Exploring for Sulfides in USA and Australia using Adrok's electromagnetic scanners

Adrok survey for sulfides in USA and Australia

	Project	Target result	Concept
Quantitative	Red Dog, Alaska (and all other Adrok projects)	Use High-Low analysis of harmonic data to delineate changes in rock types and rock type (including sulfide) fingerprinting.	The "DNA" of Adrok's technique and technology. Data-based and constrained by well-defined workflow.
Qualitative	Comparative across sites Bluebush, Australia Teena-Myrtle, Australia Red Dog, Alaska + other non-sulphide rich sites	Define selected criteria from harmonic data to delineate just the sulfide component of all project areas ignoring host rock type.	The "RNA" of Adrok's technique and technology. Iterative process leading to sulfide delineation criteria (results presented here). Strong emphasis on integrating geology and facets of ore zone mineralogy into interpretations.

Final result

Formulation of a unified technique and process for sulfide delineation without the need for training scans. Independent sulfide fingerprinting.

Integrating geology and geological knowledge into the existing work frame in order to refine aspects of the fingerprinting process

Project Background

The current project develops the ability to differentiate sulfides (undefined) in an ADR scan regardless of the site and host rock composition.

In theory, many scans collected over a variety of rock and containing a variety of sulfide abundances should have at least one, if not more, geophysical responses in common relating the presence of sulfides. Accordingly, the research and analysis was carried out with the goal of determining what characterises in a scan can be sued to confirm the presence of sulfides.

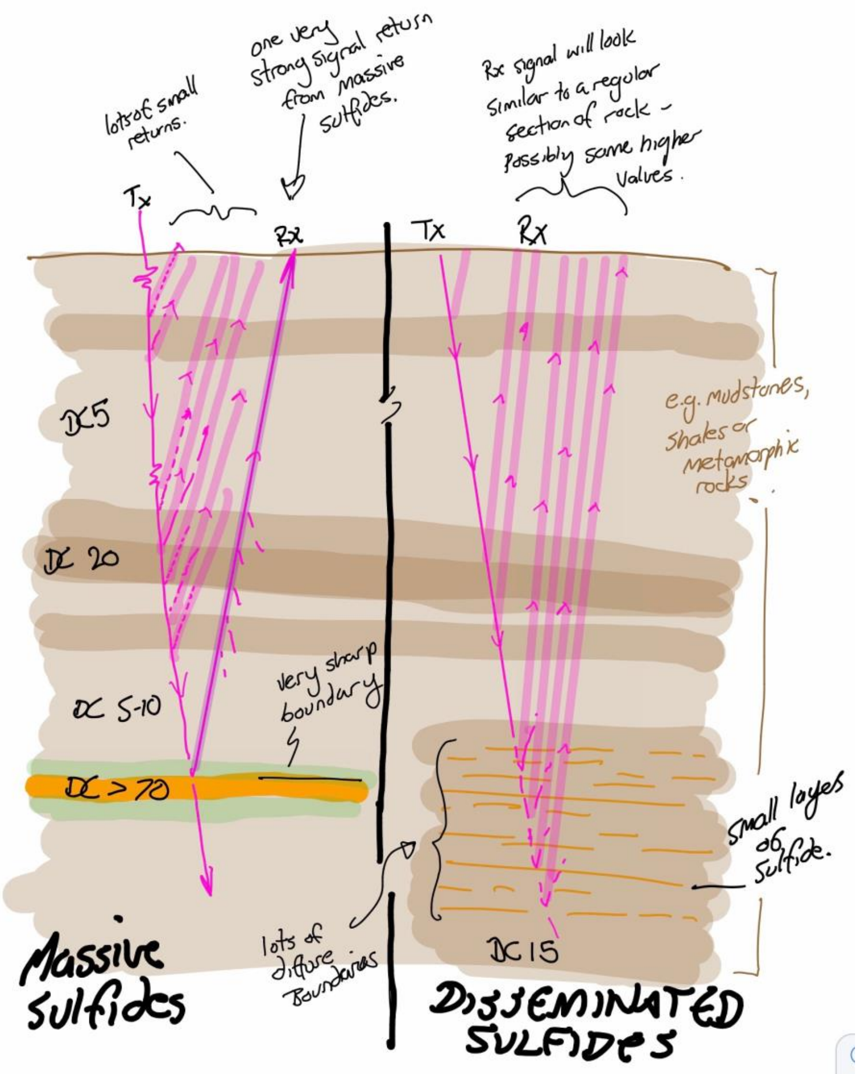
The following research also differs from some previous successful projects by Adrok targeting narrow vein gold and sulfide deposits. For cases exhibiting narrow vein sulfides, the response appears to be universal across projects whereby a strong reflection (low value) in Energy % Log typically indicates a strong return signal off the generally sharp contact between the host rocks (meta-sediments or granites for example) and the sulfides (such as galena, sphalerite, pyrite or chalcopyrite). In this case, the sulfides tend to be narrow but occur as massive sulfides.

Presented here is a slightly different approach to the delineation of high grade disseminated sulfides such as might be found in VHMS, Porphyry or SEDEX type deposits. Sulfide content (e.g. pyrite, chalcopyrite, sphalerite, galena) might reach high abundance (up to 80%) but typically the sulfide abundance is around 50% and grades (for the scans we had available) below mine grade for copper, lead and zinc for example.

Regardless of the grade, a high abundance of sulfides should be detectable using ADR. Using training drill holes from Queensland (Teena Myrtle), Northern Territory (Bluebush) and comparing these with results from Alaska (Red Dog), Adrok have been able to come up with a set of criteria that consistently provides target areas based on a qualitative Weights of Evidence (WofE) criteria.

Narrow vein v's Disseminated sulfides

Two very different targets, two very different approaches



The difference between disseminated sulfide, massive sulfide and detection limits.

Research on the response or radar to different arrangements of buried objects has been explored by many authors for GPR. The results, some of which are presented here presents an interesting explanation into the responses we see in ADR.

In summary, a radar (GPR) interpretation was generated for different cases where the radius and dielectric permittivity (Ɛ) of the target grains (this could be sulfides for example) were altered.

The clearest response (highlighted box) was gained from a case where the Dielectric Permittivity of the grains was high (Ɛ=30) and where the radius was 0.2. The dielectric contrast between the objects had a much greater impact than the radius whereby grains with an Ɛ=5 and a radius of 0.6 had no significant difference than the experiment containing the same Ɛ but a radius of only 0.2.

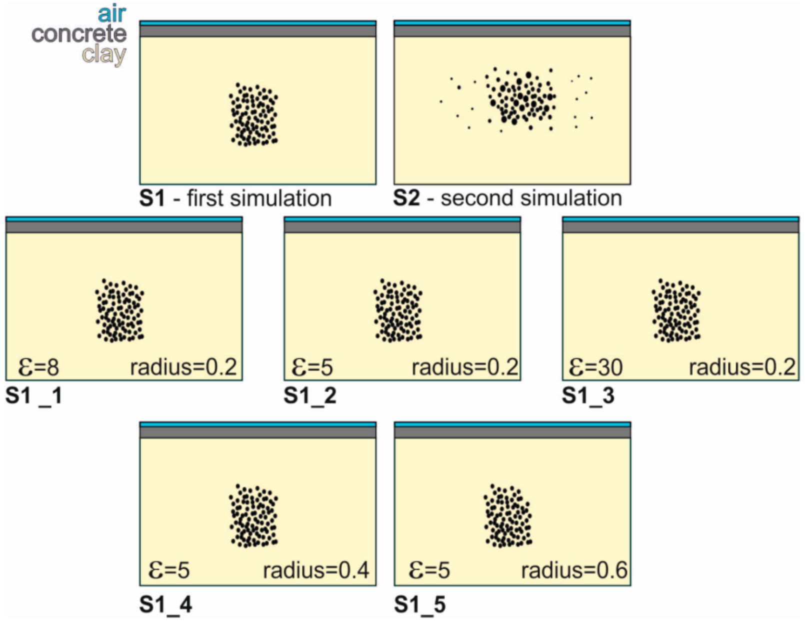
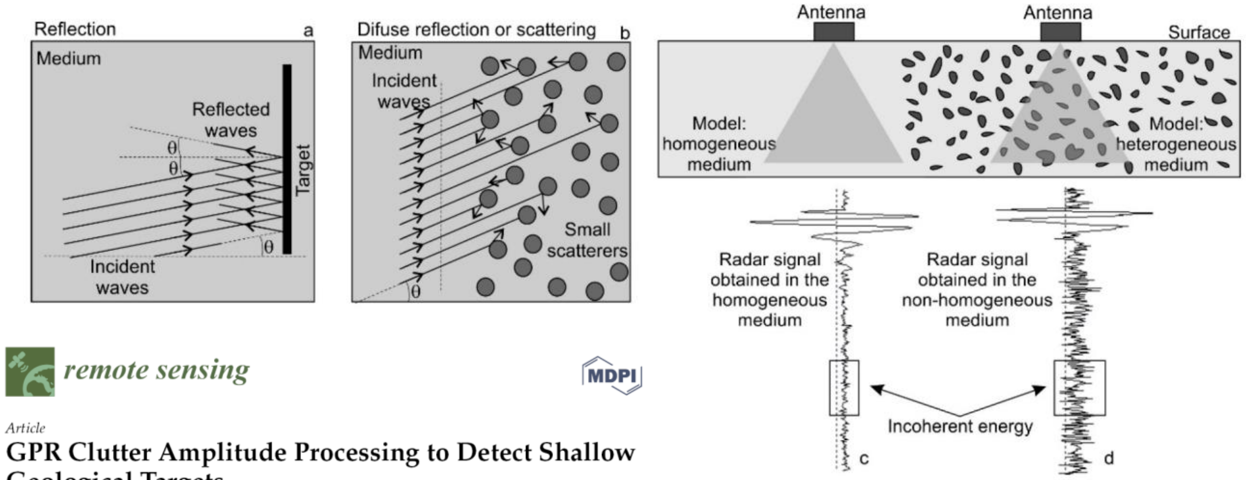


Figure 7. The two simulations (S1 and S2) based on different particles distribution. S1_1, S1_2, S1_3, S1_4 and S1_5 represent the five sub-cases considered in the first simulation (S1).



remote sensing

MDPI

Article

GPR Clutter Amplitude Processing to Detect Shallow Geological Targets

Victor Salinas Naval [1], Sonia Santos-Assunçao [2] and Vega Pérez-Gracia [3,*]

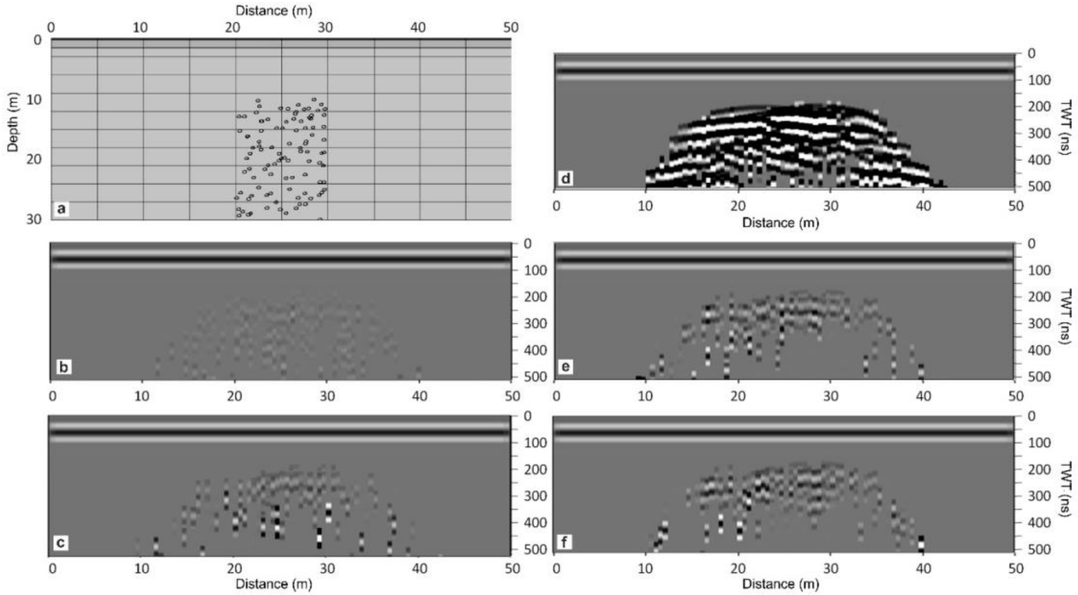


Figure 8. Three layered model with the position of the 100 scatterers (**a**) and synthetic traces for: case S1_1 (**b**); case S1_2 (**c**); case S1_3 (**d**); case S1_4 (**e**) and, case S1_5 (**f**).

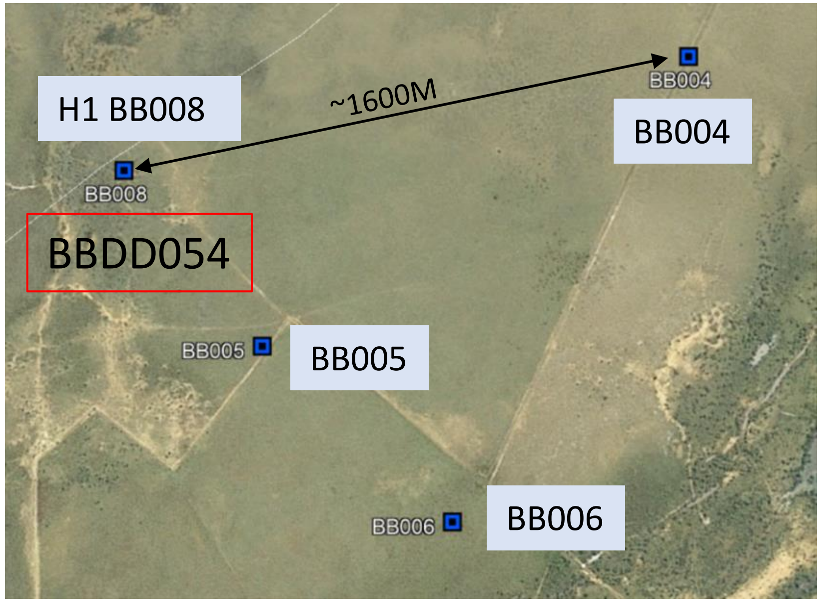
Location and Scan Selection

– Three independent sites to test sulfide-specific targeting criteria

The location of the selected scans for re-processing and analysis was defined primarily by the presence of existing drill holes with information on sulfide content. The aim of the re-processing was to unravel the SULFIDE signal, regardless of country rock type, therefore parallel drill holes were a key component of the selection criteria. In addition, several scans were selected from the vicinity where no parallel drill hole was recorded so the potential for targeting in blind trials could be undertaken. It is plausible that in the future, these scan sites may be drill tested.

Further to this, other scans from sulphide exploration sites outside of Australia, particularly Alaska, were included in the review as this formed another test of the criteria for sulfide detection.

ANALYSIS - H1 BB008 PARALLEL DRILL HOLE BBDD0054

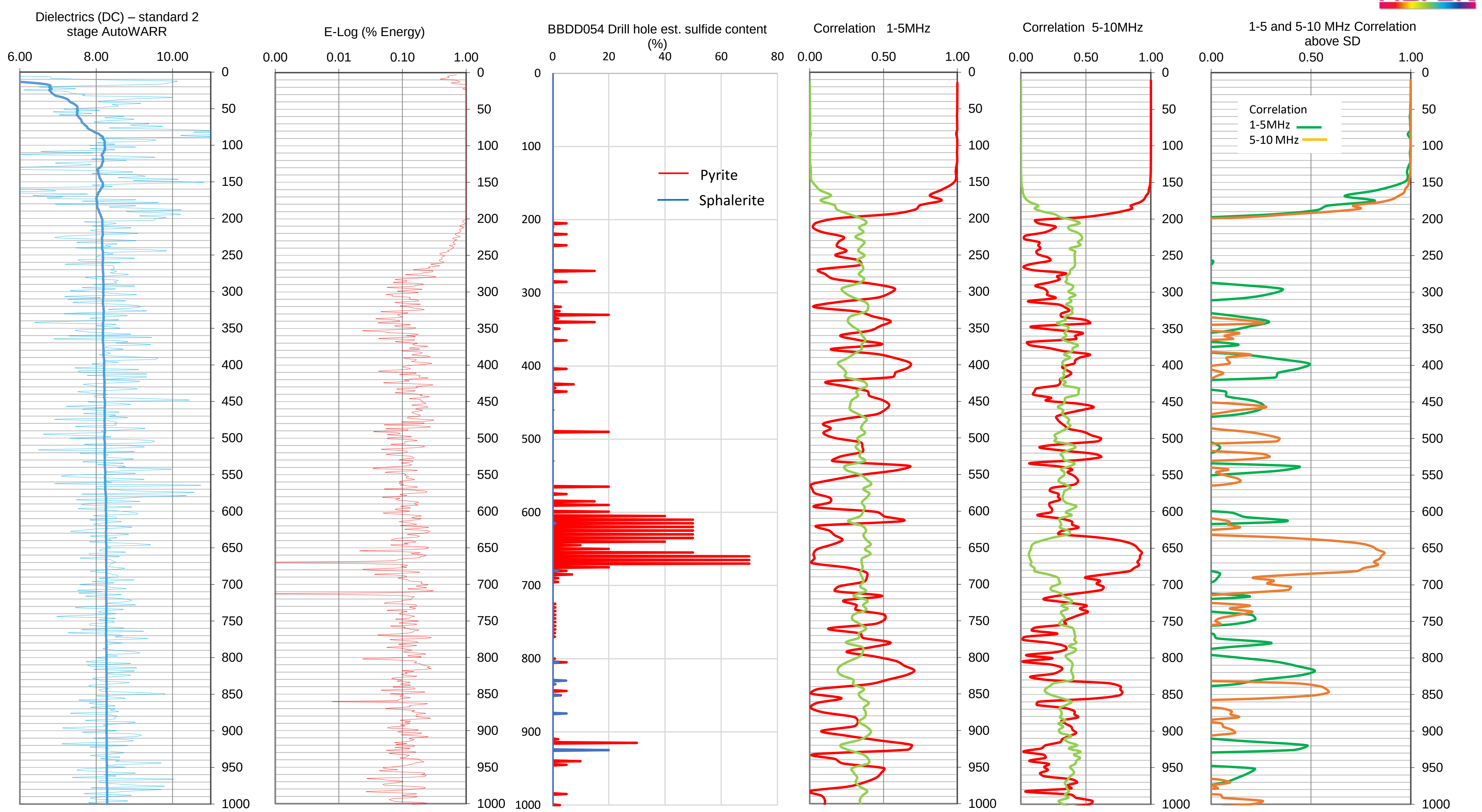


The following section presents the re-processed results for Dielectrics, Energy (E%log) and 1-5 & 5-10MHz frequency correlation. In addition, the results for both the energy and frequency are provided showing the selection criteria being developed for sulfide detection.

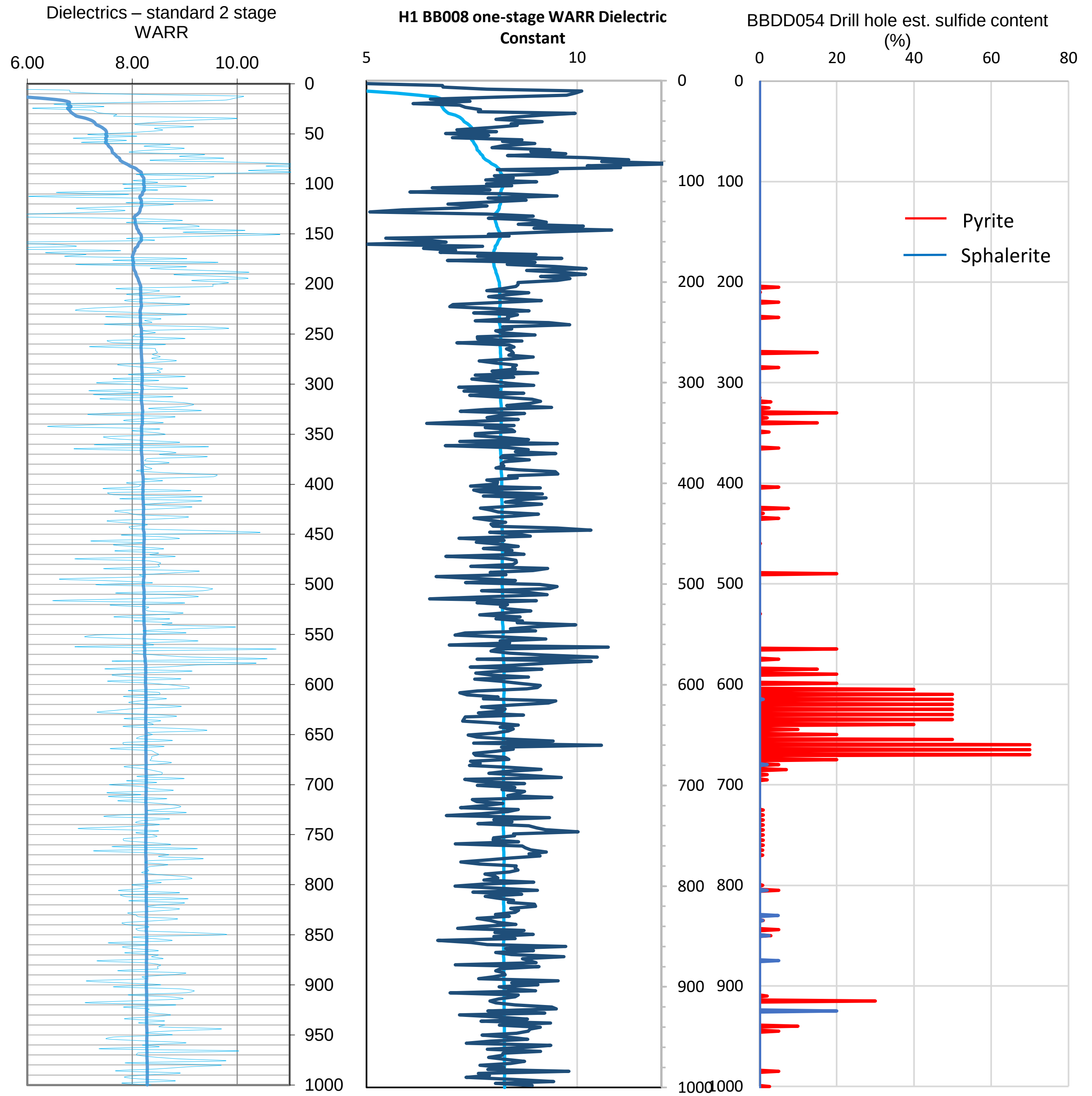
An explanation of the results is provided following the charts.

The charts presented are all the standard E- F-, Frequency correlation and DC charts that are provided to all clients as a standard set of results. Adrok purposefully utilised these results as it provided a means of correlating alongside other projects that are not presented here but where the same final datasets and charts were provided.

RESULTS - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054



RESULTS - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054



Dielectrics (method 1 v's method 2)

For this report, we have not focused the interpretation of the Dielectrics results as a new processing technique is being developed in order to provide a more viable result at greater depths. A brief comparison of the two techniques is provided here for initial comparison.

Dielectrics is a means of measuring a value that is proportional to the Dielectric Permittivity (Ɛr) or Dielectric Constant (DC) of the material at the given frequency. Experimental work measuring and categorising the Ɛr(DC) of materials dates back as far as the early 60's and has shown that water has a high dielectric (Ɛr = 80) whereas most rocks are well below Ɛr = 20. Most sulfides are measured at over 80 at laboratory frequencies.

Accordingly, (dependent upon the processing interval widths and the sulfide intersection widths etc) higher values of Ɛr(DC)should correspond with sulfides, water or water saturated rock. Some clays and/or hydrous minerals also have relatively high Ɛr(DC) values. Experimental work by Adrok has shown that, when the ADR is pointed towards the base of a waterbody and through approximately 350m of rock, the return signal indicates a DC>80 as expected.

Disseminated sulfides (mix of rock and sulfides) will likely have an ADR response DC value proportional to the amount of sulfides to rock. However, as the measurement is also, in part, relative, it is unlikely that the ADR DC values will be over 30-40.

The results shown the left fit the expected high DC corresponding with the sulfide layers.

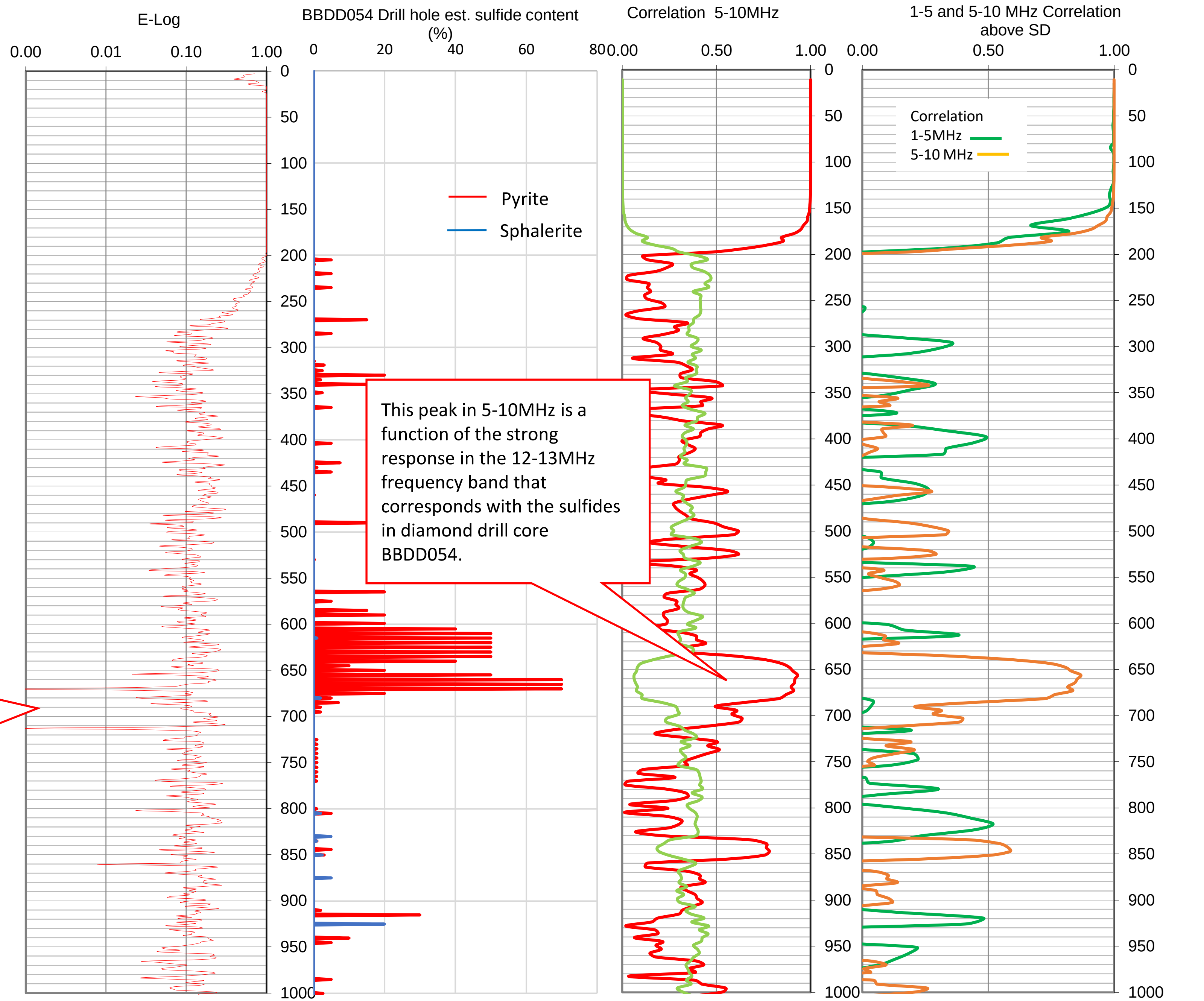
RESULTS - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054

Energy (Energy % Log)

The energy graph is one of the most reliable indicators for sulfides, but it also depends on the nature of the sulfide-country rock boundary. A sharp contact provides a strong energy response whereas a diffuse contact over a large distance may go undetected in the Energy chart.

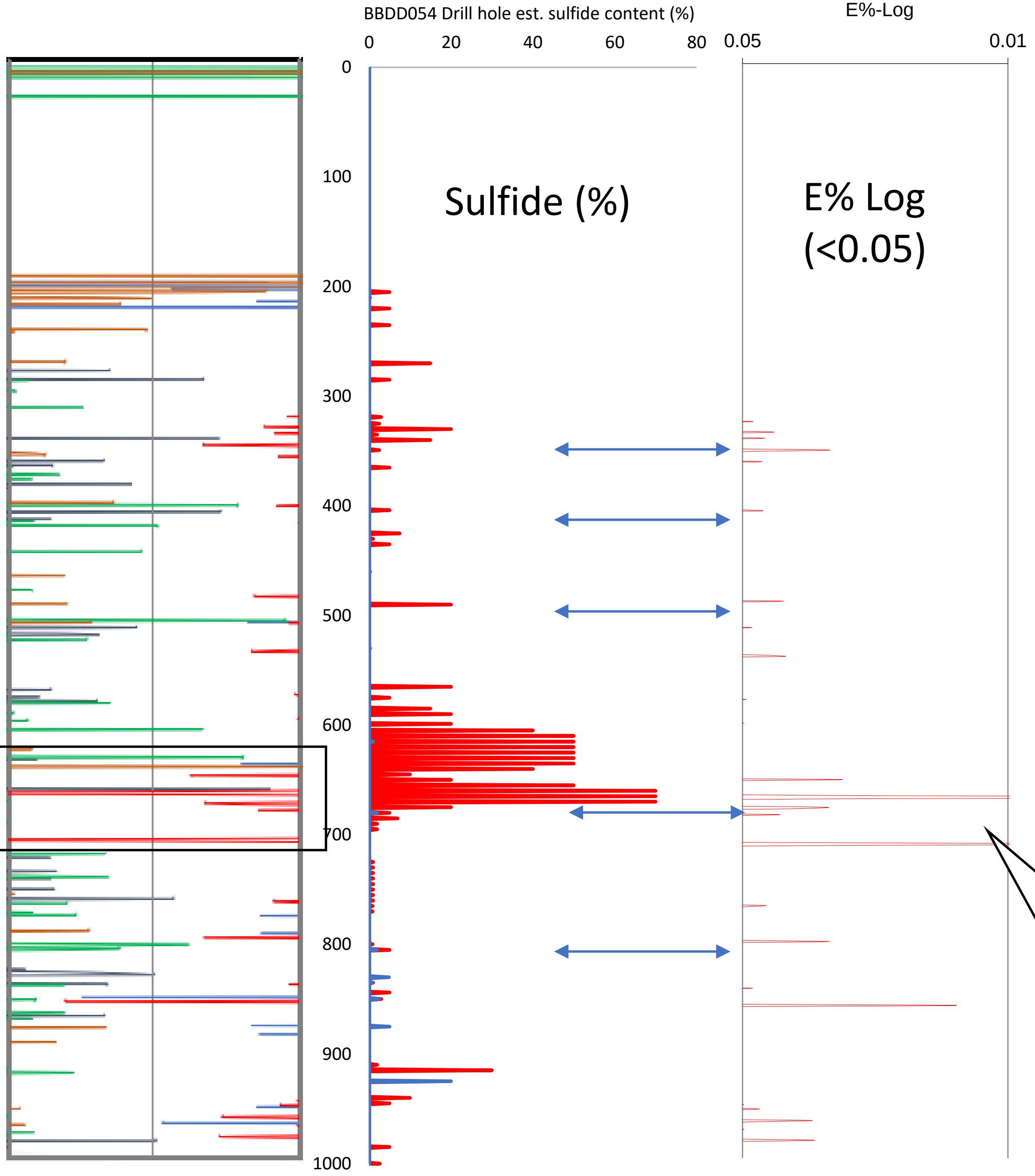
The energy response measures the intensity of the reflected energy in a return pulse. Lower values in the chart represent higher energy return. A strong signal such as presented here at ~675m is typical of a sharp boundary (i.e. a sharp contact between two rocks with contrasting DC values). An example of a sharp boundary might be the sudden increase in sulfide concentration such that a boundary between disconnected sulfide grains becomes a connected network of sulfide grains. The higher the density of sulfides in the layer, the stronger the reflection should be.

A strong response in the energy results is indicative of reflection of the pulse from a reflective boundary at depth. A reflective boundary is one where there is a contrast in the dielectric permittivity values of the rocks on either side, much like an acoustic boundary provides a strong reflector in seismic reflection surveys. Here, the energy response appears to approximately correlate with the location of the sulfides at 600-700m depth.
Strong reflected energy is a feature of many other surveys identifying massive sulfides.



Summary correlation E and E- SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054

Most number of correlations of max and/or min values identified by the greatest number of crossing lines within this interval.



Energy (Is the Energy E%log a reliable indicator on its own?)

The overall correlation between the selected criteria shown on the previous page and the major sulfide occurrence is reasonable for this scan and this drill hole result. One of the better, single correlations is that seen between the energy return (E% Log) and the sulfides. In other sulfide projects, strong return in energy is indicative of a sharp (or relatively sharp depending on frequency, depth etc) boundary between sulfides and host rocks. In the results seen here, the energy chart provides a good correlation suggesting the sulfides occur in relatively distinct layers with good boundary reflectivity. The major peaks in energy at around 700m is in good correlation with the proportion of sulfides within this zone and is also similar to other project results.

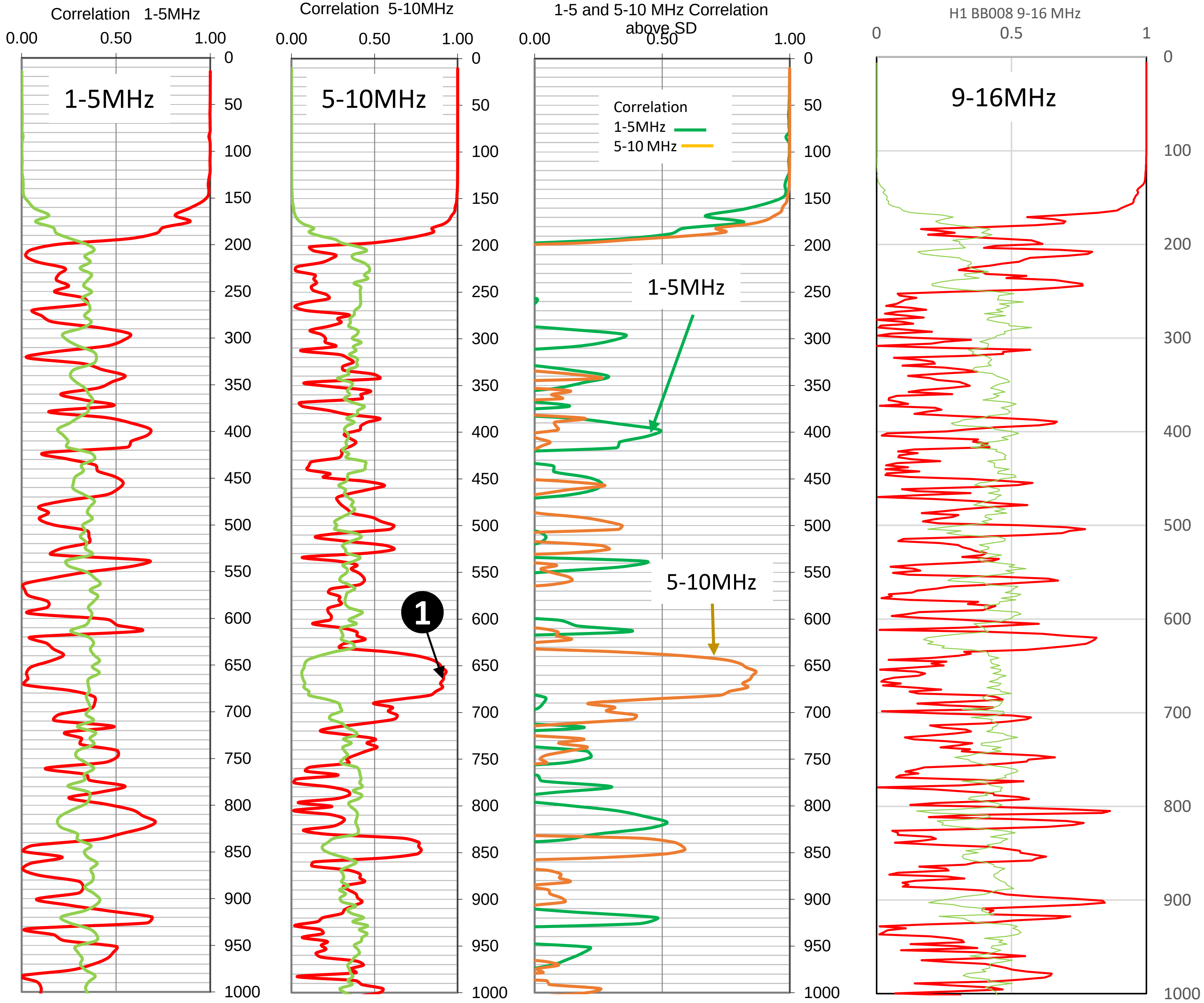
The results seen in the energy log are encouraging but they form only **one** in a number of lines of evidence for sulfides within a scan. Adrok have found that Energy, specifically the E% Log, when combined with Frequency and other energy results remains the best indicator for sulfides rather than the E% log alone.

Reasonable correlation between the energy return and the location of sulfides. The strength of the energy return* is in-part controlled/defined by the "sharpness" of the contact between the sulfides and the host rock and/or the density of the sulfides within a particular interval. Note: the energy chart here has been inverted to show the lower values on the right and higher values on the left. It should also be noted that, with increasing depth, there is the potential for depth errors of generally less than 5-10% based on results from other studies.

** The lower the value, the stronger the energy return.*

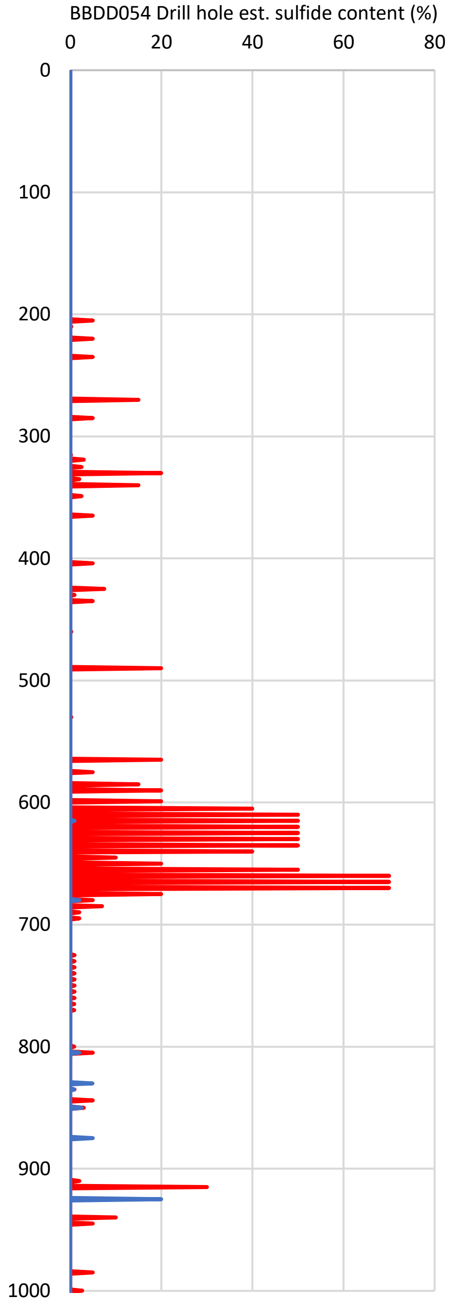
Strictly Confidential

FREQUENCY 1-5 & 5-10 CORRELATION - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054



1 The large anomalous peak in the frequency results (5-10 MHz) is triggered by a strong correlation between mineralisation and the response in the 7-8MHz frequency range as presented in more detail later in the report.

The response is missing in the 9-16MHz results as presented to the left along side the 1-5 (green) and 5-10 (orange)MHz Correlation results which simply exaggerates the frequency response relative to the standard deviation.



FREQUENCY CORRELATION VERSUS ROCKYTYPE - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054

FREQUENCY CHARTS & LITHOLOGY

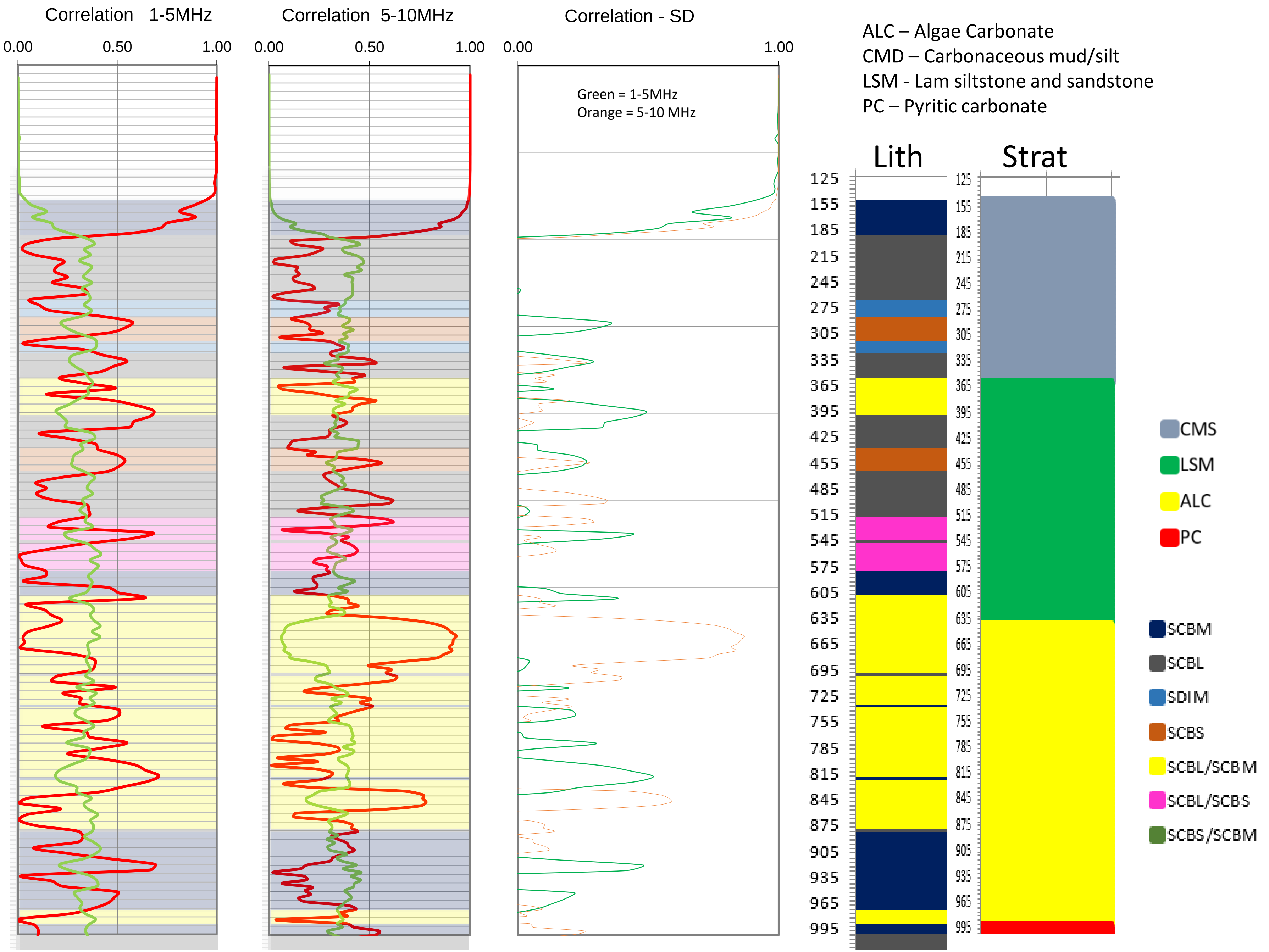
Presented here are the frequency correlation results superimposition of lithology (rock type).
Based on the results form other projects, the changes in frequency correlations, along with other key indicators in E- and F- responses, can be used to delineate rock type boundaries as the composition of the rock significantly influences its resonance frequency. In addition, the presence or absence of sulfides is also likely to significantly influence the frequency correlation results.

Changes in rock type (which also represent changes in the geophysical characteristics of that rock type) tend to appear as peaks in both 1-5 and 5-10MHz whereas internal variability is indicated by peaks in either 1-5 or 5-10MHz.

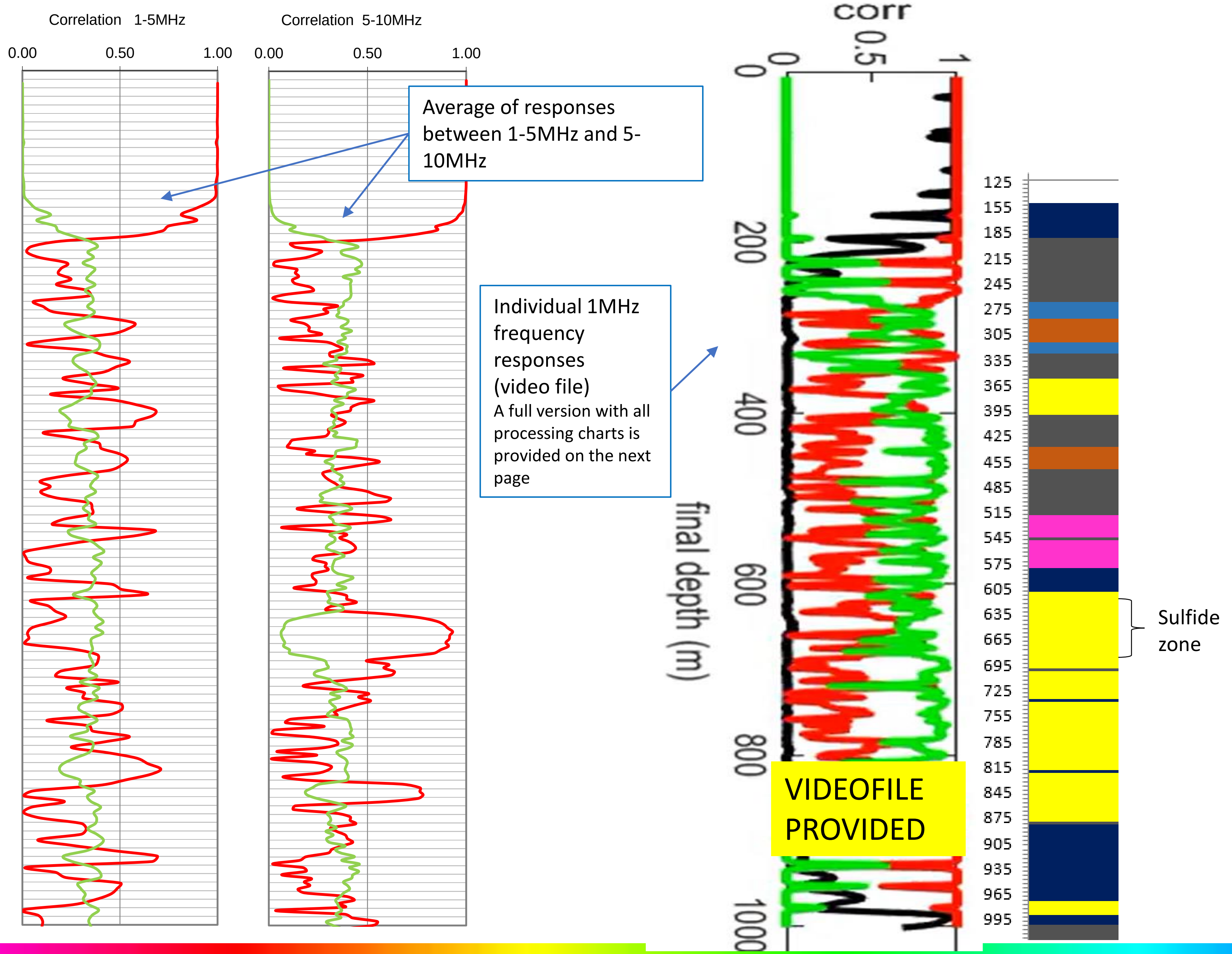
The major peak in 5-10MHz at ~650m depth signifies a significant change in the rock properties which, in this example, coincides with the presence of sulfides in drill core.

Similar responses in 5-10MHz are observed in copper porphyry systems whereby a correlation value of close to 1 in 5-10MHz is observed, albeit complicated by the presence of copper, lead and iron sulfide.

In order to better resolve the response specific to the sulfides, each 1MHz range can be processed individually and compared directly to specific rock units in order to understand the best frequency to delineate each unit and remove these from the background in order to generate a unique signal for the sulfides. Such a detailed study has not been completely resolved as part of this review but can be achieved and streamlined (i.e. developing an autonomous processing workflow).



FREQUENCY CORRELATION VERSUS ROCKYTYPE - SCAN H1 BB008 & PARALLEL DRILL HOLE BBDD054



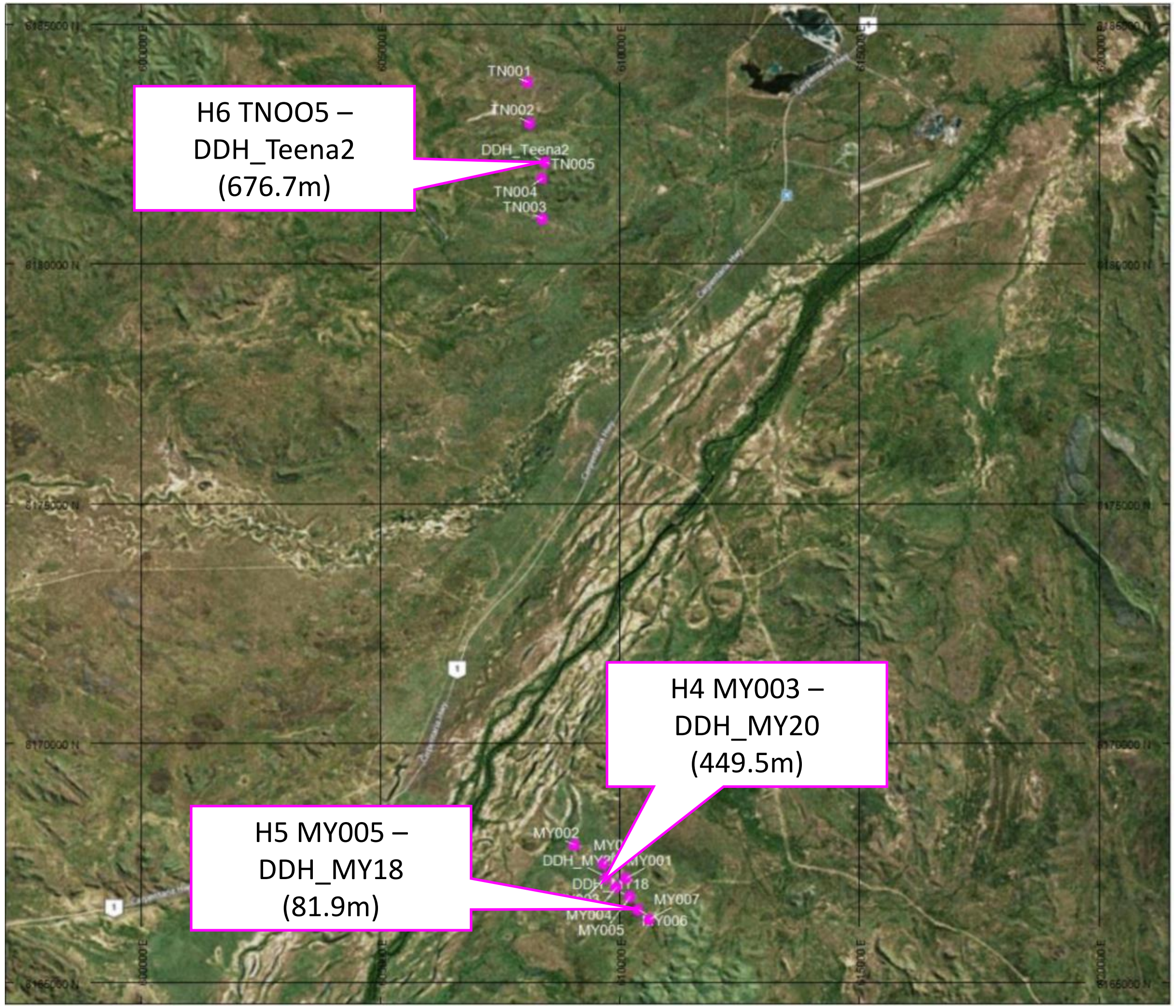
In order to better resolve whether a unique frequency response can be attributed to a certain rock type or the presence of sulfides, each scan was processed at 1MHz bands between 1-50MHz. In order to resolve the specific frequency response for the sulfides, each 1MHz band has been processed and compared directly with the drill log and the sulfides.

Provided here is a video file compilation of each 1MHz response correlation. Each frame represents 0-1MHz, 1-2MHz, 2-3MHz…..49-50MHz.

It can be seen from the individual bands that certain features (rocks, boundaries etc) appear as different responses. This is similar to traditional mineral spectroscopy whereby different minerals respond at different wavelengths.

As the number of case studies in sulfide-bearing rocks increases, we are starting to develop an understanding of the unique fingerprint of sulfides at different frequency ranges.

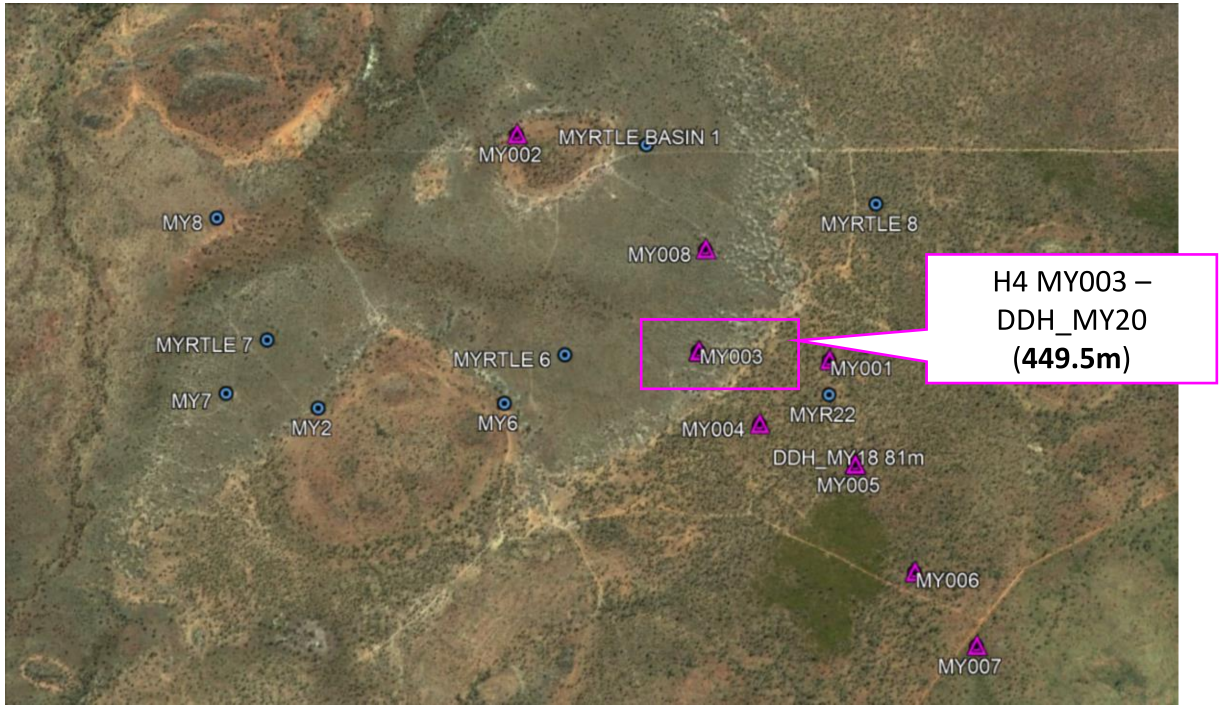
TEENA-MYRTLE, NT, AUSTRALIA



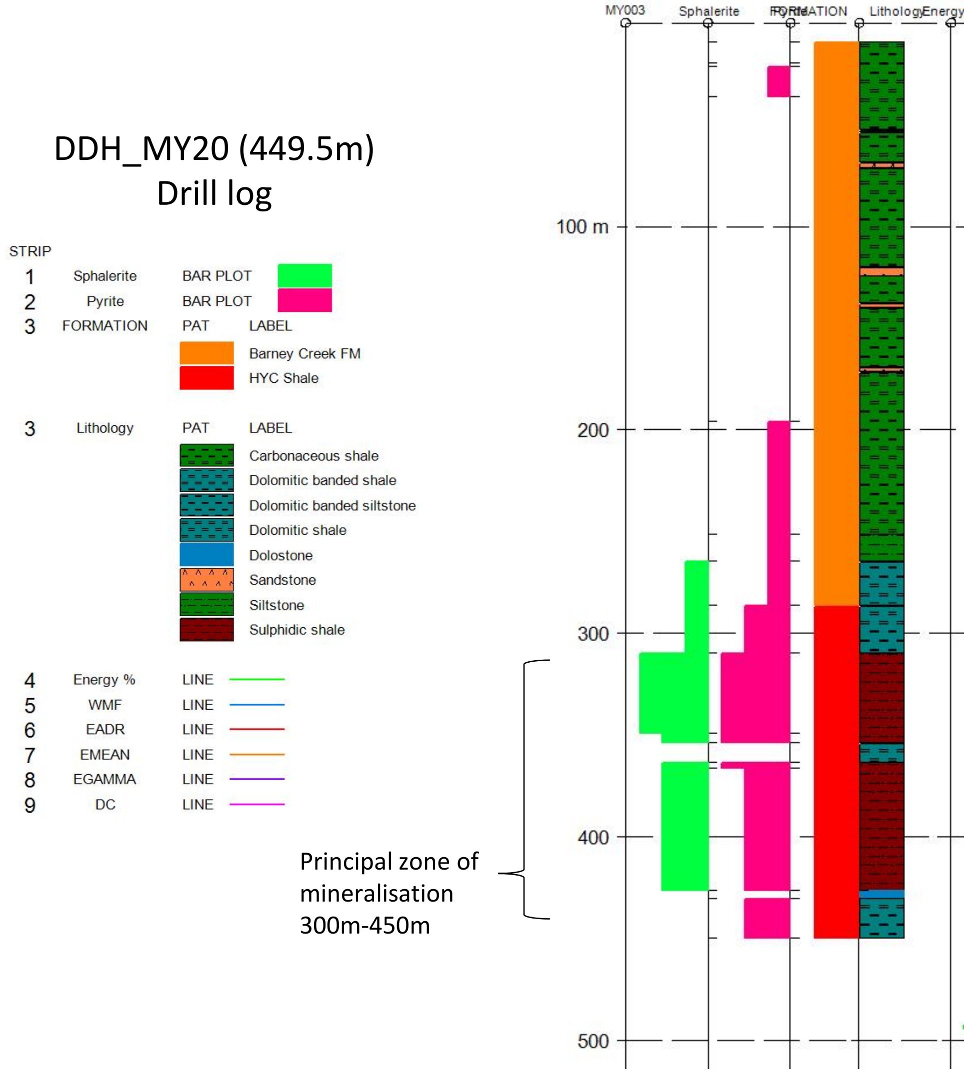
H4 MY003 MYRTLE NT

BACKGROUND

The Teena-Myrtle prospect was reprocessed and analysed according to the same criteria as set out for the Bluebush prospect outlined above. Two main drill holes were provided for training purposes, however, the aim for the prospect was to carry through the selection criteria defined for BB008 and determine whether these criteria could be use at an unrelated prospect thereby testing the capacity for targeting sulfides without prior training scans. The drill holes were, however, useful to check the results and to later determine if any modifications were required to the selection criteria.



DDH_MY20 (449.5m)
Drill log



Multi-evidential domain selection

The sulfide selection criteria based on the correlations observed at BB008 have been used here as a guide for selecting the sulfide zone. The list of positive criteria for the mineralised zone are provided to the right. It should be noted that the low Energy % Log values that usually associated with strong energy return of a reflective surface is not present within this zone which may be attributed to the very disseminated and transitional nature of the boundary between sulfide-rich zones and the country rock. The reader is reminded of the reference to radar reflection presented earlier in the report.

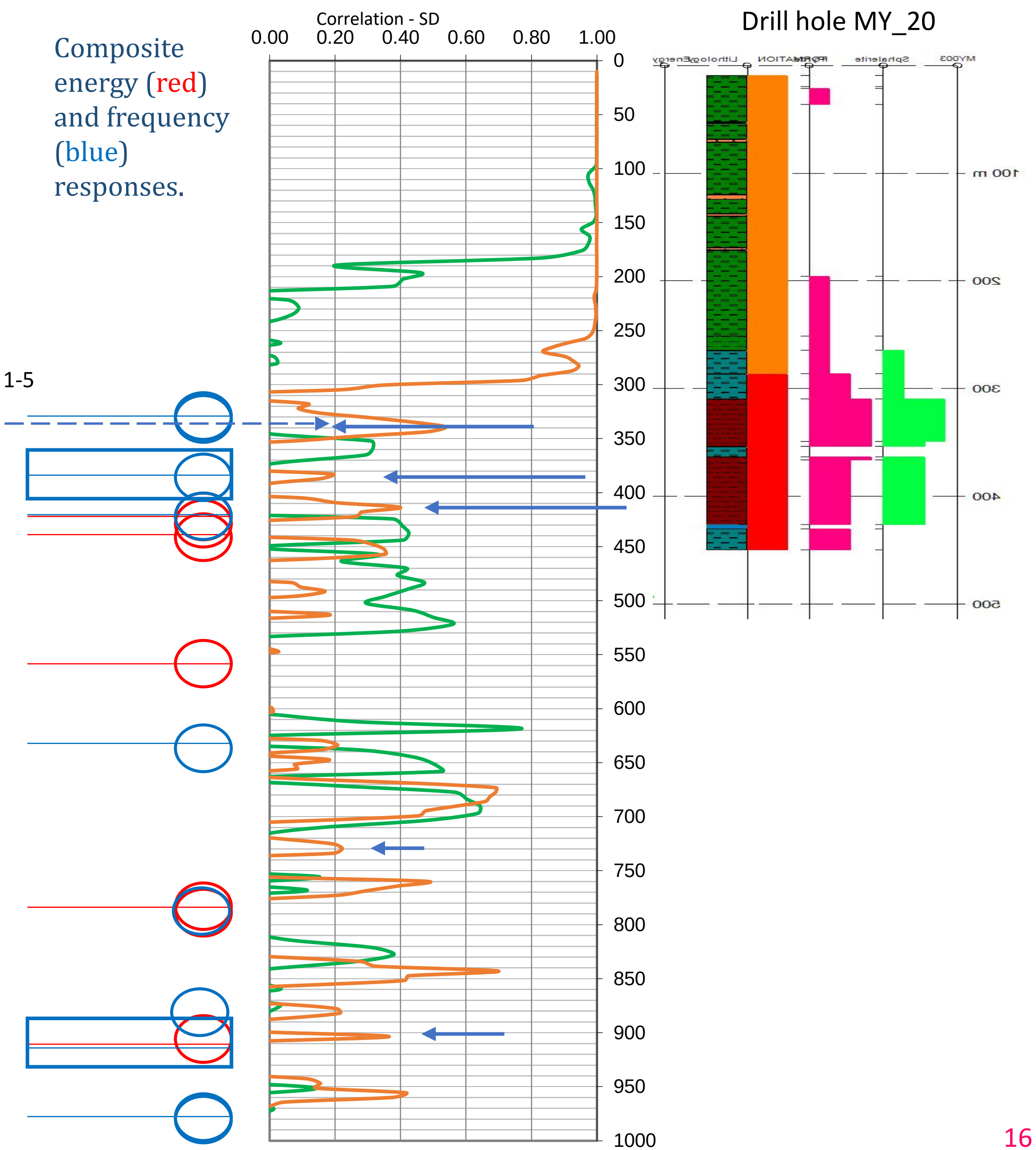
The zone of mineralisation is not targeted directly by a single line of evidence, rather, the combination of results s used to delineate the zone of highest probability of sulfides. The process used here follows the basic principle of "weights of evidence". Regions (points down the scan) where the highest number of correlative points align or are closely associated is selected as a zone of principal mineralisation.

The selection criteria assume that there are sulfides in the core. For this case example, the technique can be used for tracking sulfide-bearing zones from an area with known sulfides.

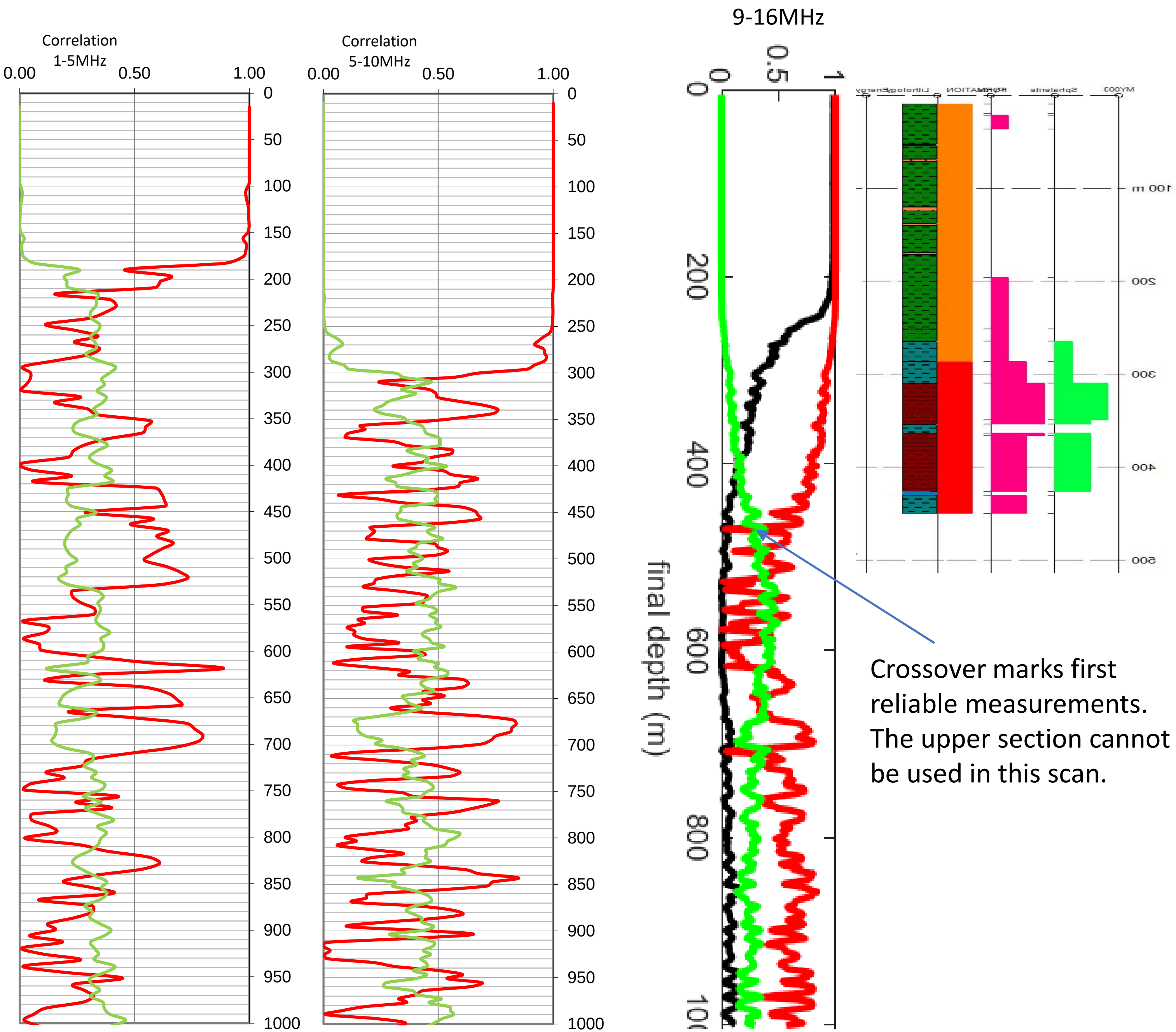
Zone of 5-10MHz correlation without 1-5 MHz correlation.

Zone of greatest number of positive responses to the selected criteria using BB008 as a guide to criteria selection

Composite energy (red) and frequency (blue) responses.



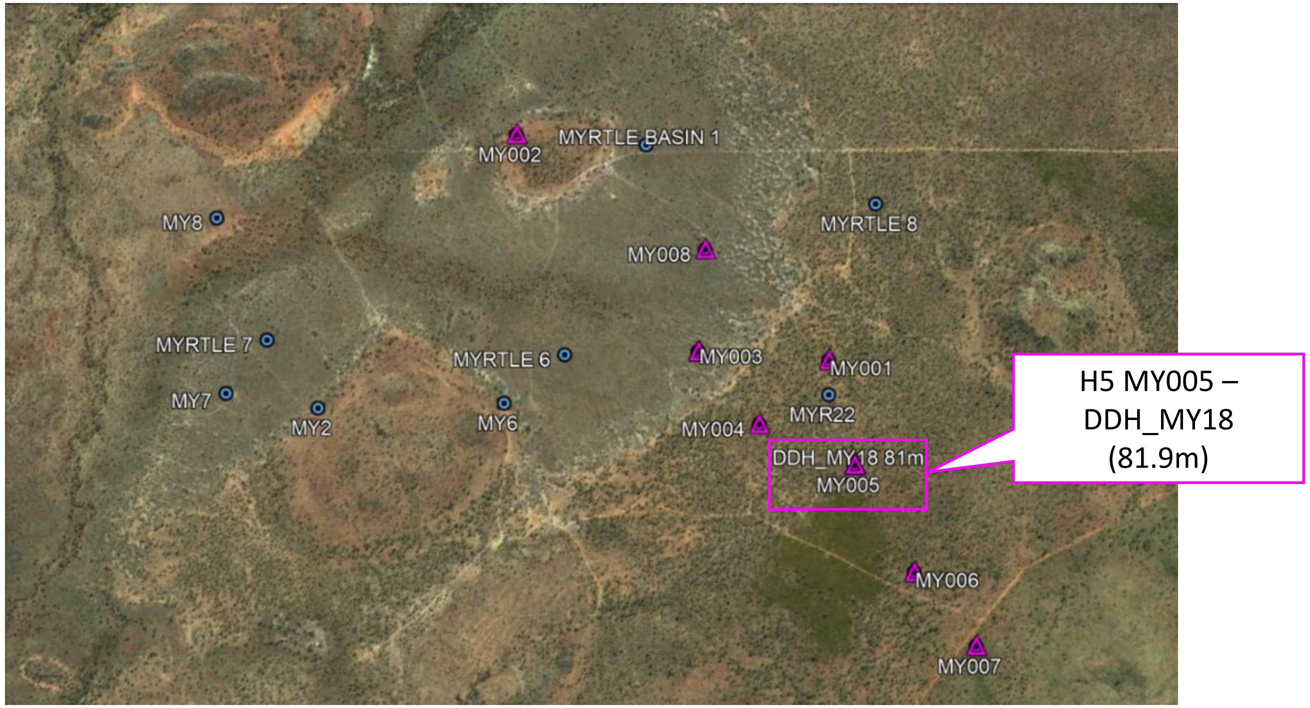
INTERPRETATION - SCAN H4 MY003



1-5MHz, 5-10MHz and 9-16MHz frequency processing

Examining the frequency correlation results, it is apparent that the sulfides in MY003 were not detected in the 1-5, 5-10 or 9-16MHz correlation. Based on the relatively shallow depth of the sulfides, Adrok will process this scan using the 1MHz bands up to higher frequencies (1-50MHz) as presented for BB008. It is anticipate that the response will be detected at frequencies over 16MHz.

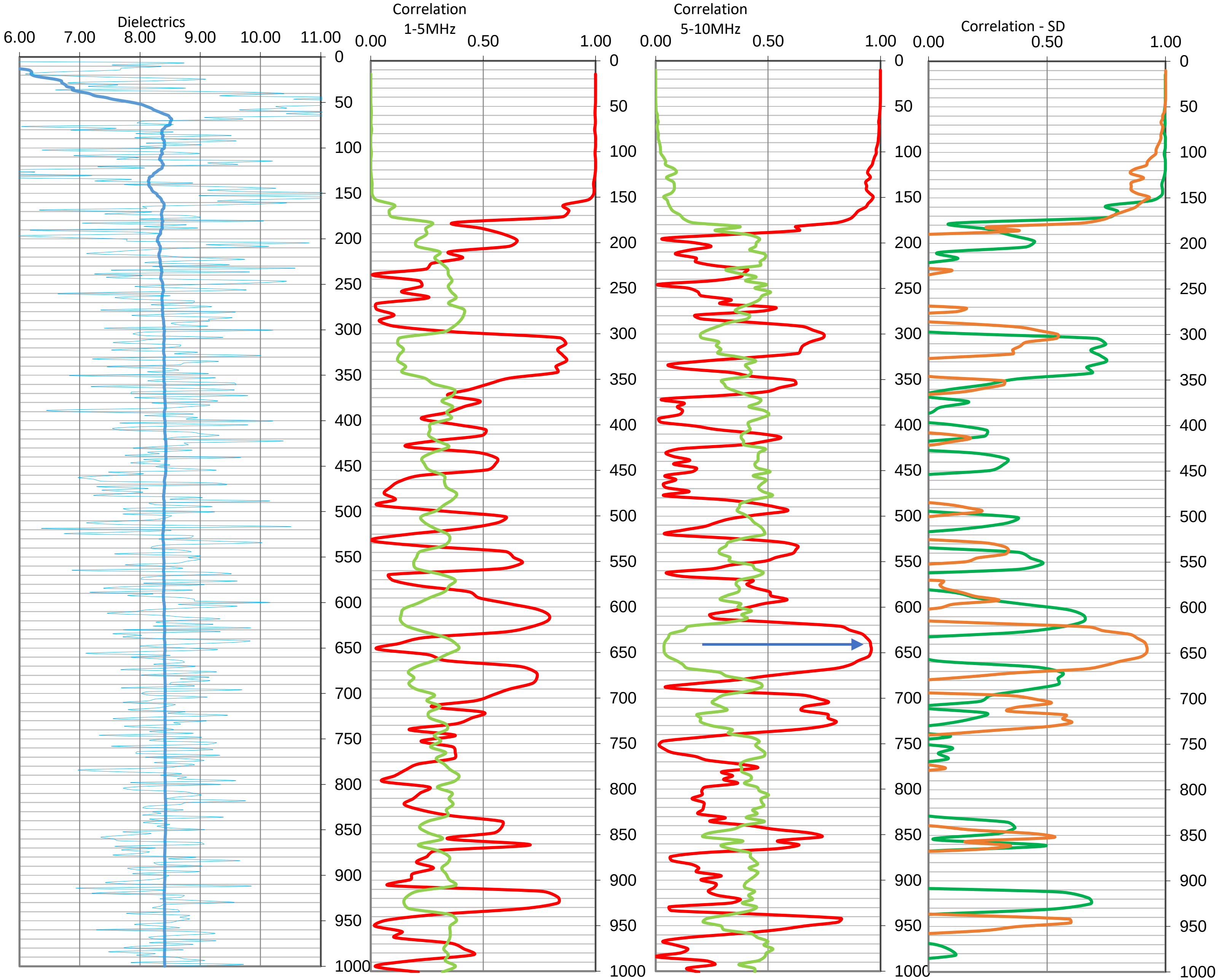
H5 MY005 MYRTLE NT



SCAN H5 MY005 – PARALLEL DRILL HOLE DDH_MY18

ADR results were collected to a depth of 100m but the parallel drill hole (DDH_MY18) extends to a maximum depth of almost 82m and therefore couldn’t be used to correlate any sulfide targets. Nevertheless, the results presented here utilise the same selection criteria as discussed above.

RESULTS - SCAN H5 MY005



Correlation criteria

F-Charts

Low F-Gamma

High F-ADR

High F-SD

Step change in F-Mean

(high F-Mean)

E-Charts

High E-Mean

Low E-Log

High E-SD

E-ADR (high &/or Low)

Transition ←→ E-Gamma

F-Corr charts

Peak in 5-10 MHz + no peak in 1-5MHz (intensity of peak corresponding to % sulfides

DC (Dielectrics)

Change from high variability from SD to low variability.

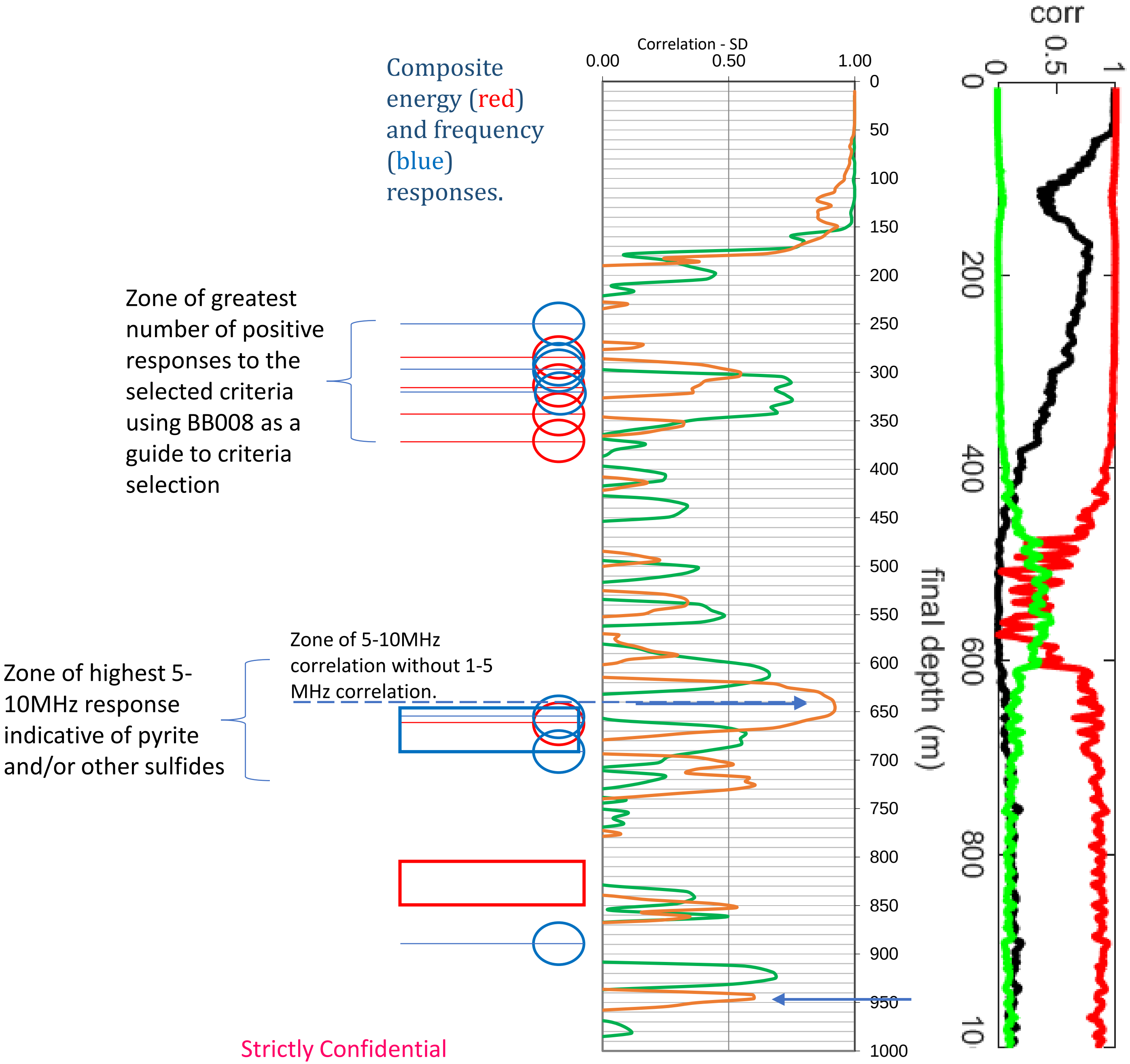
Multi-evidential domain selection

The sulfide selection criteria based on the correlations observed at BB008 have been used here as a guide for selecting the sulfide zone. The lack of sulfides in drill core for this scan means that this is a blind scan whereby sulfides can be targeted using the same evidential criteria as presented for previous scans.

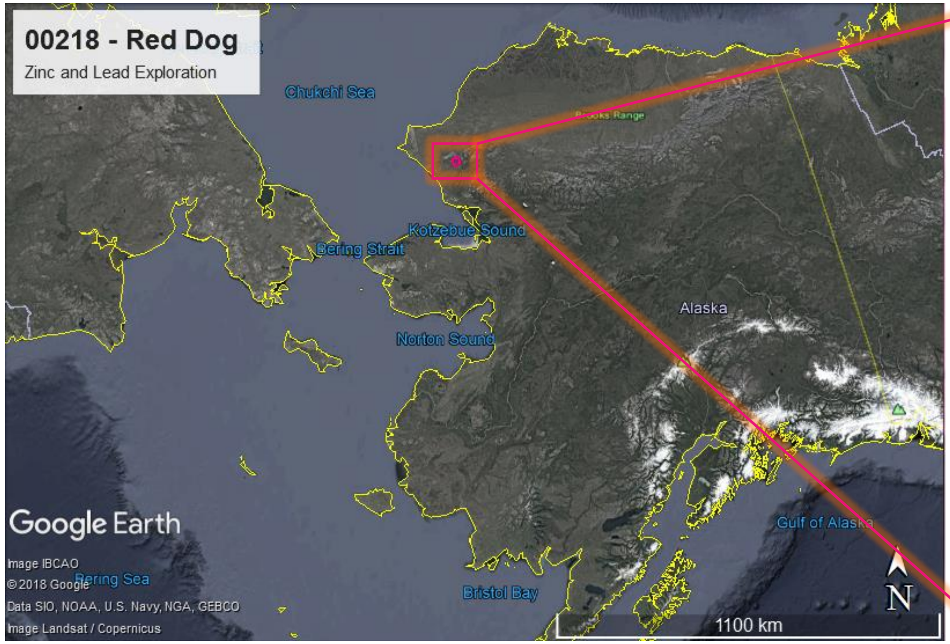
The zone containing the majority of correlations lies between 250m and 350m. There is no corresponding response in the 5-10MHz correlation which, according to other scans, is a principal piece of evidence.

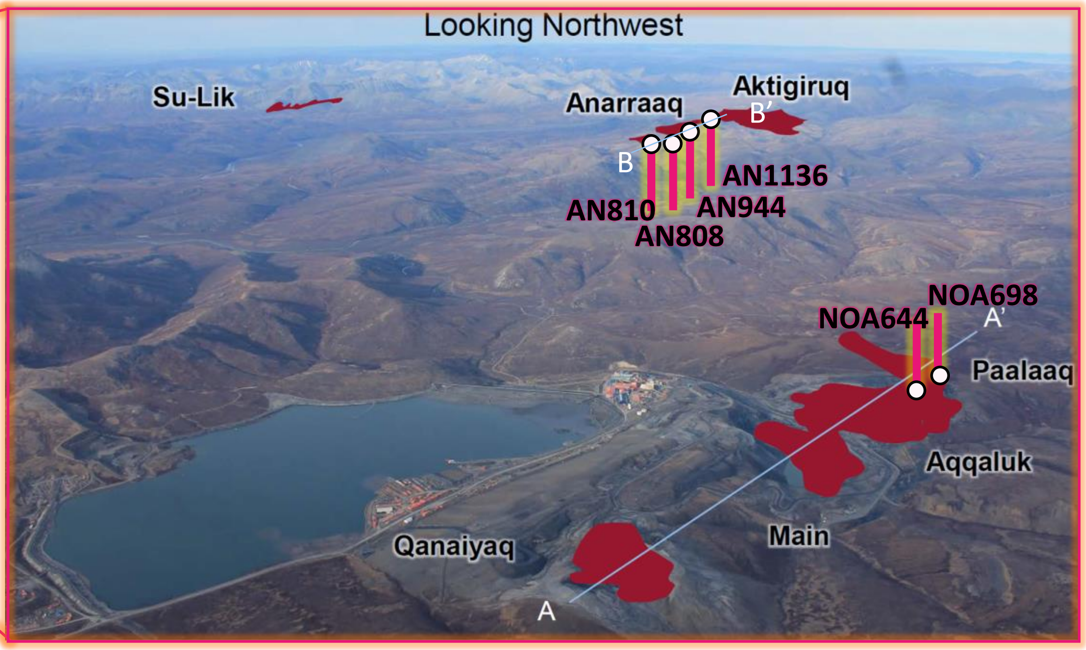
A second zone where there is some correlation lies at 650m depth where there is a peak in the 5-10 correlation. This is one scenario where geophysics in general relies on numerous case studies to determine how to priorities the different features.

Scan MY005 is located in an area of the Northern Territory (McArthur River) where many dill holes have been completed. In order to refine the technique access to additional drill holes is critical and will help transition to a quantifiable sulfide targeting technique.



Red Dog Location

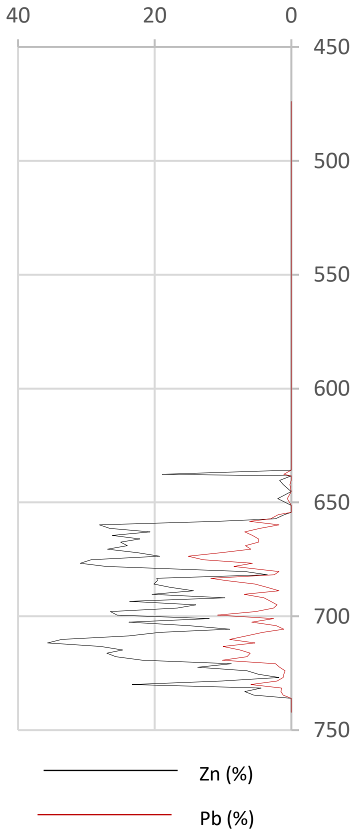




Scans Completed - in the order that they are presented

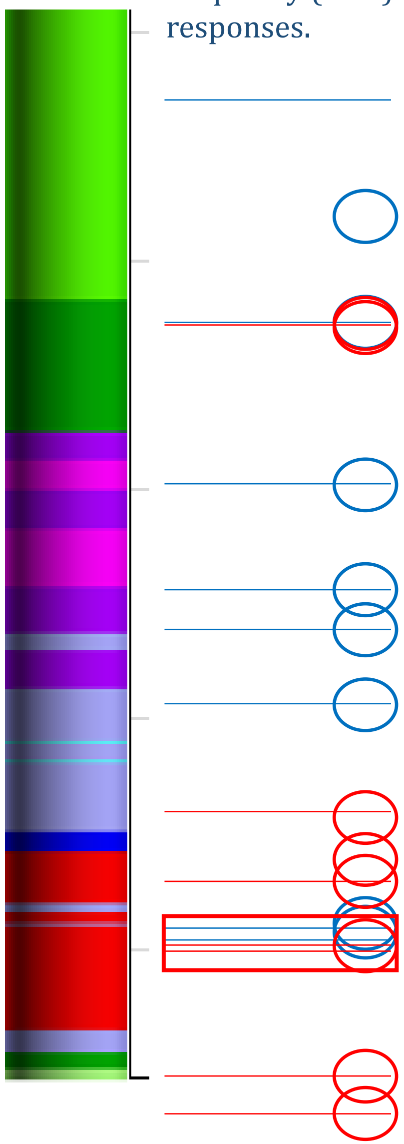
H1 AN810
H3 AN944
H2 AN808
H5 AN1136
H4 NOA644

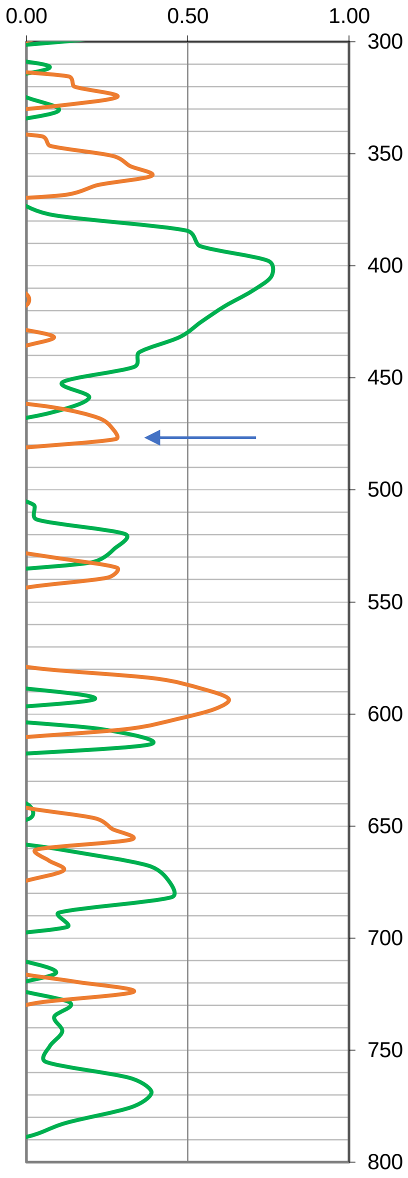
Grade down hole
Red
(AN810)

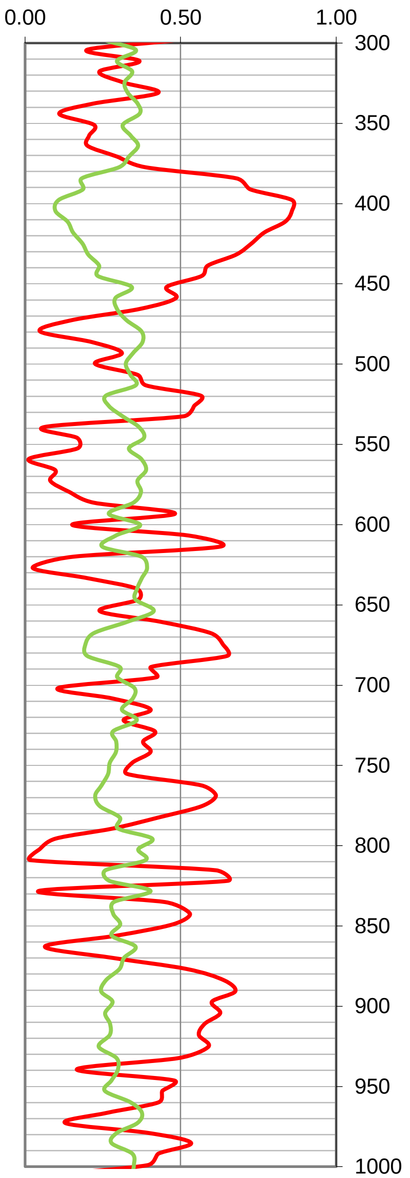


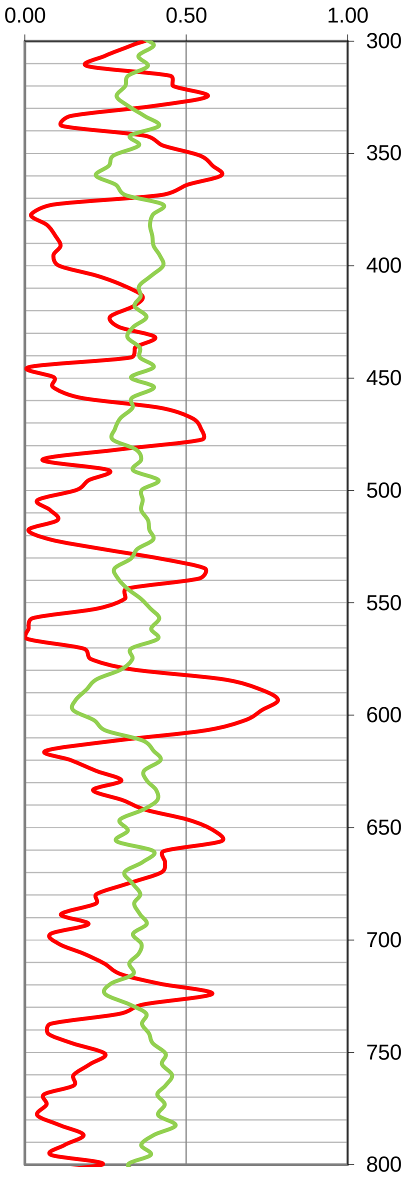
Drill log
Lithology
(AN810)

Composite energy (red) and frequency (blue) responses.





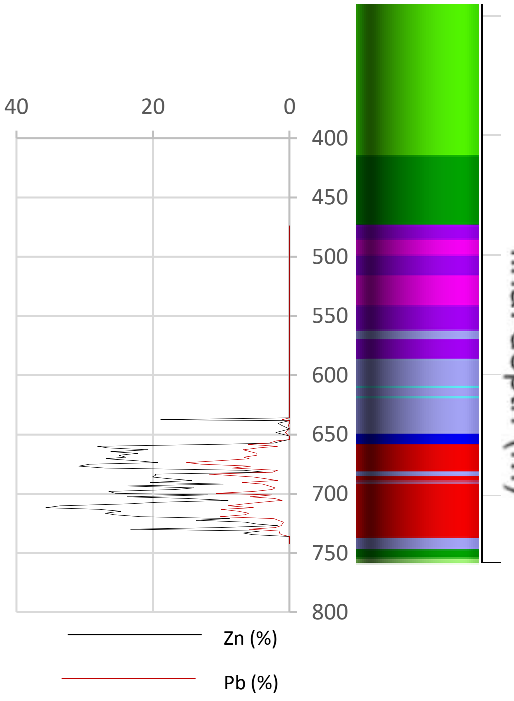


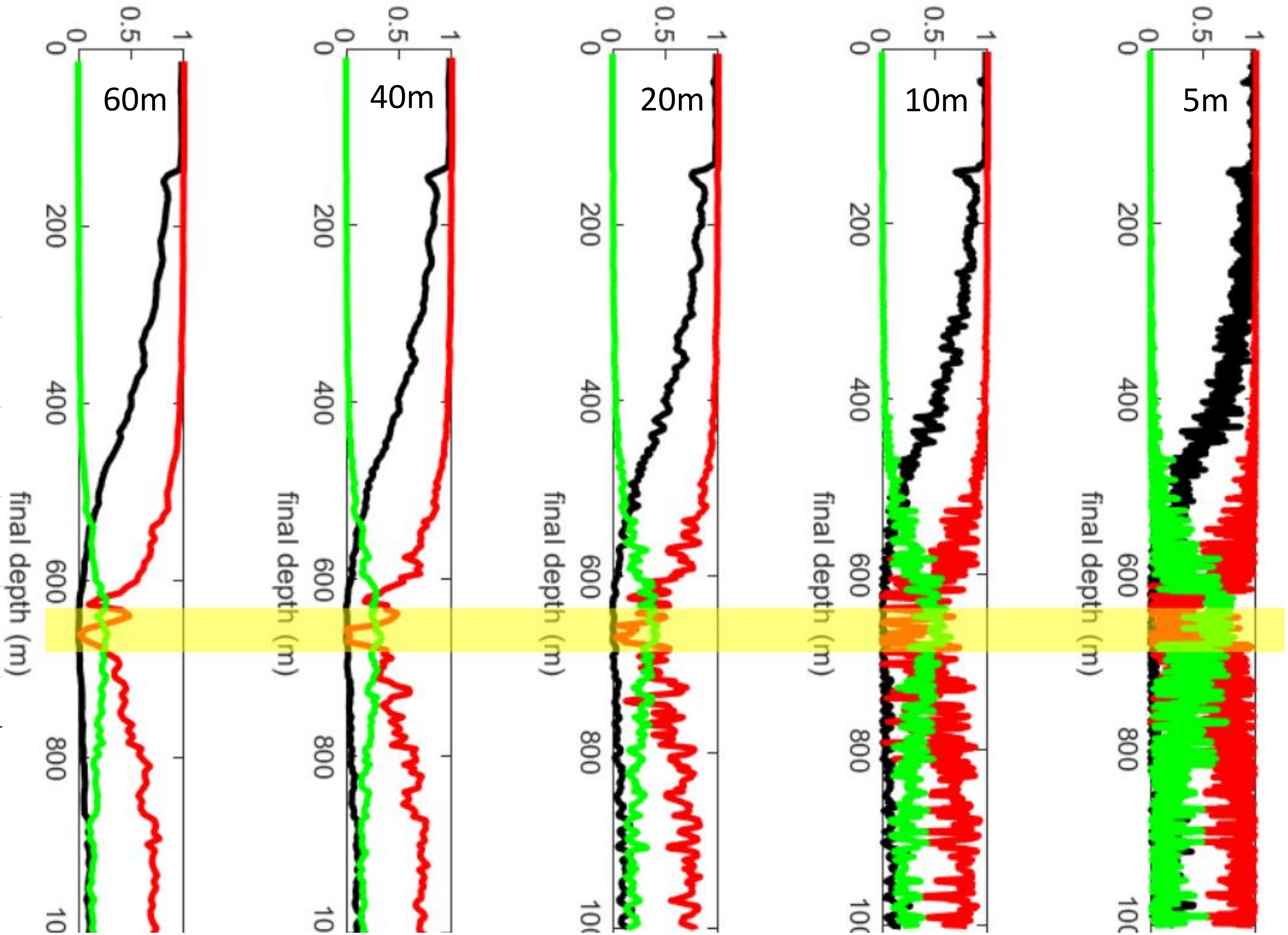


9-16MHz PROCESSING

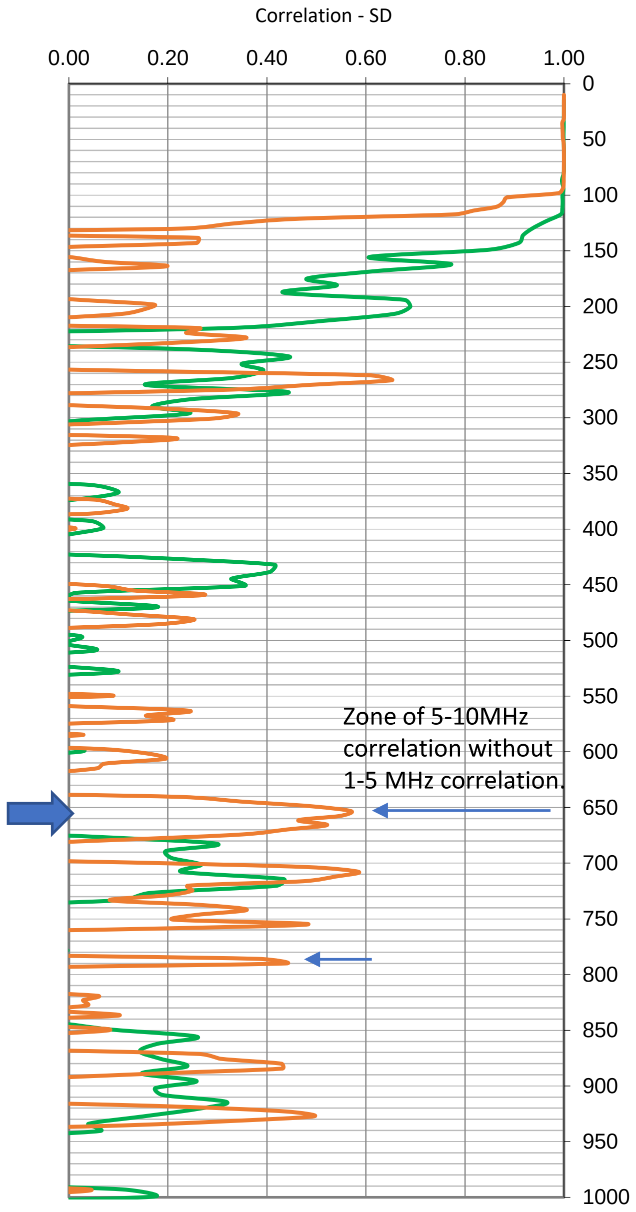
The following charts present the 9-16MHz frequency correlation results at different processing intervals. The greatest level of resolution, but also variability, exists in the 5m processing interval.

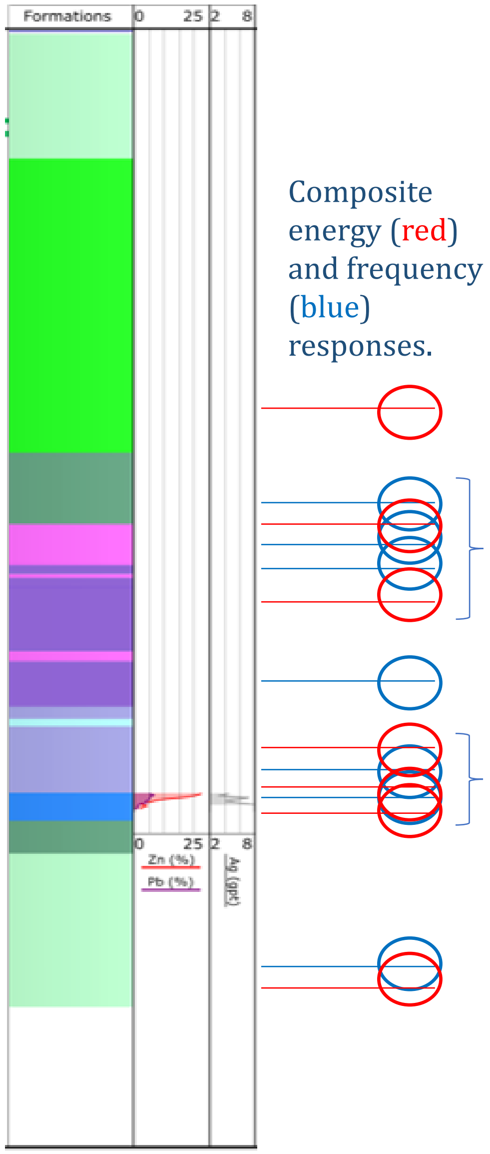
Drill core lithology and grade are shown at the same depth interval. The frequency results show a dip in the correlation (red) at approximately the same depth as the sulfide occurrence.





RESULTS – RED DOG - SCAN H3 AN944





Composite energy (red) and frequency (blue) responses.

Two potential zones of mineralisation based on a cluster of points around 450m depth and 675m depth. Deciding between the two relies on the 5-10MHz anomaly. If the 5-10 shows up a strong correlation, the WofE can be forced towards the corresponding cluster of points.

Correlation criteria

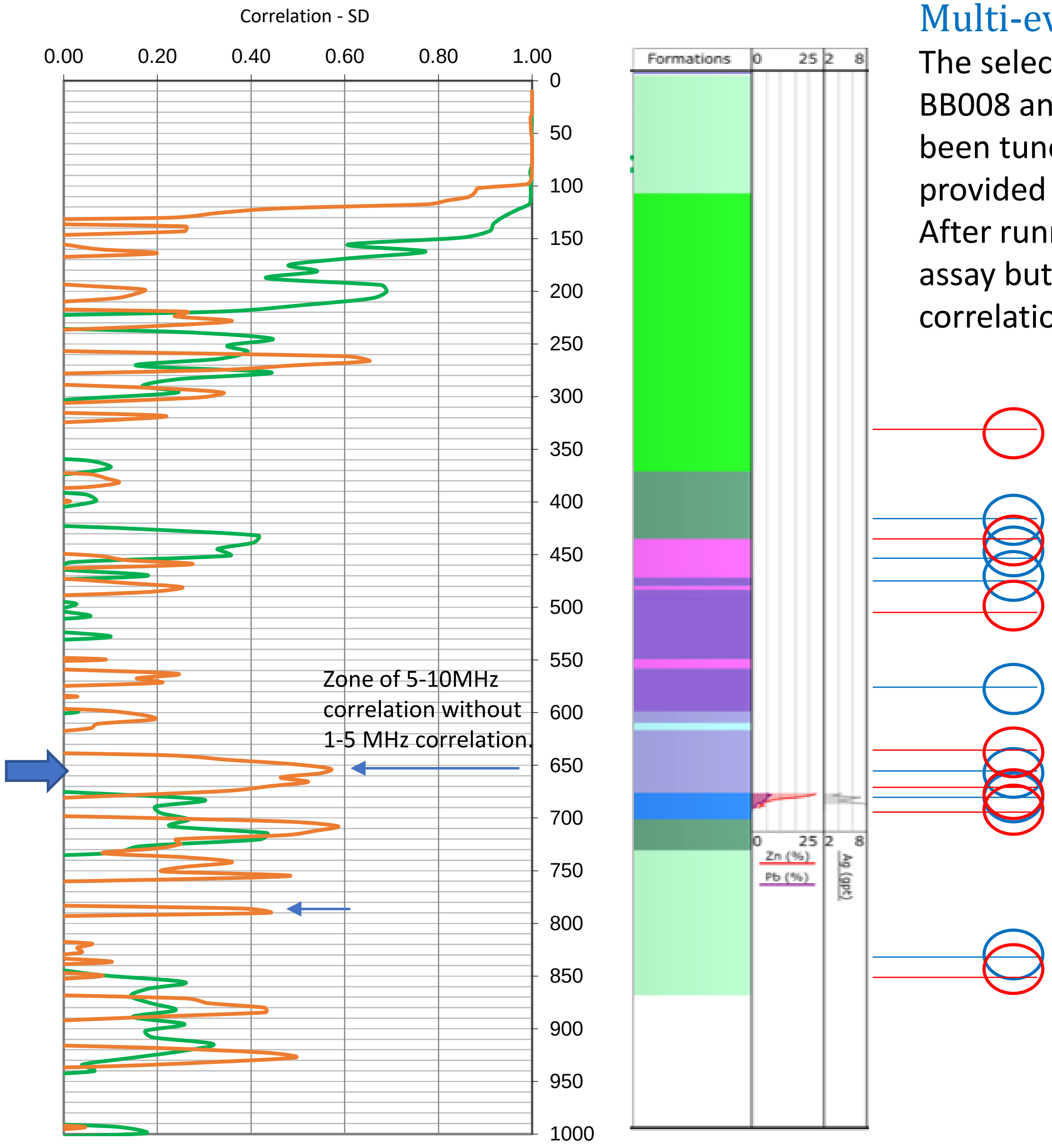
F-Charts
Low F-Gamma
High F-ADR
High F-SD
Step change in F-Mean
(high F-Mean)

E-Charts
High E-Mean
Low E-Log
High E-SD
E-ADR (high &/or Low)
Transition ←→ E-Gamma

F-Corr charts
Peak in 5-10 MHz + no peak in 1-5MHz (intensity of peak corresponding to % sulfides

DC (Dielectrics)
Change from high variability from SD to low variability.

INTERPRETATION – RED DOG - SCAN H3 AN944



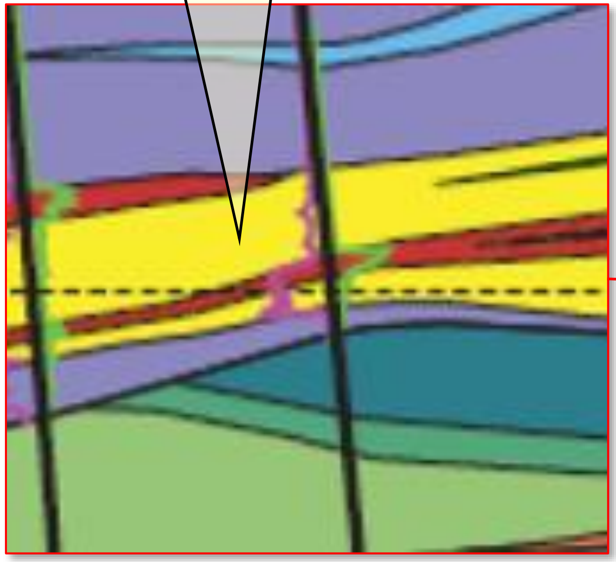
Multi-evidential correlation

The selected criteria for sulfide detection based on BB008 and modified across the different scans has been tuned for Pyrite as this is the principal sulfide provided in drill cores.

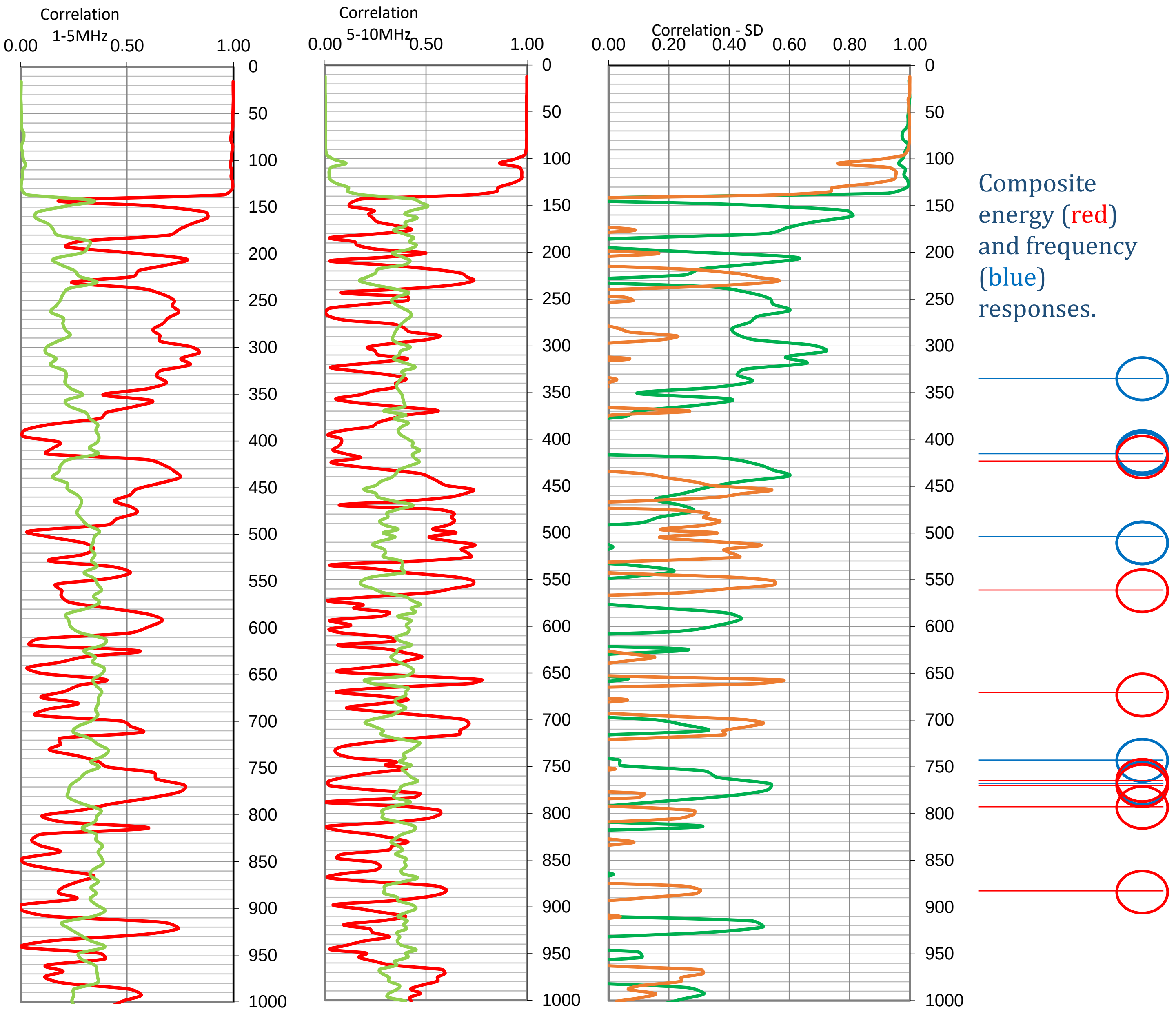
After running the correlation and comparing with assay but also drill interpretation, it appears that the correlation has correctly identified the Pyrite zone!

Ikalukrok Fe-Sulfide zone

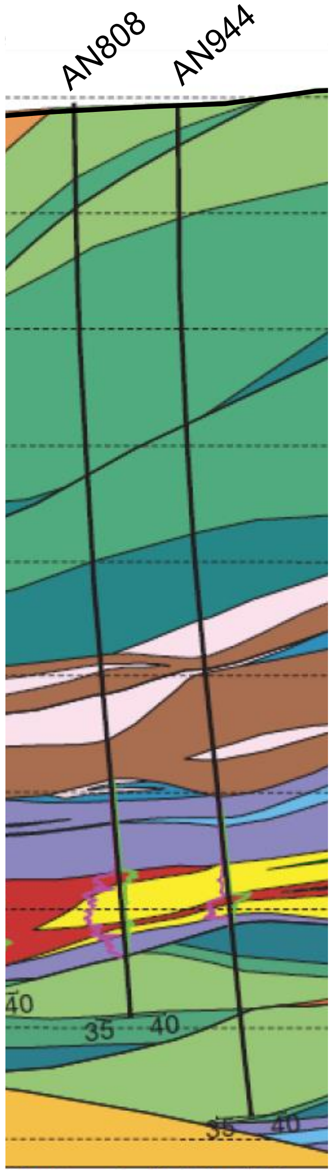
Pyrite



INTERPRETATION – RED DOG - SCAN H2 AN808



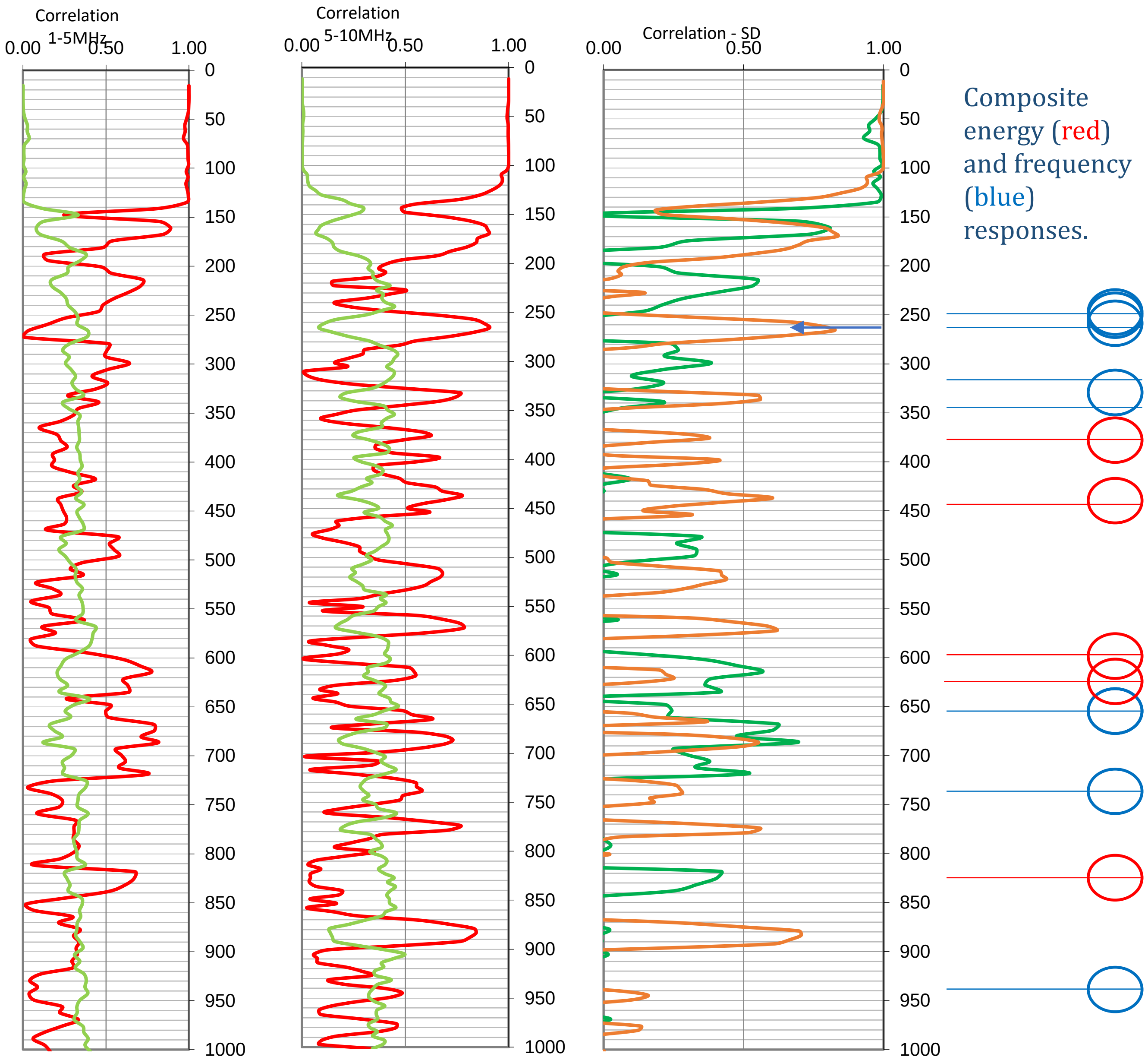
Composite energy (red) and frequency (blue) responses.

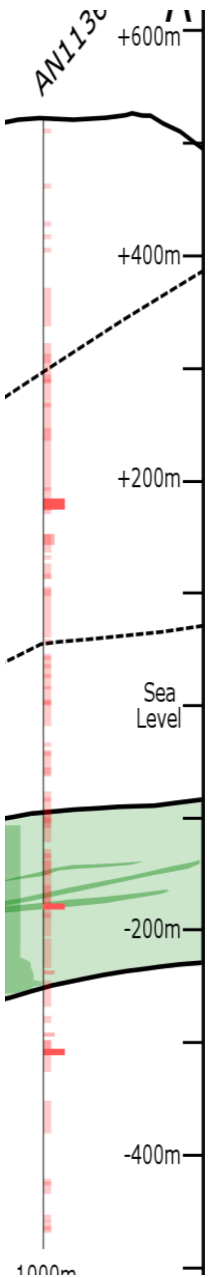


Multi-evidential correlation

The results obtained for H2 AN808 indicate the highest potential at 750-800m below the scan collar. If compared with the interpreted cross section provided for earlier report (Prj 00218), it is evident that the main pyrite zone and associated sulfides are at 675-750m depth. Accordingly the results place mineralisation at approximately 50m deeper than found in drill core. It is also plausible that the location of the drill collar an interpreted cross section are not in precisely the same location and, due to the dip of the mineralised units, the ADR targeting might be correct. Nevertheless, the targeting results also appear to be successful in this instance.

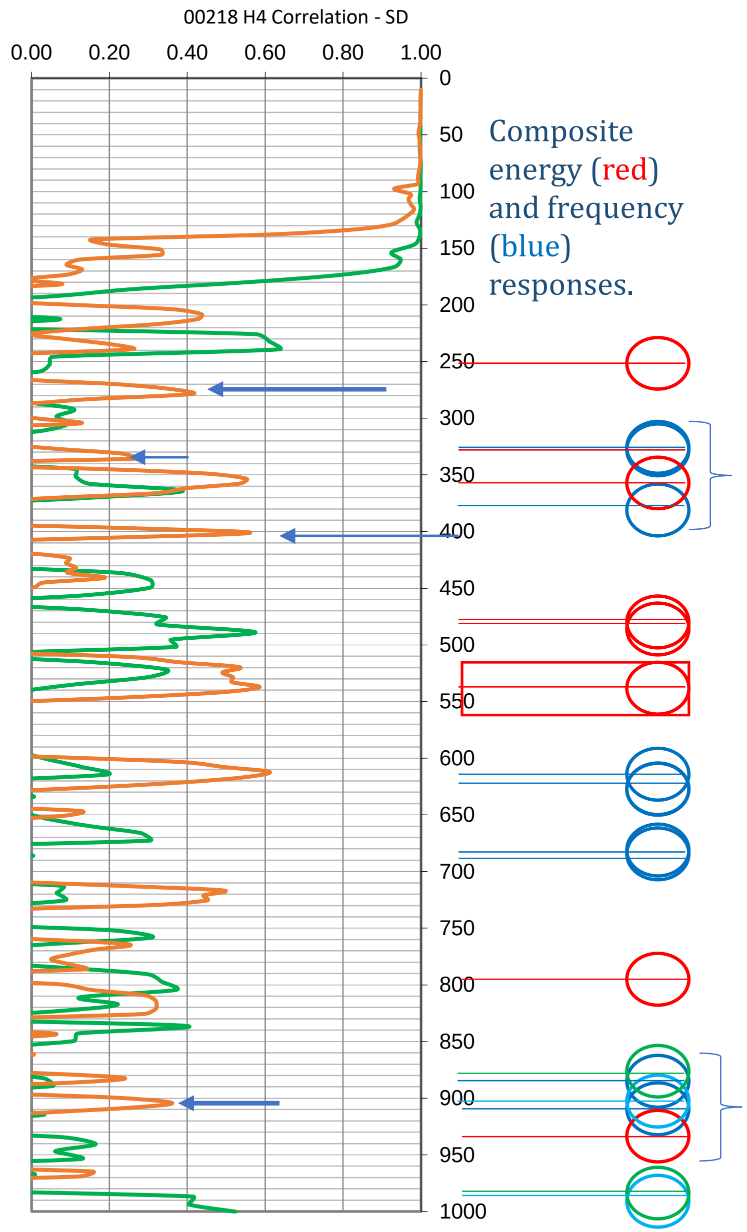
INTERPRETATION – RED DOG - SCAN H5 AN1136 RED DOG

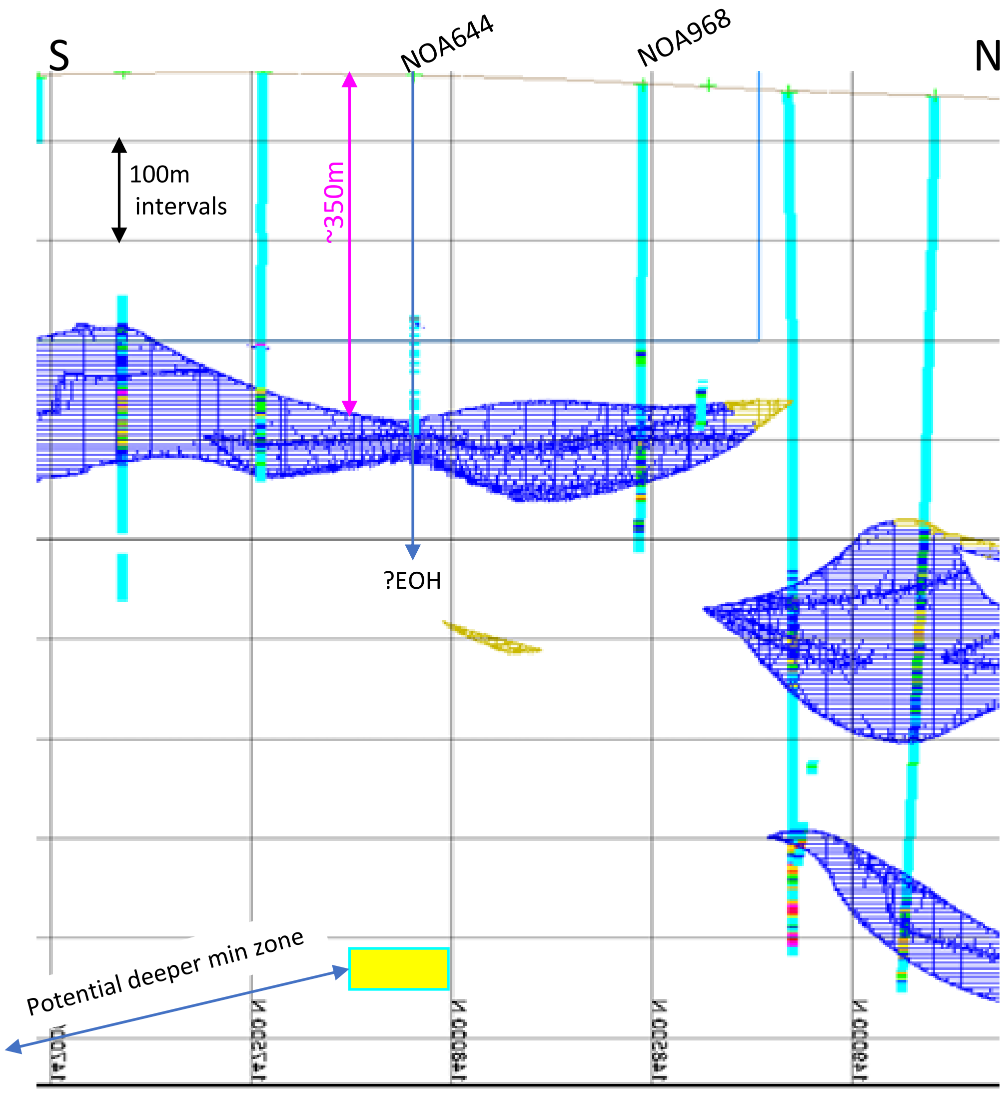




Multi-evidential correlation

The results obtained for H5 showed low overall correlation for sulfides according to the selection criteria. The only zone showing multiple positive criteria lies at around 250m depth down scan which does not correlate to any known sulfides in the available cross section interpretation. Inferred sulfides exist at approximately 600-750m down scan. No drill hole details, or any confirmation of sulfides was provided for this scan, therefore the results can only be checked at a later date against a known, parallel drill hole. At this stage, this was the only scan on which the selection criteria were trialled that did not present a sound result.





Multi-evidential correlation

Excellent targeting correlation between the criteria defined for BB008 sulfides and the interpreted depth to sulfides in NOA644. A comparison is made here based on cross section interpretations of drill hole data. The depth to min zone in NA644 is approximately 650m and the depth to the shallow criteria-defined zone is also 350m. No significant peak in 9-16, however, suggests that the min zone is likely to be low concentration of sulfides.

An interesting solution provided by the ADR data is the occurrence of a high number of criteria at approximately 900m depth down scan. Unfortunately, there is no cross section or drill hole information to confirm this target. The high number of positive criteria, however, provide a good level of confidence of sulfides at approximately 900m depth.

CONCLUSIONS – RED DOG COMPARISON SITE

Five scans from the Red Dog mine and surrounding prospects were analysed using the criteria defined for sulfide definition at the Bluebush prospect, Queensland, Australia H1-AN810, H3-AN944, H2-AN808, H5-AN1136 and H4-NOA644. All scans were analysed using the basic Frequency- Energy and 1-5MHz & 5-10MHz processed data which has been submitted previously as part of project 00218. In addition, 9-16MHz frequency correlation was processed for H1-AN810 and 1MHz bands for the range 1-50MHz was also processed in order to delineate any further unique frequency responses corresponding with the sulfide zone.

The selection criteria developed for sulfides in BB008 successfully identified the min zone in NA810 at around 700m

9-16MHz processing also delineated a low correlation at the sulfide zone which is similar to observation from other scans containing relative abundance of sulfides.

No prominent anomaly was observed within the 5-10MHz range for H1 AN810 as we have seen of pyrite-rich or pyrite-bearing sulfide zones (*potential pyrite discrimination from other sulfides).

The selection criteria for Scan H3 AN944 also successfully identified two min zones based on high correlation criteria. The more significant of the two was also associated with a prominent anomaly in the 5-10MHz. After closer examination of cross section details, it was found that H3 intersected a zone of mineralisation containing abundant pyrite.

The selection criteria successfully targeted mineralisation in H2 AN808, however the target zone was 50m below the interpreted depth of sulfides on the cross-section diagram. It is plausible that the interpretation, combined with lateral distance between the scan and the cross-section could account for the slight variation in depth.

No prominent min zone was delineated for H5 AN1136. Further quantitative analysis will be undertaken on this scan in particular to determine whether small variations and no prominent anomalies in the data reflect low grades of sulfides. Further work is being carried out on this scan.

Scan H4 NOA644 was found to have two possible min zones delineated using the same criteria as above. The upper min zone corresponds with the location of sulfides marked on the cross section image, however, the lower, more prominent min zone represents a target well below the limit of drilling and the cross section at approximately 850-900m beneath the collar of NOA644. Owing to the high correlation in E and F results, Adrok encourages the owner to complete a single vertical drill hole at the collar location of H4.

Our Value Proposition becomes part of the solution

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CONVENIENT

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Harms the environment in no way

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