THE APPLICATION OF STEP RESPONSE EM DATA TO PRECIOUS METALS EXPLORATION

In this presentation, it will be shown how the inductive source resistivity (ISR) method can be used in gold exploration, with particular emphasis on cost-effective mapping of geophysical anomalies under conductive pediment and thick overthrusts in Nevada.

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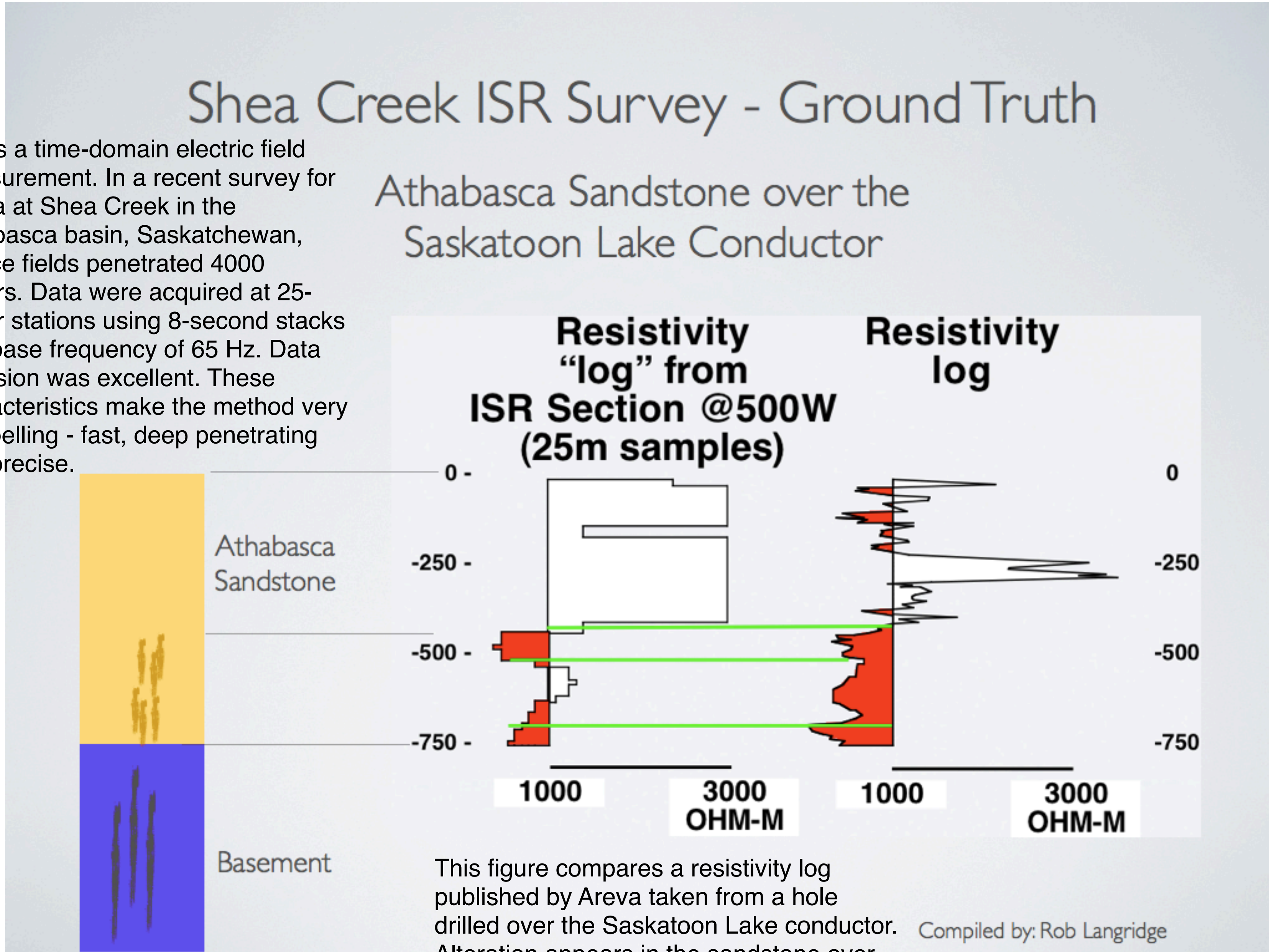
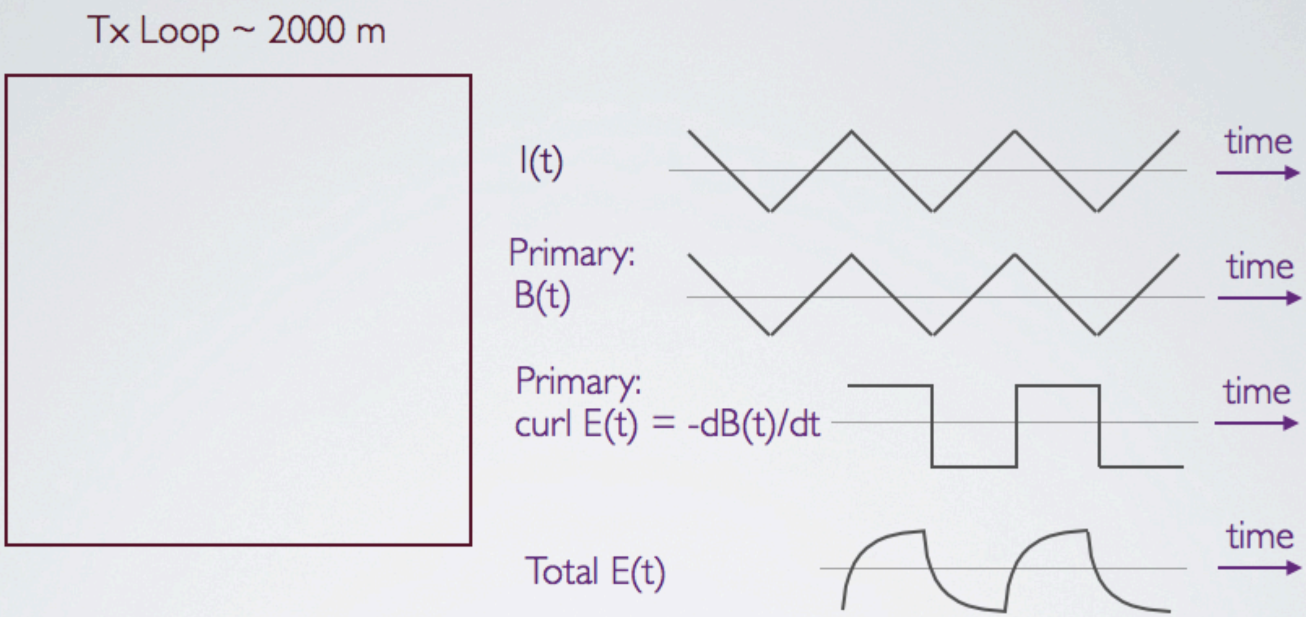
KEGS 2010 Precious Metals Symposium

ISR is a time-domain electric field measurement. In a recent survey for Areva at Shea Creek in the Athabasca basin, Saskatchewan, source fields penetrated 4000 meters. Data were acquired at 25-meter stations using 8-second stacks at a base frequency of 65 Hz. Data precision was excellent. These characteristics make the method very compelling - fast, deep penetrating and precise.



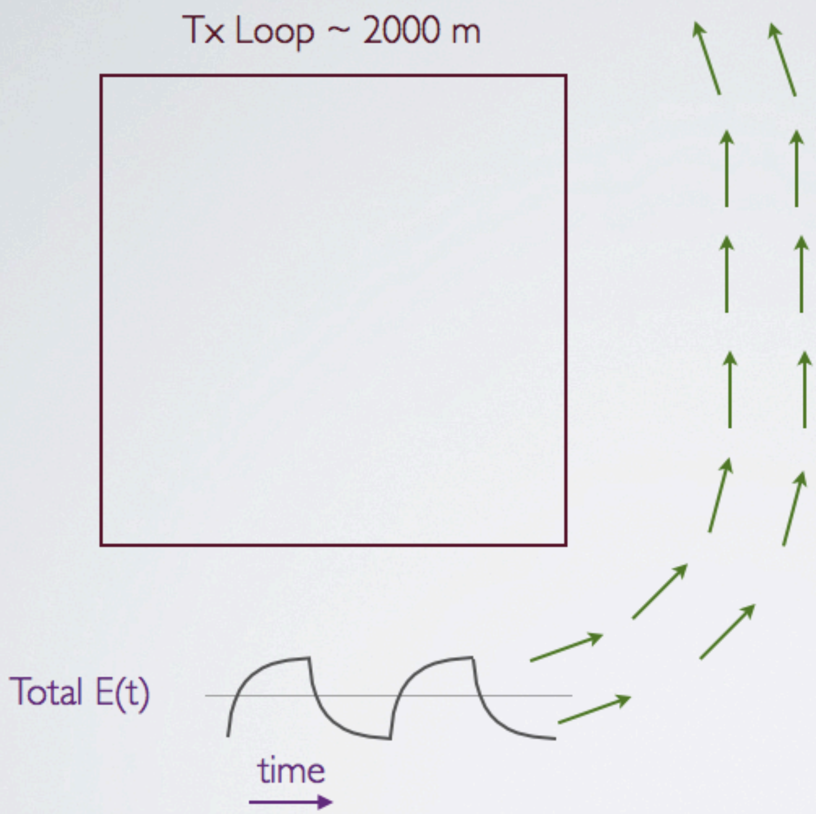
This figure compares a resistivity log published by Areva taken from a hole drilled over the Saskatoon Lake conductor. Alteration appears in the sandstone over the conductor. Both ISR and the log indicate alteration from 400-750 meters

The ISR Method - Overview



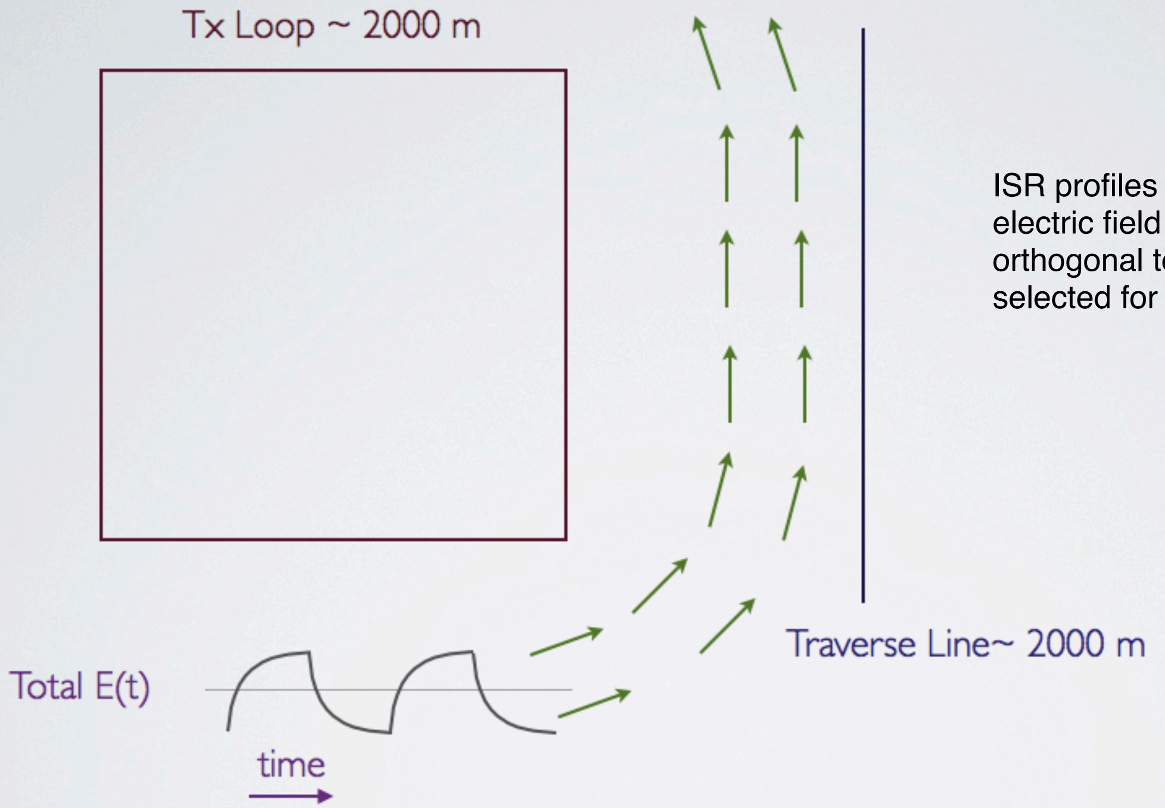
ISR uses a large loop inductive source with a time-varying saw-tooth current to create a magnetic field. The primary electric field is the time derivative of the magnetic field, and so is a square wave. The primary electric field passes through the earth and is low-pass filtered to generate the total field as shown.

The ISR Method - Overview



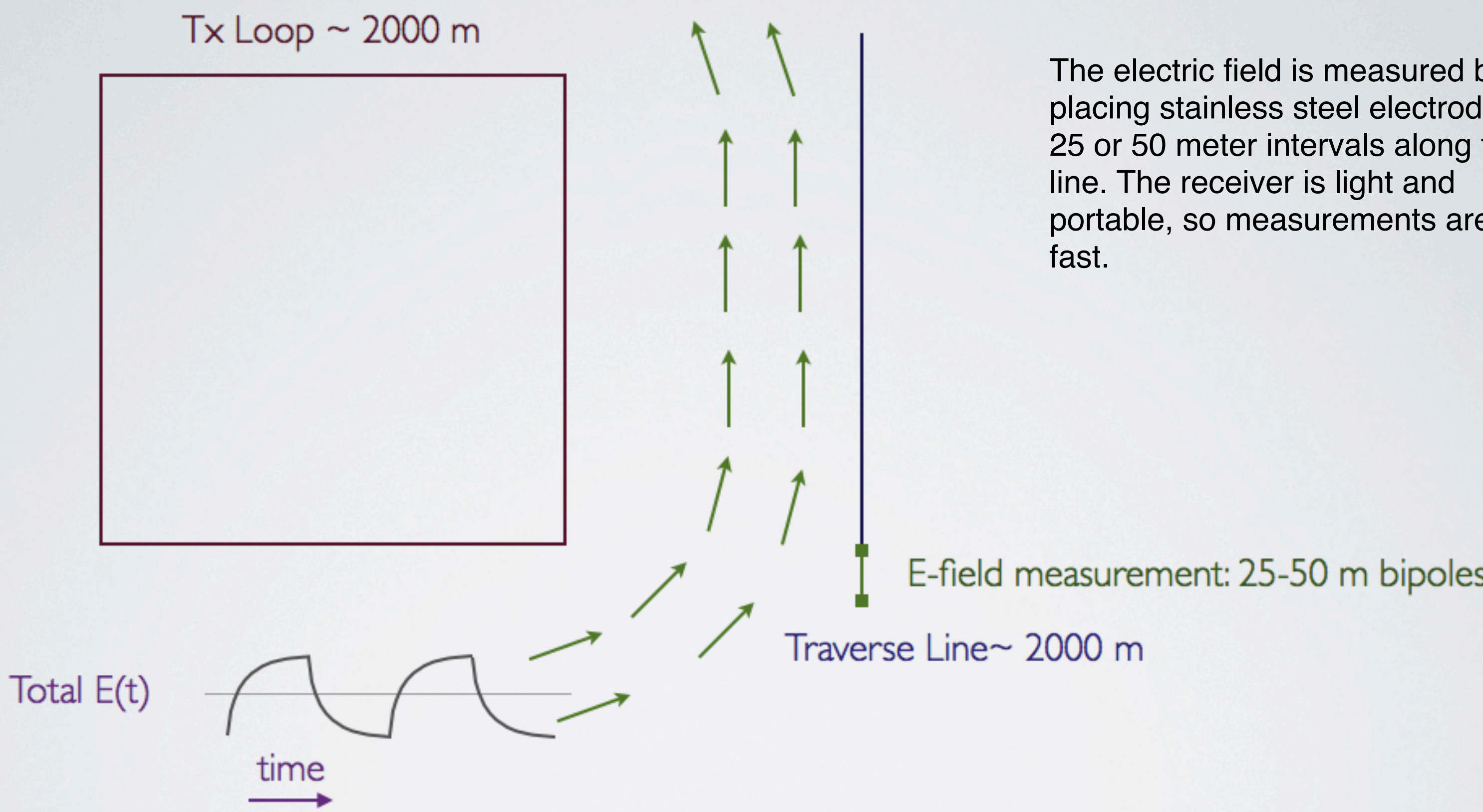
The total electric field race-racks around the loop in the manner shown, varying in time as illustrated.

The ISR Method - Overview



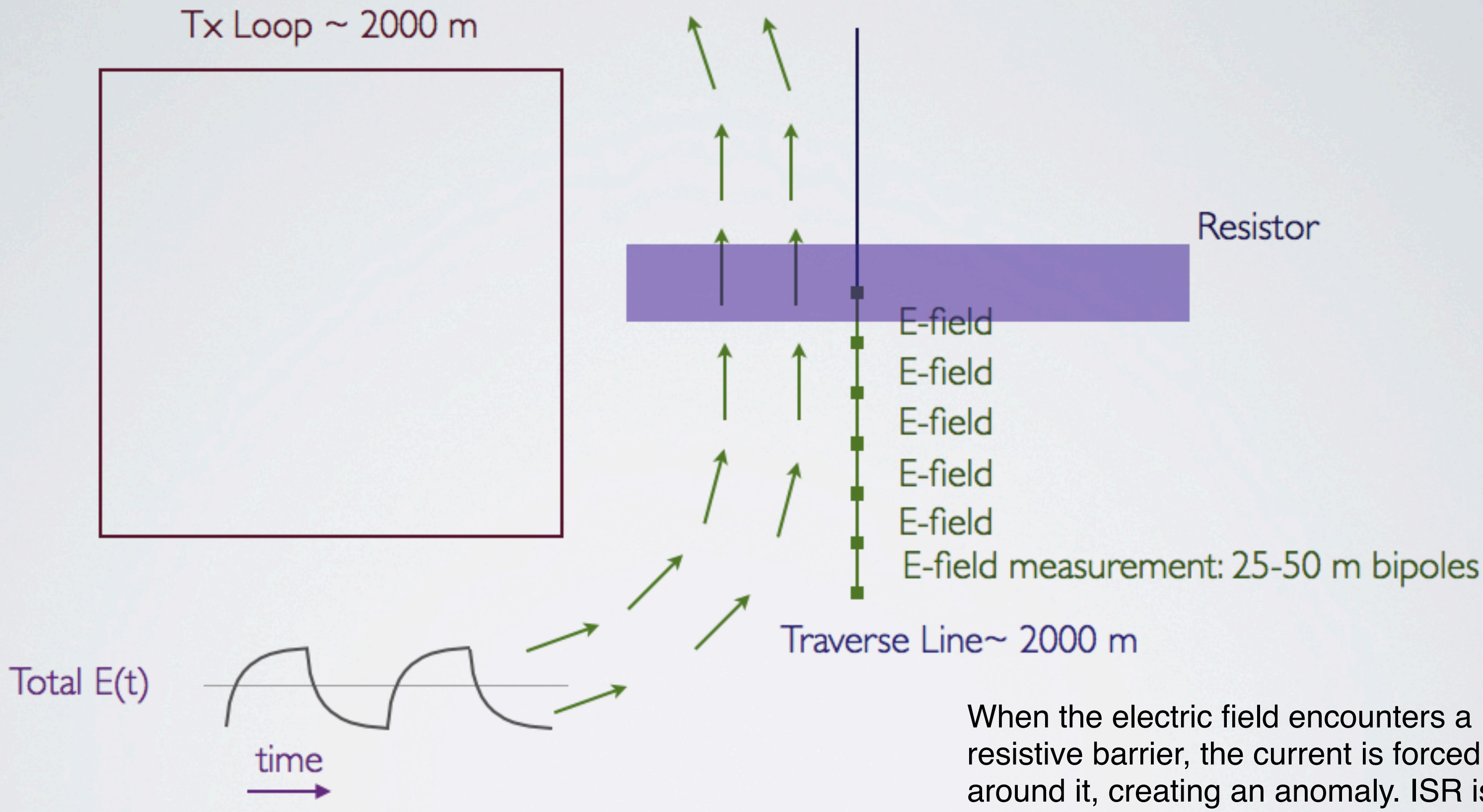
ISR profiles are run parallel to the electric field from the loop. This is orthogonal to the direction usually selected for magnetic field surveying.

The ISR Method - Overview



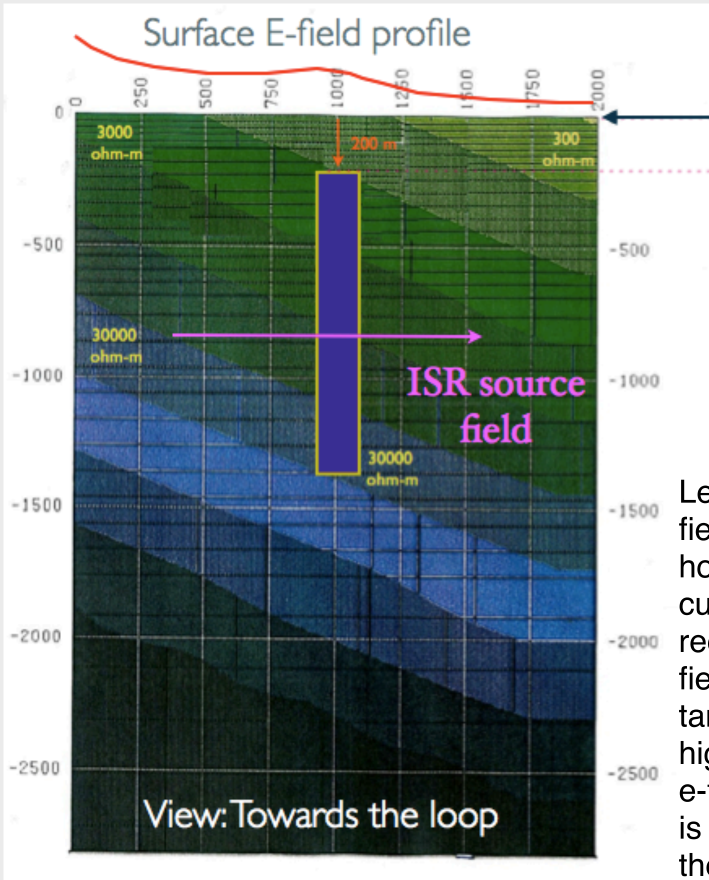
The electric field is measured by placing stainless steel electrodes at 25 or 50 meter intervals along the line. The receiver is light and portable, so measurements are quite fast.

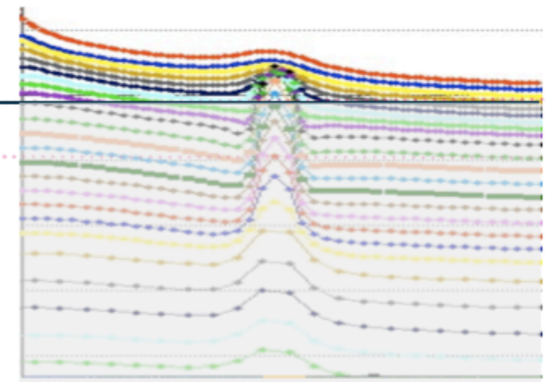
The ISR Method - Overview



When the electric field encounters a resistive barrier, the current is forced around it, creating an anomaly. ISR is most sensitive to resistors that cross the electric field. The next slide shows a section through the resistor looking toward the loop.

Illustrative model: Response of a resistor





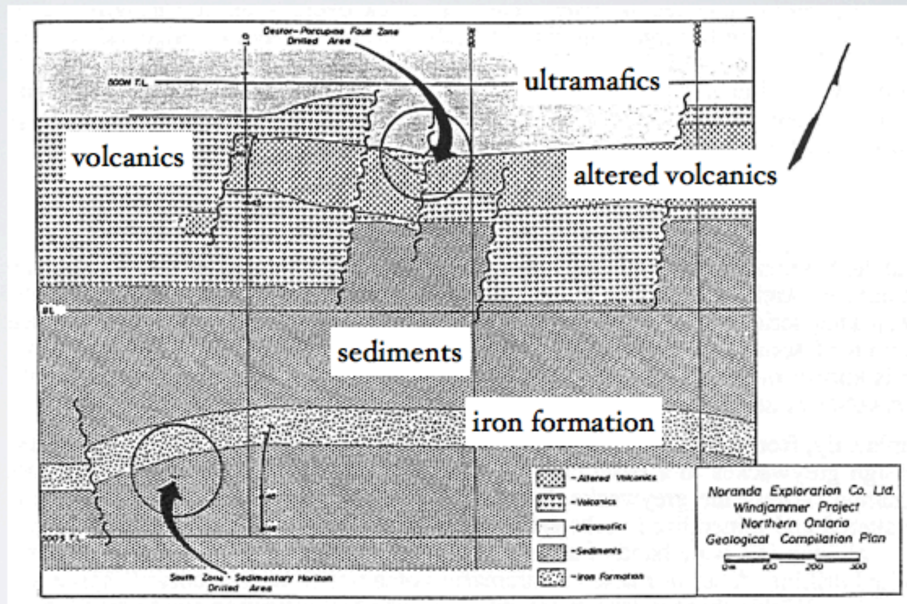
E-field profiles in the ground

Left is a view looking towards the loop. The incident electric field (magenta) crosses the resistor. On the vertical edges, horizontal current is continuous across the resistor. Since current is the product of conductivity and electric field, a reduction in conductivity causes an increase in the electric field, creating an e-field high in the conductor. Since the tangential e-field at the top of the resistor is continuous, this high is carried into the medium above the resistor, creating an e-field high in the e-field profile on the surface above (profile is shown in red). The diagram to the right shows profiles of the electric field at various levels in the ground. The amplitude of the electric field anomaly inside the resistor diminishes with depth due to the increase in the background resistivity with depth. This changes the resistivity contrast of the anomaly, and hence the change in the internal electric field. The gradient in the surface e-field profile (left panel, top) is also due to the change in the resistivity, which decreases from left to right along the top of the modelled earth.

WINDJAMMER ISR SURVEY

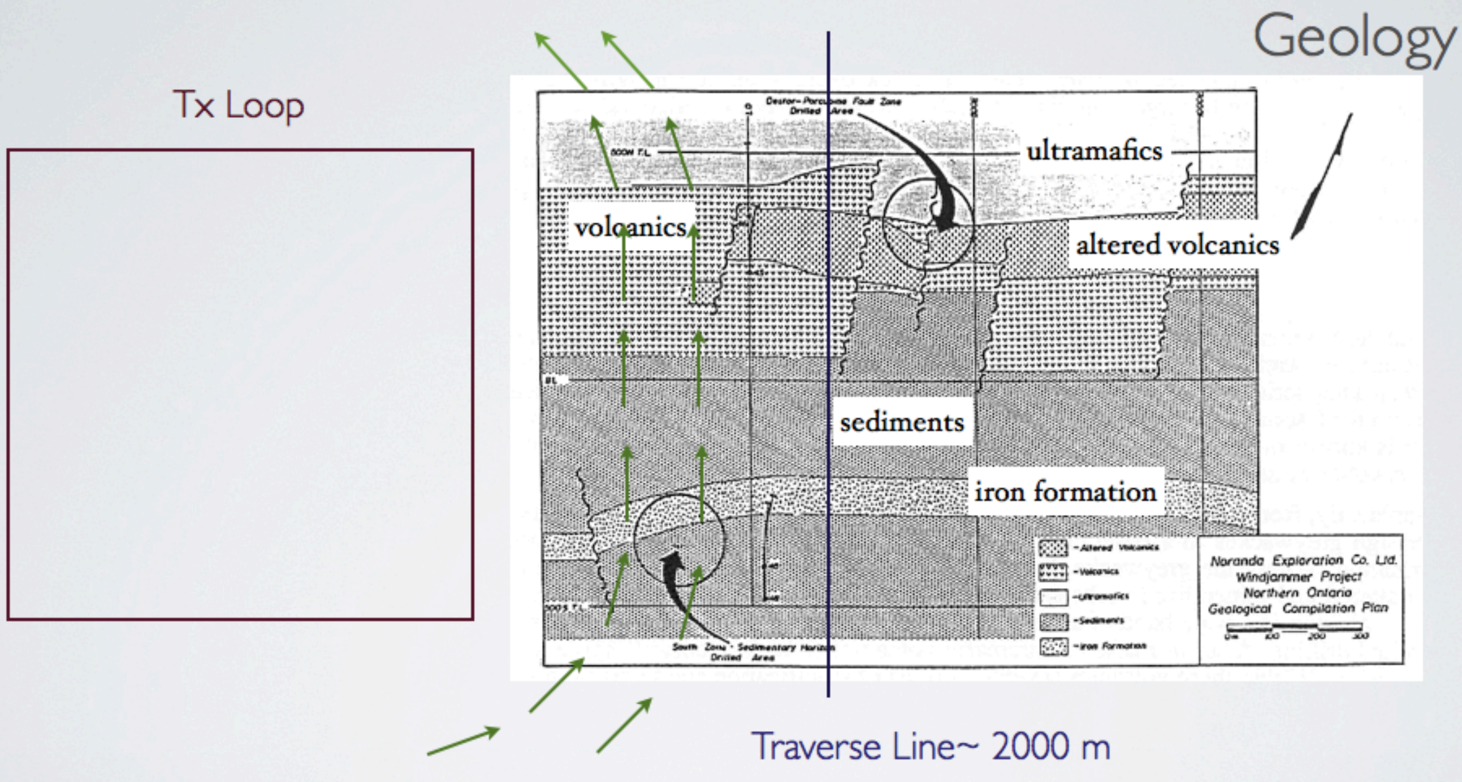
An example of ISR field data acquired over the Windjammer (Noranda) gold prospect on the Porcupine-Destor fault is shown next. Two drill target areas are shown in circles. The property is fairly typical of Canadian Shield gold plays, containing ultramafics, altered volcanics, volcanics, sediments and iron formation.

Geology



Acknowledgement: Macnae & McGowan, Lamontagne Geophysics Ltd.

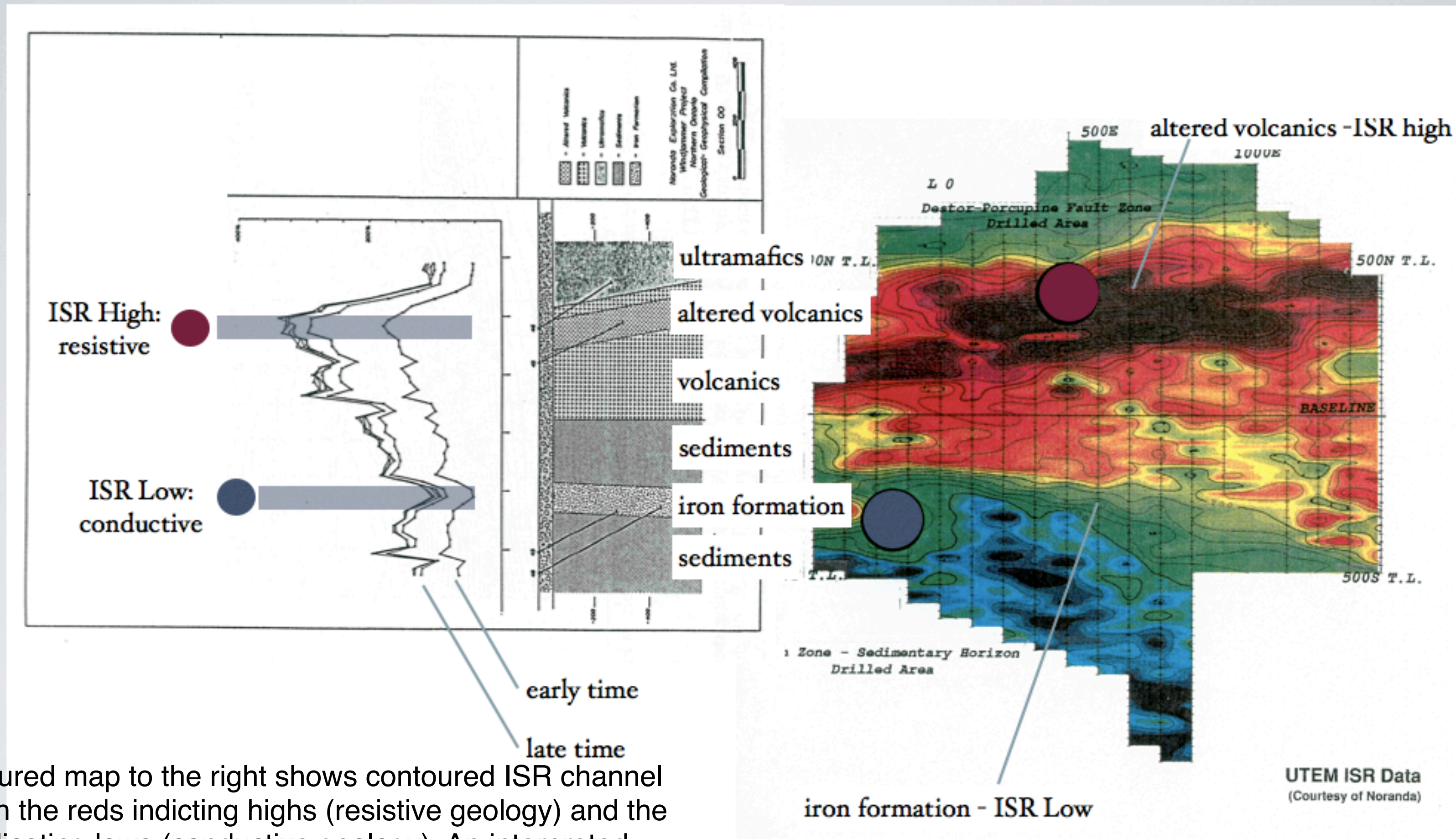
WINDJAMMER ISR SURVEY



An ISR survey over such geology would be set up to create an electric field that crosses the contacts.

Acknowledgement: Macnae & McGowan, Lamontagne Geophysics Ltd.

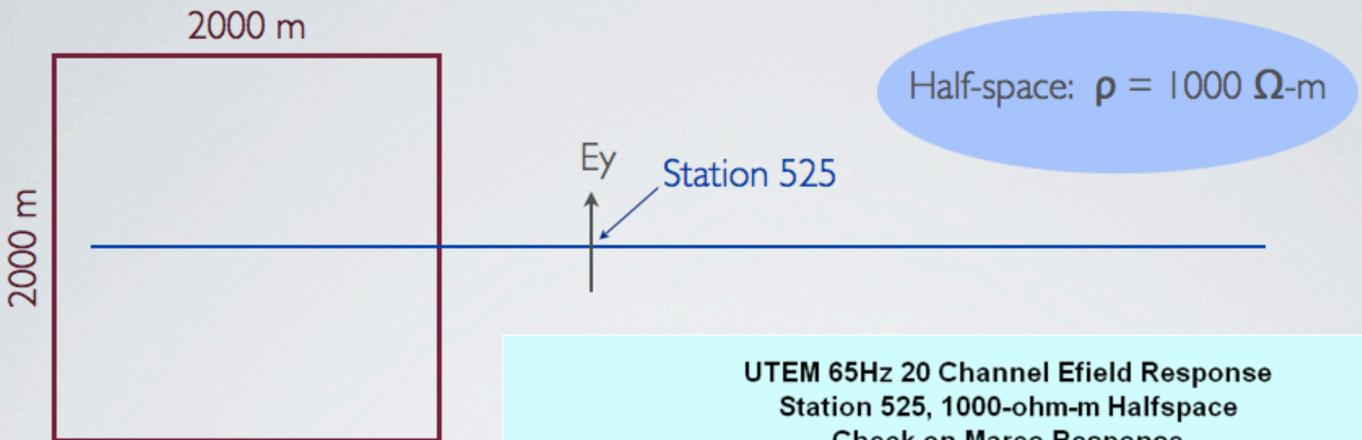
WINDJAMMER ISR DATA

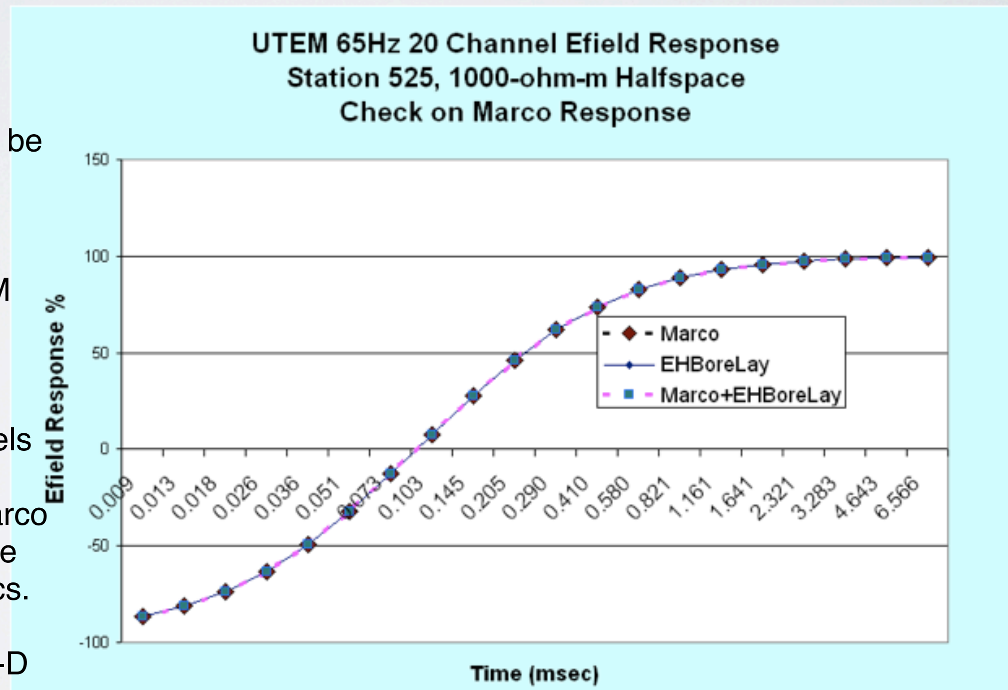


Acknowledgement: Macnae & McGowan, Lamontagne Geophysics Ltd.

The coloured map to the right shows contoured ISR channel data, with the reds indicting highs (resistive geology) and the blues indicating lows (conductive geology). An interpreted section, with ISR data is shown to the left. Coloured dots indicate the stratigraphic location of the profile on the plan map to the right. The underlying stratigraphy can be inferred from the sharp breaks in the profile. Because ISR is a time domain measurement, the early time data are sensitive to near surface conductivity, while late time data would be sensitive to deeper conductivity.

Half-space model verification





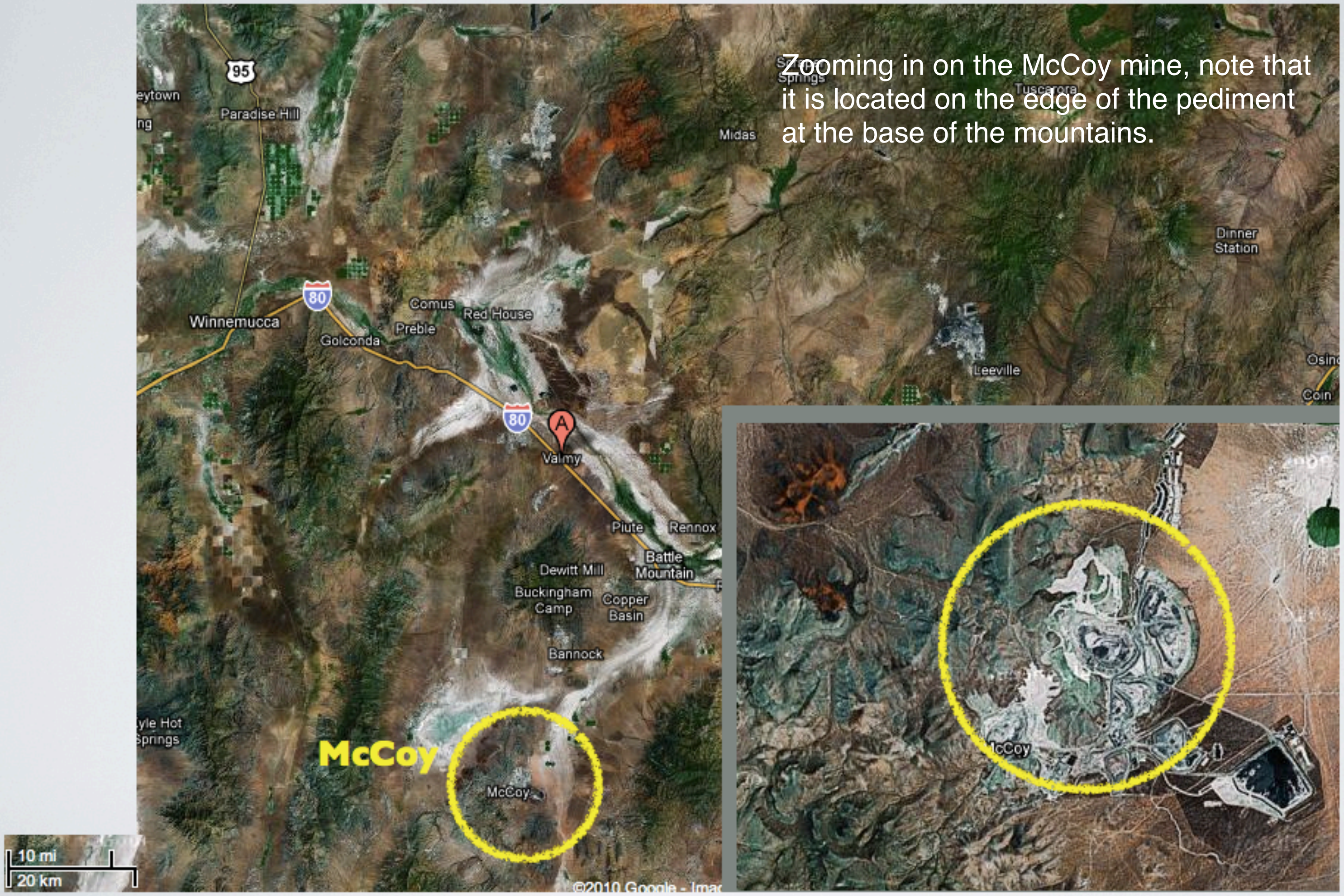
Now we begin to look at how ISR can be used in gold exploration in rocks underlying pediment cover and overthrust stratigraphy in Nevada. Modelling is done using Marco, an EM simulation program developed by AMIRA in Australia. Before any conclusions could be made, it was necessary to confirm half-space models with independent code. Here a half-space time domain response from Marco is compared with EHBoreLay, software developed by Lamontagne Geophysics. Having achieved a satisfactory comparison gives confidence in the 3-D models that will be shown next.

BATTLE MOUNTAIN AREA, NEVADA

The models that follow will be based on data published from the Brooks prospect in the Battle Mountain area of Nevada. Here is a satellite view of the Battle Mountain area. Mountains (ranges) appear greenish, while the basins or pediment areas appear as beige. To view this, select Valmy, Nevada as the zoom location in Google maps.

Acknowledgement: Google Maps

BATTLE MOUNTAIN AREA, NEVADA

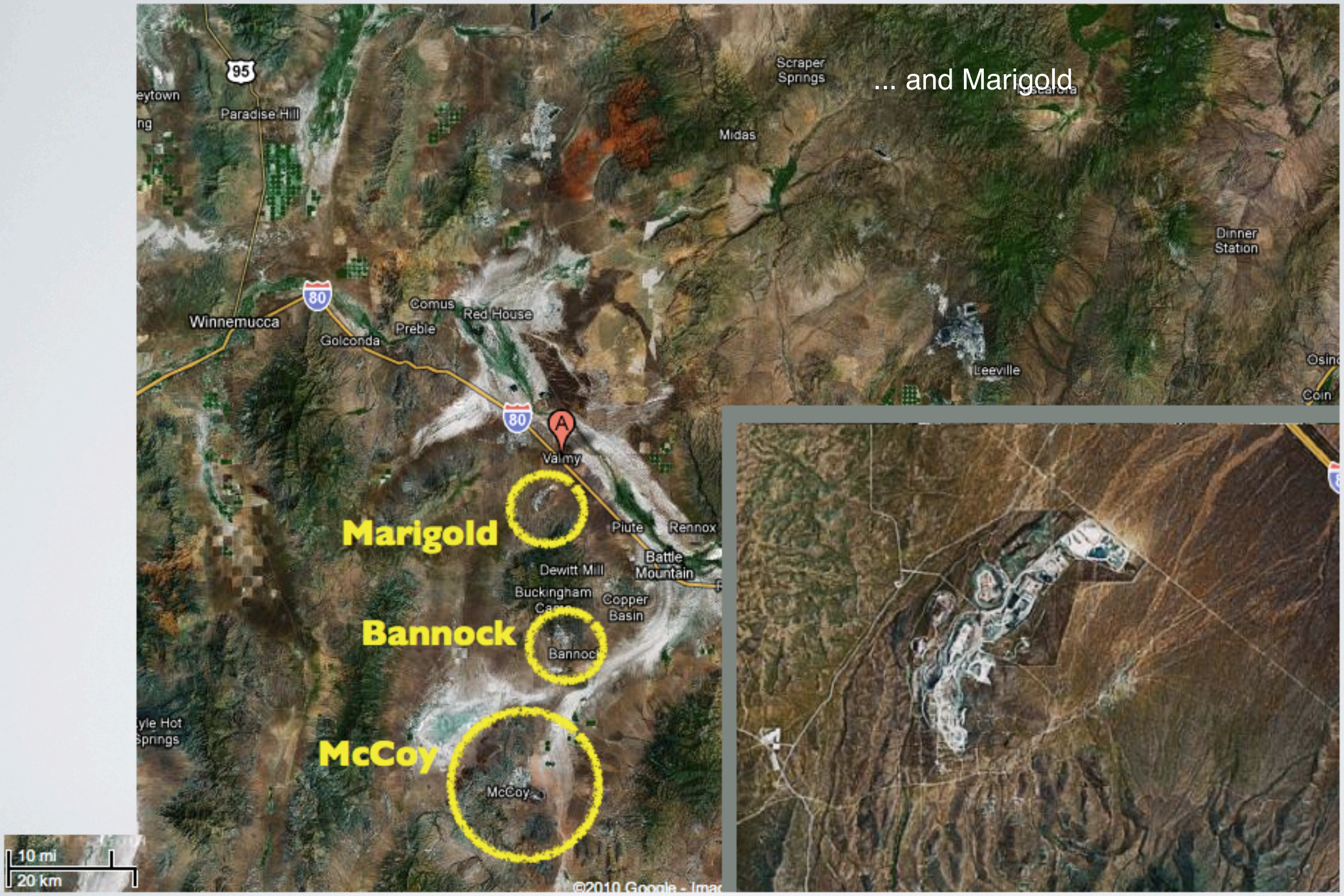


Acknowledgement: Google Maps

BATTLE MOUNTAIN AREA, NEVADA

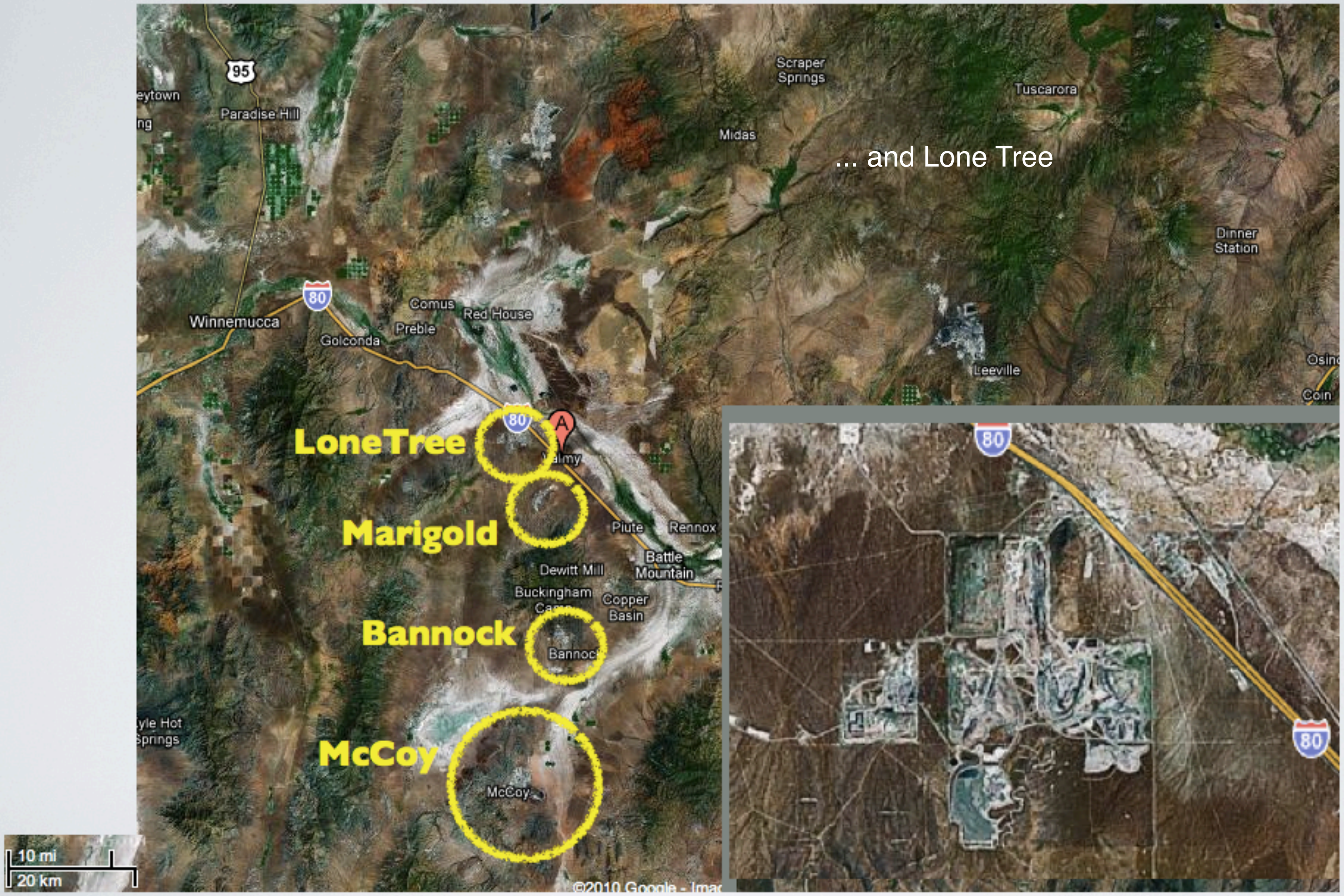
Acknowledgement: Google Maps

BATTLE MOUNTAIN AREA, NEVADA



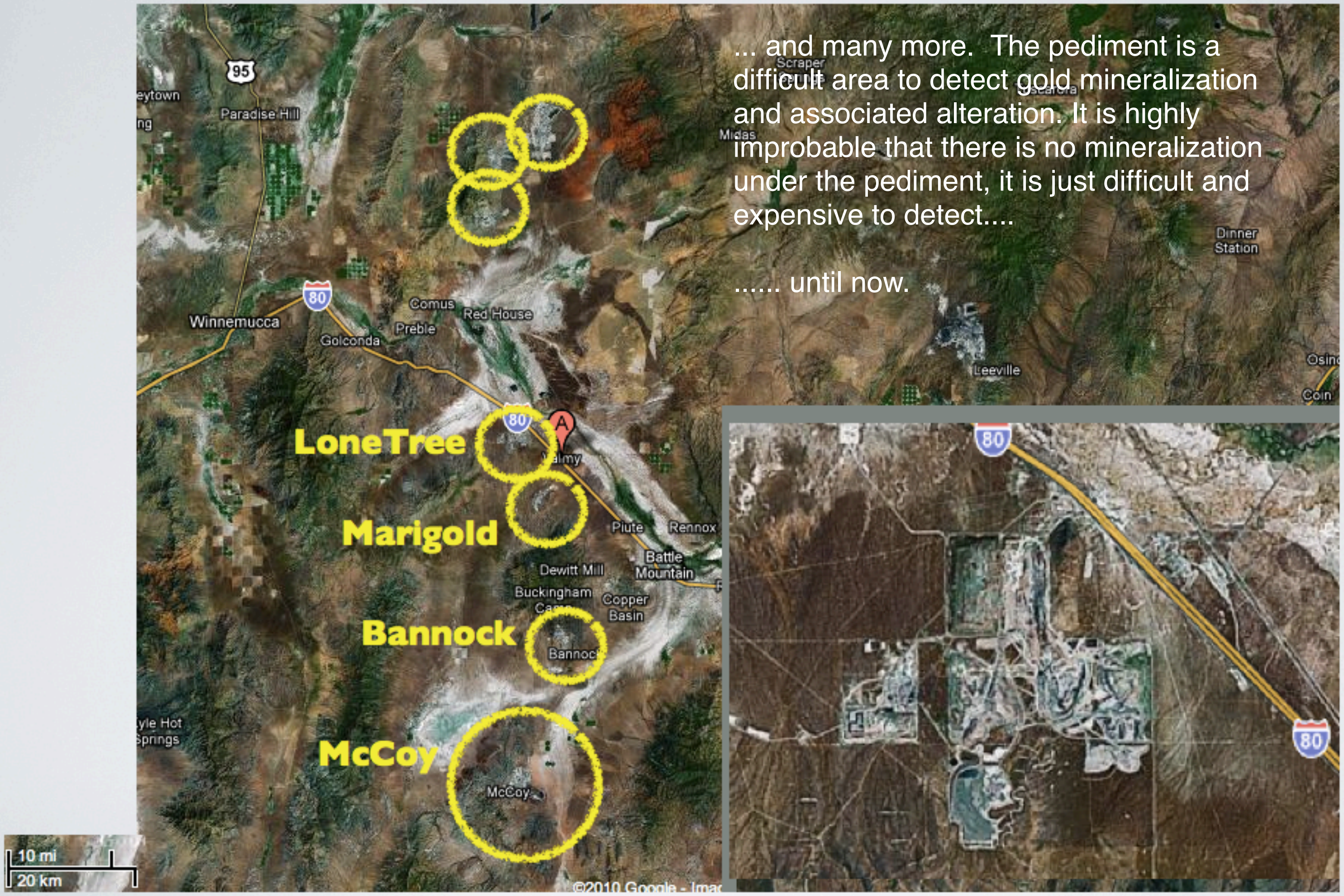
Acknowledgement: Google Maps

BATTLE MOUNTAIN AREA, NEVADA



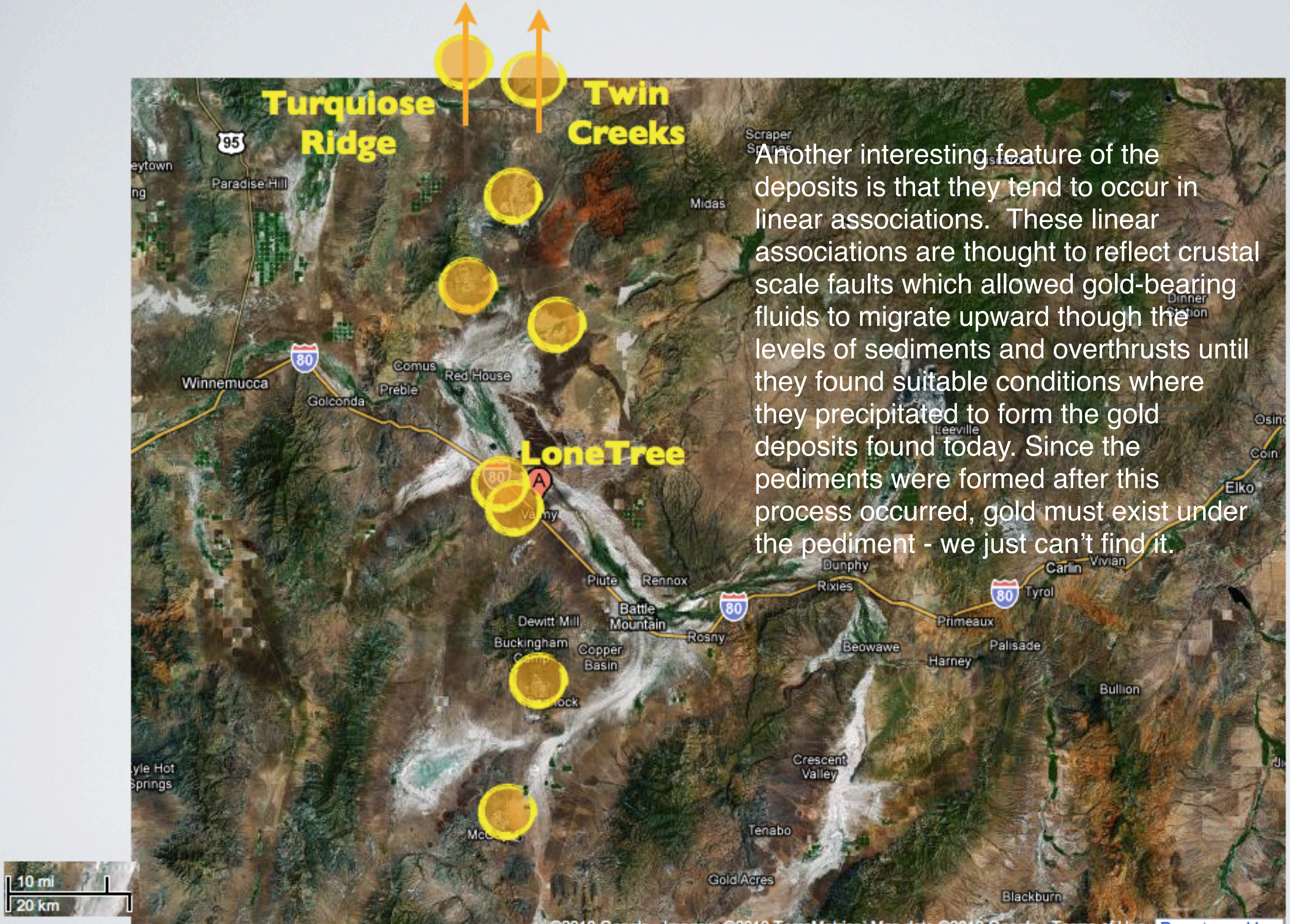
Acknowledgement: Google Maps

BATTLE MOUNTAIN AREA, NEVADA



Acknowledgement: Google Maps

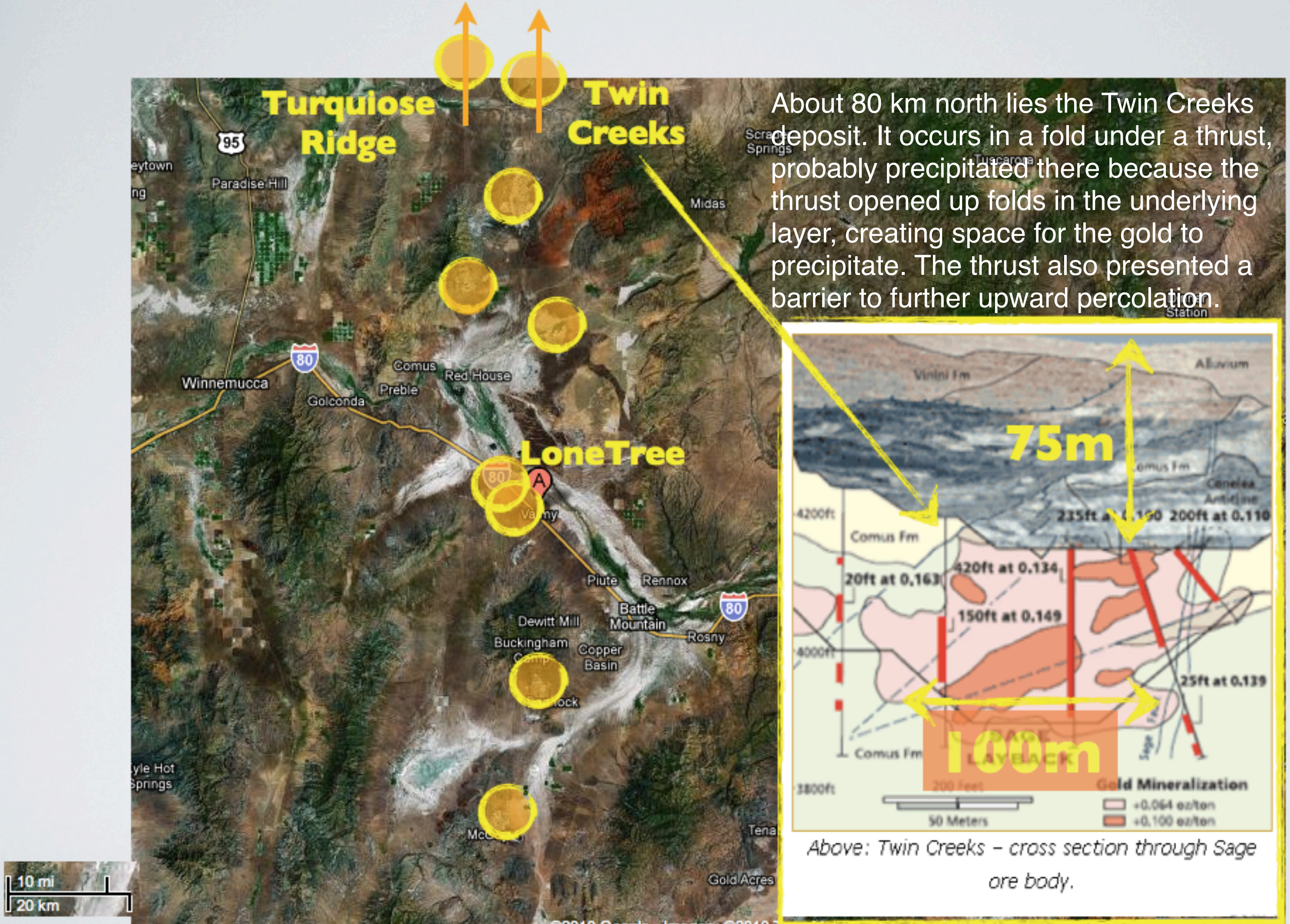
BATTLE MOUNTAIN AREA



Another interesting feature of the deposits is that they tend to occur in linear associations. These linear associations are thought to reflect crustal scale faults which allowed gold-bearing fluids to migrate upward though the levels of sediments and overthrusts until they found suitable conditions where they precipitated to form the gold deposits found today. Since the pediments were formed after this process occurred, gold must exist under the pediment - we just can't find it.

Acknowledgement: Google Maps, Newmont.com

BATTLE MOUNTAIN AREA



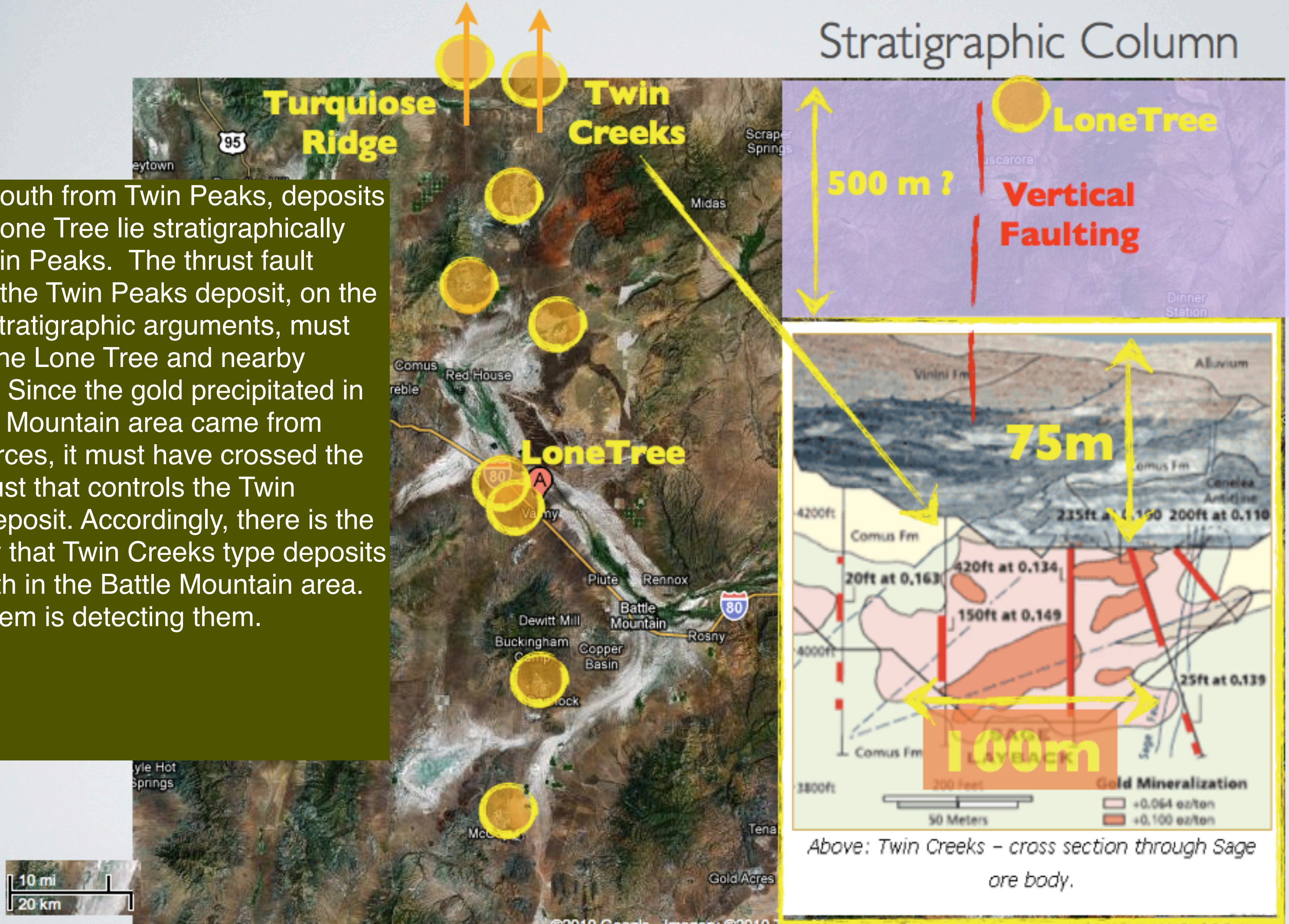
About 80 km north lies the Twin Creeks deposit. It occurs in a fold under a thrust, probably precipitated there because the thrust opened up folds in the underlying layer, creating space for the gold to precipitate. The thrust also presented a barrier to further upward percolation.

Above: Twin Creeks – cross section through Sage ore body.

Acknowledgement: Google Maps, Newmont.com

BATTLE MOUNTAIN AREA

Stratigraphic Column



Above: Twin Creeks – cross section through Sage ore body.

Looking south from Twin Peaks, deposits such as Lone Tree lie stratigraphically above Twin Peaks. The thrust fault overlying the Twin Peaks deposit, on the basis of stratigraphic arguments, must underlie the Lone Tree and nearby deposits. Since the gold precipitated in the Battle Mountain area came from deep sources, it must have crossed the same thrust that controls the Twin Creeks deposit. Accordingly, there is the possibility that Twin Creeks type deposits lie at depth in the Battle Mountain area. The problem is detecting them.

Acknowledgement: Google Maps, Newmont.com

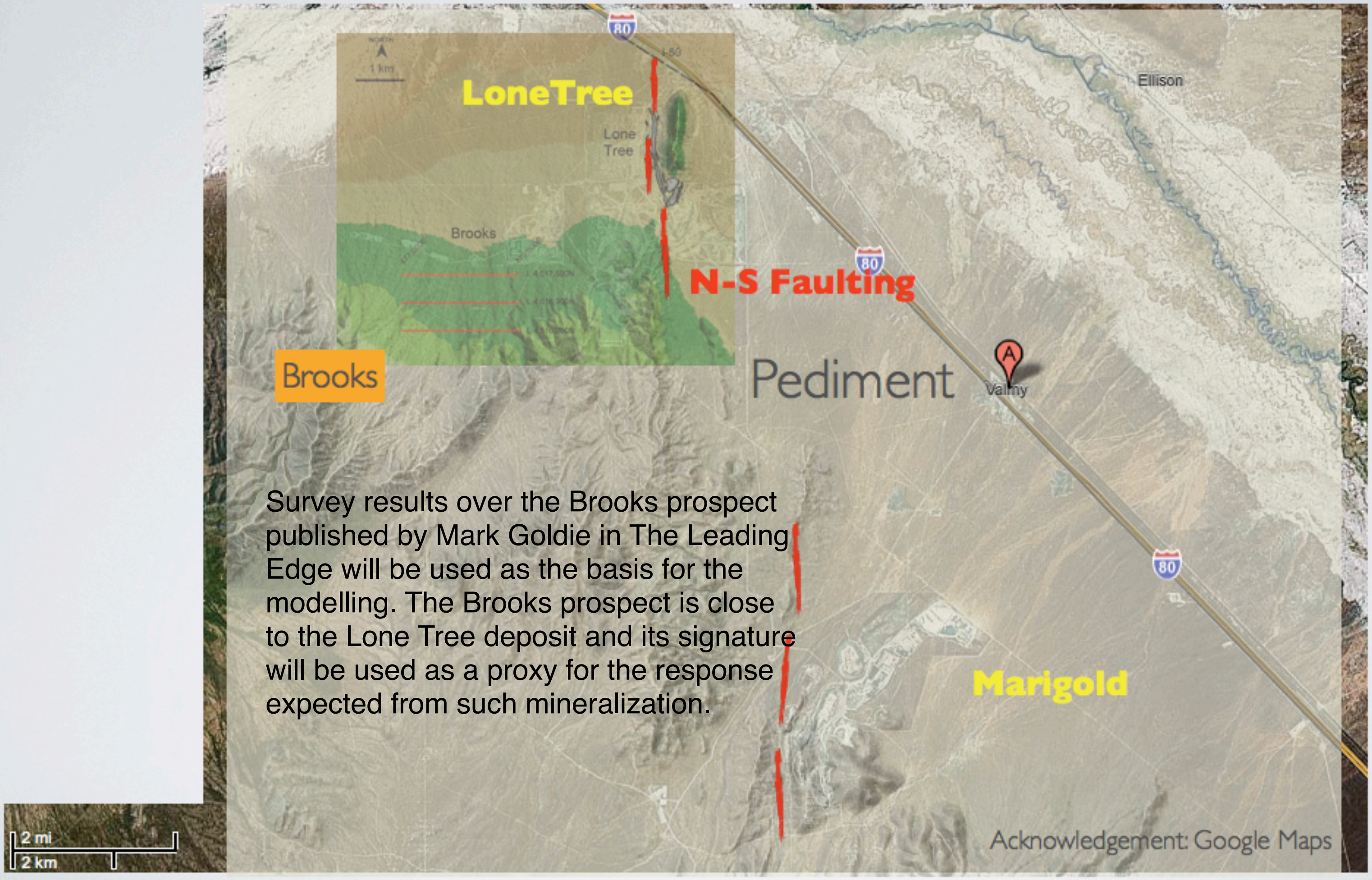
QUESTIONS

Can we detect favourable areas under the alluvium?

Can we detect favourable areas under the thrusts?

These questions will be addressed with numerical modelling using a measured resistivity signature as the basis for analysis.

LONE TREE - BROOKS AREA



Survey results over the Brooks prospect published by Mark Goldie in The Leading Edge will be used as the basis for the modelling. The Brooks prospect is close to the Lone Tree deposit and its signature will be used as a proxy for the response expected from such mineralization.

BROOKS TEST SURVEYS

Titan DCIP-MT

Conventional n=0.5 - 23.5

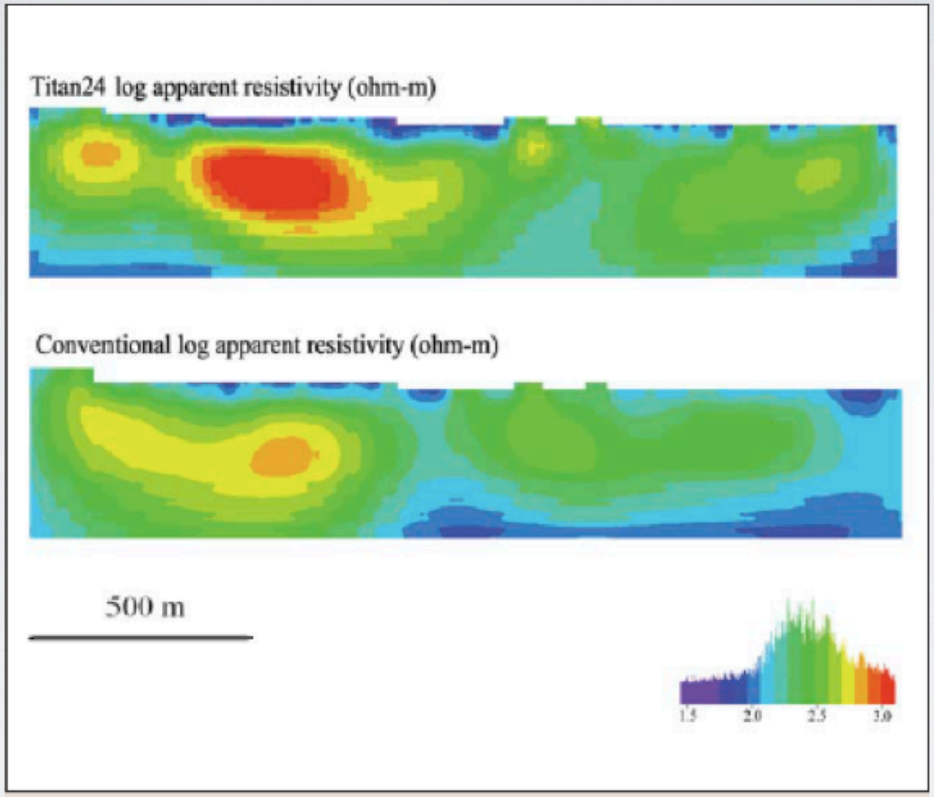


Figure 8. Direct comparison of DCIP2D inversion results of resistivity from line 4 516 900N at the Brooks prospect. Data ranges from 50 to 2000 ohm-m (blue to red). Vertical and horizontal scales in m.

US$5000/km

US$4500/km

Goldie compared a Titan survey to a pole-dipole survey. The inverted Titan results will be used as the basis for the modelling.

Acknowledgement: Goldie, The Leading Edge

BROOKS TEST SURVEYS

Titan
DCIP-MT

US$5000/km

Conventional
n=0.5 - 23.5

US$4500/km

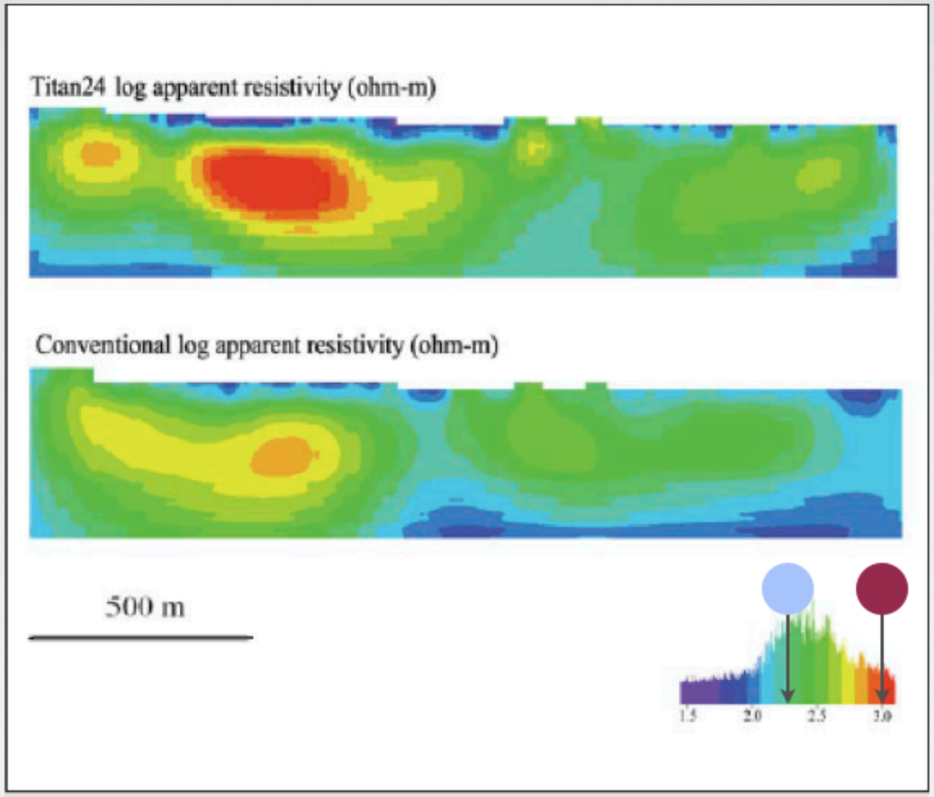


Figure 8. Direct comparison of DCIP2D inversion results of resistivity from line 4 516 900N at the Brooks prospect. Data ranges from 50 to 2000 ohm-m (blue to red). Vertical and horizontal scales in m.

A resistivity of 1000 ohm-m will be used to represent the target resistor, with the background assigned a resistivity of 200 ohm-m.

Acknowledgement: Goldie, The Leading Edge

BROOKS TEST SURVEYS

Titan
DCIP-MT

US$5000/km

Conventional
n=0.5 - 23.5

US$4500/km

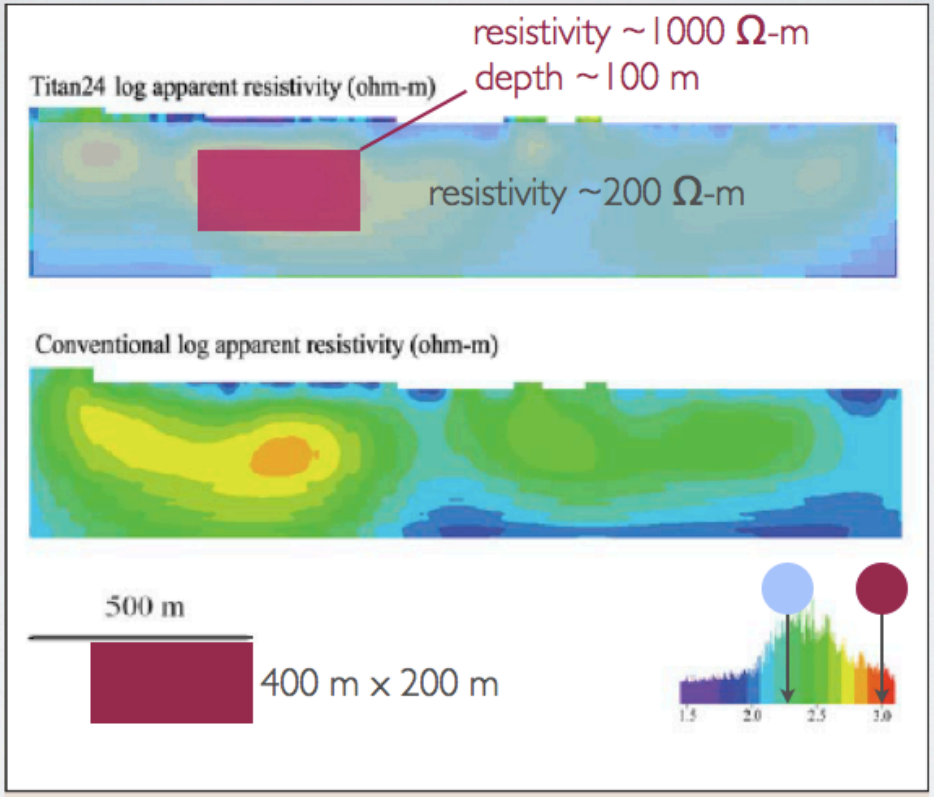
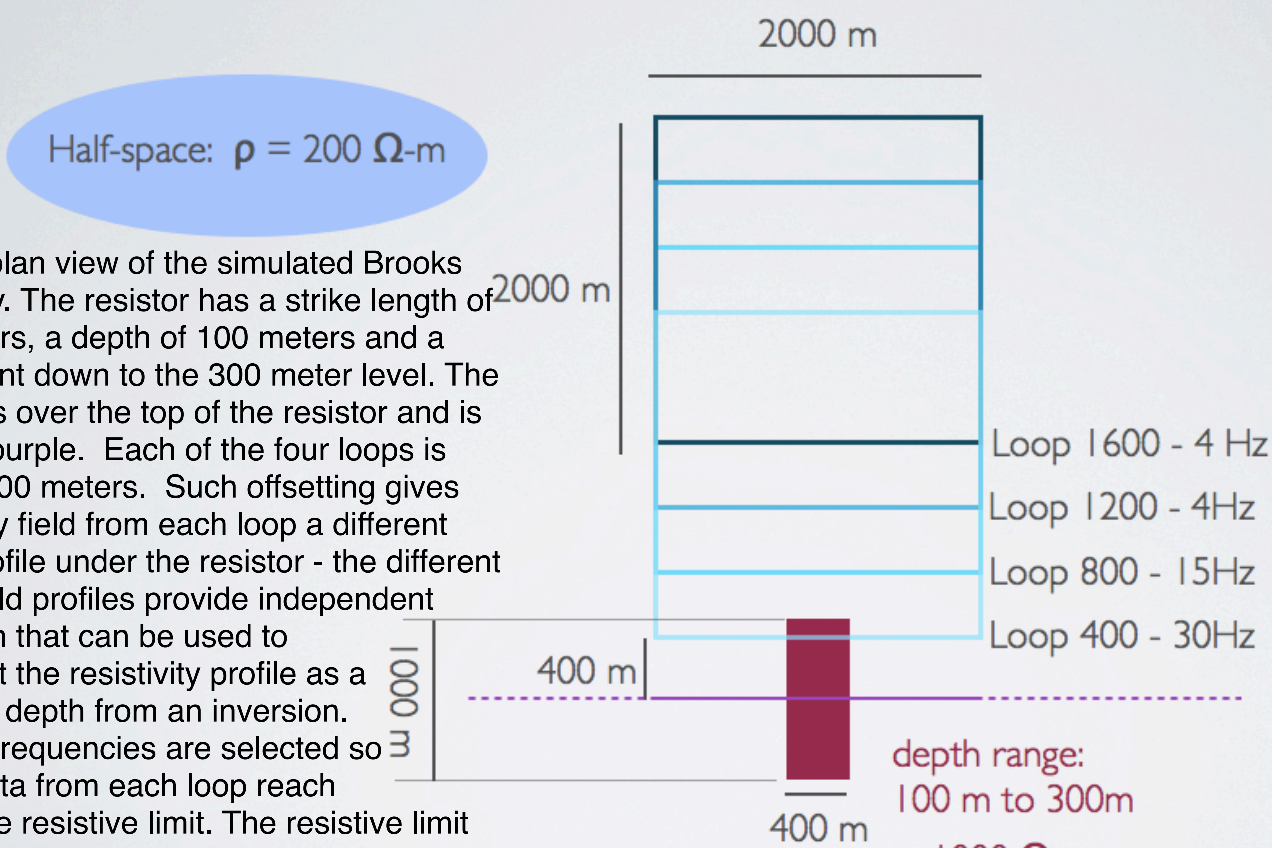


Figure 8. Direct comparison of DCIP2D inversion results of resistivity from line 4 516 900N at the Brooks prospect. Data ranges from 50 to 2000 ohm-m (blue to red). Vertical and horizontal scales in m.

The numerical model has been overlain on the inverted Titan resistivity data.

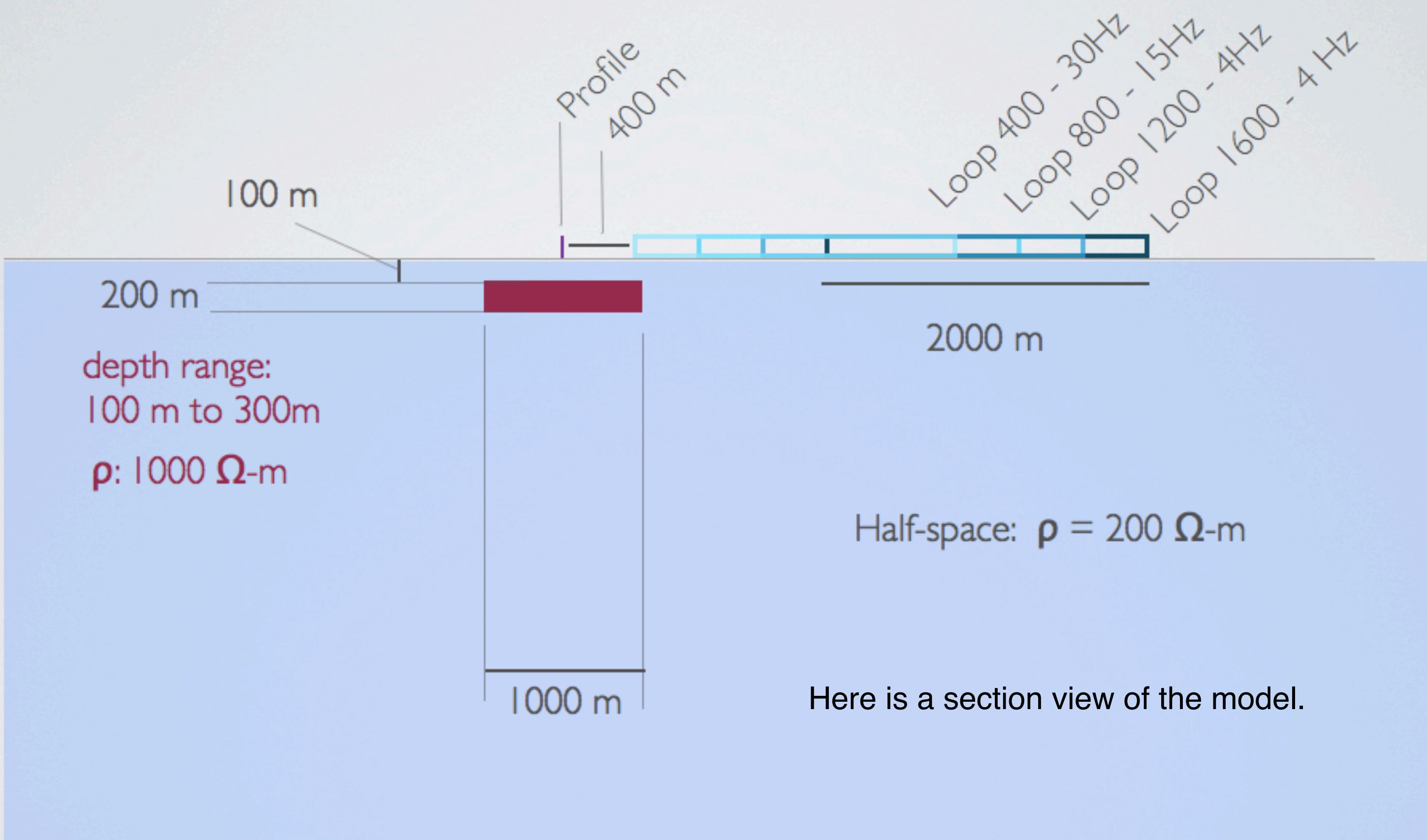
Acknowledgement: Goldie, The Leading Edge

BROOKS ISR MODEL - PLAN VIEW



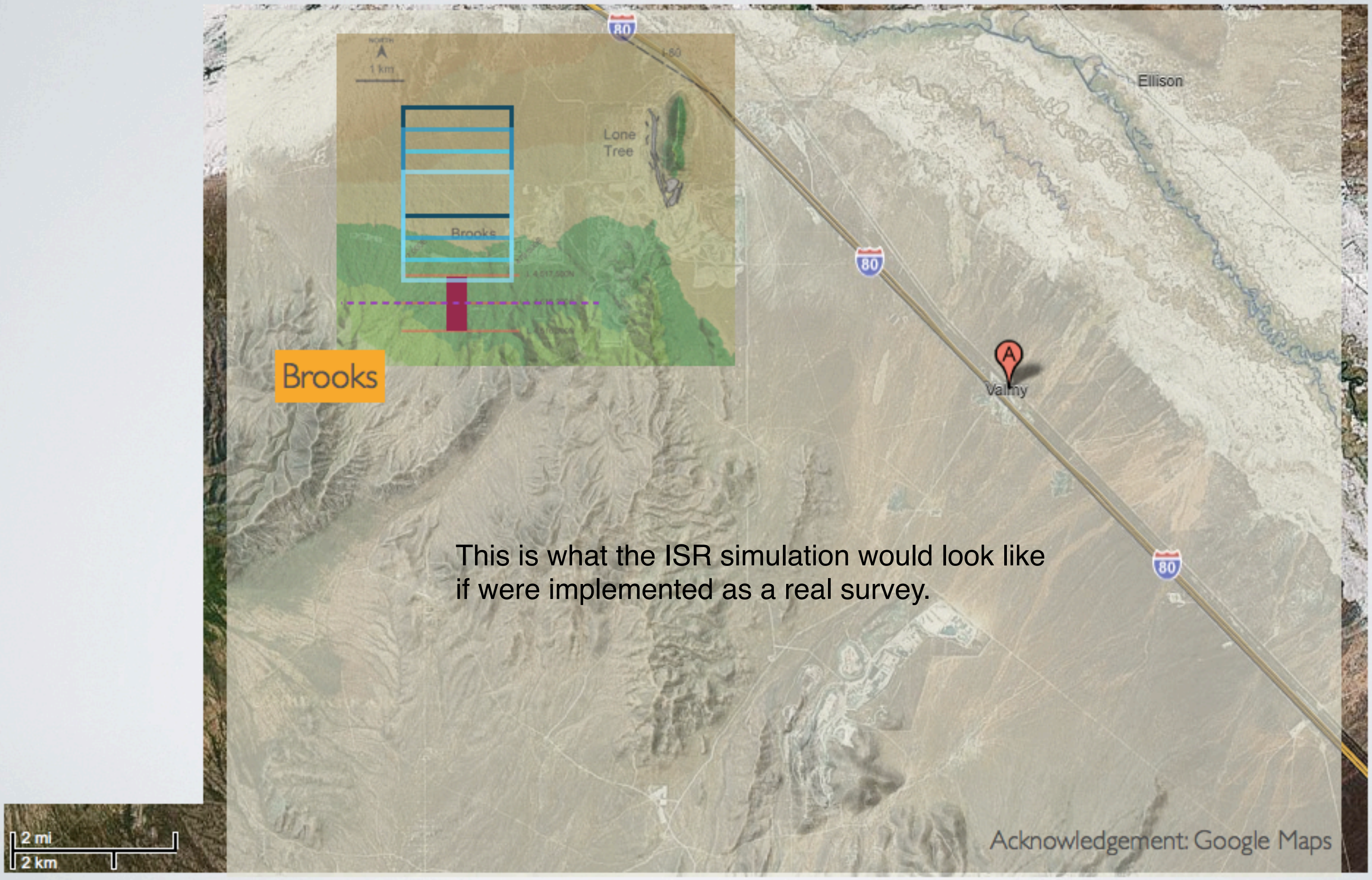
Here is a plan view of the simulated Brooks ISR survey. The resistor has a strike length of 1000 meters, a depth of 100 meters and a depth extent down to the 300 meter level. The profile runs over the top of the resistor and is plotted in purple. Each of the four loops is offset by 400 meters. Such offsetting gives the primary field from each loop a different vertical profile under the resistor - the different primary field profiles provide independent information that can be used to reconstruct the resistivity profile as a function of depth from an inversion. The base frequencies are selected so that the data from each loop reach close to the resistive limit. The resistive limit occurs at late time when induction ceases to be important in comparison to resistive dissipation of the current system.

BROOKS ISR MODEL - SECTION VIEW



Here is a section view of the model.

BROOKS AREA

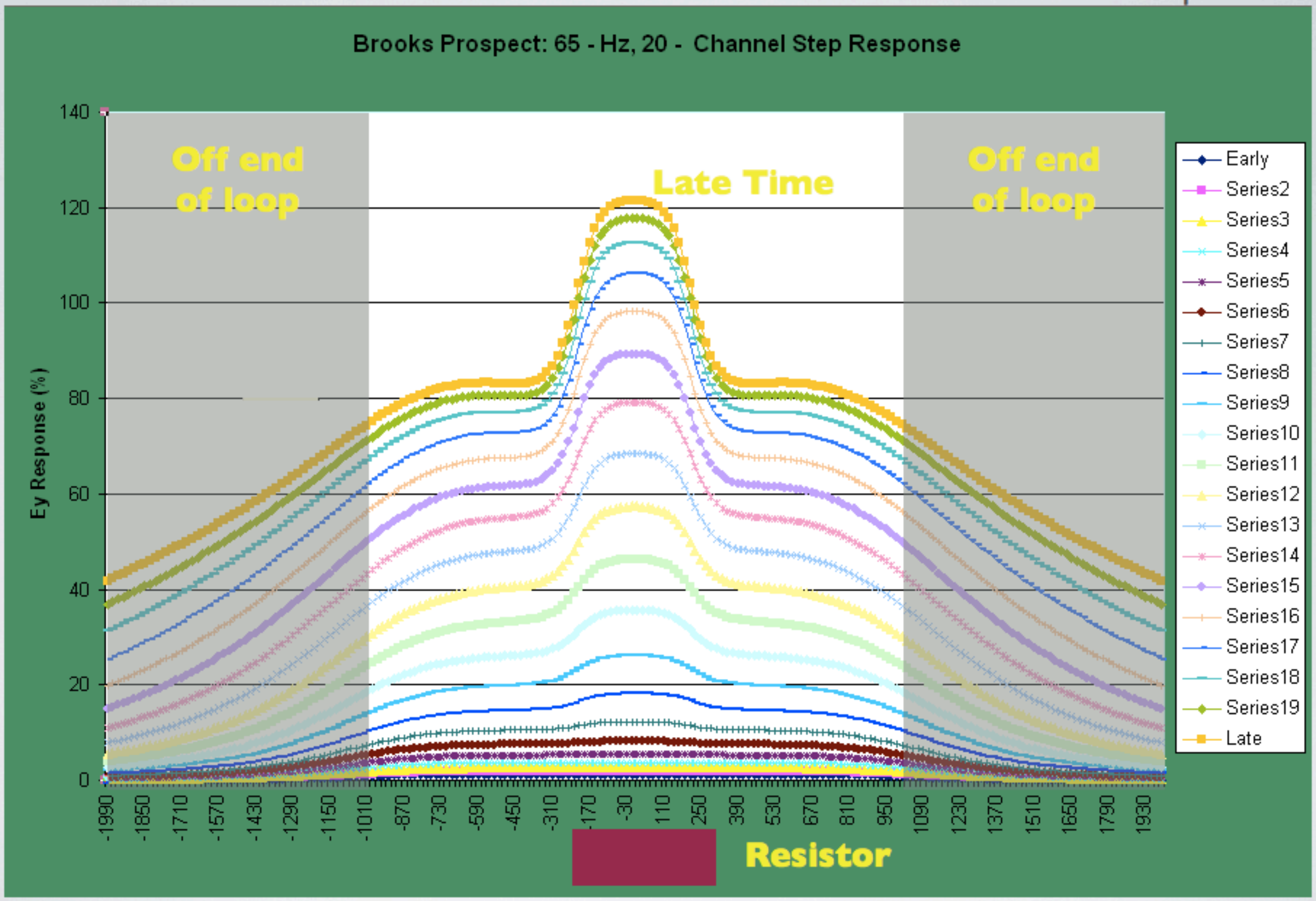


This is what the ISR simulation would look like if were implemented as a real survey.

Acknowledgement: Google Maps

BROOKS MODEL

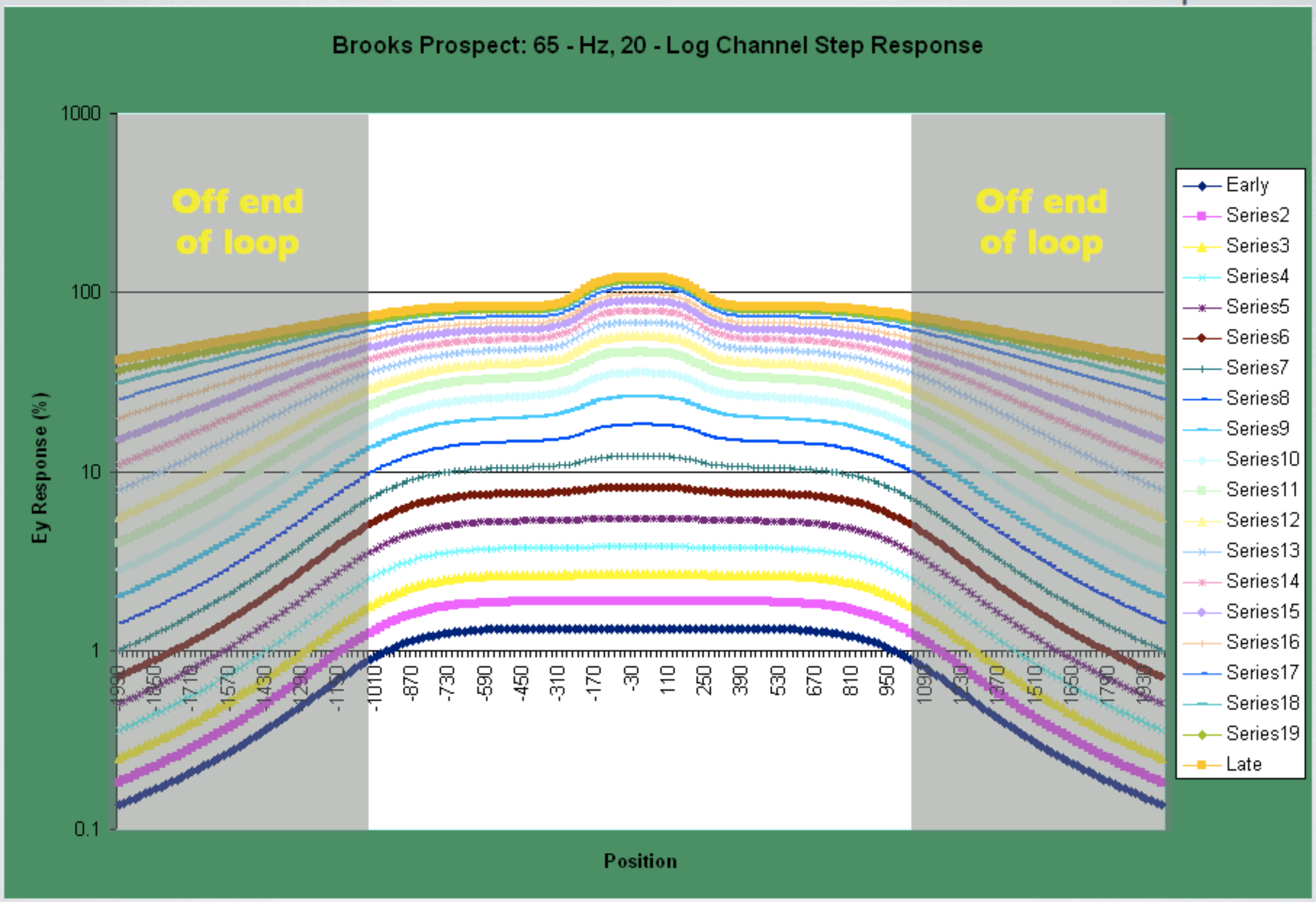
65Hz - Loop 400



Acknowledgement: AMIRA

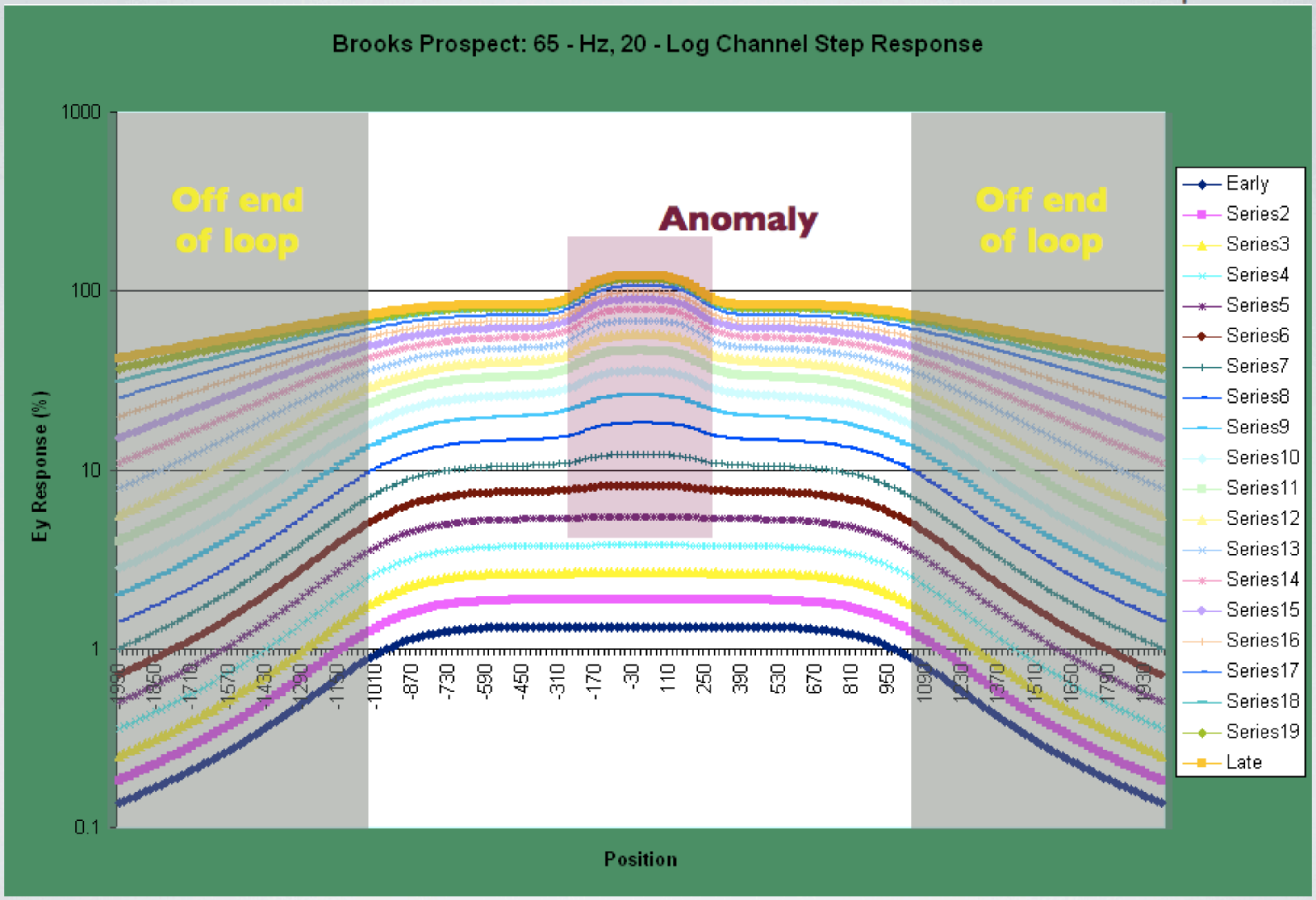
As a first test, the response at 65 Hz of the 400 meter offset loop was computed. Acquiring 65 Hz data was done extremely quickly (using 8-second stacks) in the Shea Creek survey, and as the model shows, could easily detect the Brooks target. From this, it is apparent that running ISR in a 65-Hz "reconnaissance mode" using a single loop would be a cost effective method to detect Brooks-type targets to well past 100 meters in depth in the pediment.

65Hz - Loop 400



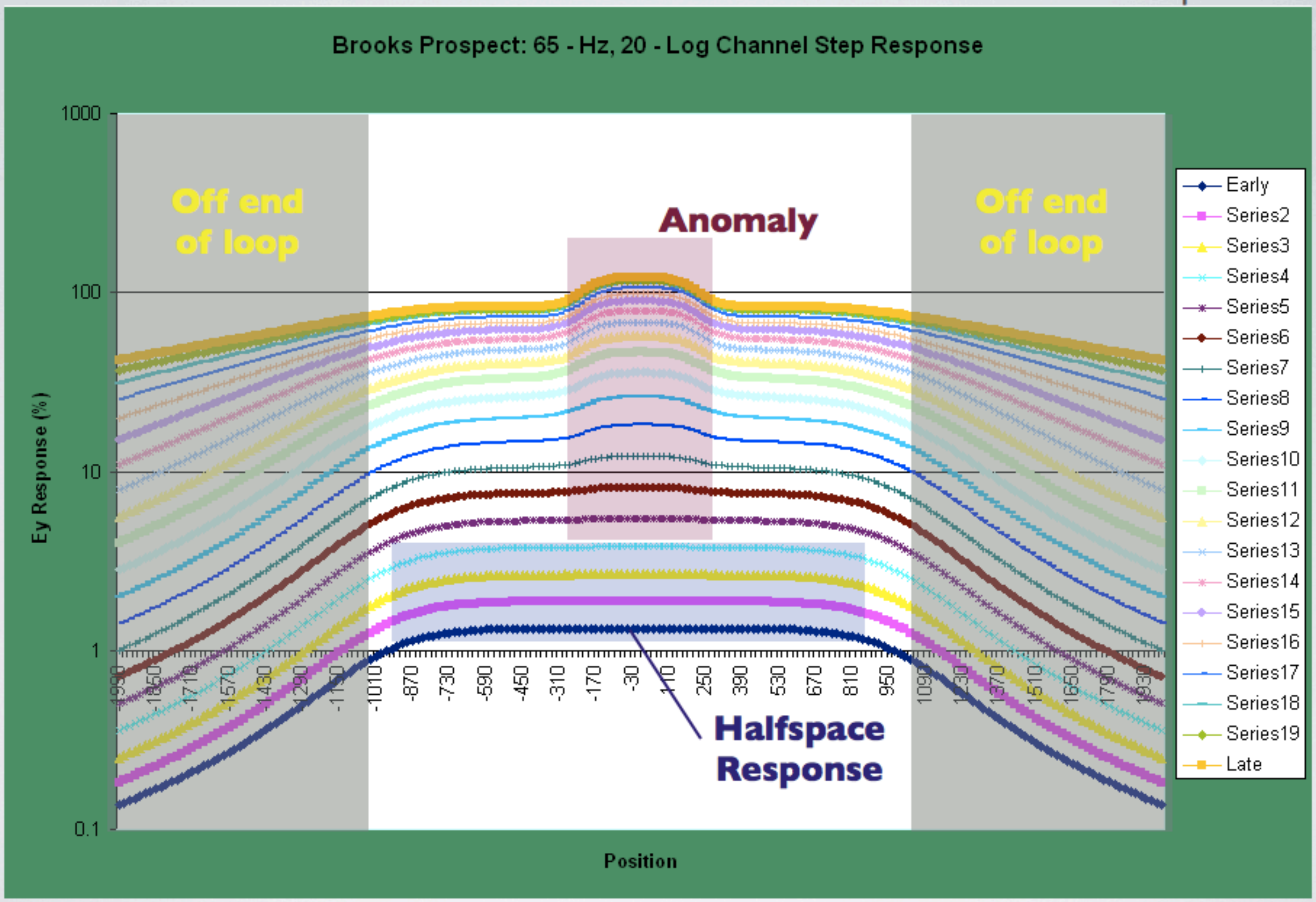
Here are the logarithm of the simulated data from the 65 Hz 400-m offset loop are plotted.

65Hz - Loop 400

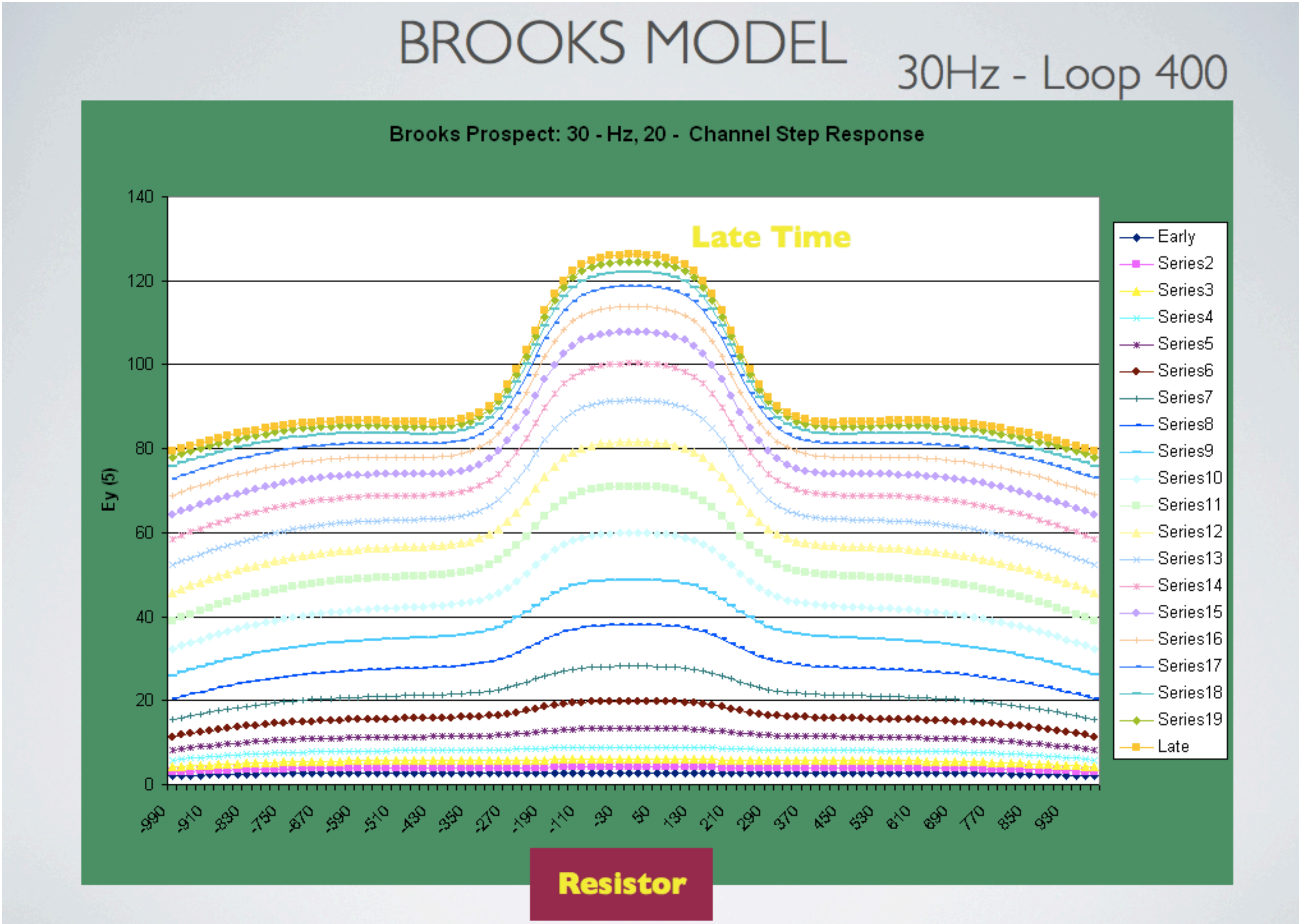


By plotting the log of the data, the early time channels are shown to generate a uniform response over the profile. The anomaly appears in the later channels as the electric field diffuses through the half-space to the level of the anomaly. Resistors create positive anomalies, as seen here.

65Hz - Loop 400



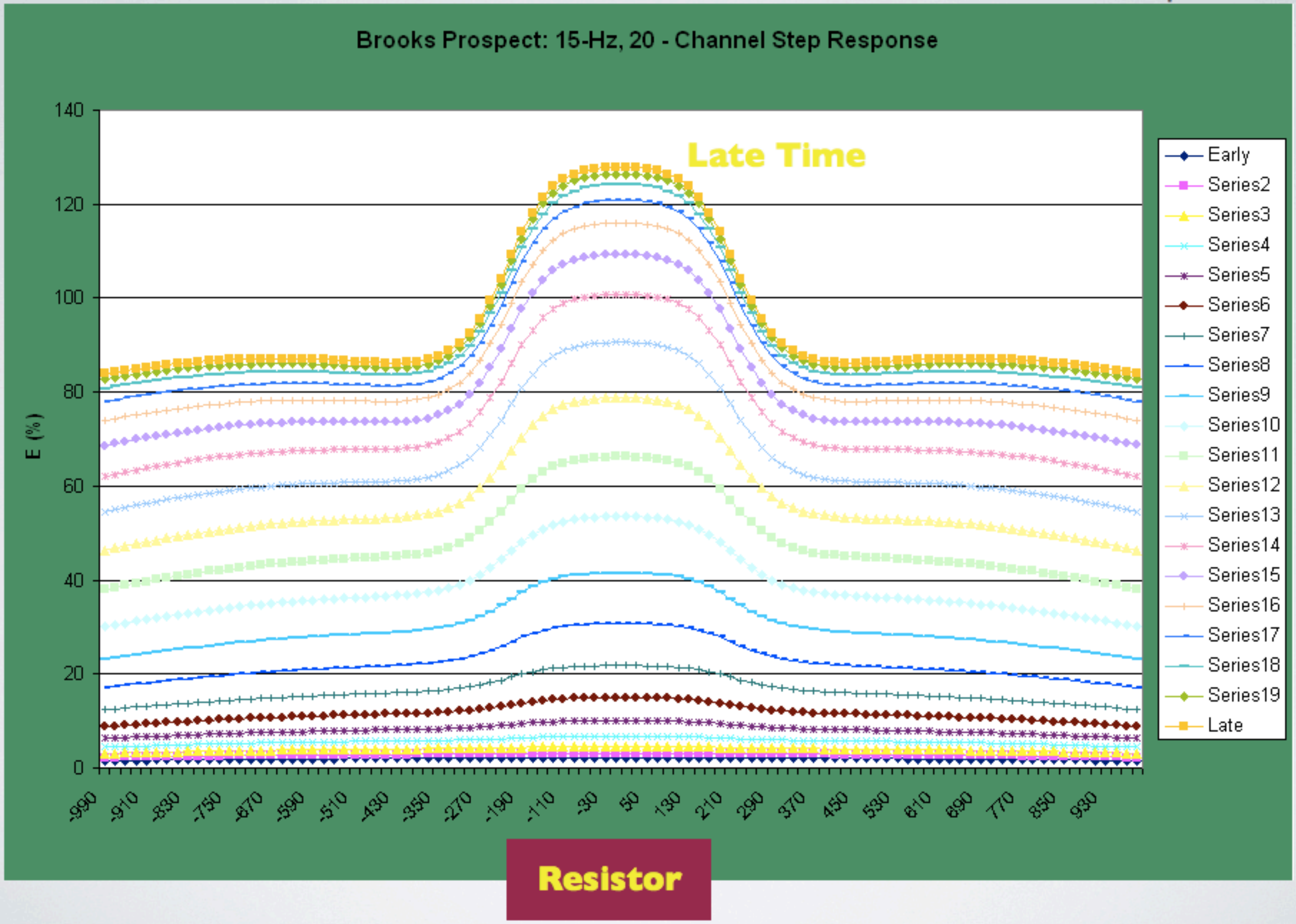
The log of the data shows the uniform response of a half-space in the early time channels before the diffusing current system interacts with the resistor. When a target is found from reconnaissance mode profiling, a multiple loop ISR survey could be deployed as a follow-up method. Such a 4-loop survey was completed by a 2-man crew with a helper in under 3 days at Shea Creek. The simulated multiple loop data are plotted next.



The Brooks survey will now be simulated, and the simulated data input into an inversion. Here are the simulated loop 400 data used in the inversion.

BROOKS MODEL

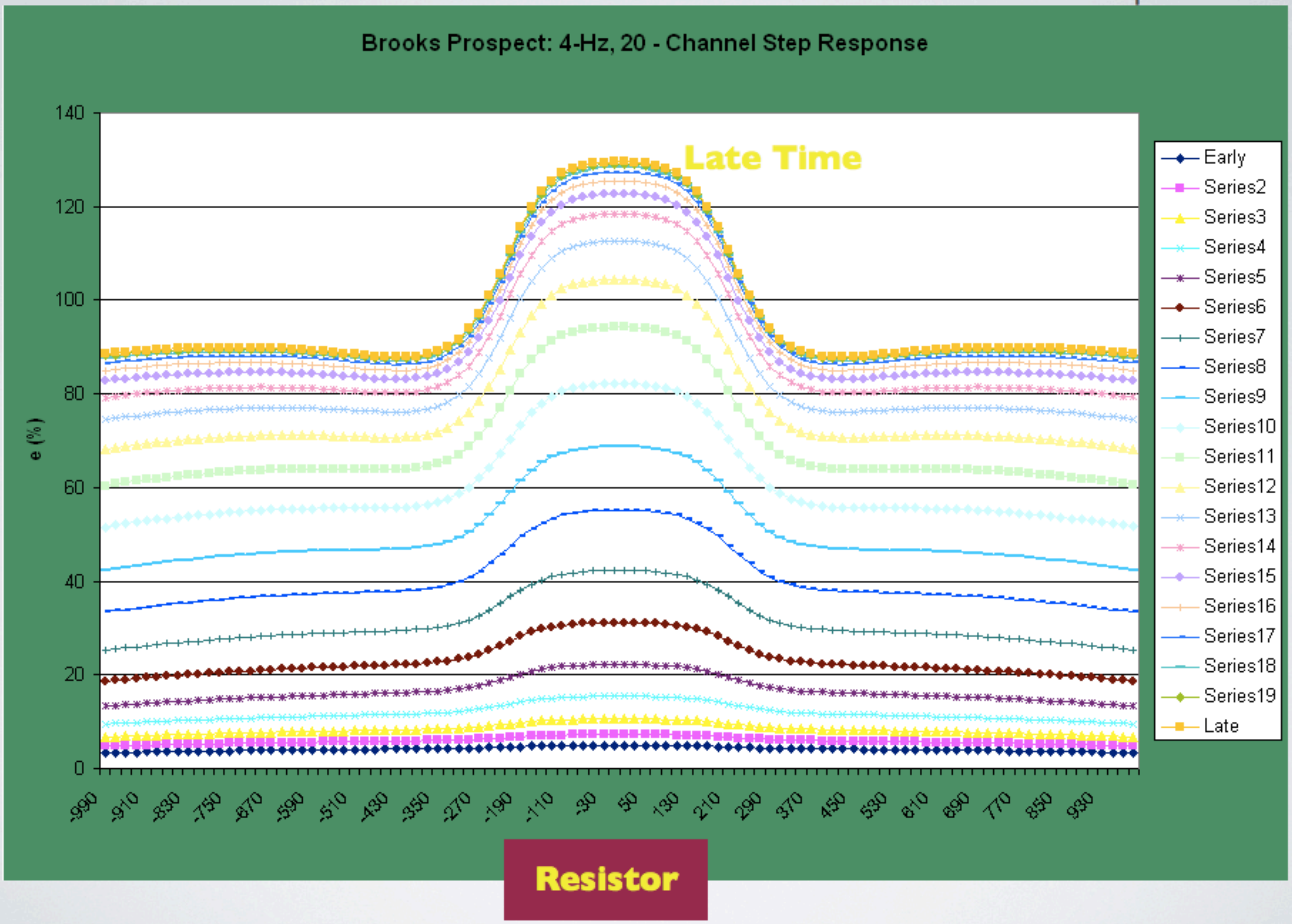
15Hz - Loop 800



Here are the simulated loop 800 data used in the inversion.

BROOKS MODEL

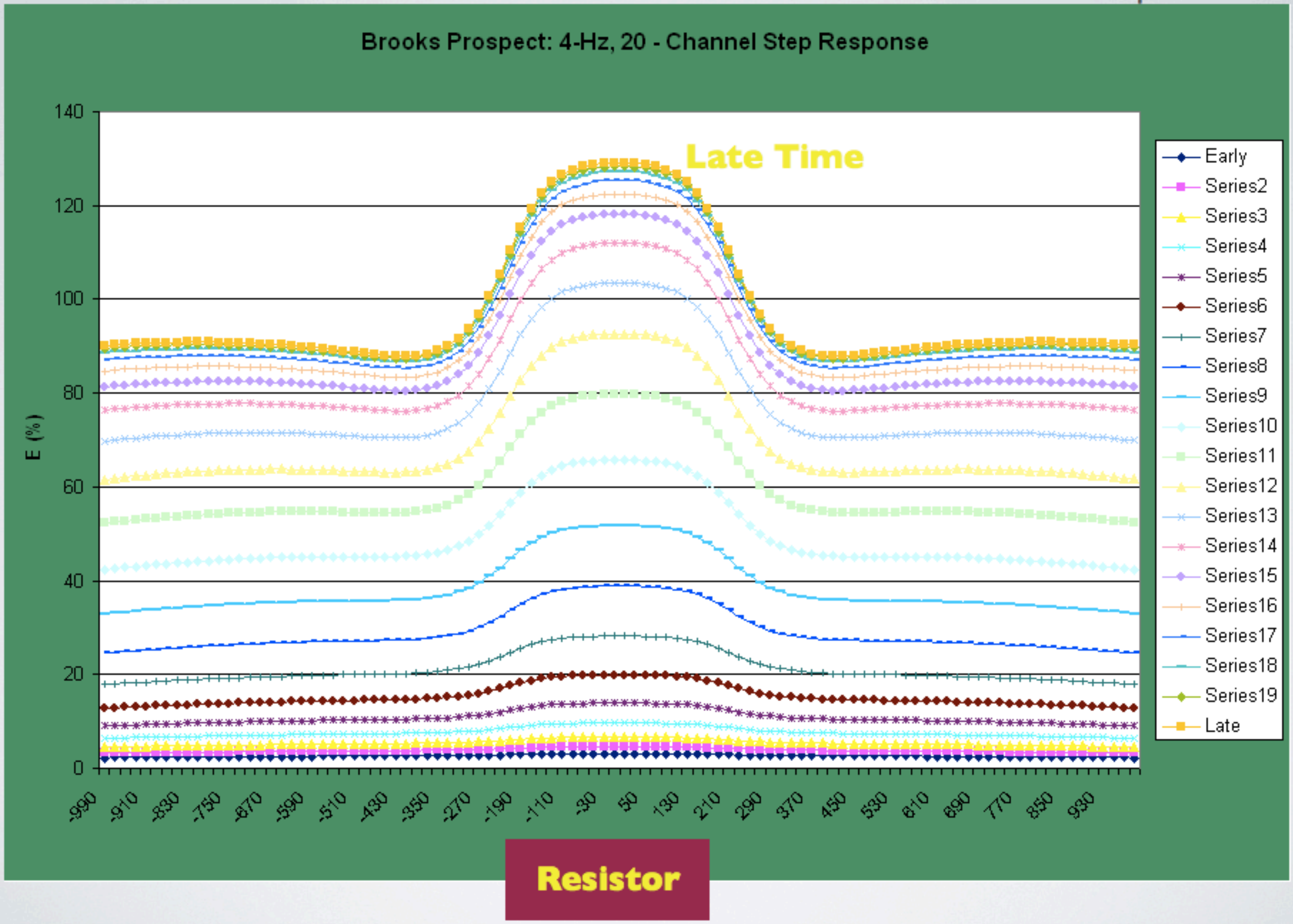
4Hz - Loop 1200



Here are the simulated loop 1200 data used in the inversion.

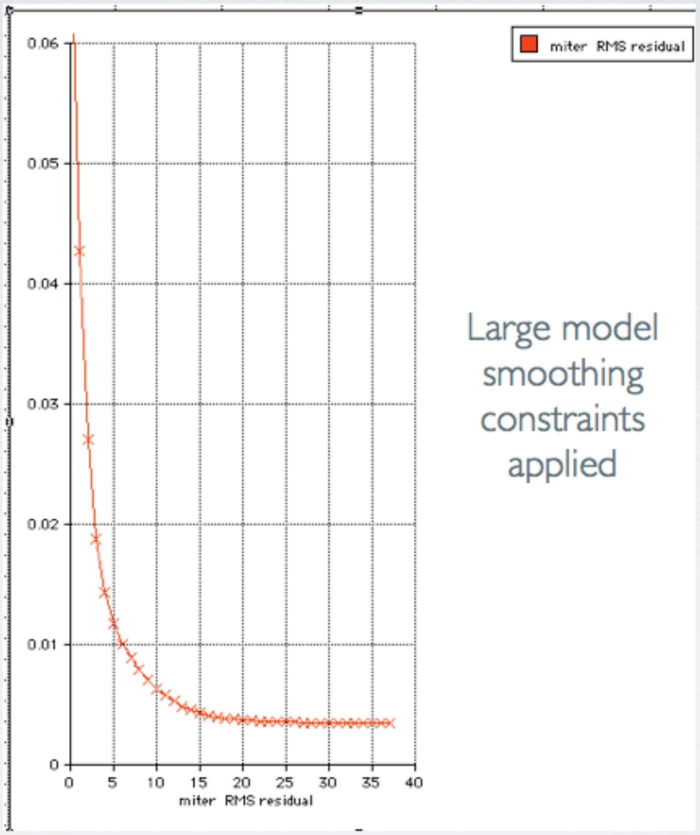
BROOKS MODEL

4Hz - Loop 1600



Here are the simulated loop 1600 data used in the inversion.

BROOKS 4 LOOP ISR INVERSION

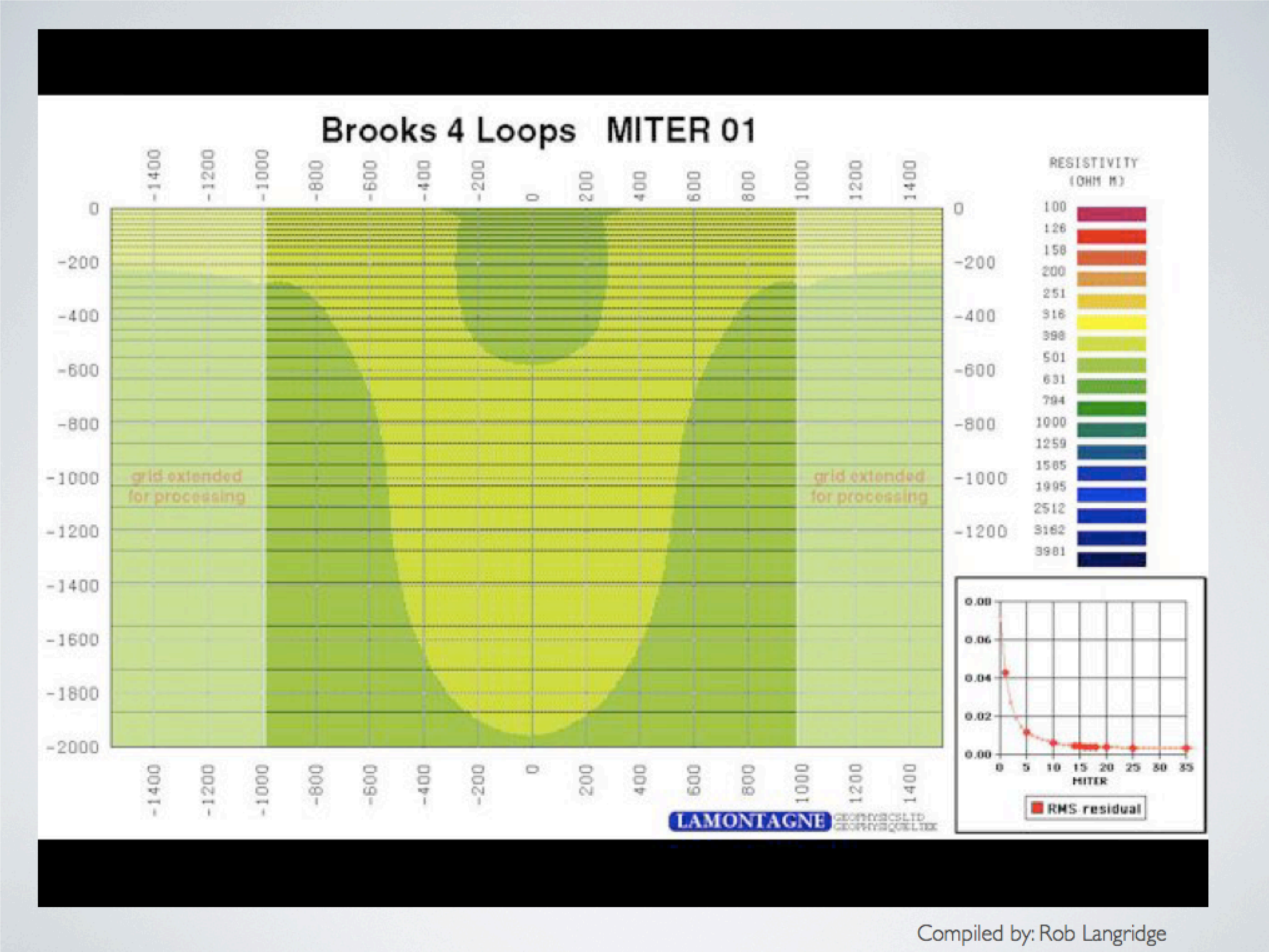


RMS Residual

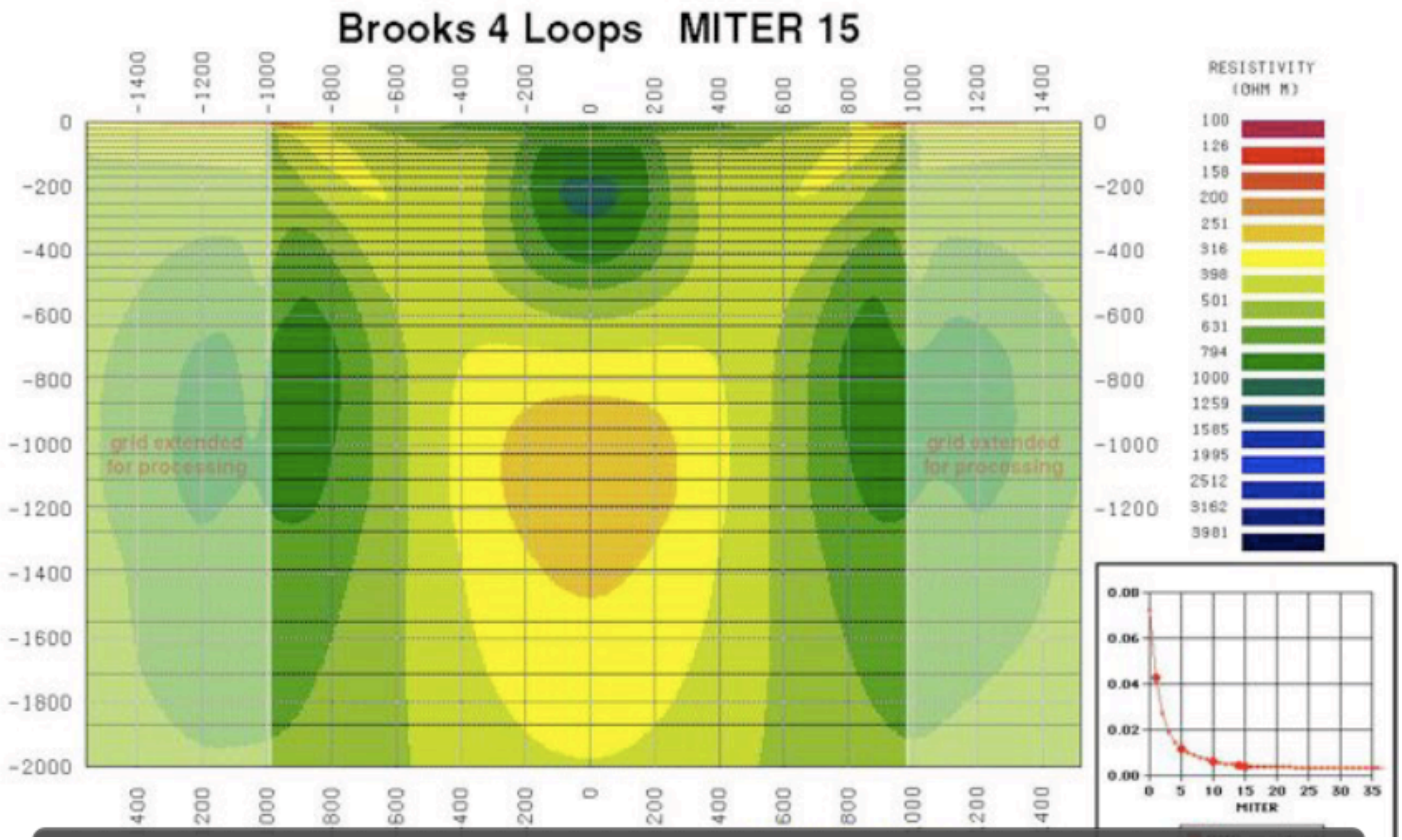
Large model smoothing constraints applied

Iteration Number

Here are the RMS errors computed for each iteration in the inversion. After iteration 20, the RMS error ceases to decrease significantly, and this should be considered to be the optimal model. Later iterations add structure that does not meaningfully decrease the RMS error.

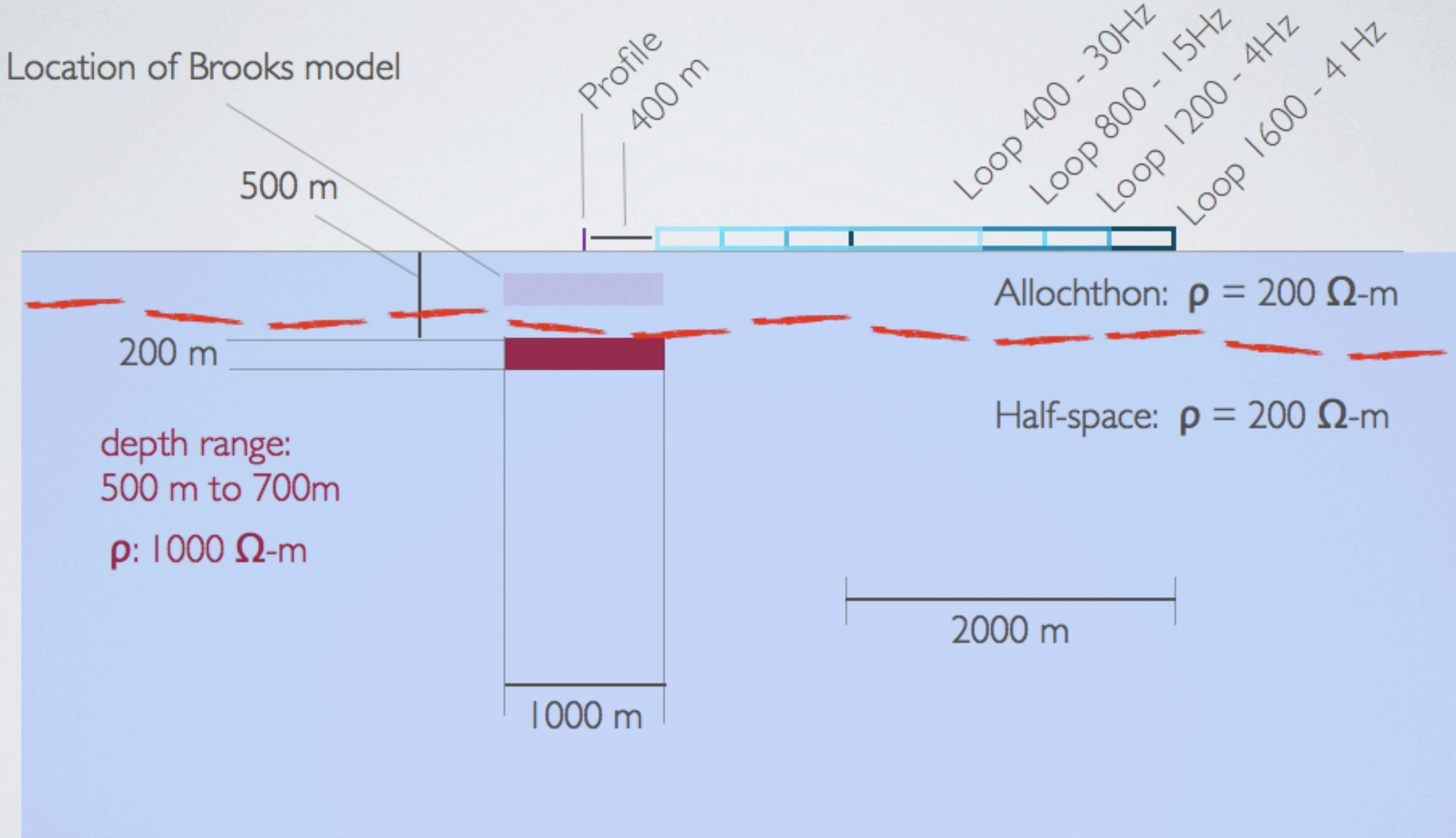


Here is the first iteration of the resistivity inversion. A resistor begins to form in the centre of the profile. The model smoothing constraints are fairly strong.



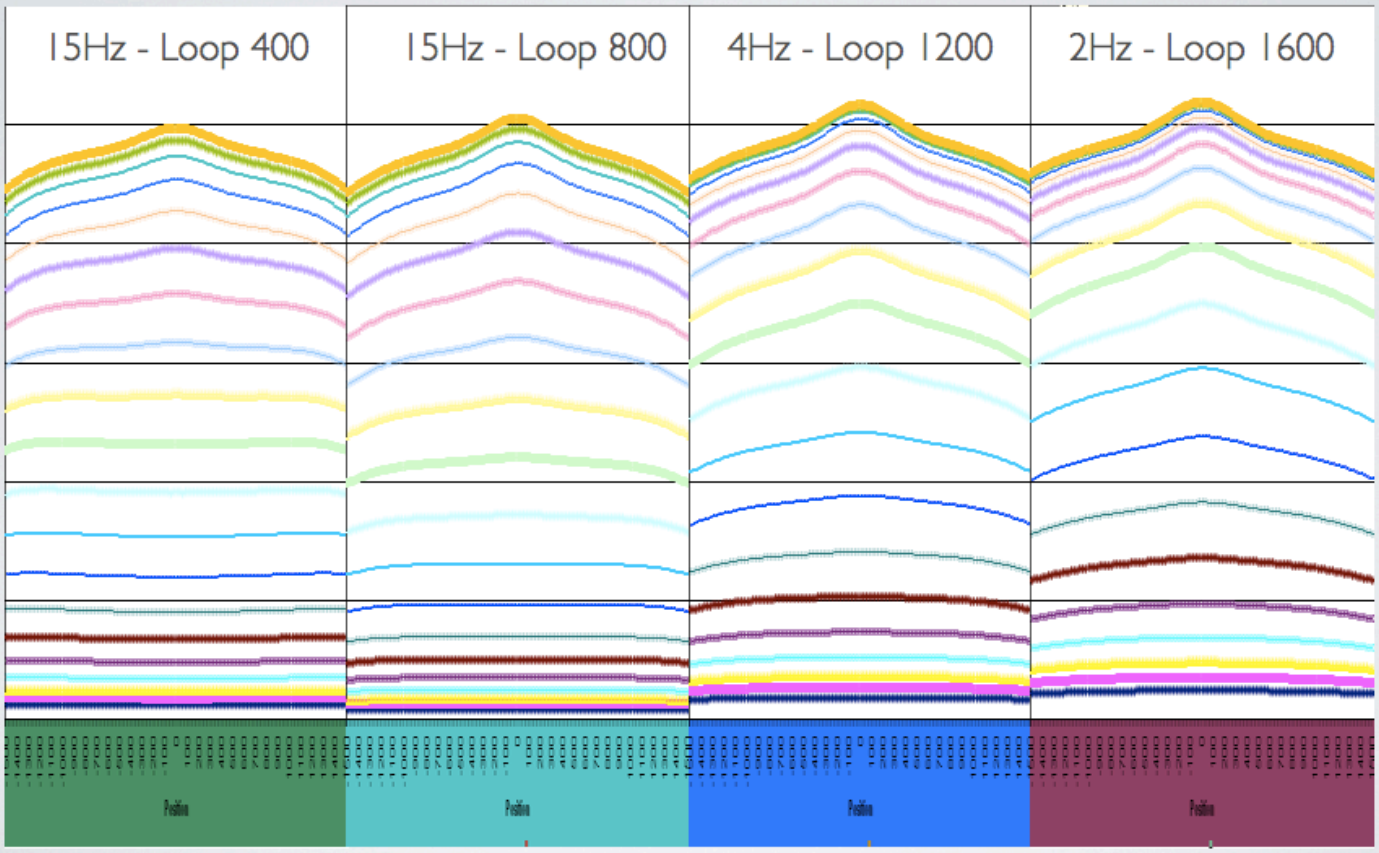
By iteration 15, the resistor has formed with a flat top at 100 meters depth. It works pretty well, but there is some structure in the background that is probably the result of long wavelength errors in the fit to the response of the resistor because strong model smoothing constraints have been applied.

BROOKS OVERTHRUST MODEL



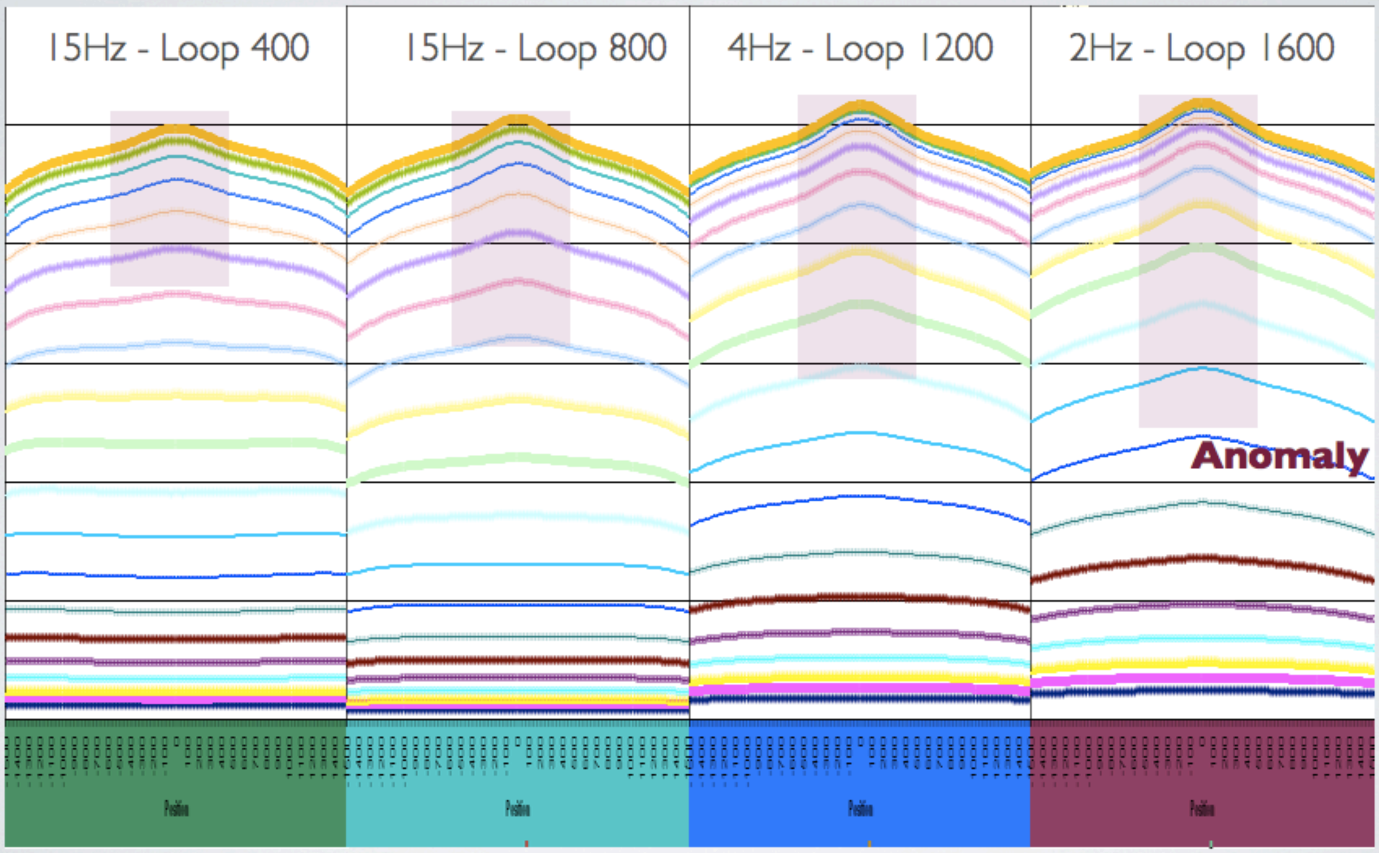
Now the resistor is dropped to a depth of 500 meters to its top to simulate the response of a Brooks-like resistor under an overthrust allochthon. Can such a resistor be detected by ISR at this depth? If so, perhaps detecting a Twin Creeks deposit at this depth is also possible.

BROOKS OVERTHRUST MODEL
ISR RESPONSE



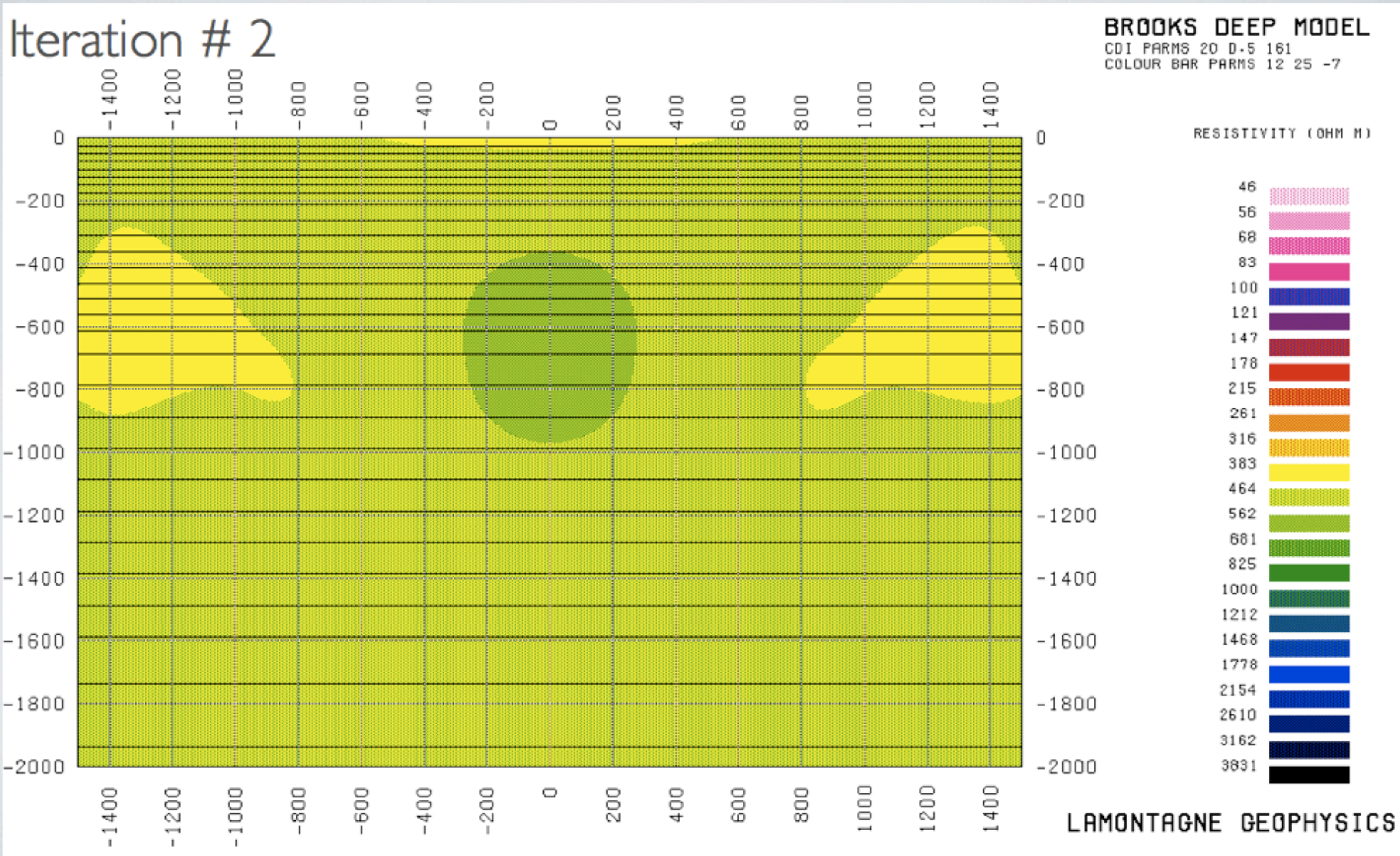
The same loops are used in this simulation as in the previous model. Even at 500 meters depth, the anomaly caused by the resistor is clearly visible. The early time, near loop data are constant (left panel, low amplitude data), reflective of a half-space response until the time where diffusion reaches the resistor, near the light blue profile. Full scale is 120%.

BROOKS OVERTHRUST MODEL
ISR RESPONSE



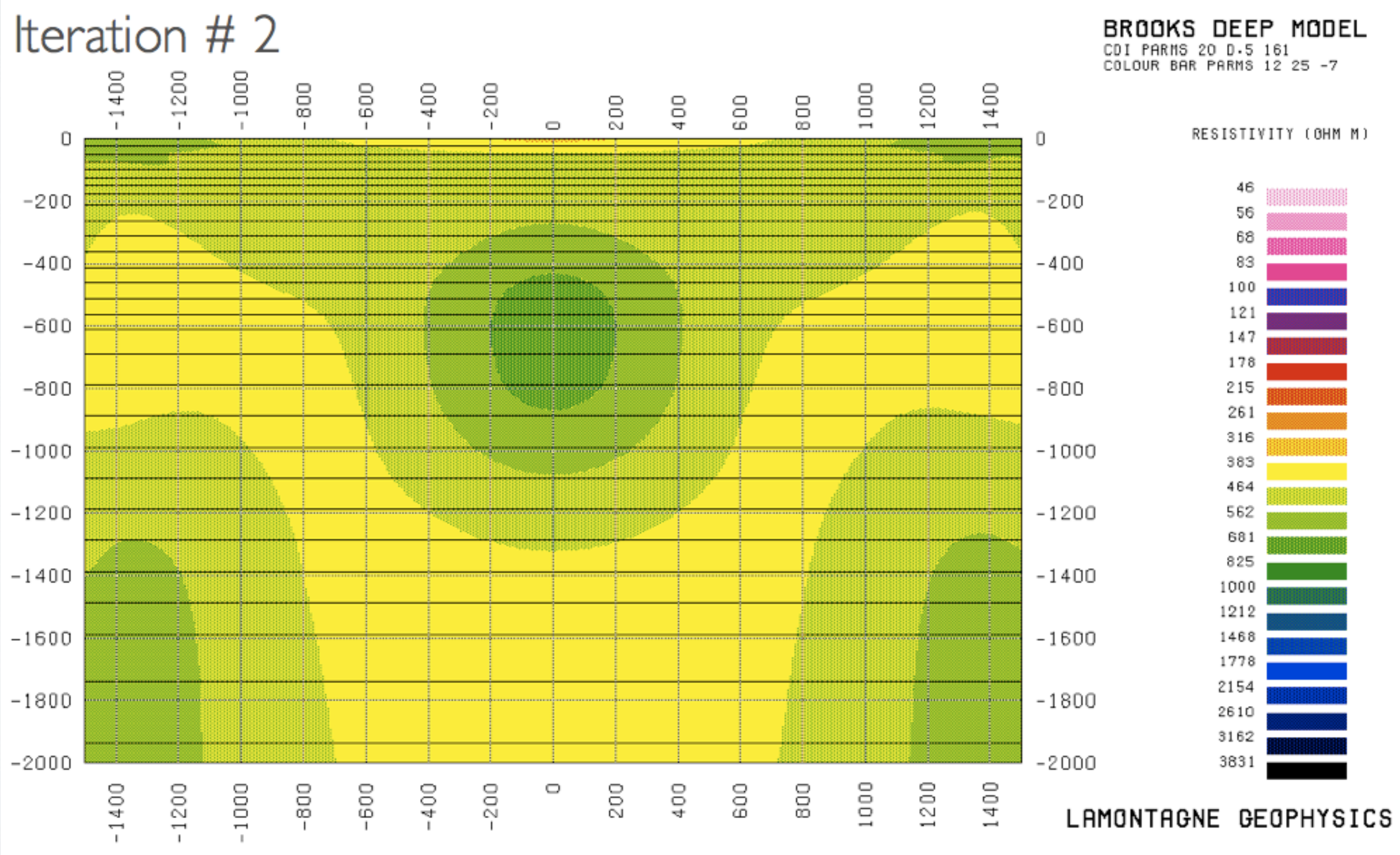
The anomaly is highlighted.

BROOKS OVERTHRUST MODEL
ISR INVERSION



The simulated data in the previous panel are now inverted; here the resistor begins to form.

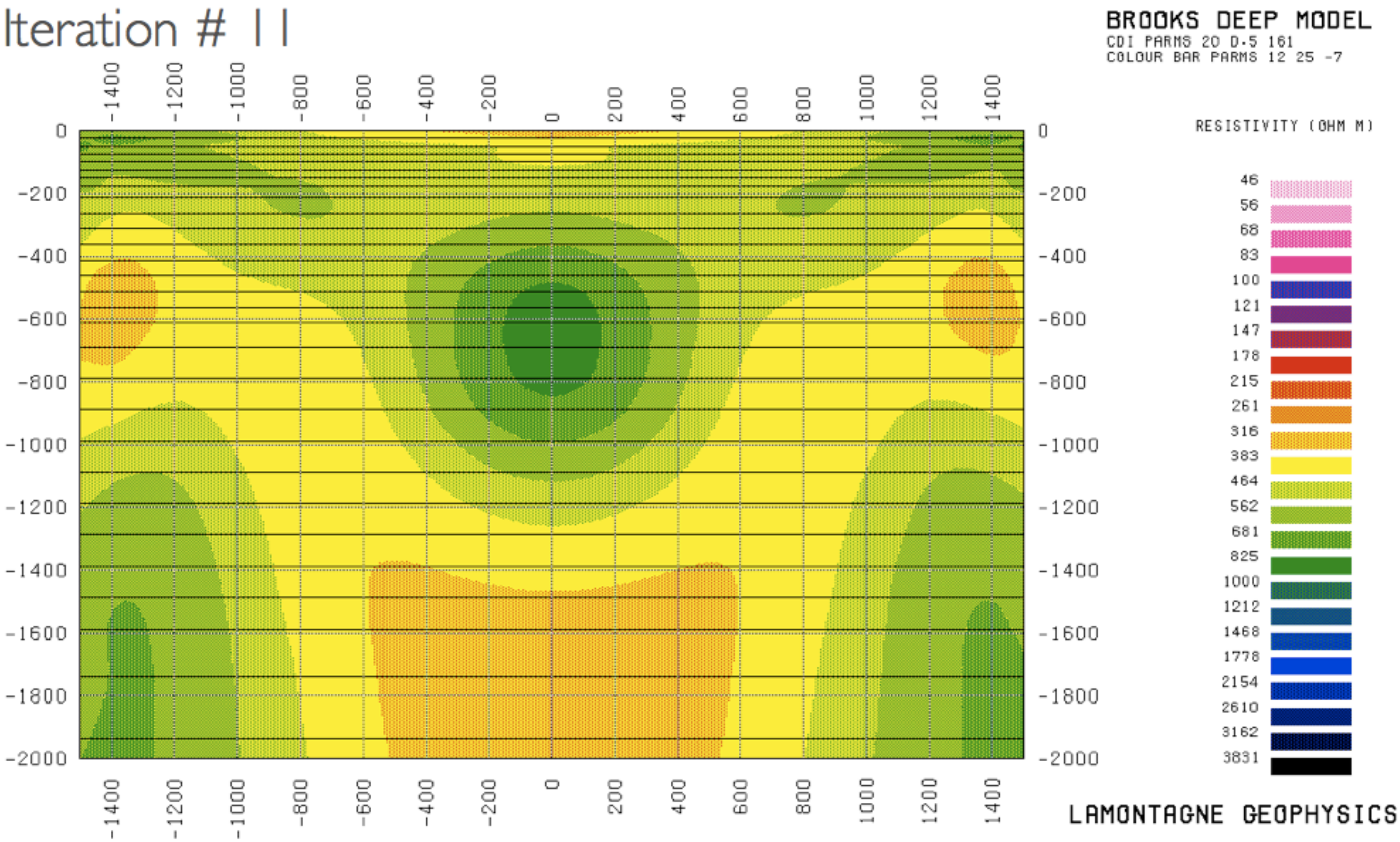
BROOKS OVERTHRUST MODEL
ISR INVERSION



As the inversion proceeds, the resistor develops.

BROOKS OVERTHRUST MODEL
ISR INVERSION

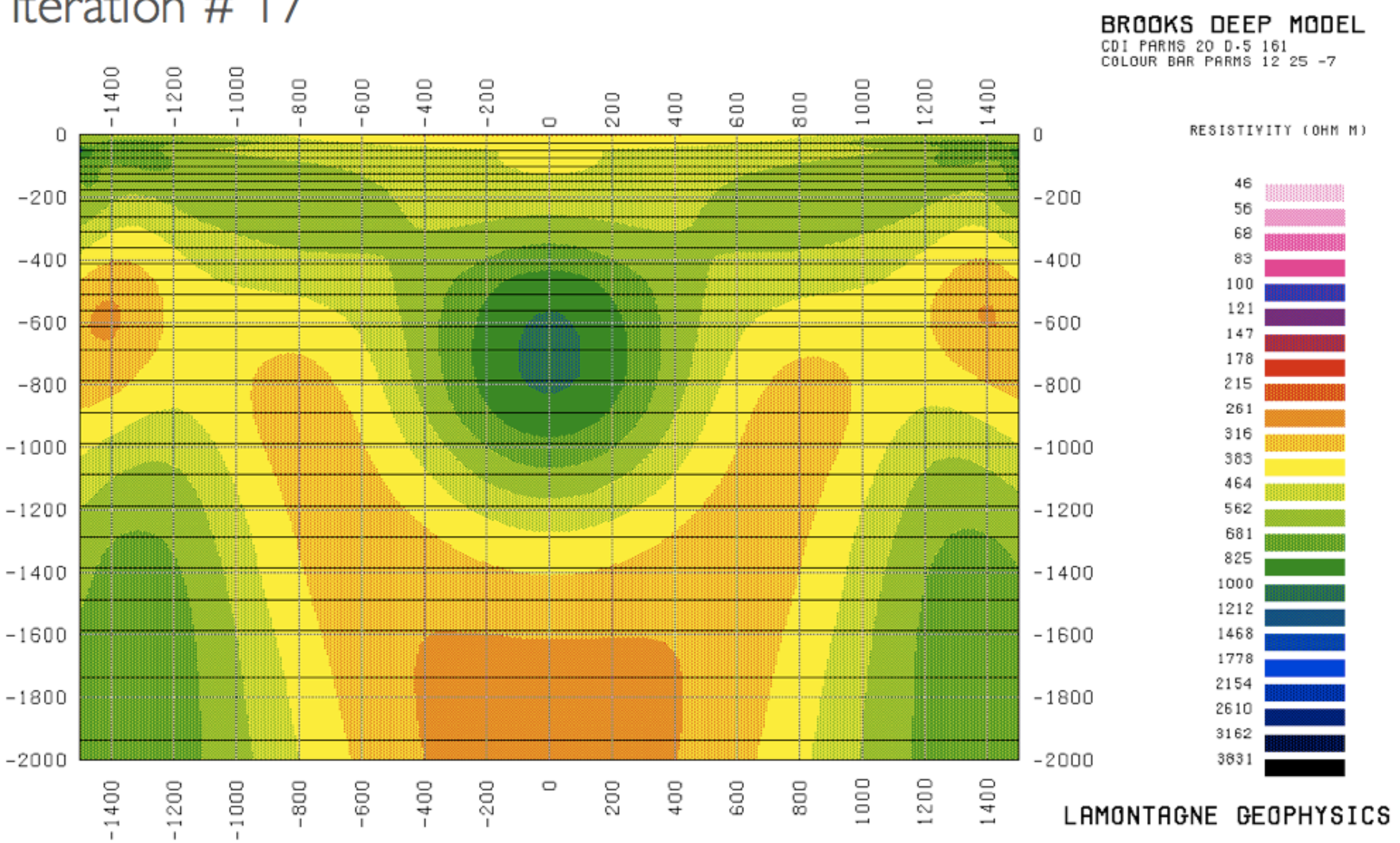
Iteration # 11



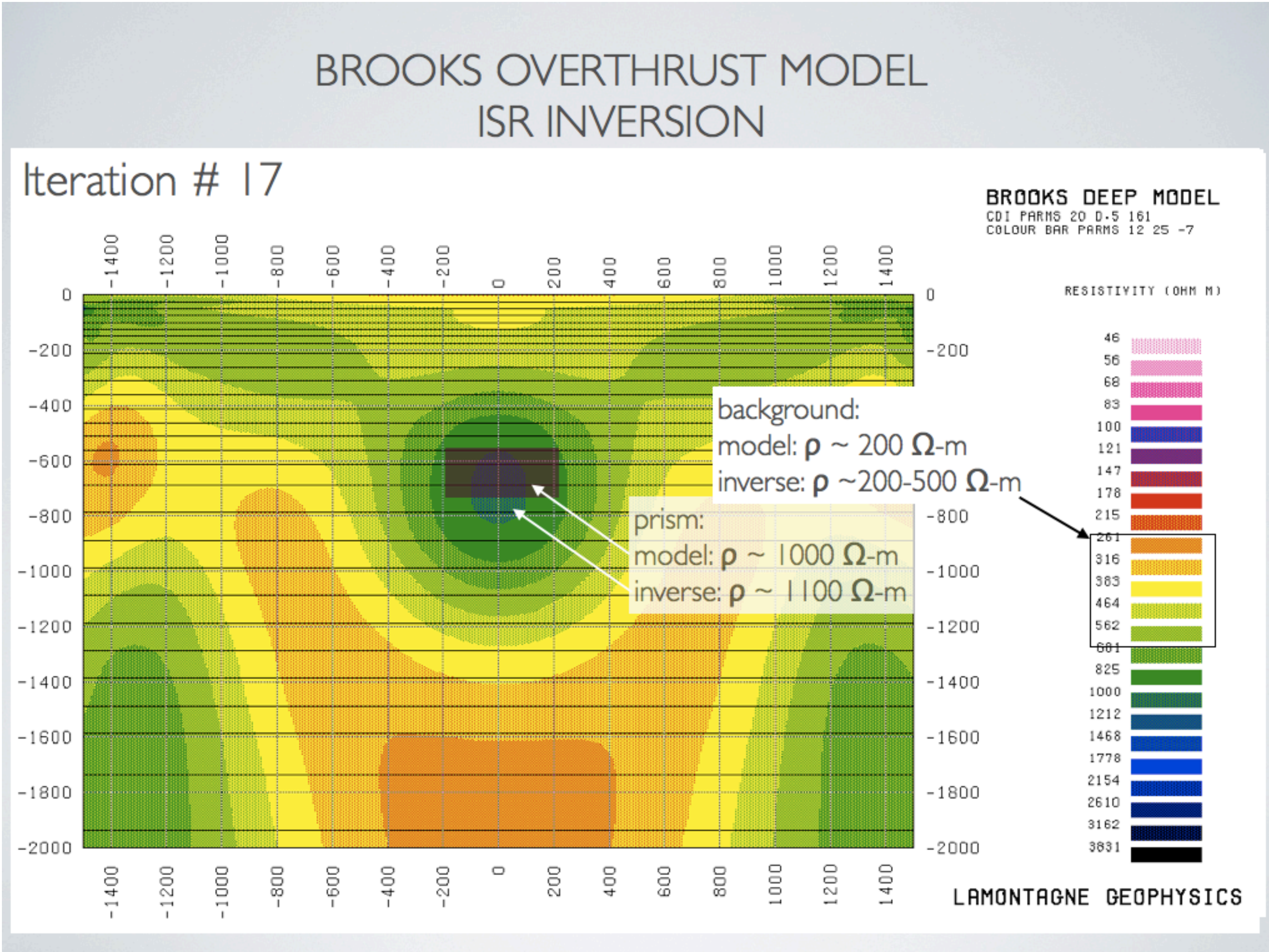
A resistive core forms between 500 and 800 meters in depth.

BROOKS OVERTHRUST MODEL
ISR INVERSION

Iteration # 17

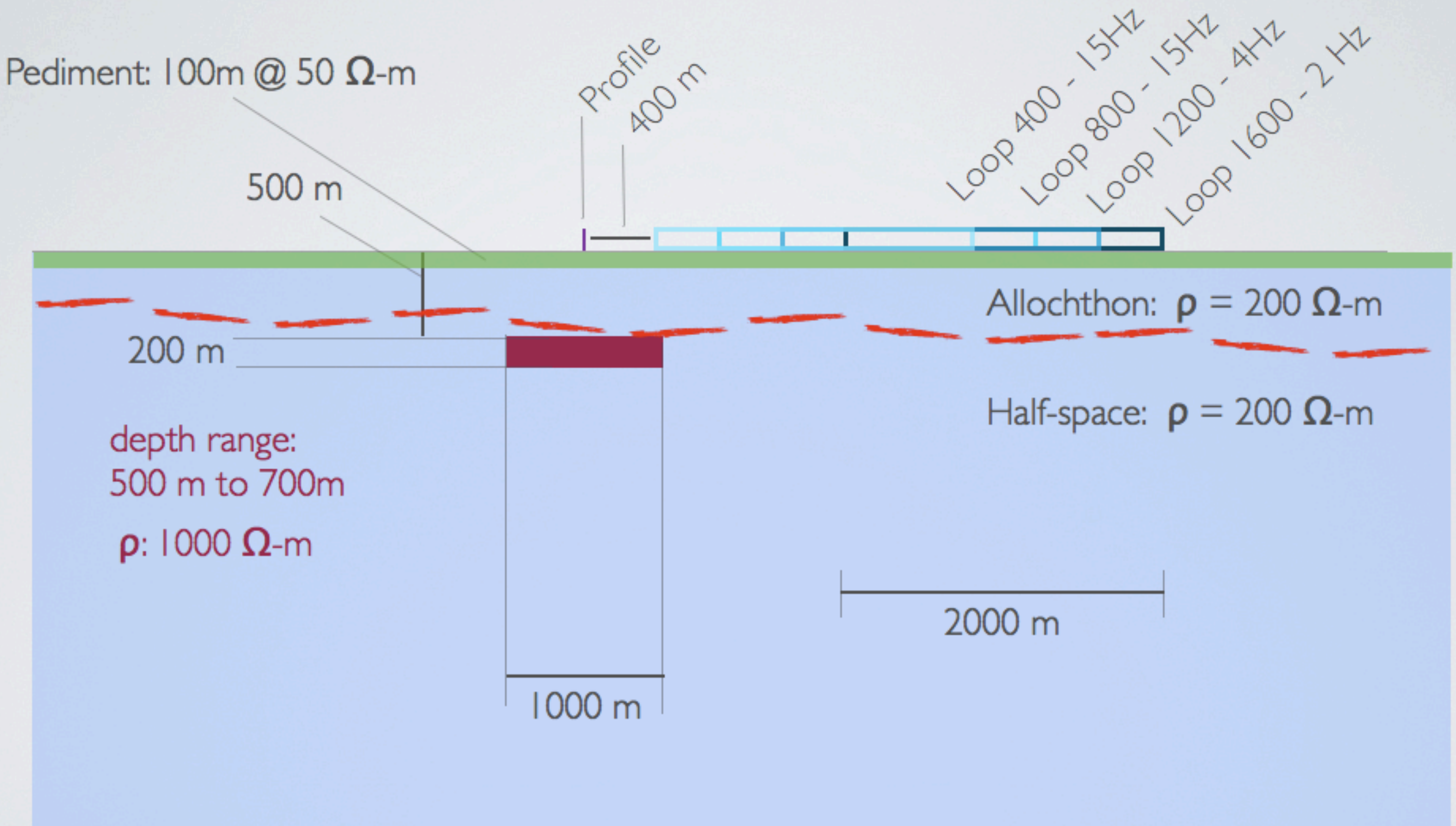


The best model, where the RMS error begins to flatten out produces a resistor at approximately 550 - 800 meters depth.



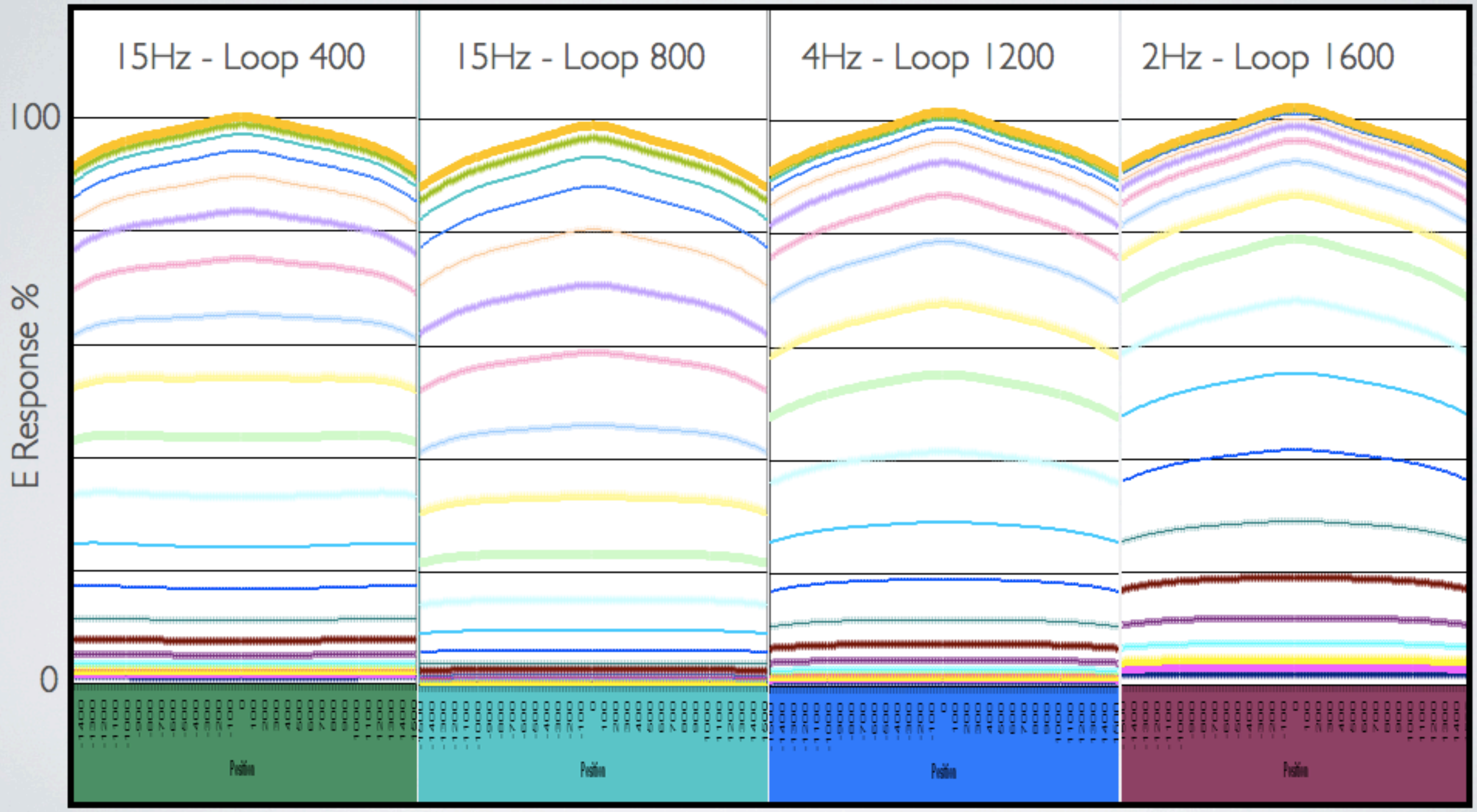
A comparison with the original model shows a reasonable fit. The background resistivity is somewhat overestimated, and some of the residual resistive structure in the background is due to long wavelength errors in fitting the principal anomaly from the resistor. It is clear that ISR is sensitive to a Brooks-type resistor at 500m depth.

BROOKS OVERTHRUST + PEDIMENT MODEL



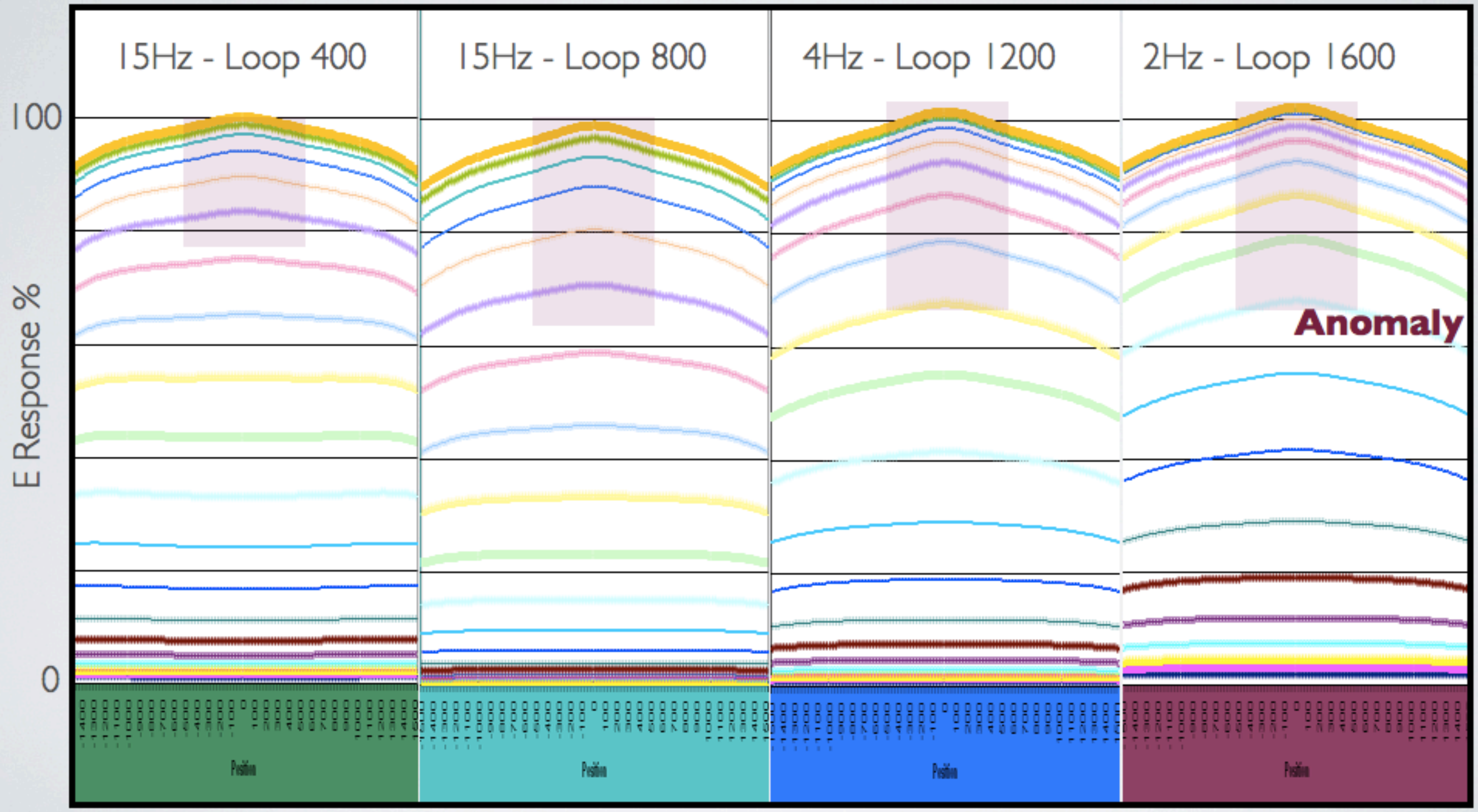
Next, a conductive layer is added to simulate pediment. Can a Brooks type resistor be seen under a thick overthrust covered by conductive pediment sediments? If so, deep exploration under pediment areas may be possible.

BROOKS PEDIMENT + OVERTHRUST MODEL ISR RESPONSE

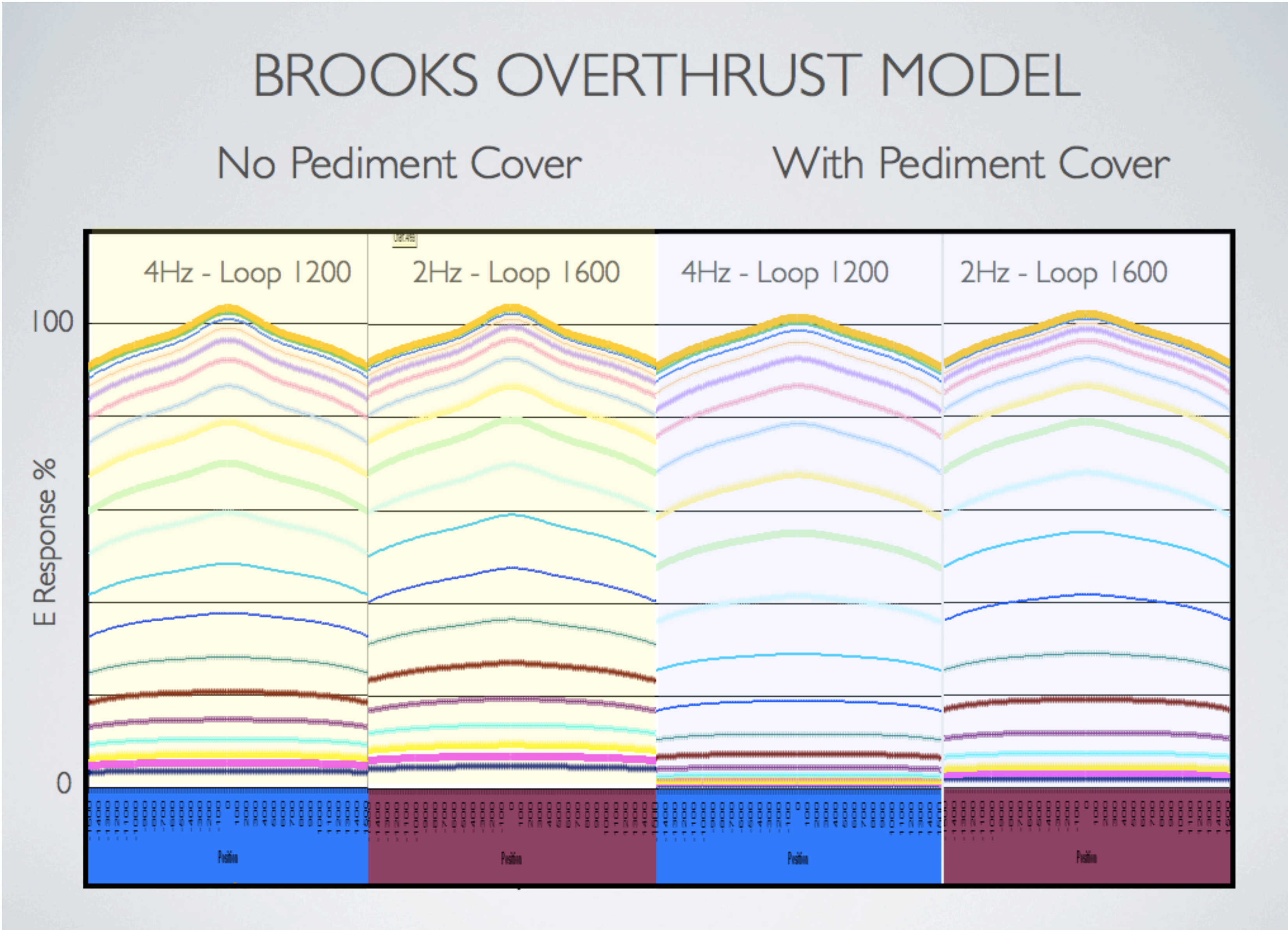


Here are the simulated data. As in the previous case, the anomaly is visible but not as sharp.

BROOKS PEDIMENT + OVERTHRUST MODEL ISR RESPONSE

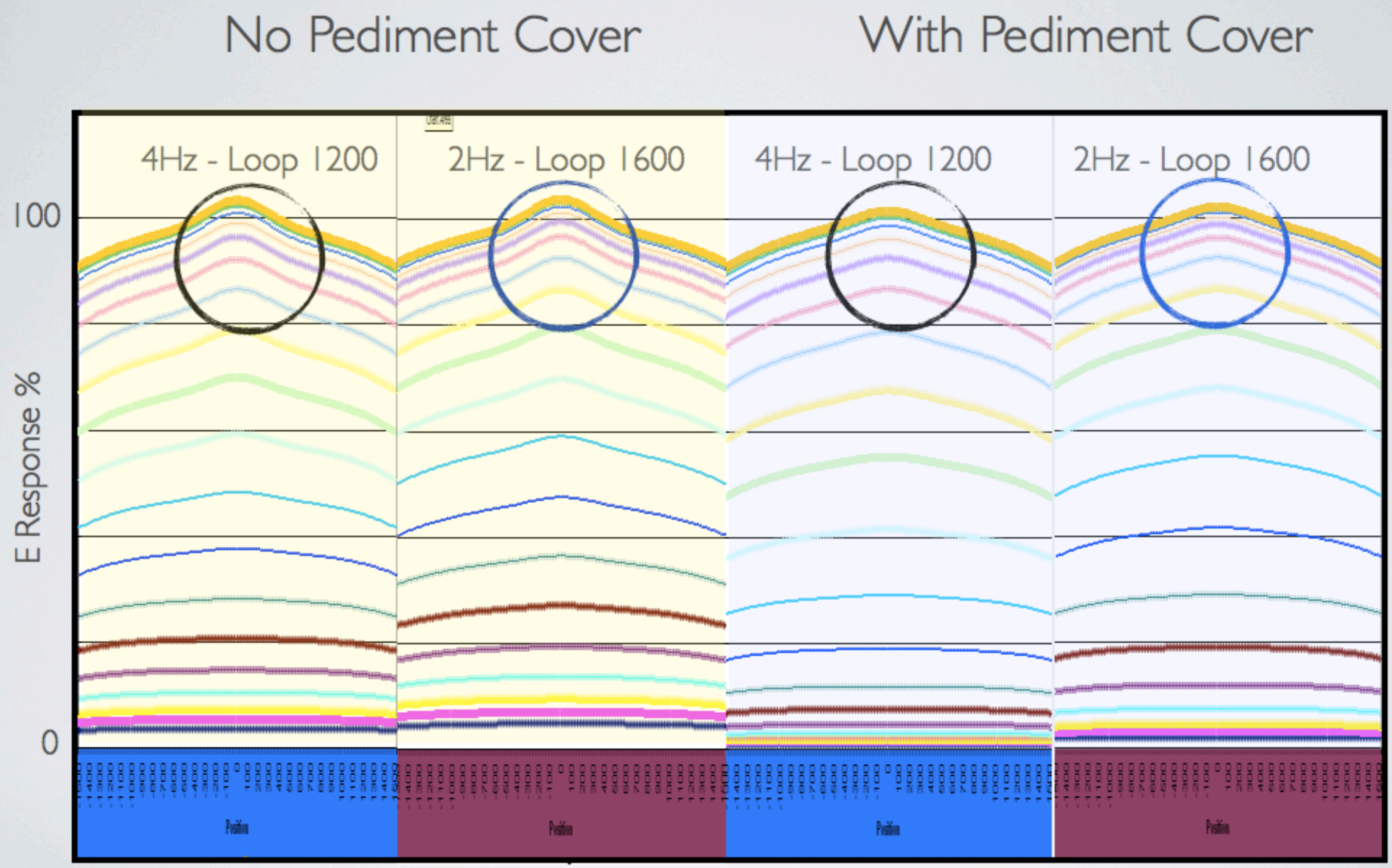


The anomalous parts of the simulated data are highlighted.

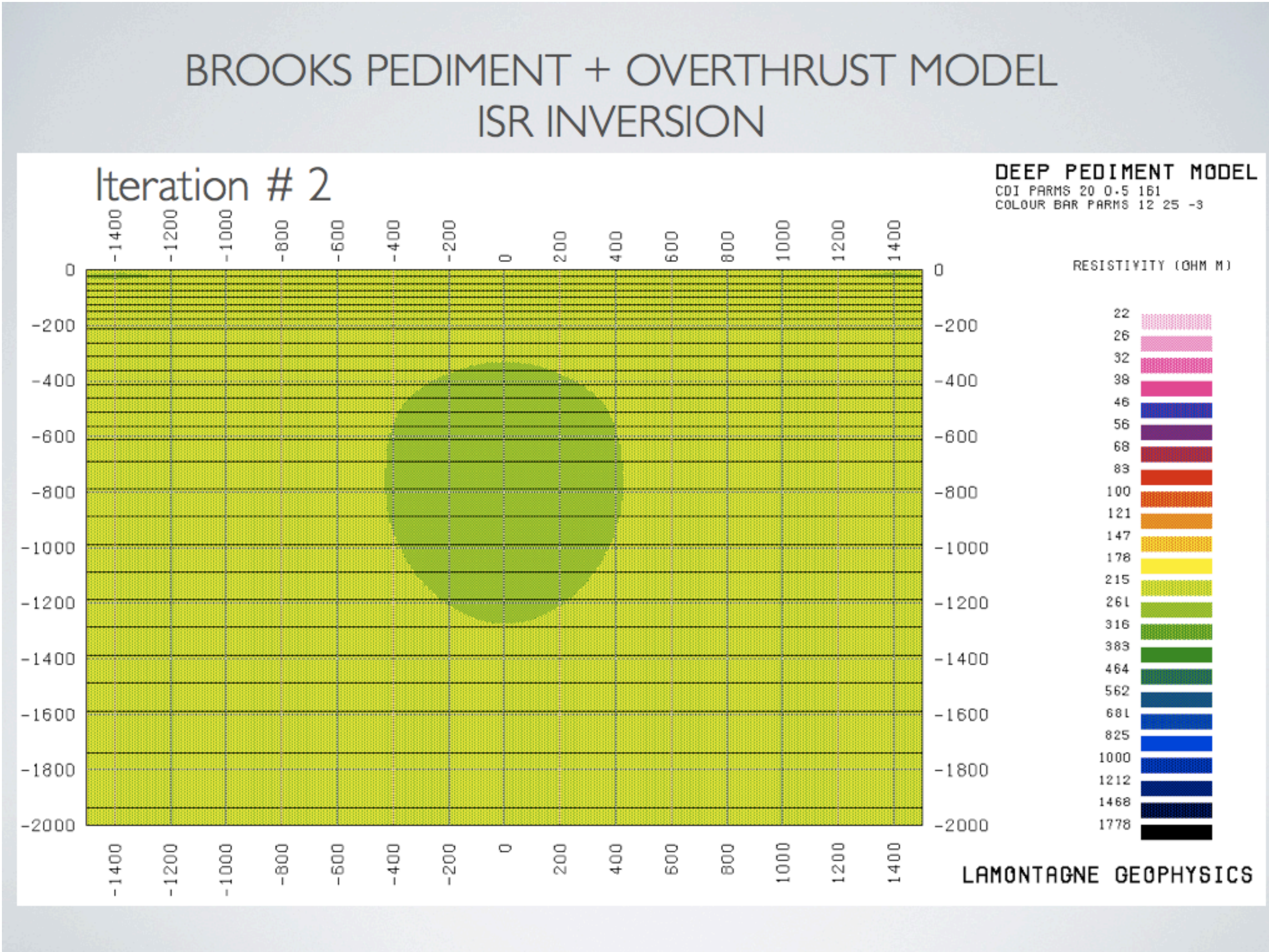


A comparison with the previous model illustrates the effect of the pediment cover. The pediment profiles are more rounded, indicating some detailed (high wavenumber) geometric information about the resistor has been either lost or dispersed. The pediment also delays the response, particularly in the loop 1200 data (compare equivalent coloured profiles in the 1200 m offset loop data with and without the pediment cover).

BROOKS OVERTHRUST MODEL

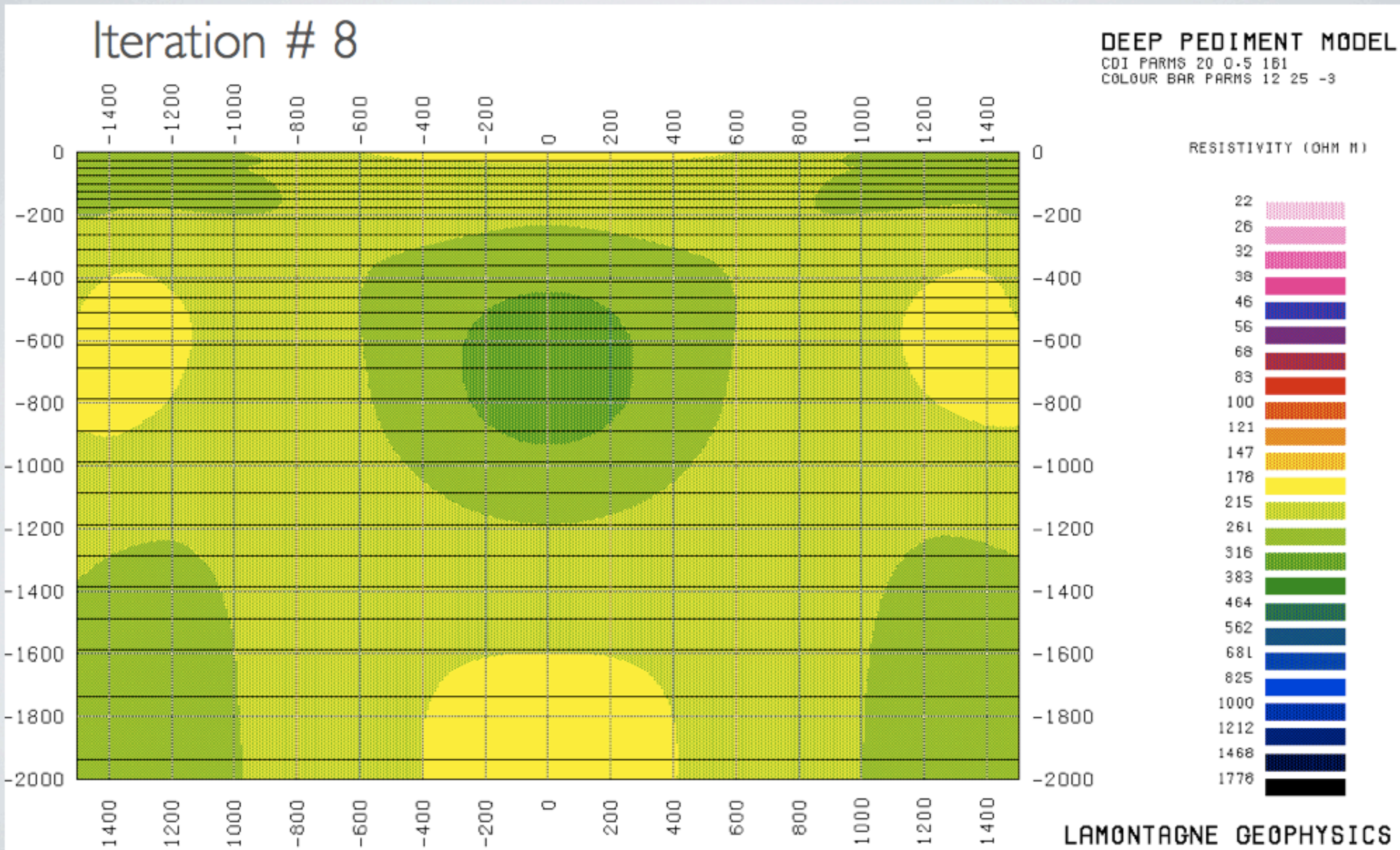


The anomalies from each loop offset are highlighted in the same colour.



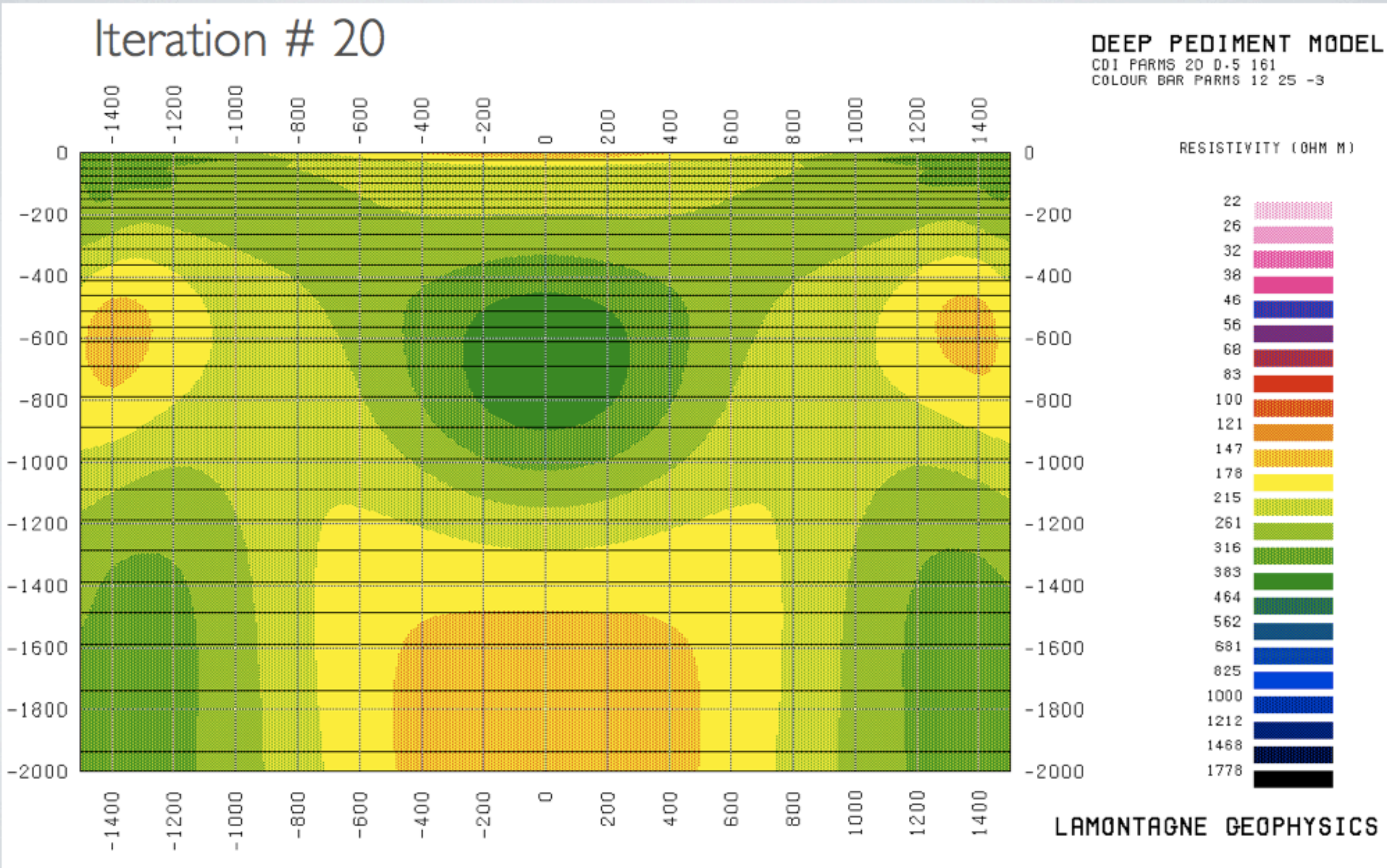
As the inversion begins on the simulated pediment data, a resistor begins to form.

BROOKS PEDIMENT + OVERTHRUST MODEL
ISR INVERSION

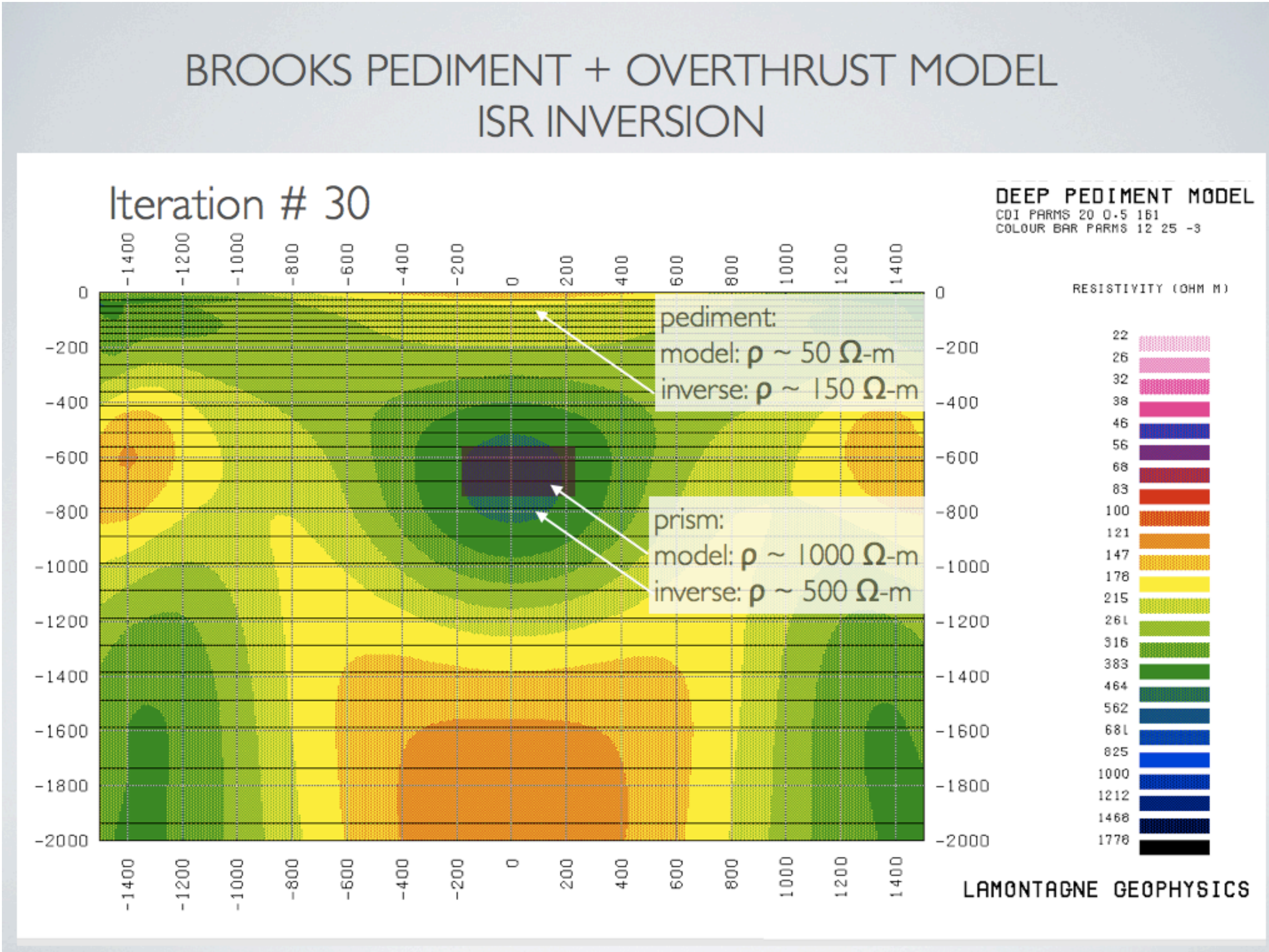


Here is the result after iteration 8.

BROOKS PEDIMENT + OVERTHRUST MODEL
ISR INVERSION



The inversion is not as convergent as in the previous model. The conductive pediment has made the anomaly information more diffuse, so the resistor is more difficult to reconstruct.



By iteration 30, the optimal inversion has been reached. The resistance of the anomaly is underestimated and that of the pediment is overestimated. Nevertheless, the resistor is identified.

CONCLUSIONS

- Reconnaissance mode 65-Hz ISR is a rapid, low cost method for detecting prospective mineralization under 100 m of pediment
- Once detected, ISR can image and map a Brooks type target at a favourable cost
- A Brooks type anomaly would generate a measurable ISR response under a 500 m overthrust

.....previously blind, deep deposits may be detectable

Modelling based on measured target parameters has shown that ISR is a viable method for mapping Brooks-type resistors under conductive pediment. Such resistors can be easily detected with 65-Hz reconnaissance mode profiling surveys at depths of 100m, and modelling indicates that ISR will respond to Brooks type resistors under 500 meters of overthrust. Thus it may be possible to detect Twin Creeks type deposits at depth in the Battle Mountain area using ISR. ISR could potentially extend the mineralization trend stopping a Cortez Hills, as well as other trends terminated by thick overthrusting.

ACKNOWLEDGEMENTS

Lamontagne Geophysics

Yves Lamontagne - inversion and figures

Rob Langridge - figures and video

Ted Chew - utilities

Marigold Mine

James Carver - gold geology

Pioneering work

Jim Macnae, Dick Irvine, Pat McGowan

This work was only possible due to the significant contributions of the people mentioned above. The modelling was done with Marco, a computer simulation code produced by AMIRA. ISR surveys are offered by Lamontagne Geophysics Ltd.