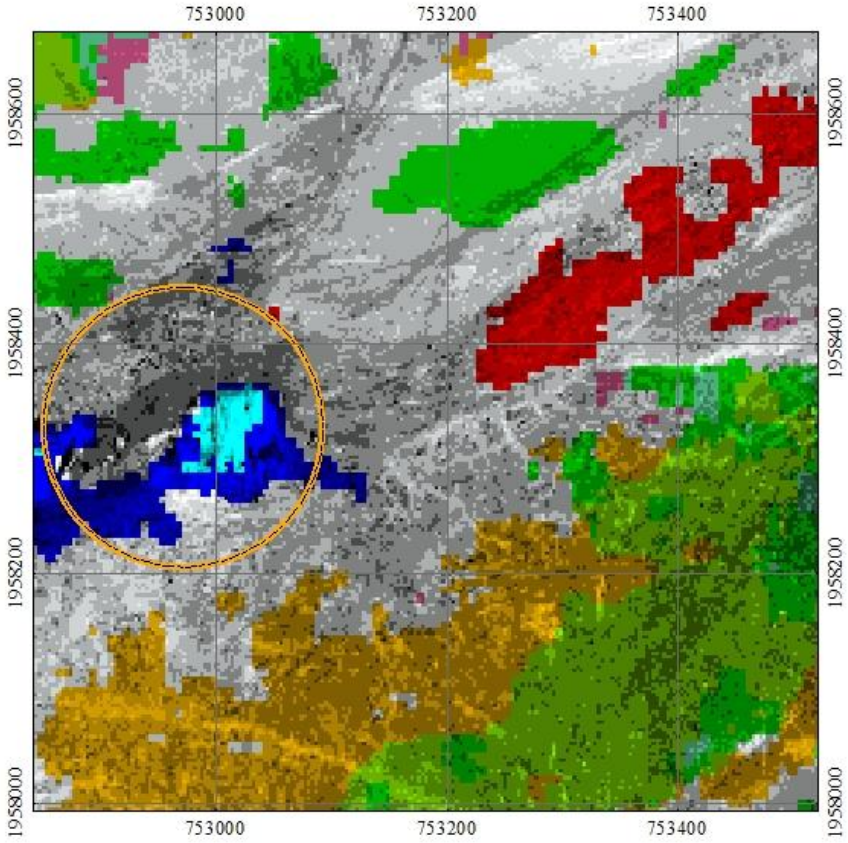
AIRBUS

Target 16 – Grade 2

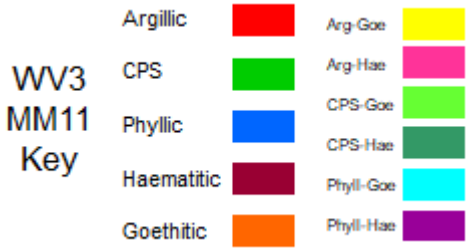
This feature is positioned at the western margin of the exploration area. There is a moderate sized Clay-Iron anomaly associated with Phyllic and mixed Phyllic-Goethitic signatures. This appears to be another similar assemblage to the known mineralisation at Target 14 and should therefore be visited and sampled as a priority.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



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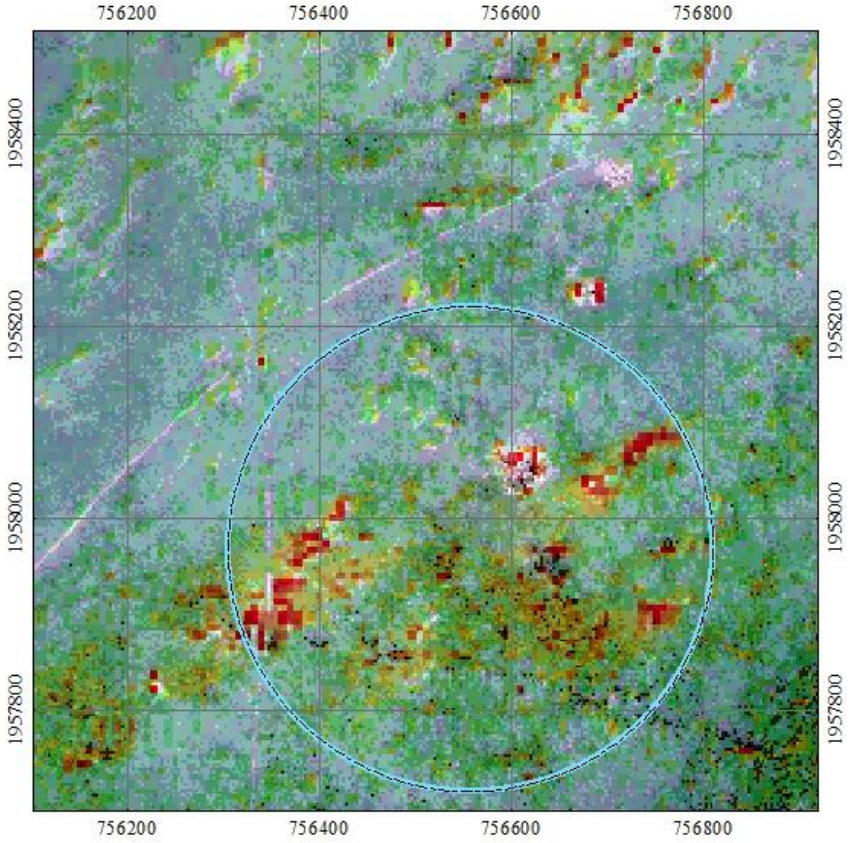
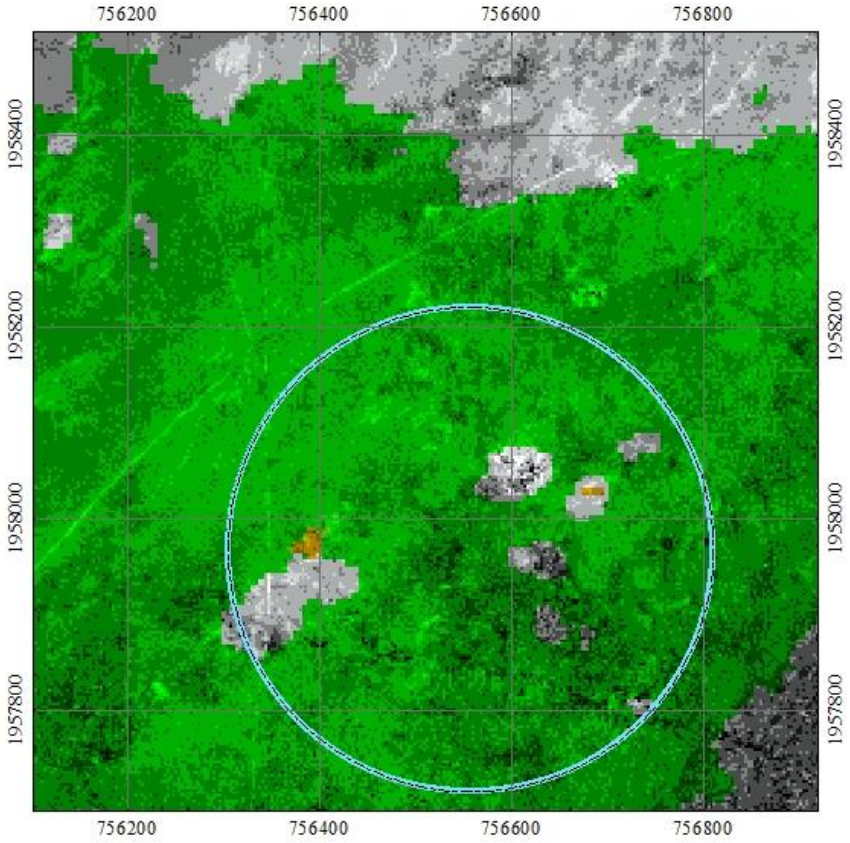
Target 17 – Grade 4

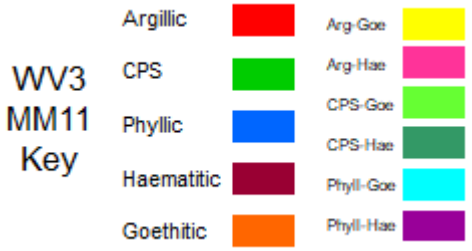
In this area there are two roughly linear zones of moderate density Clay-Iron features trending from SW-NE. They are situated in an area of CPS signatures – possibly chlorite bearing metavolcanics? – but the Clay-Iron features are not associated with any Mineral Mapping signatures save for a couple of small patches of Goethitic type signatures. These are curiosities that can be field checked if time allows as lesser priority targets.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



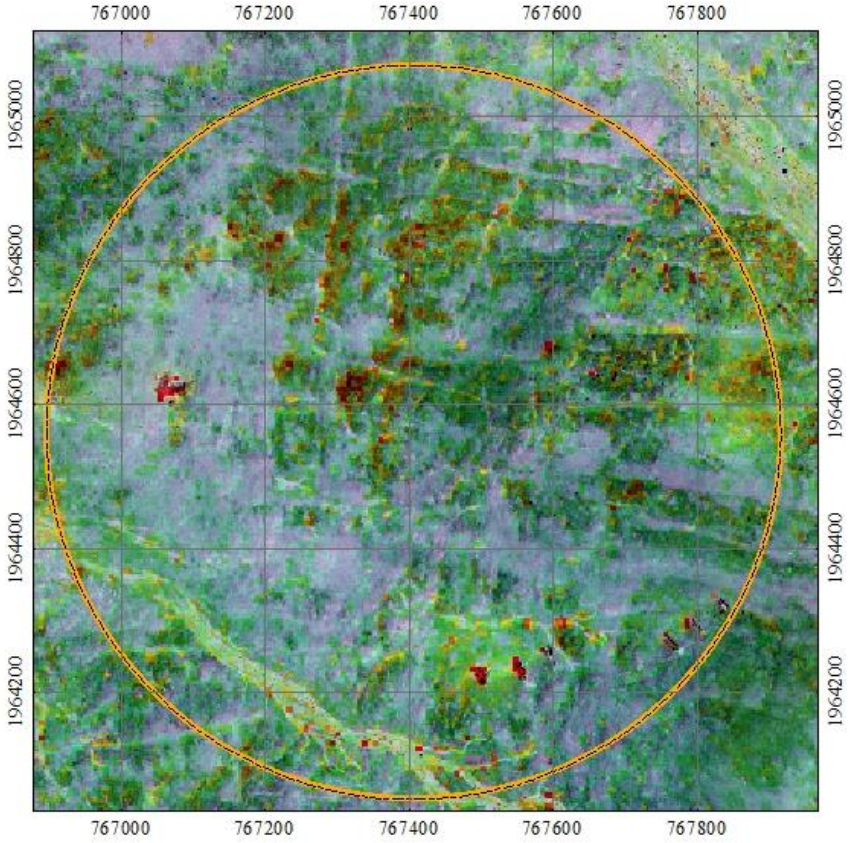
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



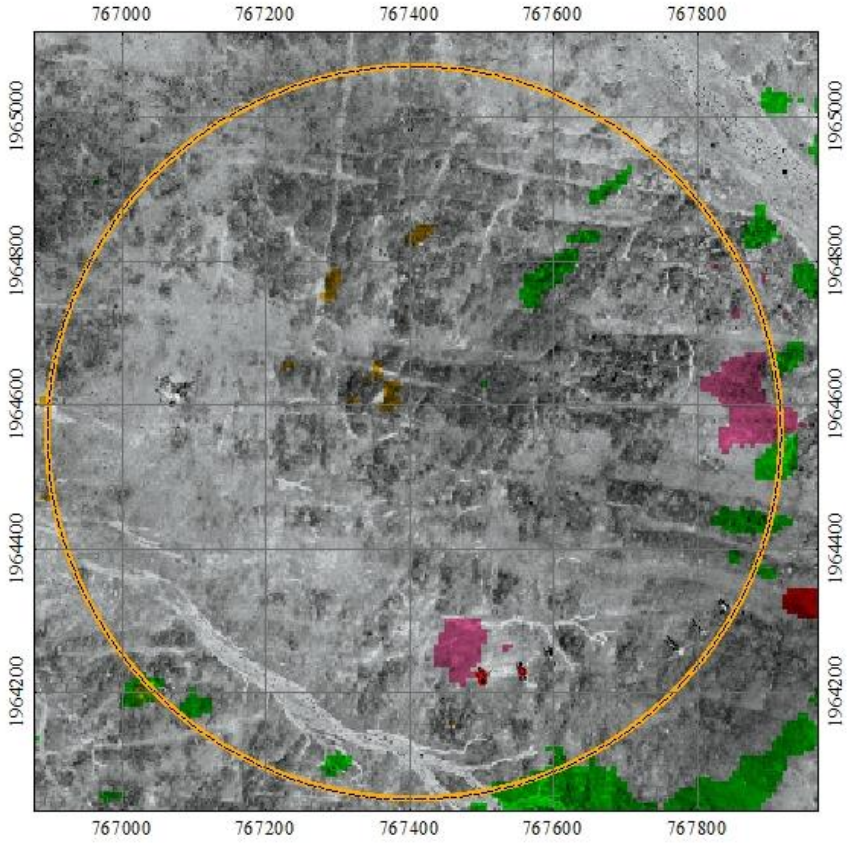
AIRBUS

Target 18 – Grade 2 - 1

In this area we find a small Clay-Iron anomalies in the southern part of the circle where some trenching appears to have been done. Significantly we can see vector mapping of Iron Oxides on two of the trenches. This indicates possible presence of gossans. Apart from a small patch of haematitic signatures there is no other information coming from the WV-3 Mineral Mapping. There is also a small Clay-Iron anomaly in the WNW part of the circle but this does not have any accompanying Mineral Mapping signatures. The area in the south of this target should definitely be visited to check for the presence of gossans with sampling if they are found.



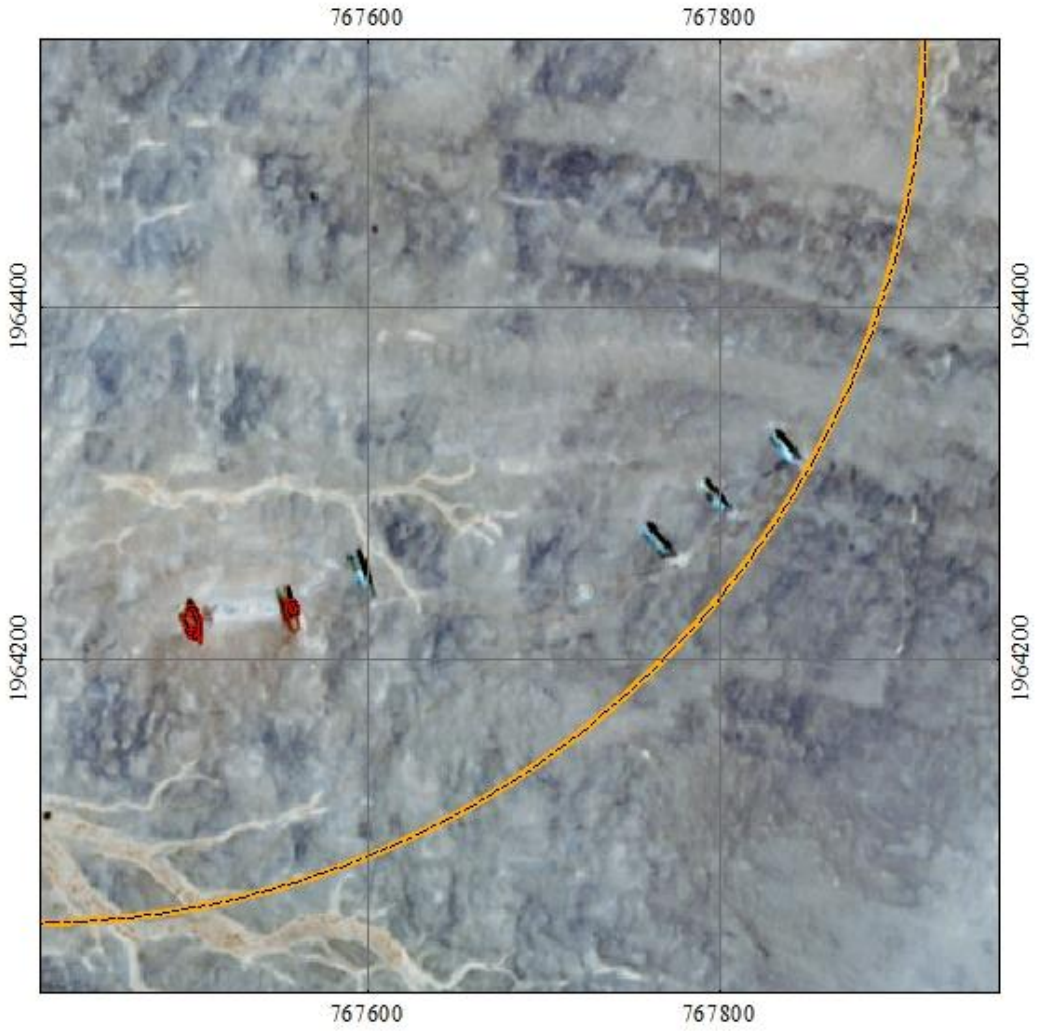
WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

AIRBUS

Target 18 – Grade 2 - 2



This is a zoomed-in portion of Target 18 showing the trenching in the southern part of the area. Possible gossans are mapped by NDII in the two western-most trenches. The other 4 trenches show no sign of iron oxides in this 1.2m pixel Simulated True Colour WV-3 FCC532.

A more detailed view of the trenching in the southern part of Target area 18.

Image is Simulated True Colour (STC) WV-3 FCC532 at 1.2m pixel. The red-orange colours of possible gossans are seen in the areas picked out by the NDII Iron Oxide mapping vectors in red.

Coordinates in UTM36N WGS84
Grid spacing 200m.

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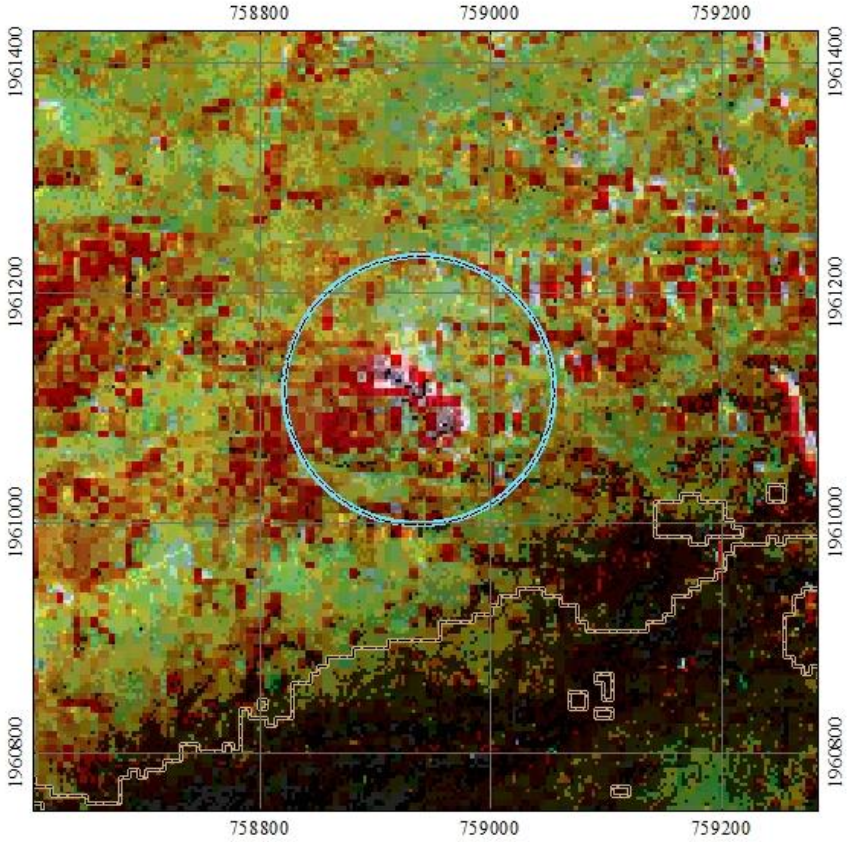
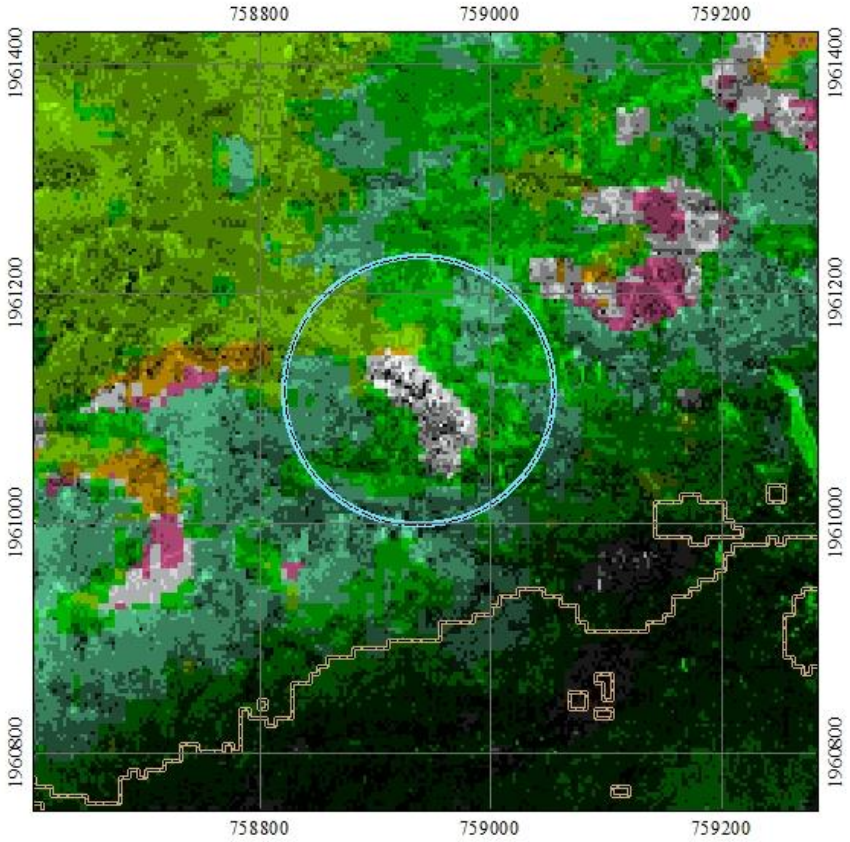
Target 19 – Grade 4 - 1

This target is centred on a NW – SE trending excavation that has moderately strong Clay-Iron signatures but no accompanying Mineral Mapping profiles. It lies in an area of CPS type signatures with mixed CPS-goethitic and CPS-haematitic zones. It would be interesting to see what rock types these different Mineral Mapping profiles correspond to. As there is no particularly strong Clay-Iron anomaly and no Mineral Mapping profile indicated then this is classed as a Grade 4 anomaly. There does appear to be extraction here – it would be interesting to see what the geology is and what is being extracted.



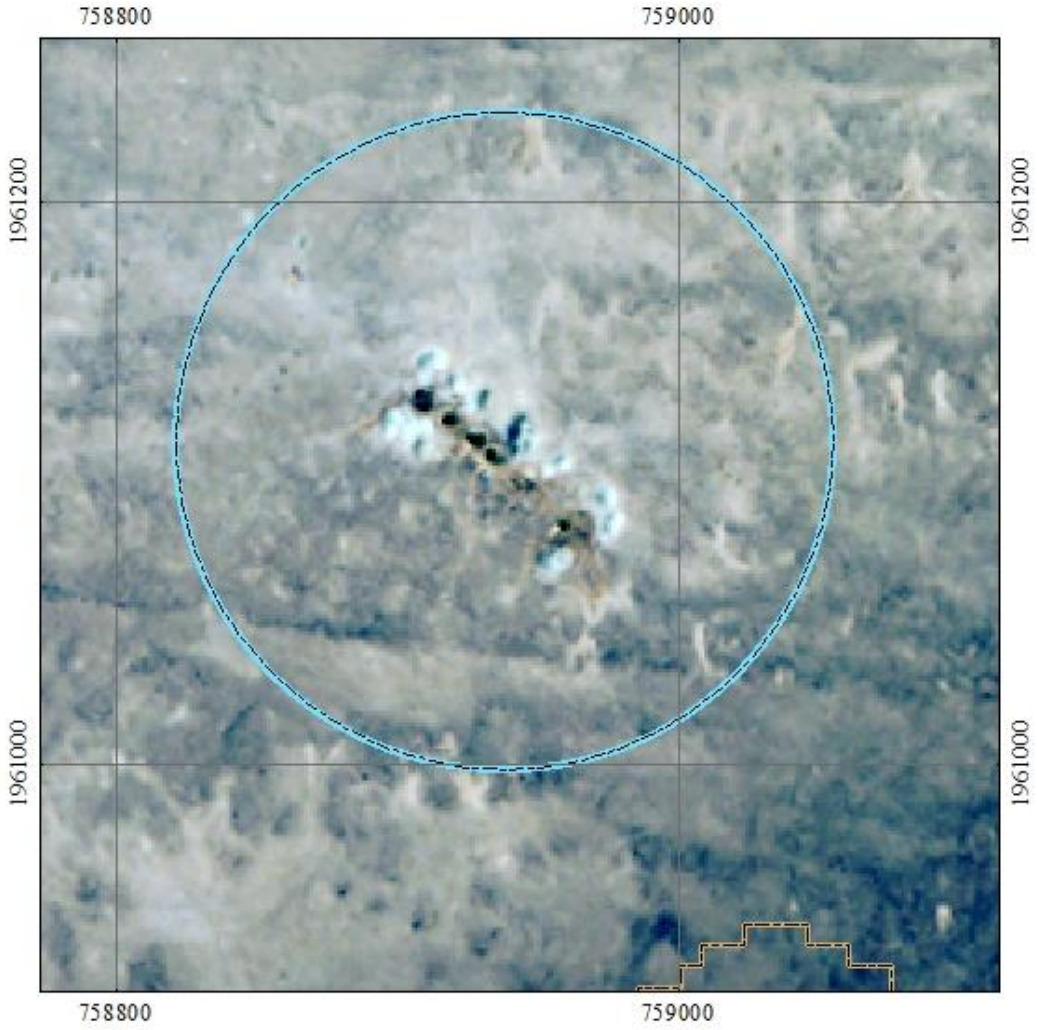
WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Dolomite areas displayed in beige coloured outlines. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

AIRBUS

Target 19 – Grade 4 - 2



This STC WV-3 FCC532 image utilises the superior resolution of the VNIR at 1.2 m pixel to get a more detailed view of the extraction pits at Target 19.

A more detailed view of these features is available from the pan sharpened mosaic images

Detailed view of the excavation pits in Target area 19.

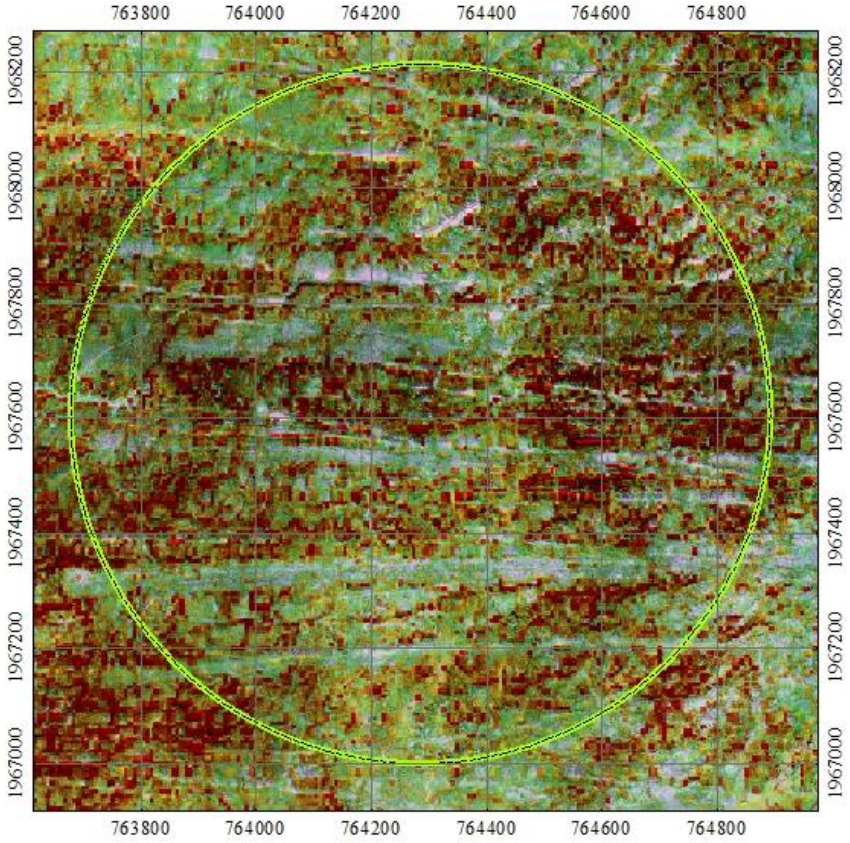
Image is Simulated True Colour (STC) WV-3 FCC532 at 1.2m pixel.

Coordinates in UTM36N WGS84
Grid spacing 200m

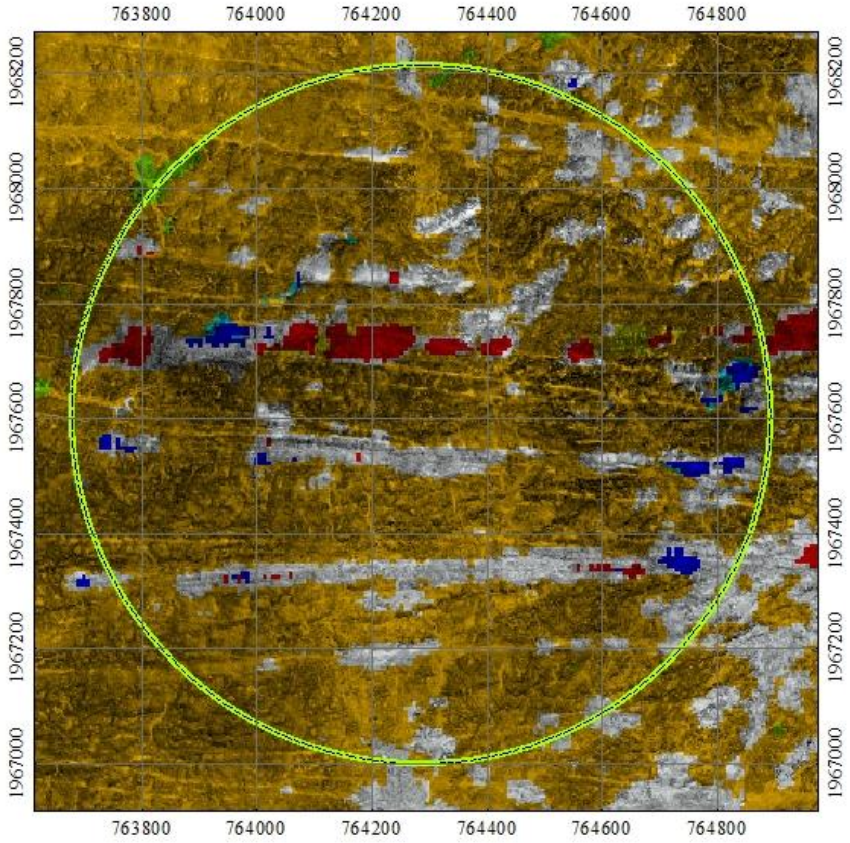
AIRBUS

Target 20 – Grade 3

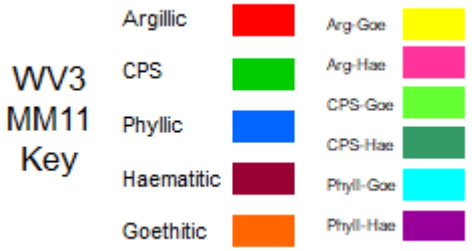
In this target area the features of interest have lower Clay-Iron signatures than their host rocks. They are a series of E-W trending probably felsic dykes – some with argillic Mineral Mapping profiles. In places these have phyllic and phyllic-goethitic signatures. There is a possibility that this may be hydrothermally related but this is probably a lesser chance. This Grade 3 target could be checked out as a lower priority.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



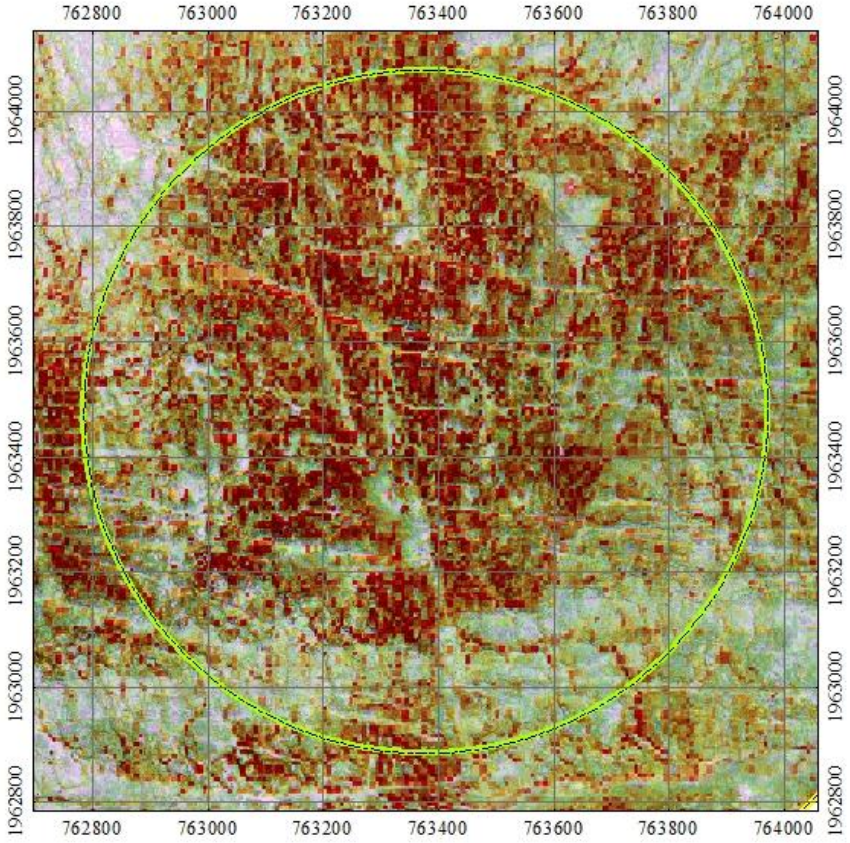
WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



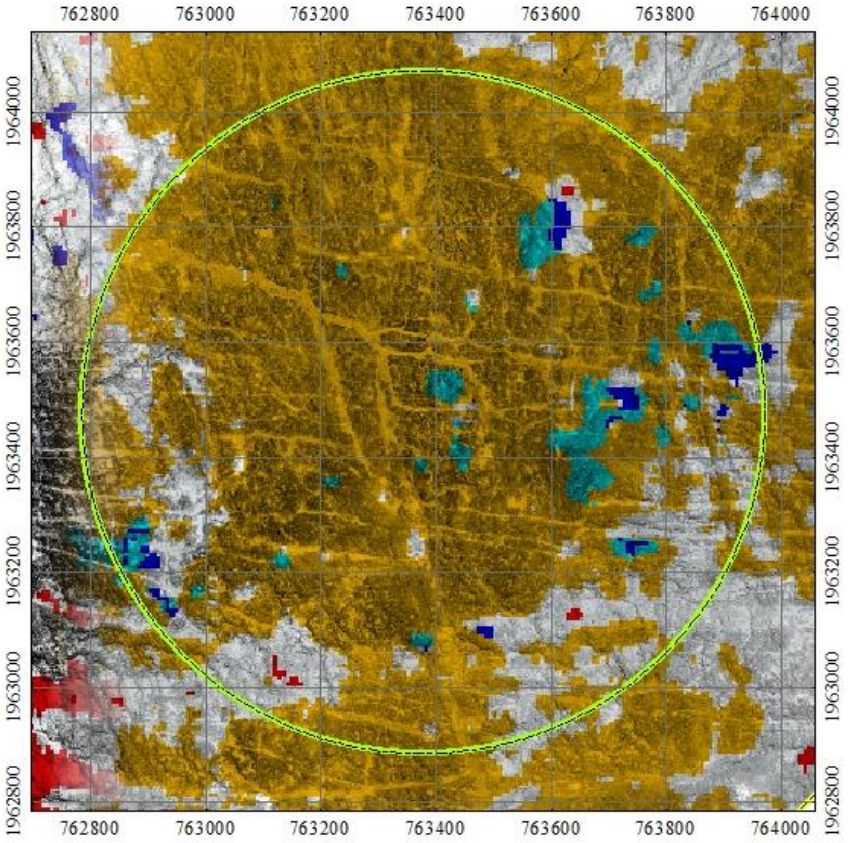
AIRBUS

Target 21 – Grade 3

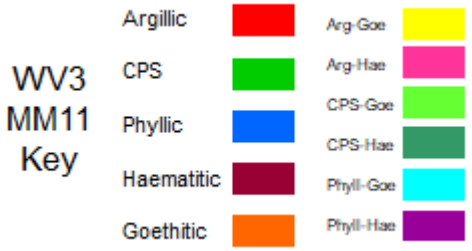
This area is similar to the situation in Target 21 where the spectral anomalies have lower Clay-Iron signature than their host rocks. Here we see patches of phyllic-goethitic profiles in a broad goethitic area. We must be aware that this is in the central band of artefact goethitic signatures so the whole situation may well be created through the image haze rather than being anything of interest on the ground. As there is an apparent Mineral Mapping anomaly here this has qualified as a Grade 3 target. Field follow-up should be carried out as a lower priority.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .



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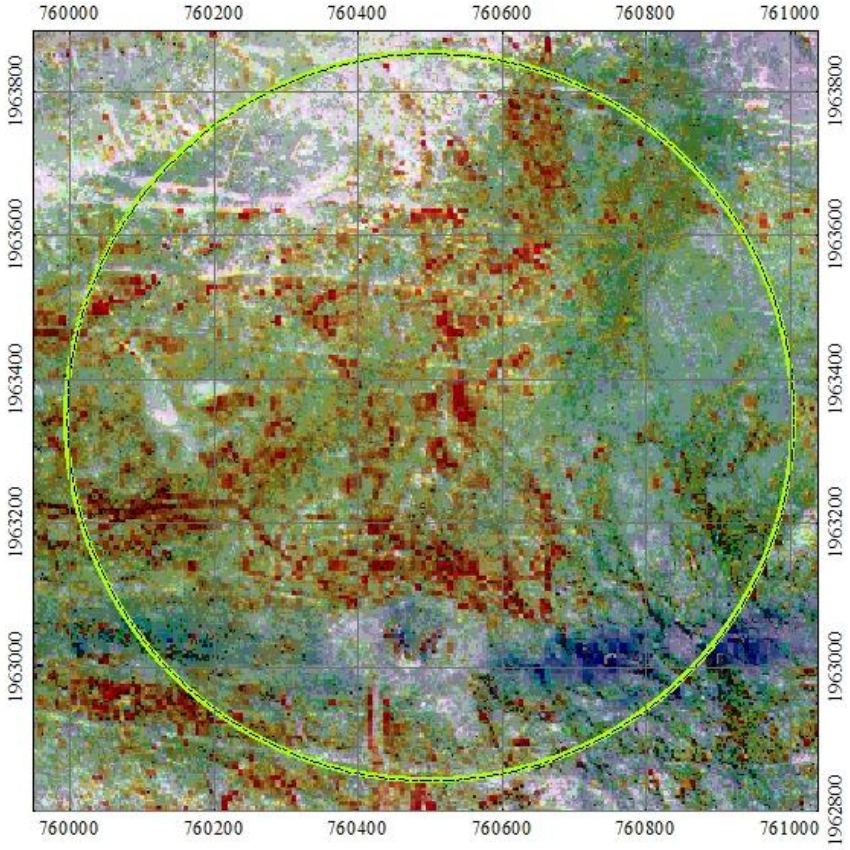
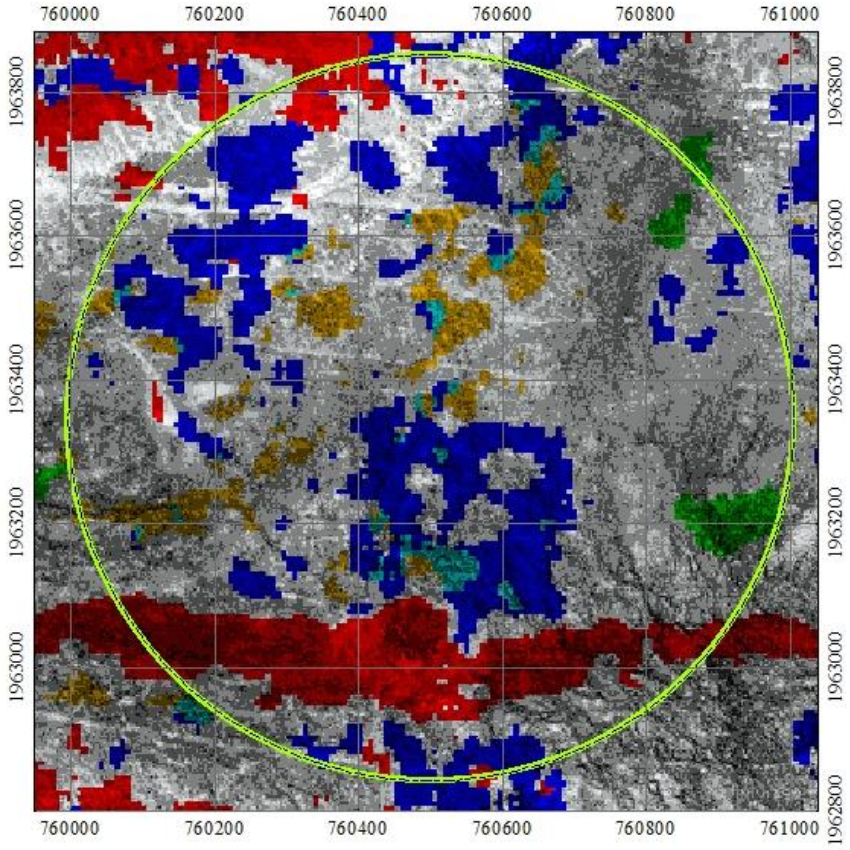
Target 22 – Grade 3

In this area we see an area that contains an irregular network of elevated Clay-Iron values associated with some phyllic, goethitic and mixed phyllic-goethitic signatures in the Mineral Mapping. A felsic dyke with an argillic signature trends East-West through the southern part of the target area. As these features fall in an area of the imagery NOT affected by haze artefacts then there is a higher possibility that there is a geological reason for them. This area should be treated as a lower priority area for field follow-up.



WV3 Clay-Iron Image. VNIR-SWIR processed at 7.5m pan-sharpened to 3m. Imagery shows strong reds indicating possible alteration. Coordinates in metres UTM36N WGS84 with grid spacing 200m



WV3 Minmap11-Topo Image. Colour code in key above. Coordinates in metres UTM36N WGS84 with grid spacing 200m .

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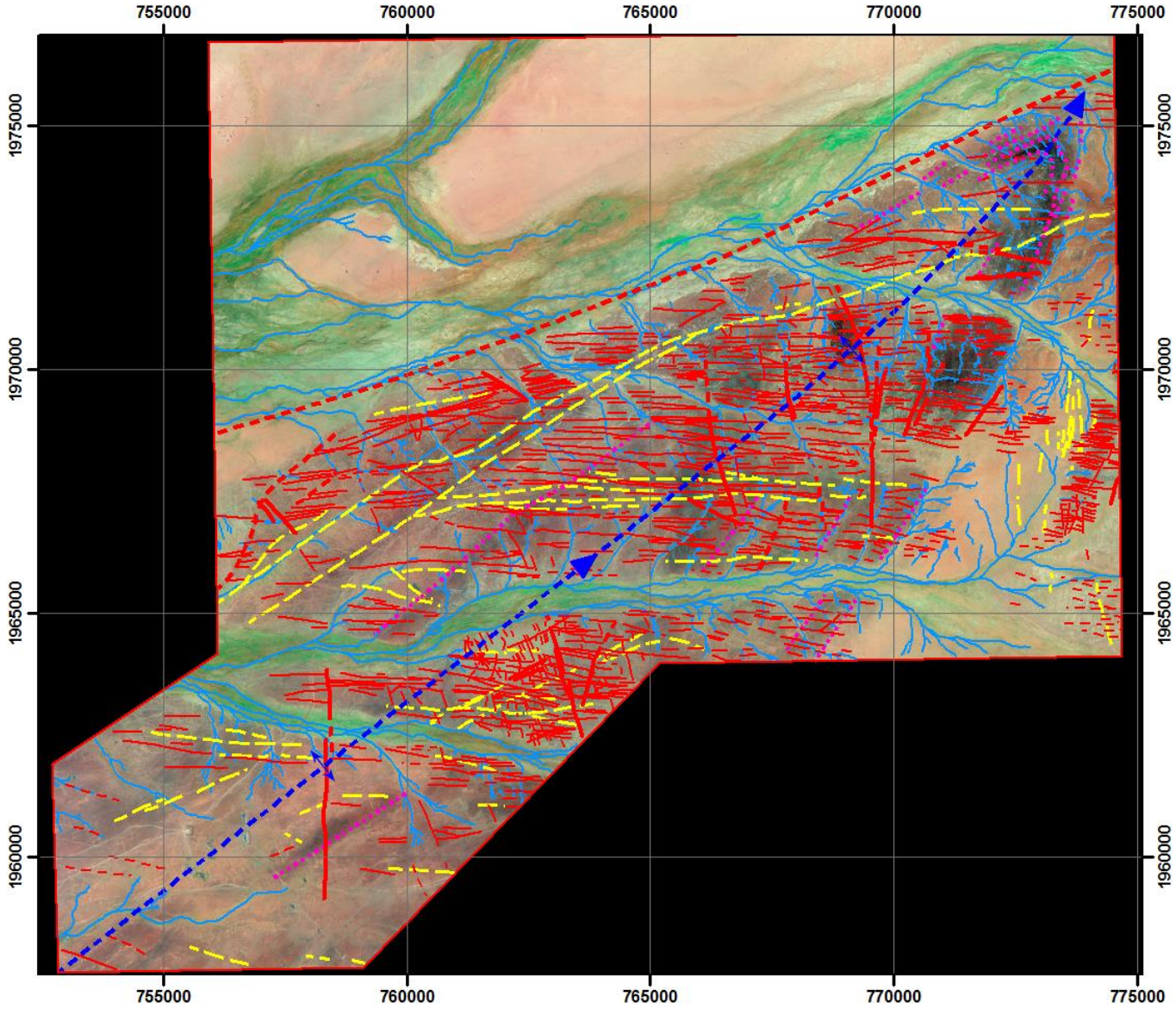
Structural Interpretation Overview



WV-3 SWIR mosaic with structural interpretation

- The following observations can be made:
  - A large near-isoclinal fold structure is apparent with a SW-NE trending fold axis and a fold closure in the NE. The fold is interpreted to be bounded and truncated on its NW side by a large fault structure.
  - Frequent minor faults / fractures predominantly trend E-W or NNW-SSE
  - Major faults trend N-S or NNW-SSE. Sinistral offsets have been observed
  - A series of dykes predominantly trend E-W or NE-SW and occasionally N-S in the East of the study area. A number of these are extensive, extending across the width of the AOI.
  - Sand cover obscures the underlying bedrock in the North of the area

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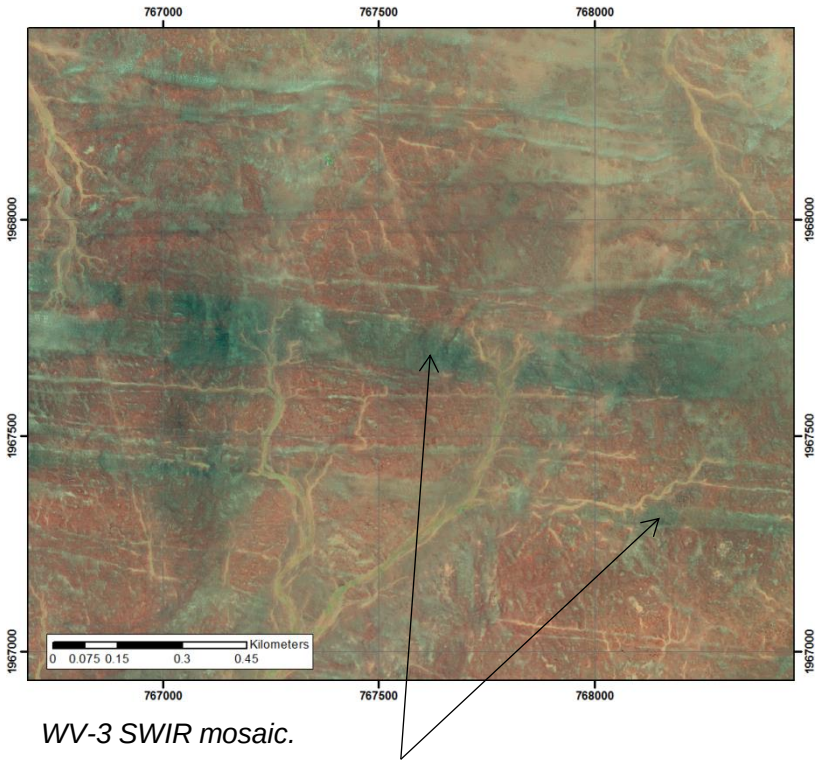
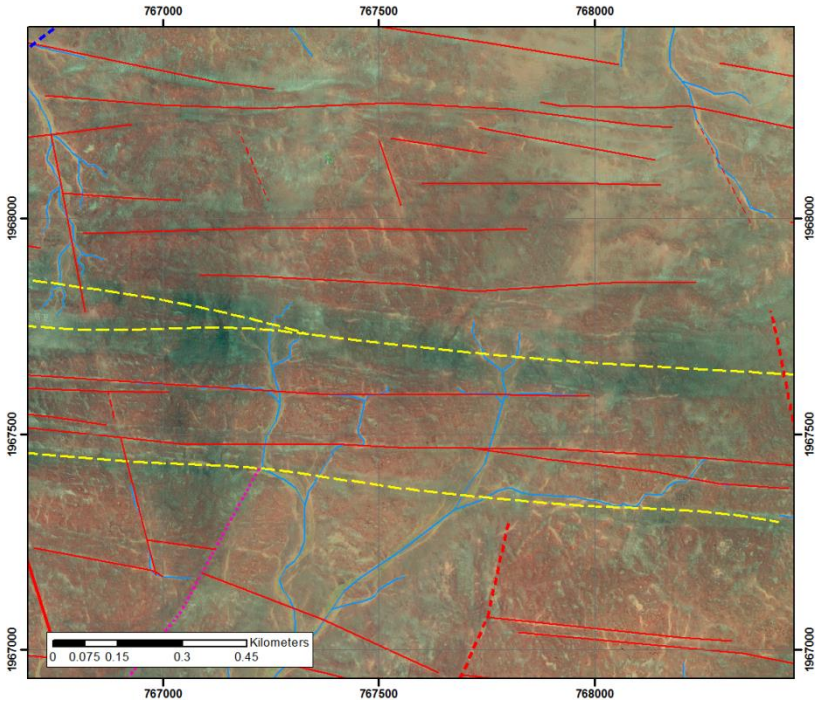
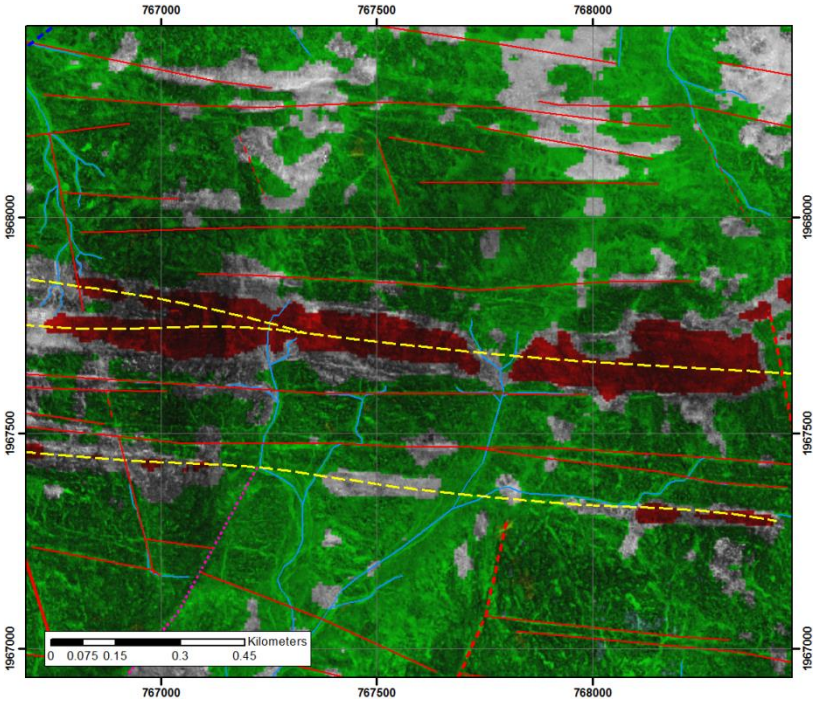
Structural Interpretation - Dykes



WV-3 SWIR mosaic.

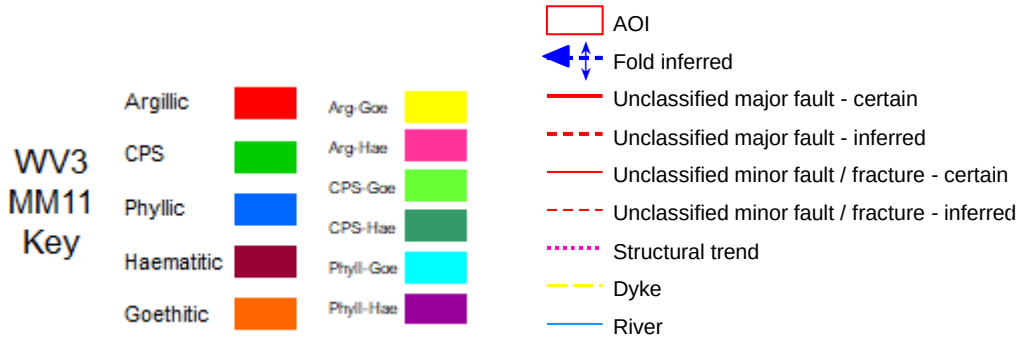


WV-3 SWIR mosaic with structural interpretation.



WV-3 WV3 Minmap11-Topo Image.

- Example illustrating E-W trending dykes with argillic signatures on Minmap11-Topo image, parallel to minor faulting / fractures



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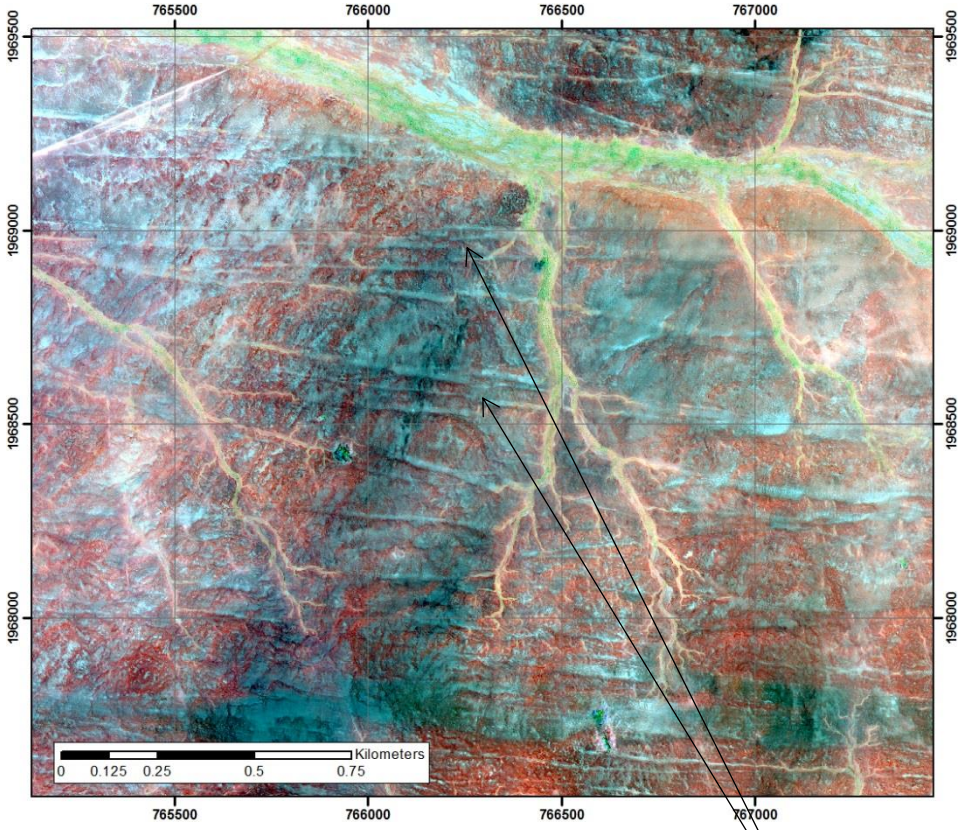
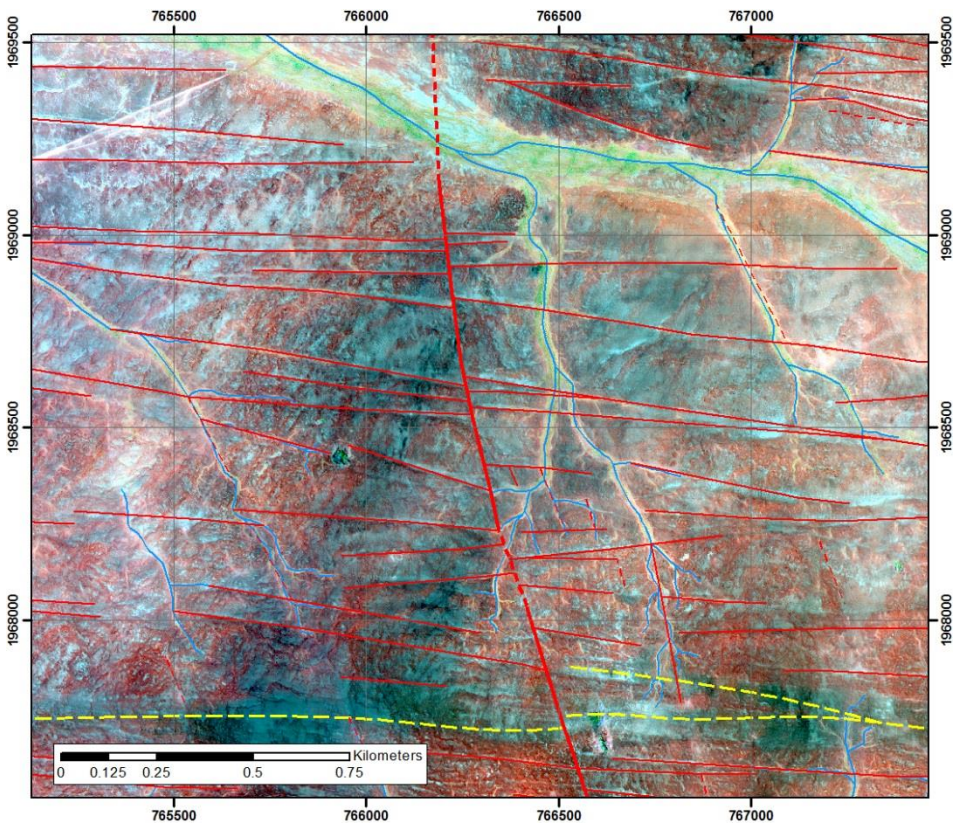
Structural Interpretation – Faulting



WV-3 SWIR mosaic



WV-3 SWIR mosaic with interpretation.

AOI
Fold inferred
Unclassified major fault - certain
Unclassified major fault - inferred
Unclassified minor fault / fracture - certain
Unclassified minor fault / fracture - inferred
Structural trend
Dyke
River

- Example showing a NNW-SSE trending major fault with sinistral offset to minor faults/fractures.

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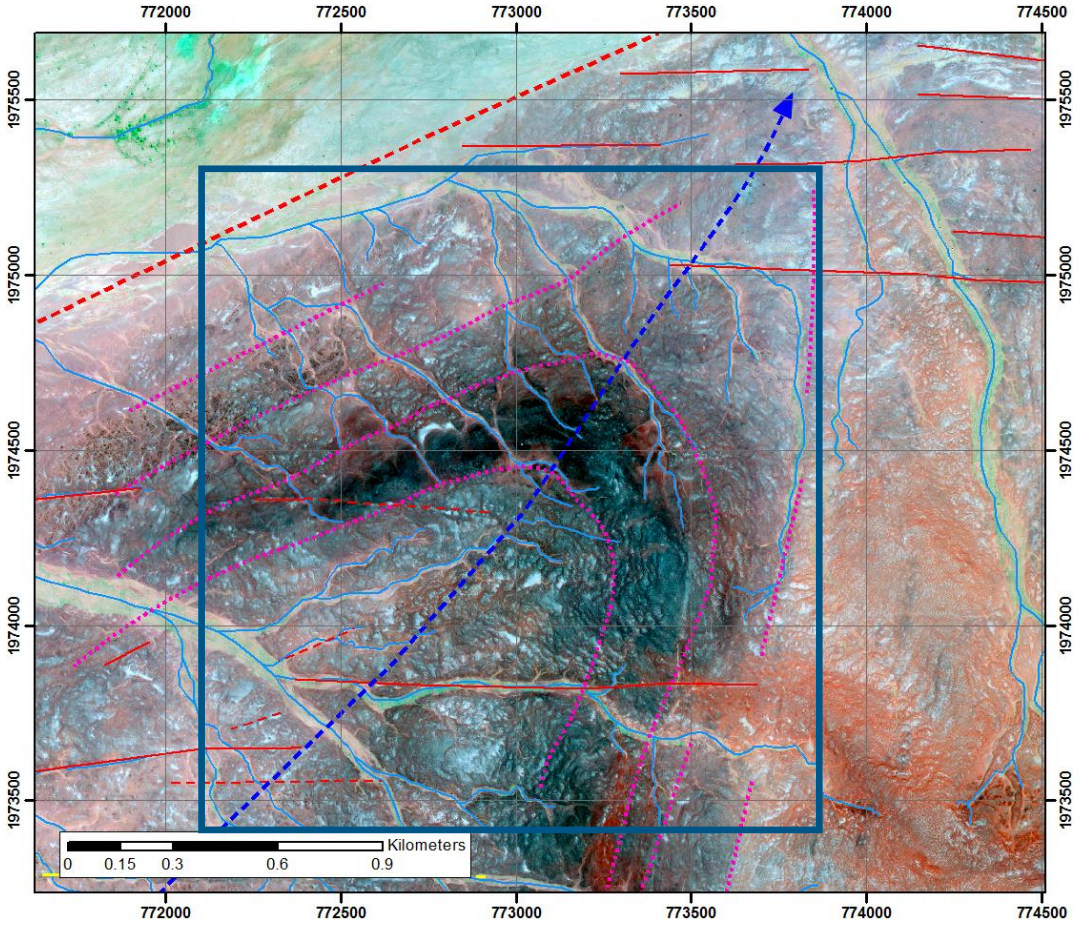
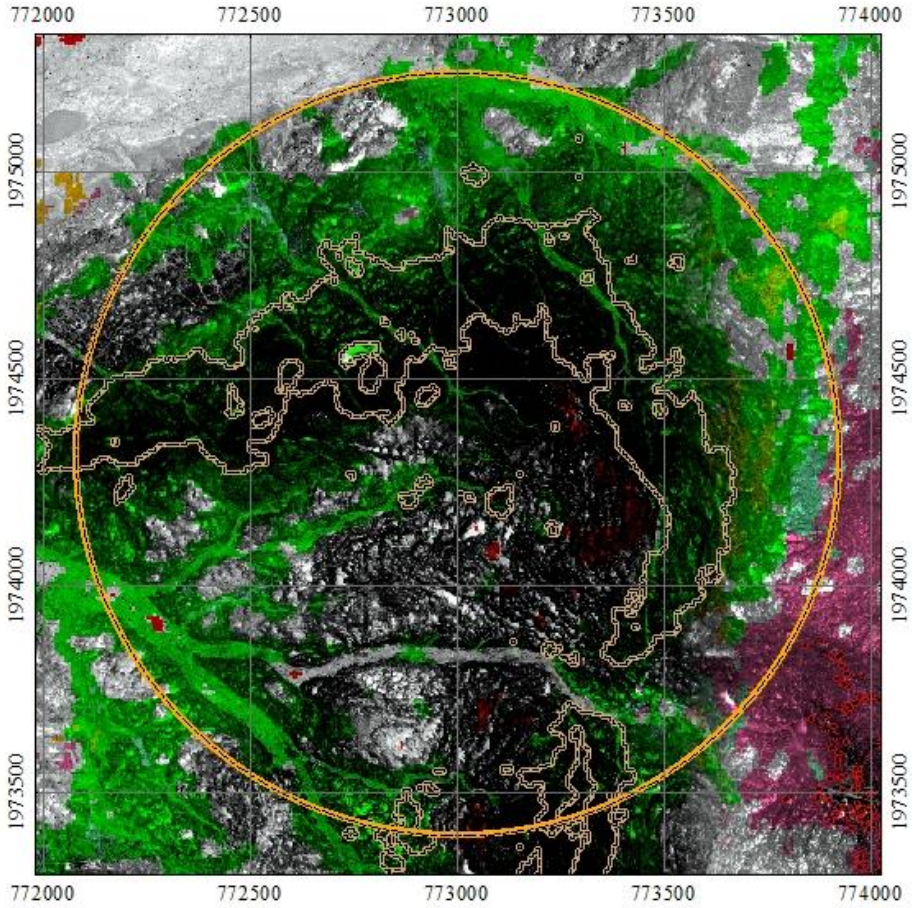
Structural Interpretation – Fold Structure



WV-3 SWIR mosaic with structural interpretation



WV3 Minmap11-Topo Image. Dolomite areas displayed in beige coloured outlines. Location shown by boxed area

AOI
Fold inferred
Unclassified major fault - certain
Unclassified major fault - inferred
Unclassified minor fault / fracture - certain
Unclassified minor fault / fracture - inferred
Structural trend
Dyke
River

WV3 MM11 Key

Argillic
CPS
Phyllic
Haematitic
Goethitic
Arg-Goe
Arg-Hae
CPS-Goe
CPS-Hae
Phyll-Goe
Phyll-Hae

- SW-NE trending fold axis and a fold closure in the NE, indicated by structural tends and distribution of dolomite signatures

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Conclusions

- WorldView-3 (WV-3) VNIR-SWIR imagery allows spectral processing over the project area in unprecedented detail. This imagery represents a significant leap in the capability of Remote Sensing imagery at VHR scales for detection of the intensity and type of hydrothermal alteration and for geological mapping. WV-3 Clay-Iron Imagery and WV-3 Mineral Map 11 Topo Imagery are produced using a direct method transfer from regional datasets LANDSAT and ASTER enabled by the unique 16 band VNIR-SWIR array of the WV3 imaging sensor. There are some artefacts in the data that may have produced false spectral anomalies. The problem appears to be mainly in the short wavelength bands – possibly due to haze and has produced over-mapping of goethitic type iron hydroxides. Most of the Mineral Mapping profile types rely on data from longer wavelength bands and these appear to be unaffected.

- The central part of the exploration area is occupied by a large near-isoclinal fold structure with a SW-NE trending fold axis and a fold closure in the NE. The fold is interpreted to be bounded and truncated on its NW side by a large fault structure. The folded rocks are dominated by CPS Mineral Mapping signatures. These are probably mainly chlorite bearing metavolcanics. Some felsic metavolcanics with argillic signatures are probably also present. There are also a number of E-W trending felsic dykes intruded into the folded meta-volcanics – these also have argillic signatures. The areas to the NW and SE of this structure are largely covered by recent deposits with very little bedrock exposure. There appears to be no significant spectral information on the nature of the underlying basement rocks.

- Mineral Mapping of dolomite has revealed a “marker horizon” bearing dolomite-like spectral profiles and can be seen in both limbs of the fold structure as well as mapping out the fold nose in the NE. If these rocks are dolomite then they may well be exhalative sediments associated with base-metal mineralisation. This signals the possibility of VMS style mineralisation. Re-distribution of metal sulphides during deformation also raises the possibility of the development of saddle reefs in the region of the fold nose in the NW. There are other possibilities for mineralogy to produce these spectral profiles – an iron rich chlorite for example. Field checking of these spectral features should provide answers. Mineral Mapping of iron oxide rich rocks that include gossans has been carried out using just the VNIR at 1.2m pixel. The areas defined by this are dominantly iron-oxide rich sediments in the wadis but a few small areas of possible gossan have been defined in the bedrock. If bedrock gossans are undisturbed then they will not be mapable using this technique as a thick black desert coating obscures the underlying spectral features.

Conclusions

- A total of 22 Mineral Exploration targets have been defined, all within the central area of folded meta-volcanics running diagonally SW-NE across the exploration area. These are graded based on their size and the quality of the spectral information from the WV-3 data. There are 3 Grade 1 targets. One appears to be known mineralisation in excavations and trenches across sub-parallel veins aligned at a high angle to the fold axis. The other two are probably part of a single unit of altered rock assemblages either side of an E-W trending wadi. The Grade 2 targets have both Clay-Iron and Mineral Mapping spectral features but are smaller, except for the possible dolomites at the fold nose where possible saddle reefs are a speculation. Grade 3 targets have only Clay-Iron OR Mineral Mapping features, not both, and Grade 4 targets may have no spectral features but show geology that may be of interest.

- Frequent minor faults / fractures are present predominantly trending E-W or NNW-SSE. Major faults trend N-S or NNW-SSE, with evidence of sinistral offsets

Recommendations / Further Work

- Users of this report are asked to bear in mind that the results and conclusions arrived at herein are solely based on spectral analysis/interpretation of WV3 imagery and field knowledge of other similar areas in the Arabian-Nubian Shield. No information from the ground has been taken into account.

- Due to resolution the SRTM DEM provided only general information on topography. A higher resolution 1m DEM could be generated with the capture of stereo Pleiades satellite imagery

References

1	Geological & Minerals Dept. Sudan & BRGM France	1981	Geological Map of The Sudan at 1:2m scale. Geological Society of London Map Library
2	M A Brown	2014	32 years of RS Spectral Mapping Presentation at the Geological Remote Sensing Group of the Geological Society of (GRSG) annual meeting at Burlington House, Piccadilly, London

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Key to abbreviations

WV-3 Mineral Mapping terms

Arg	argillic type spectra
Arg-goe	mixed argillic-goethitic type spectra
Arg-hae	mixed argillic-haematitic type spectra
CPS	Chlorite – Propylite – Serpentine type spectra
CPS-goe	mixed CPS-goethitic type spectra
CPS-hae	mixed CPS-haematitic type spectra
Goe	goethitic type spectra
Hae	haematitic type spectra
Phyll	phyllic type spectra
Phyll-goe	mixed phyllic-goethitic type spectra
Phyll-hae	mixed phyllic-haematitic type spectra

* These are explained on P8 and in reference Brown 2014

Geological Terms

Gossan	Concentration of iron oxides/hydroxides developed above massive sulphides
Propylite	Chlorites and Epidote – minerals found in propylitic alteration
VMS	Vo lcanogenic Massive Sulphide – deposit of Cu/Pb/Zn often with Au rich cap

Remote Sensing terms and abbreviations

Albedo	The overall brightness of a surface material
ASTER	US/Japanese satellite – first super-spectral SWIR
Clay-Iron Image	Image designed to highlight hydrothermal alteration in bright red
ETM+	Enhanced Thematic Mapper – the imaging instrument on board LANDSAT-7
FCC	False Colour Composite – a colour image generated by displaying 3 image bands in Red Green Blue (RGB).
LANDSAT	Series of NASA imaging satellites 1972 – present
Mineral Map Topo Image	Mineral spectral types mapped in user specified colours over monochrome topographic image
Millennium Tiles	World coverage of ETM+ mosaics in FCC742 split into rectilinear tiles in UTM projection. Produced for year 2000 by NASA.
MM	Mineral Mapping – possible with “super-spectral” devices ASTER & WV3
NDII	Normalised Difference Iron Index – high values of this over very haematitic lithologies including gossans
Super-Spectral	6-8 bands in the VNIR and/or SWIR
SWIR	Short Wave Infra-Red (1300 – 2500nm)
VHR	Very High Resolution – (spatial) ca 30 – 300cm pixel
VNIR	Visible and Near Infra-Red (450 – 1300nm)
WV3	WorldView-3 satellite sensor