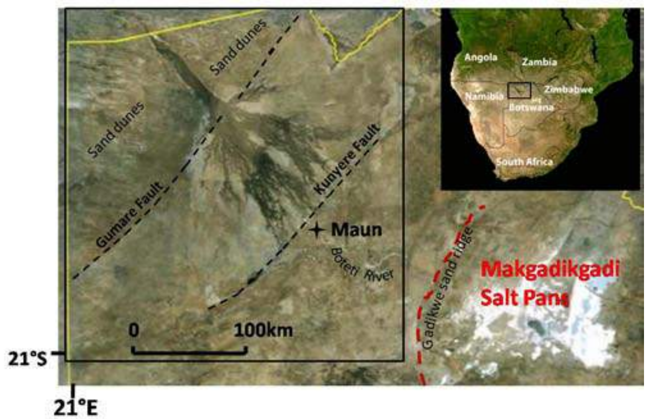
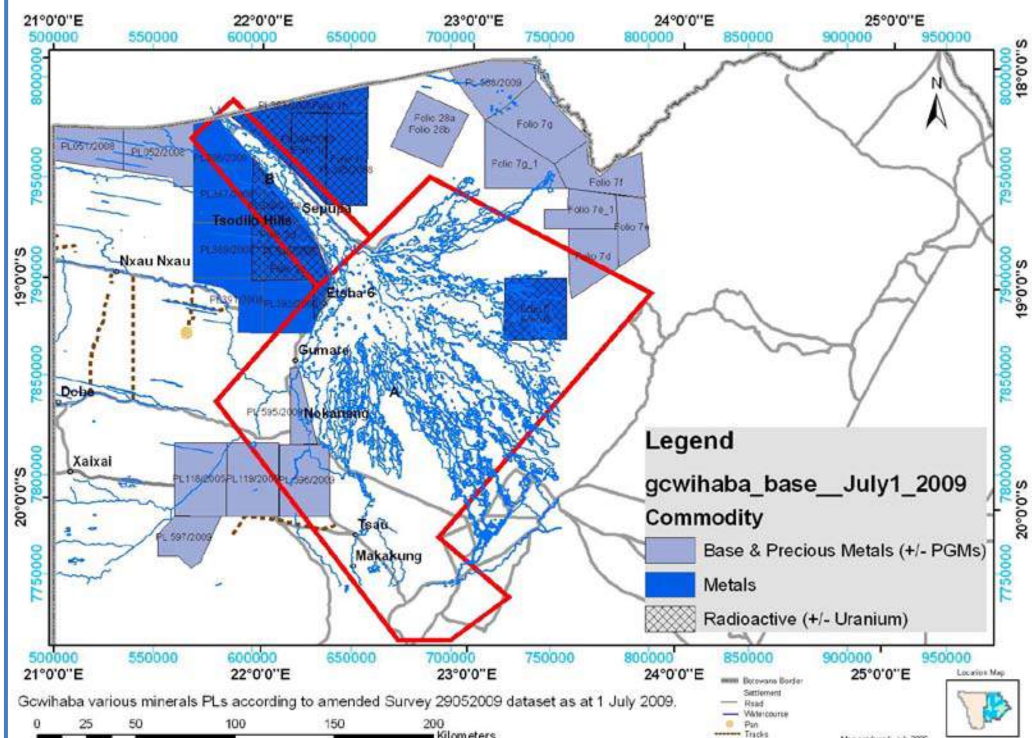
Application of airborne and ground geophysical methods for base metal exploration in the NW part of the Ngami Region – Botswana. [Tsodilo Prospect]



Located northwest of the nascent Okavango Rift Basin (ORB).

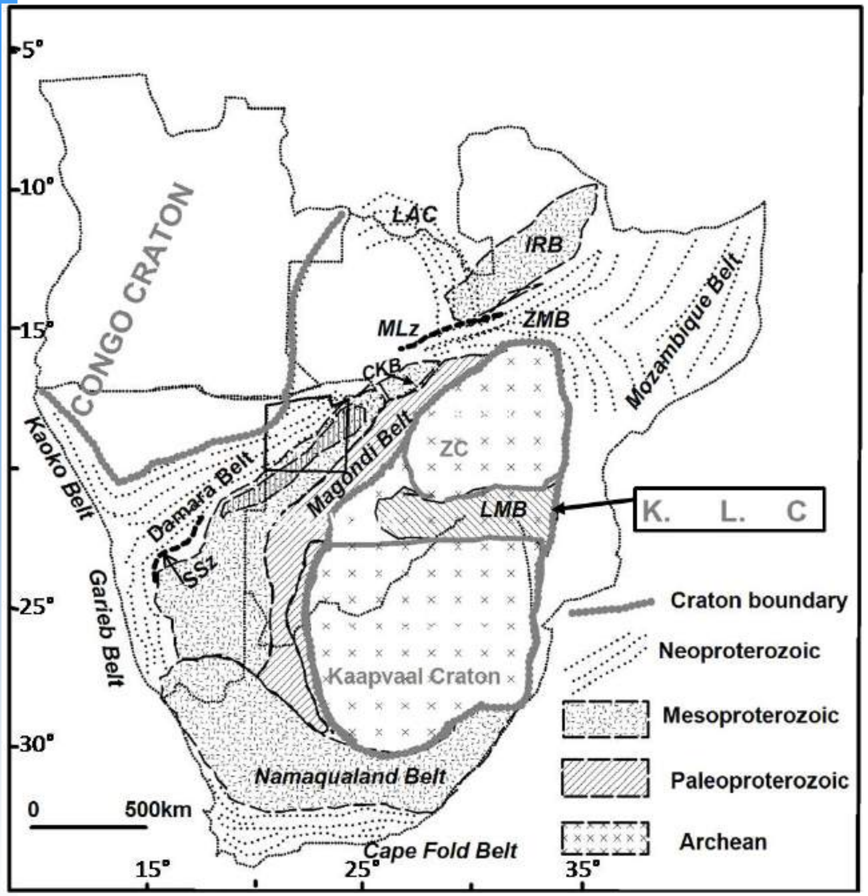
The ORB is bounded by the Gumare Fault (G) to the northwest and the Kunyere Fault to the southeast.



- Sulfides were discovered in this prospect while doing Kimberlite exploration.
- We will focus more on part of the prospect covered by Versatile Time-domain Electromagnetic Method (VTEM).

Geological Background

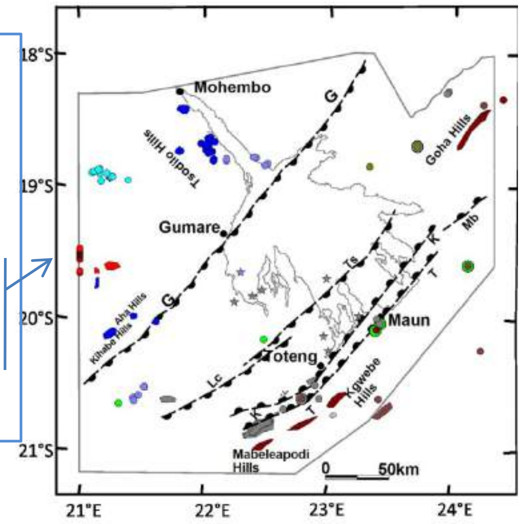
Regional Tectonic Setting

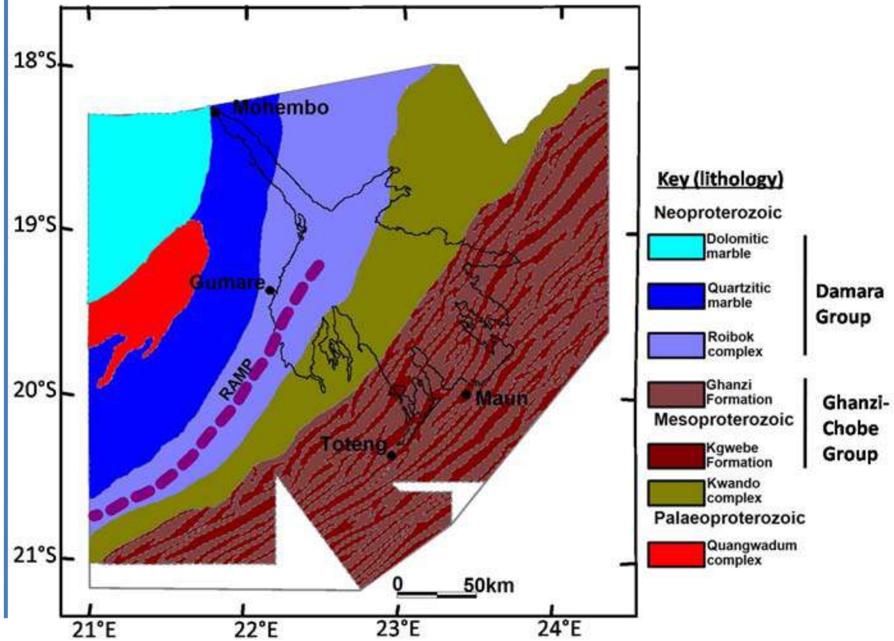


Located within the Neoproterozoic Damara Belt .

Geology is mostly covered by sand.

Simplified geological map derived from drillhole data, scatered outcrops and regional magnetic surveys.





FALLS WITHIN THE DAMARA MOBILE BELT [e.g., Key 2000 and Singletary et al, 2003]

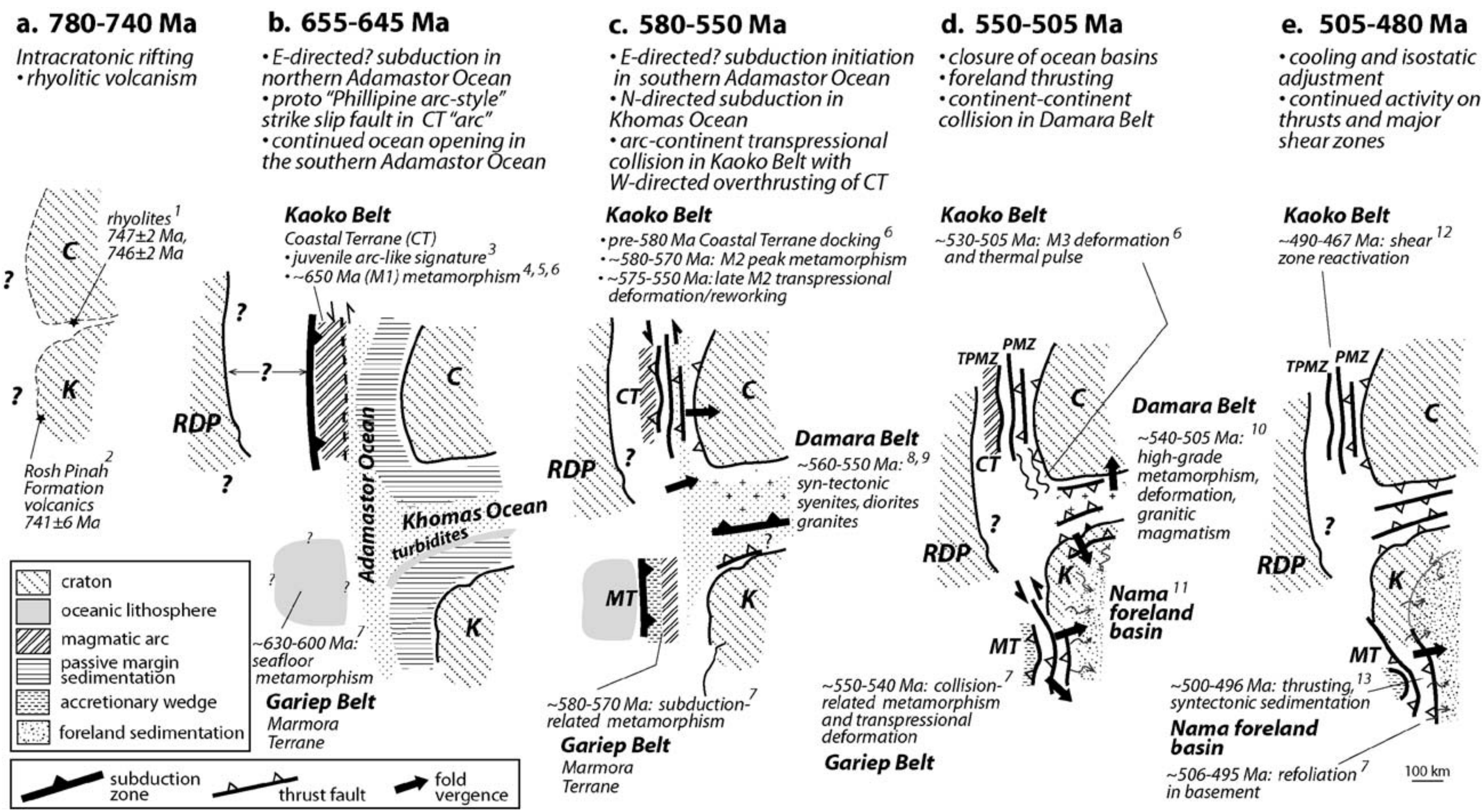


ILLUSTRATION OF RIFTING AND CONSEQUENT REVERSAL DURING THE NEOPROTEROZOIC ERA THAT LED TO THE DAMARA OROGENESIS. [From Gray et al, 2006]

The following make rift structures sites of good potential for mineralization:

They are often sites of thick clastic sedimentation – hold vast amounts of brines which may get into contact with reducing sediments; carbonaceous shales (ready supply of sulphur/sulphate). This makes them highly corrossive. Brines get expelled during diagenesis and move up the rift faults and in the process leach up considerable amounts of metals. Cooling of the brines as they rise up the faults leads to precipitation of metals. Presence of oxidising meteoric waters penetrating down the rift faults enhances metal precipitation due to mixing.

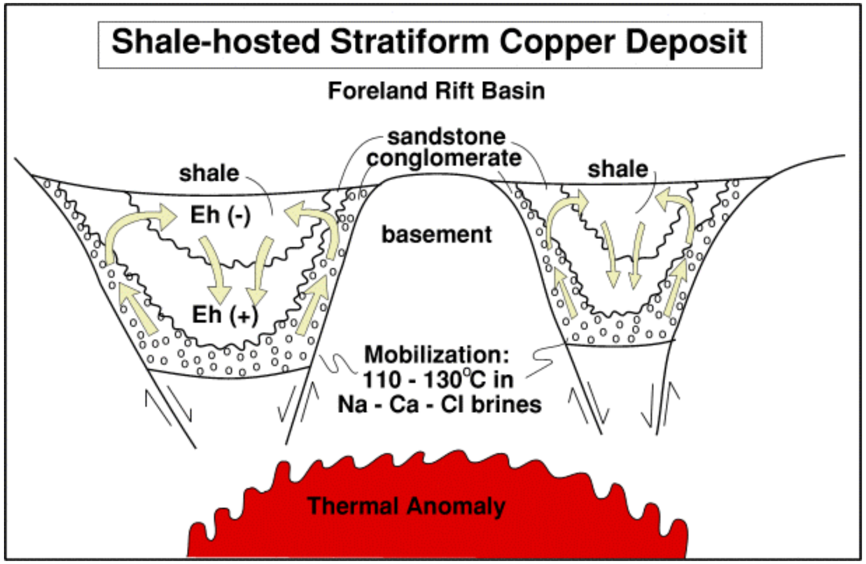


Figure from: http.le.ac.uk/geology/art/gl209/lecture3/lecture3.html

Thermally anomalous hot zones– underlain by igneous intrusions. The magmatic heat drives the hydrothermal systems and may last for several millions of years, leading to ample time for metal leaching from the rift system.

Rift zones may be sites of diverse rocks – in particular basaltic lavas which can release metals due to hydrothermal alteration. The deep seated nature of major rift faults allows for a component of deep fluids and metals.

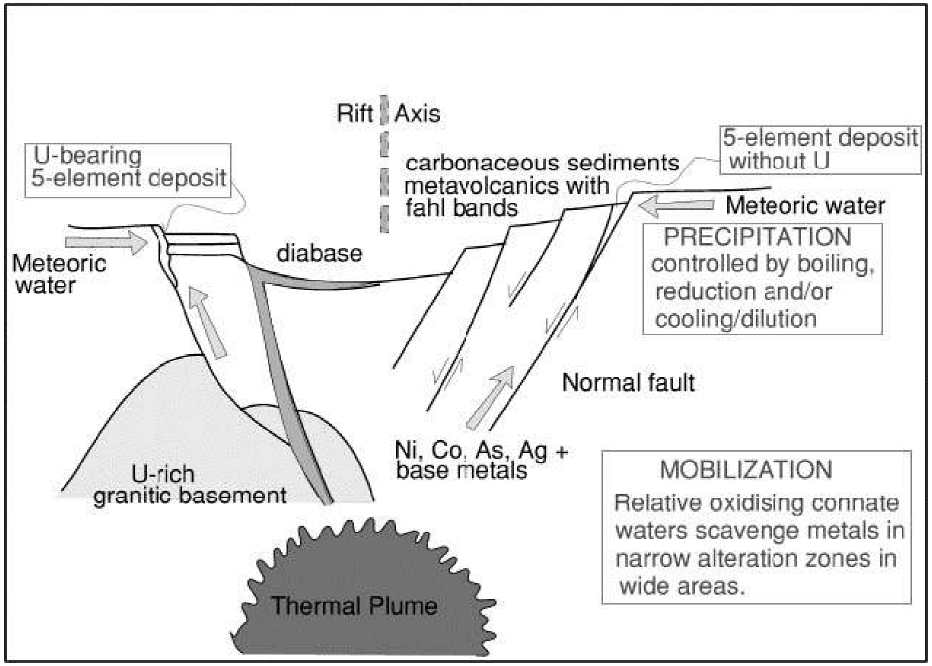


Figure from: http.le.ac.uk/geology/art/gl209/lecture3/lecture3.html

The role of geophysics as an exploration tool in our area – the geology is unexposed and hence the critical role played by geophysical methods in basement mapping.

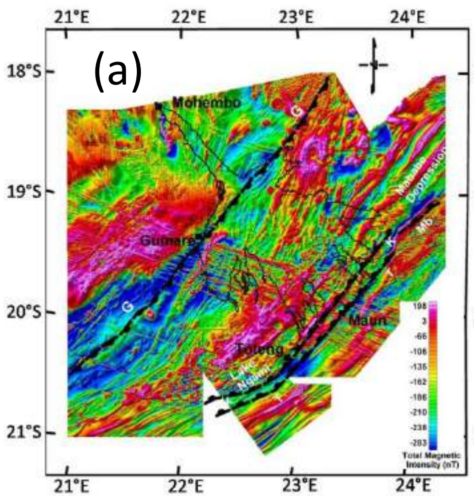
We mainly rely on magnetic and electromagnetic data for mapping basement and overburden.

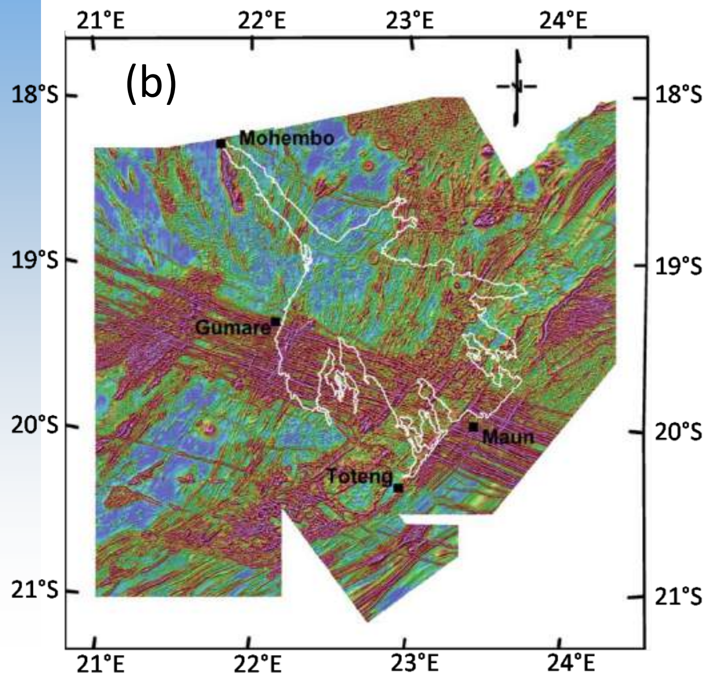
Both aeromagnetics and airborne electromagnetics (AEM) data sets were acquired from Department of Geological Surveys (DGS).

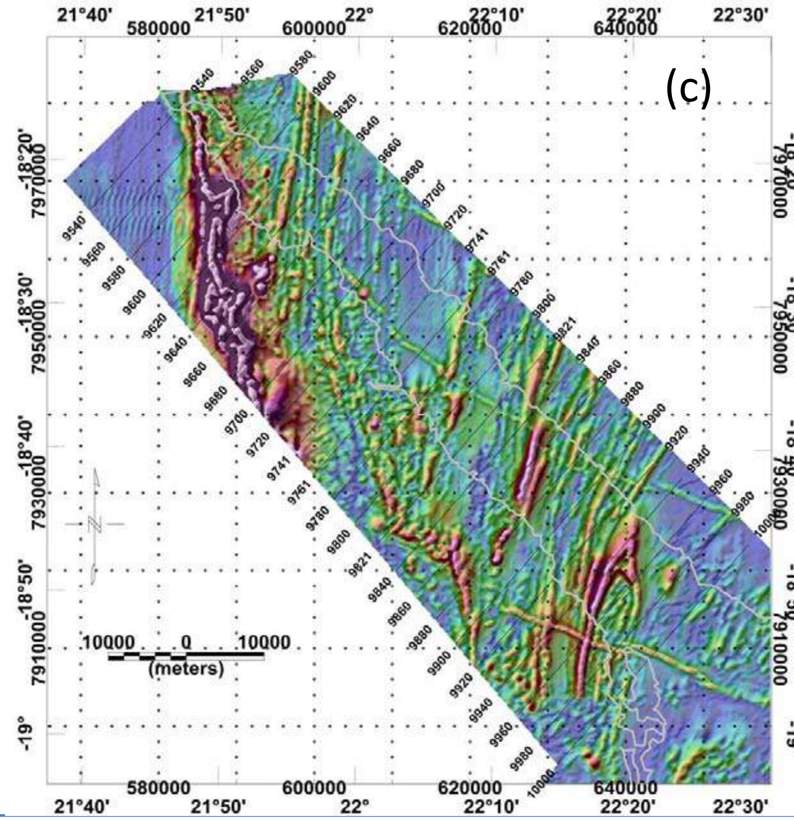
Filter processing of aeromag was carried out to map regional basement fabric.

AEM data is critical for mapping conductors – this may hold both semi-massive to massive or disseminated metal sulfides.

High resolution ground magnetics survey is underway to locally map basement.







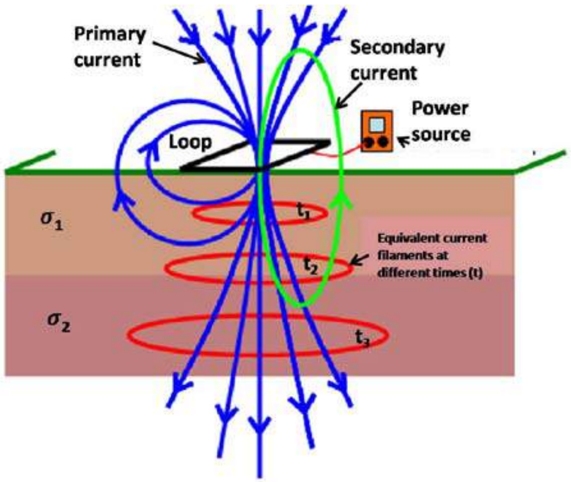
(a) Total regional total magnetic intensity map – shows that the main basement fabric trends NE- SW.

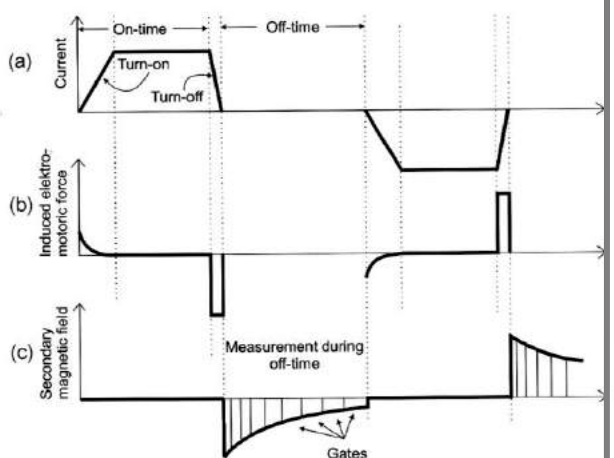
(b) Filtered image of (a) to enhance structure – second vertical derivative drapped over analytic signal.

(c) The Panhadle area (our Tsodilo Prospect) – the magnetic data shows that the basement fabric swings from NE in the southern part to North in the northwestern part .

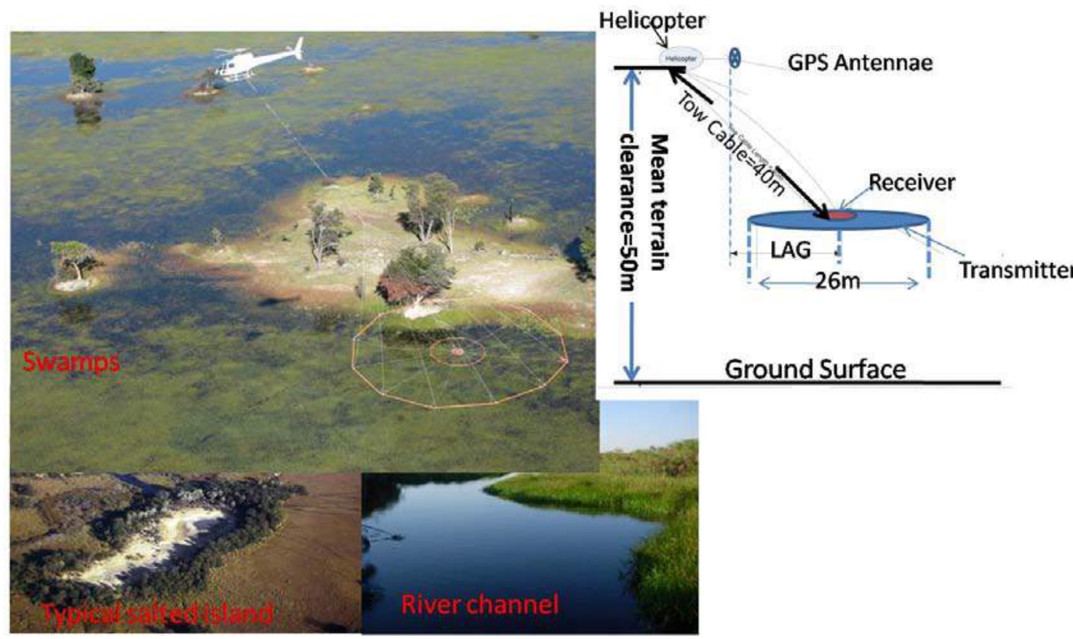
Sulfides were initially discovered whilst drilling circular magnetic anomalies for kimberlite exploration.
Efforts has since been intensified for base metal exploration by exploiting AEM data.

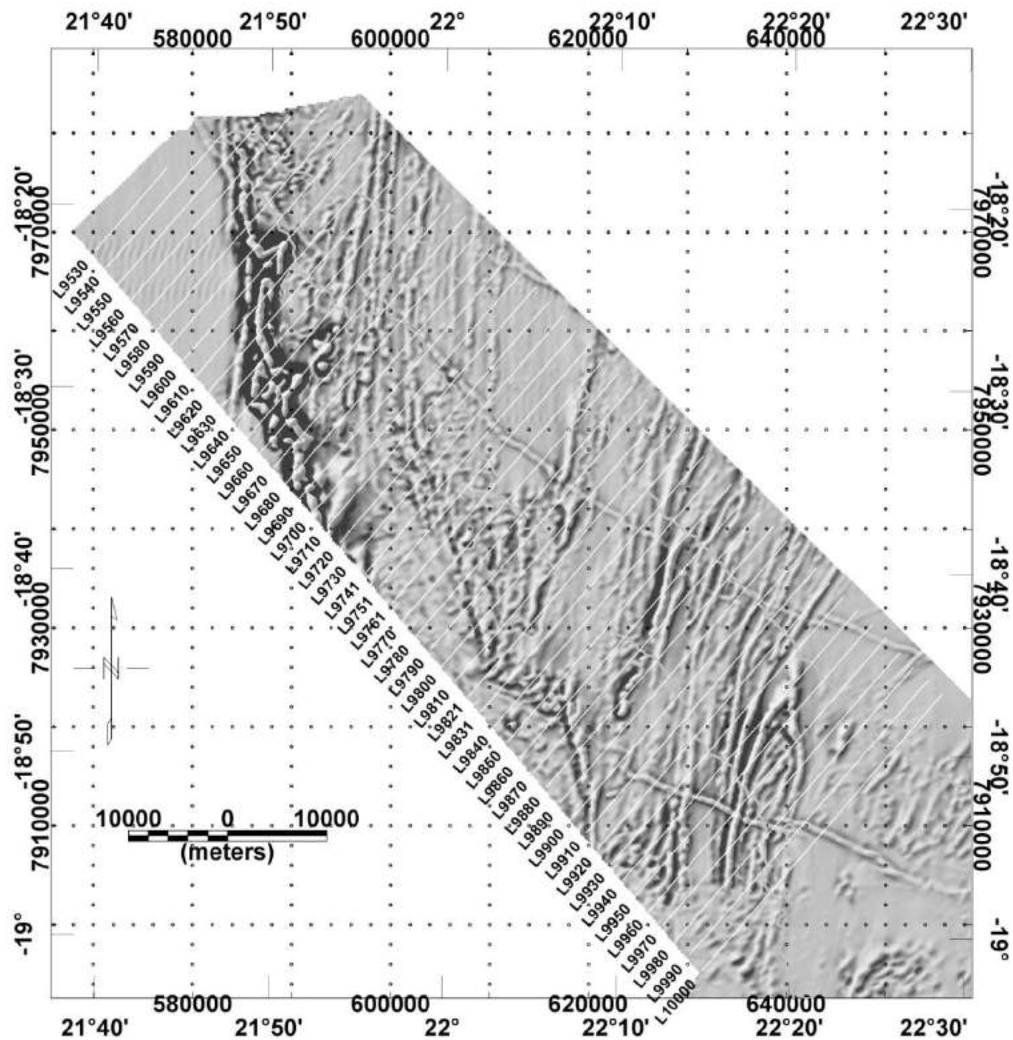
Principle of EM induction





Acquisition of AEM data over the delta using the Versatile Time-domain Electromagnetic (VTEM) system of Geotech (Pty) Ltd





Location of VTEM survey lines overlaid on a gray scale second vertical derivative of the total magnetic intensity.

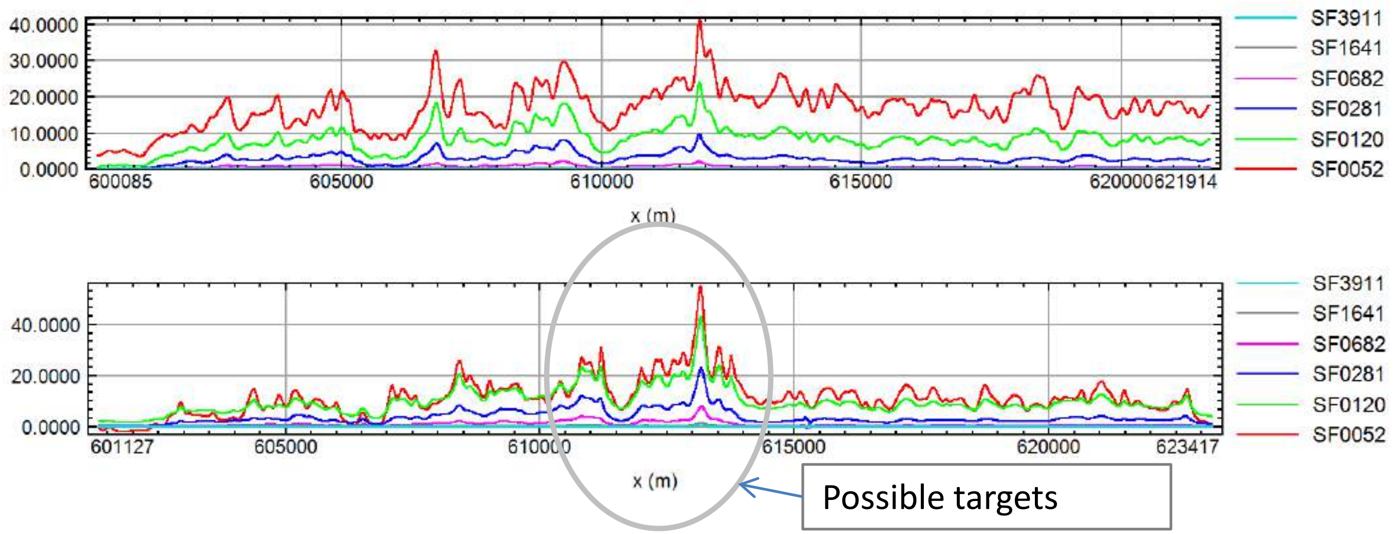
•The ultimate goal of an EM survey is to map the electrical conductivity of the ground – this is not measured directly but it is rather a product of processing raw data.

•The traditional method of target location in mineral exploration (in particular base metals) is to use raw data plots – high well defined anomaly responses are targeted. Sometimes 1D inversion schemes are used but these suffer from 3D effects and therefore not suitable for mapping discrete conductors. An example of these 1D routines include the pseudo 2D Laterally Constrained Inversion (2D LCI), e.g., *Auken et al (2004).*

•In this area, the situation is quite complex in the sense that we do not only have conductive clayey overburden but also clay filled weathered fractured zones!!

•We therefore opted for the S-transform method of *Tartaras et al (2000)* as improved by *M. Cornbrinck (2006).* Here we get conductivity depth images (CDI's) along survey profiles. [Generally a good and very fast method for locating targets although it has the tendency to underestimate the depths to the conductor !!]

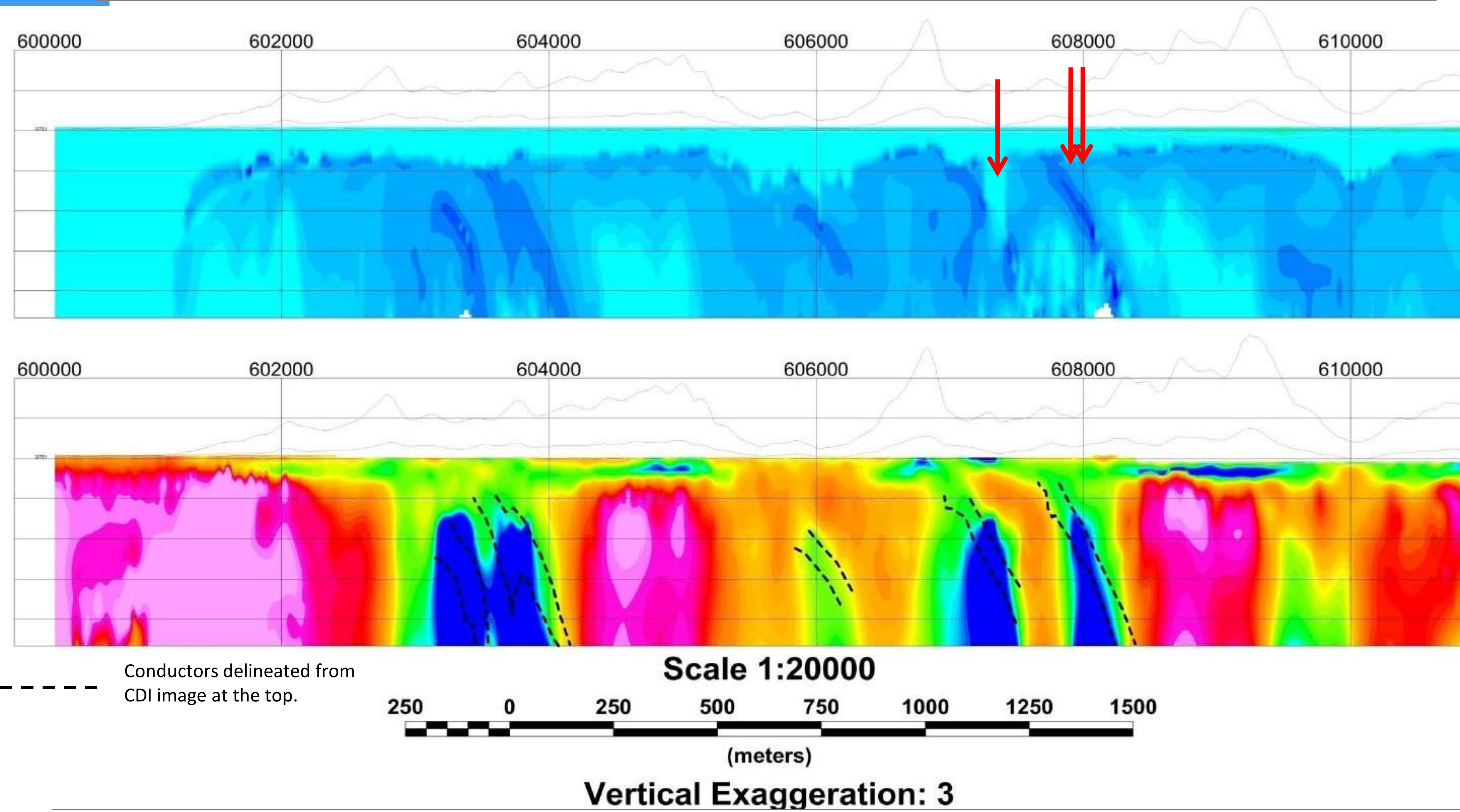
Examples of raw data plots along profiles in our prospecting area.



SF3911, SF1641, e.t.c, represent different VTEM gate times in *μs*, e.g., SF3911 is time gate 3911 μs after current turn-off.

Signals from early time gates map the shallow subsurface whereas those from the late time gates map the deeper part of the subsurface. Penetration depth is a function of both the frequency of the survey and the electrical conductivity of the ground.

S-transform (top) -vs- LCI inversion (bottom) – drillholes at conductor sites indicated with arrows intercepted dipping mineralised shales. Notice how the LCI poorly models these conductors. Also notice how difficult it would have been to pick the target drilled at station 60800m using raw data (blue and red profiles plotted over the sections).



SE

CDI examples – please note here that we have converted conductivity to resistivity!!

L10000

L9900

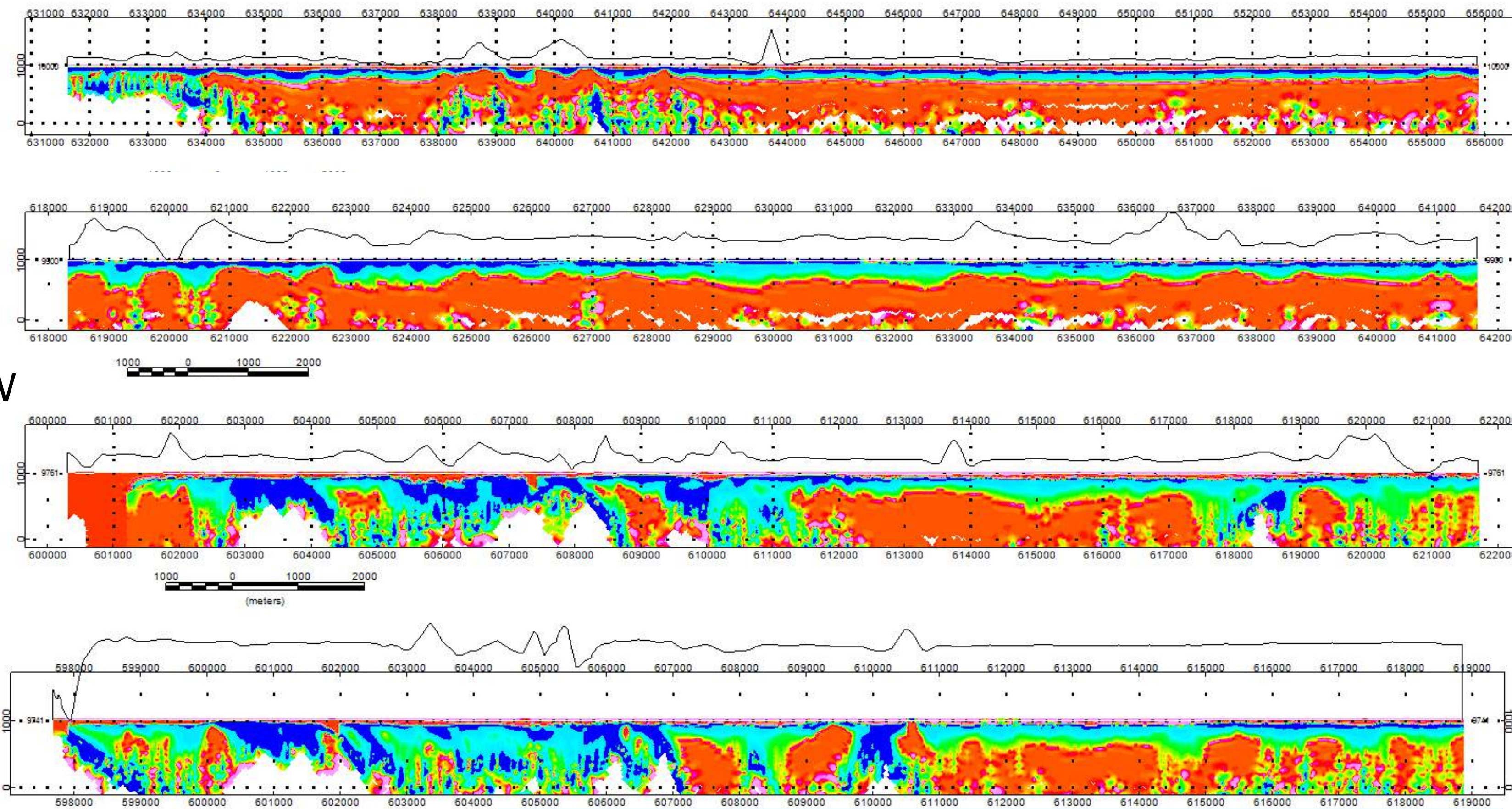
L9761

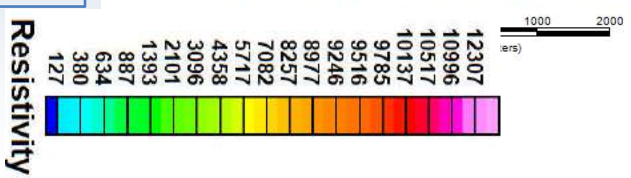
L9741

NW

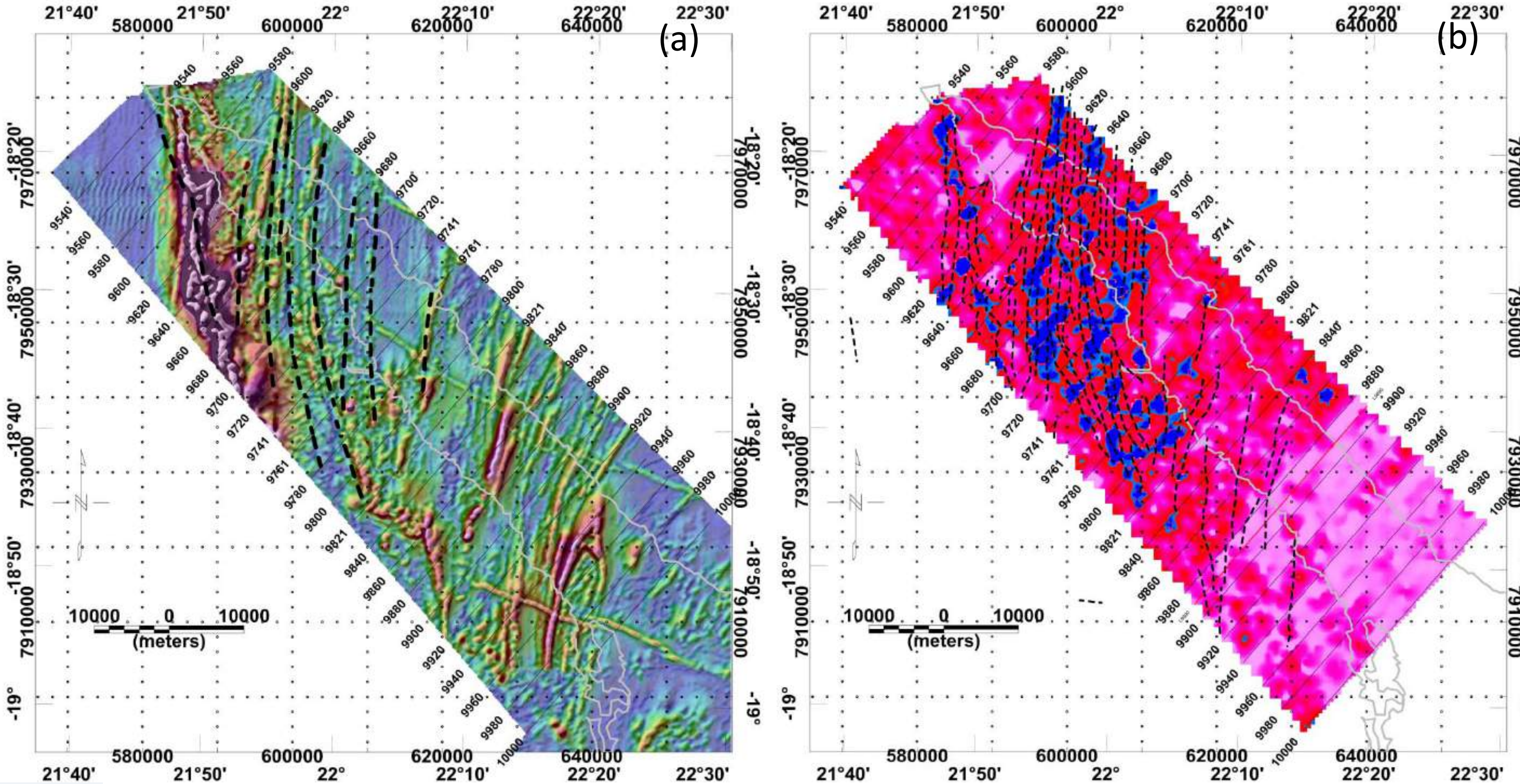
SW

NE

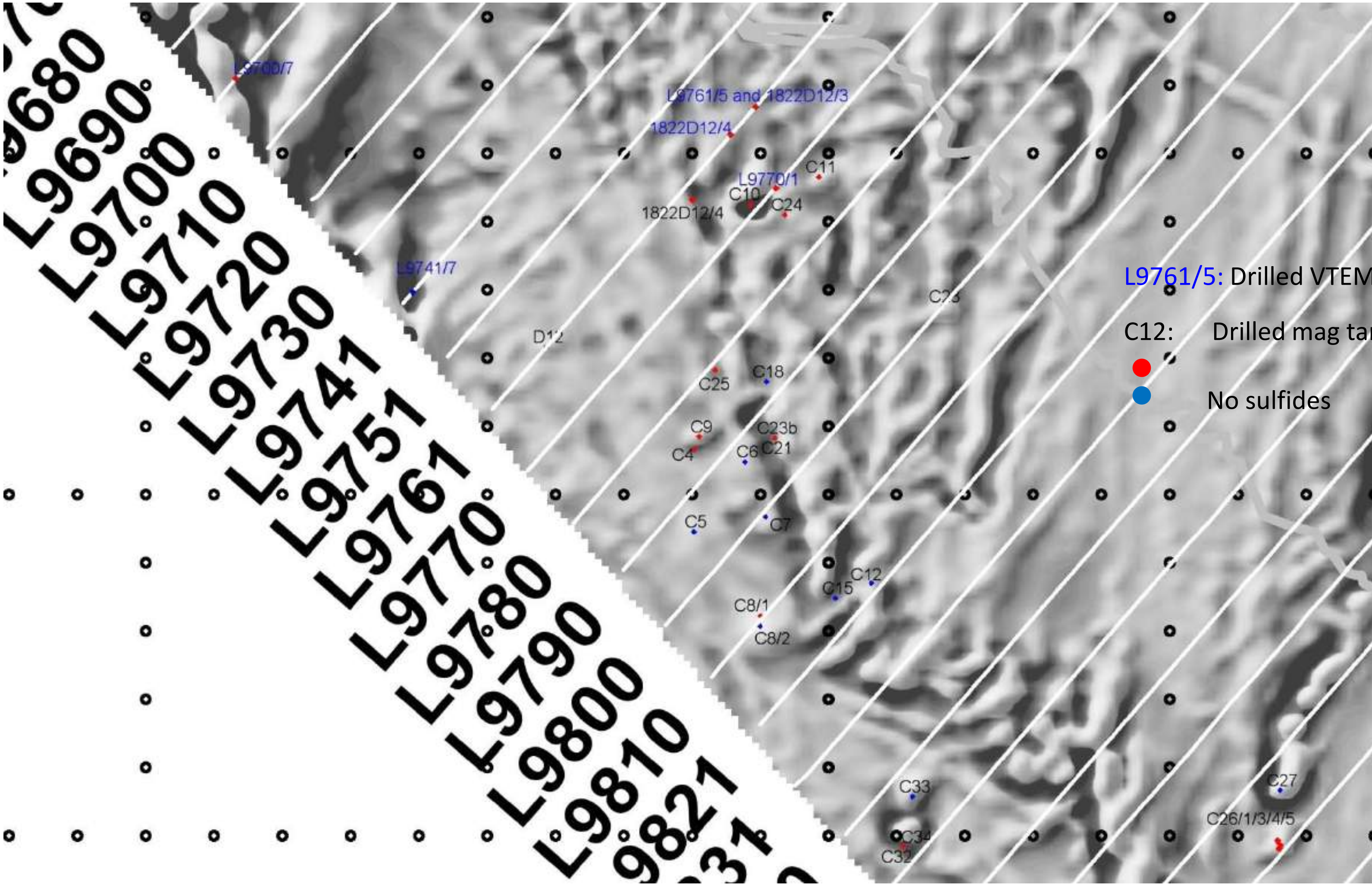




Resistivity cross-sections along some of the VTEM survey lines. Blue dipping zones are interpreted as discrete conductors. Line profiles over the sections are samples from the second vertical derivative of the aeromagnetic data. Generally we dont find discrete conductors in the south (e.g., L9900 and L1000) untill we approach L9840.



(a) shows conondutors traced from the VTEM data superimposed on the aeromag image whereas (b) show the basement fabric superimposed on the resistivity data [blue lineations mark the conductors marked on (a)] . Notice that there is a good correlation between the trend of the conductors and that of the basement fabric in the northwestern part of the map. The southeastern part of the map is virtually void of such conductors although the magnetic fabric is still present.

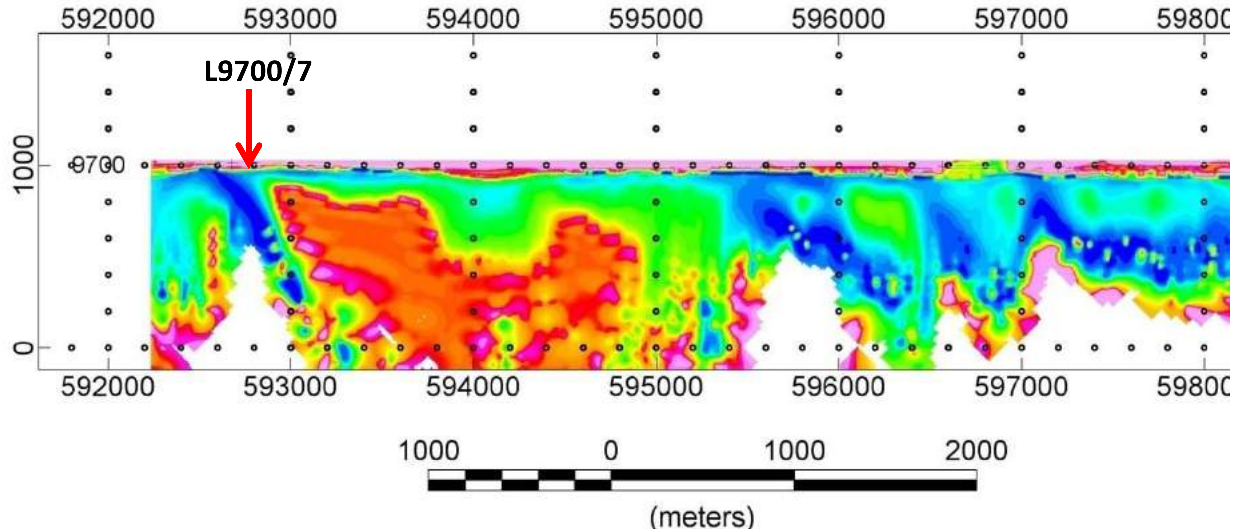


L9761/5: Drilled VTEM targets.

C12: Drilled mag targets.

No sulfides

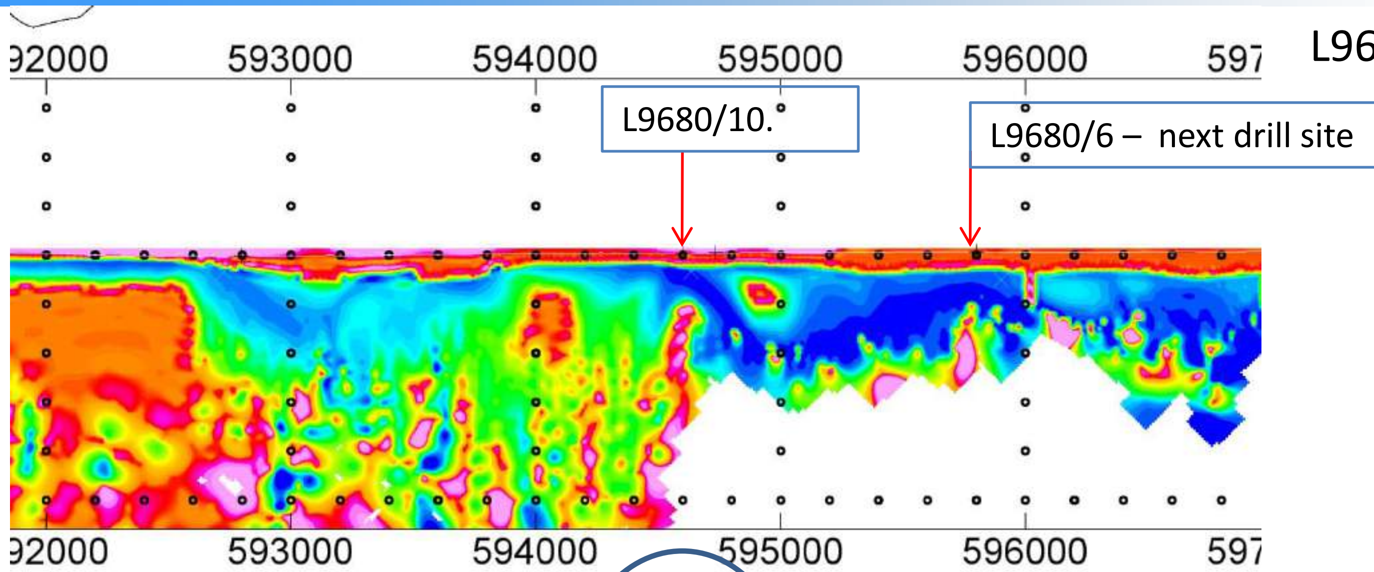
Eight targets so far drilled on the discrete conductors have encountered mineralised black shales within the conductor zones. Some of these holes are heavily mineralised with pyrrhotite whereas others have pyrite and some copper sulfides.

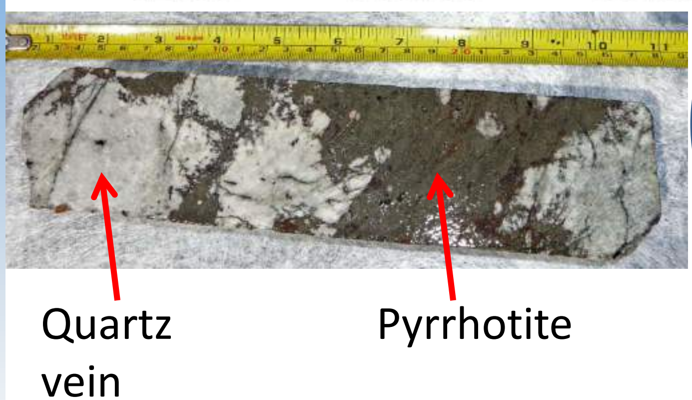

592000
593000
594000
595000
596000
597000
59800
L9700/7
1000
9700
0
1000
0
1000
2000
(meters)

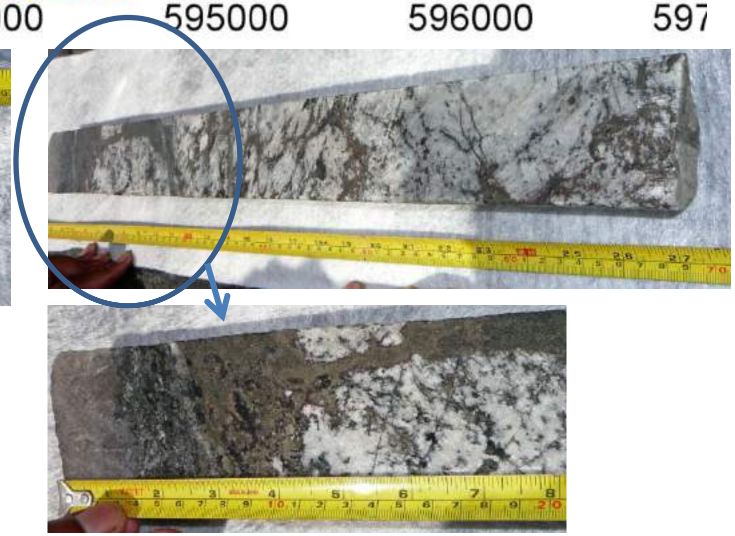

Mostly pyrrhotite


Mostly pyrrhotite

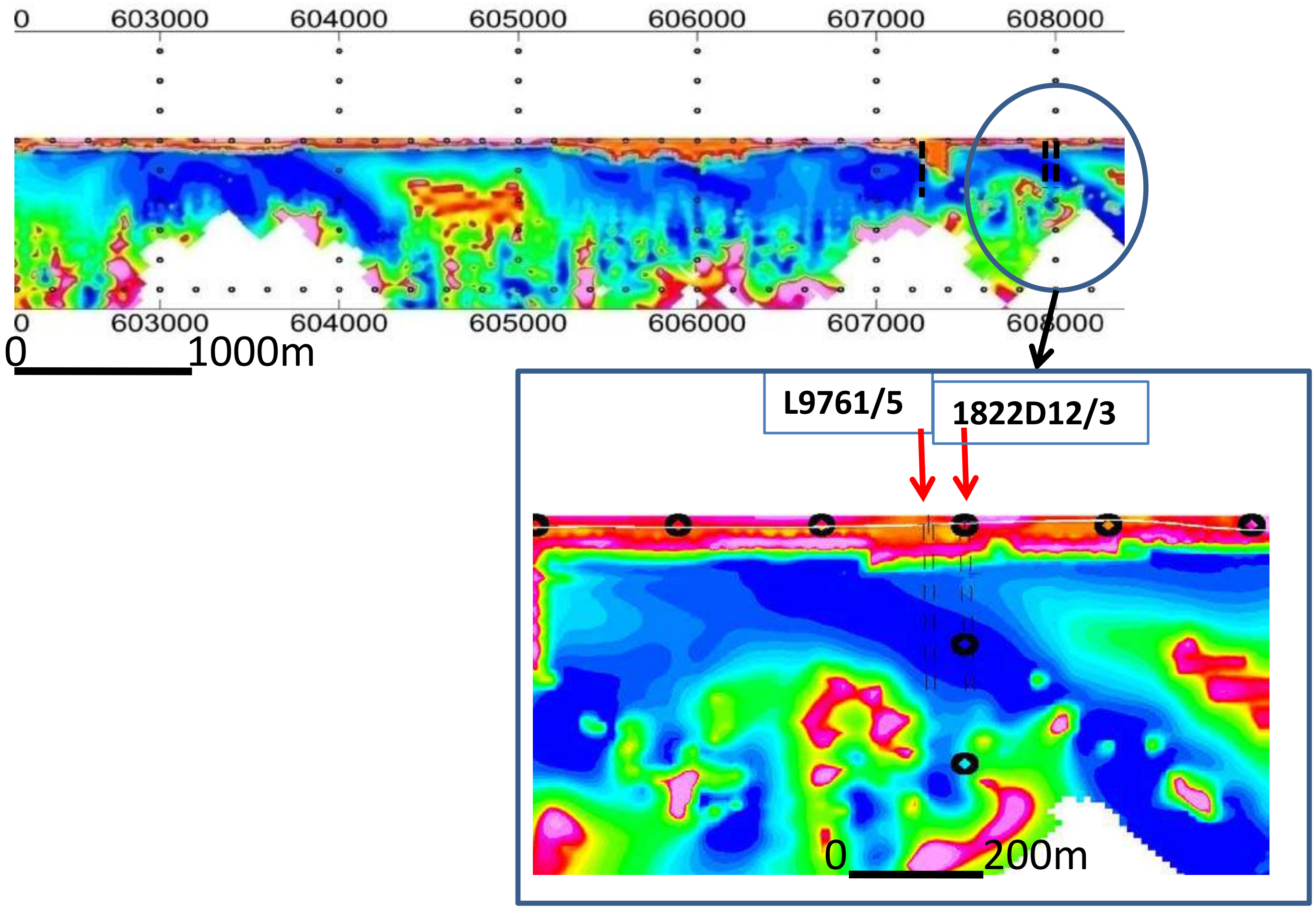
L9680



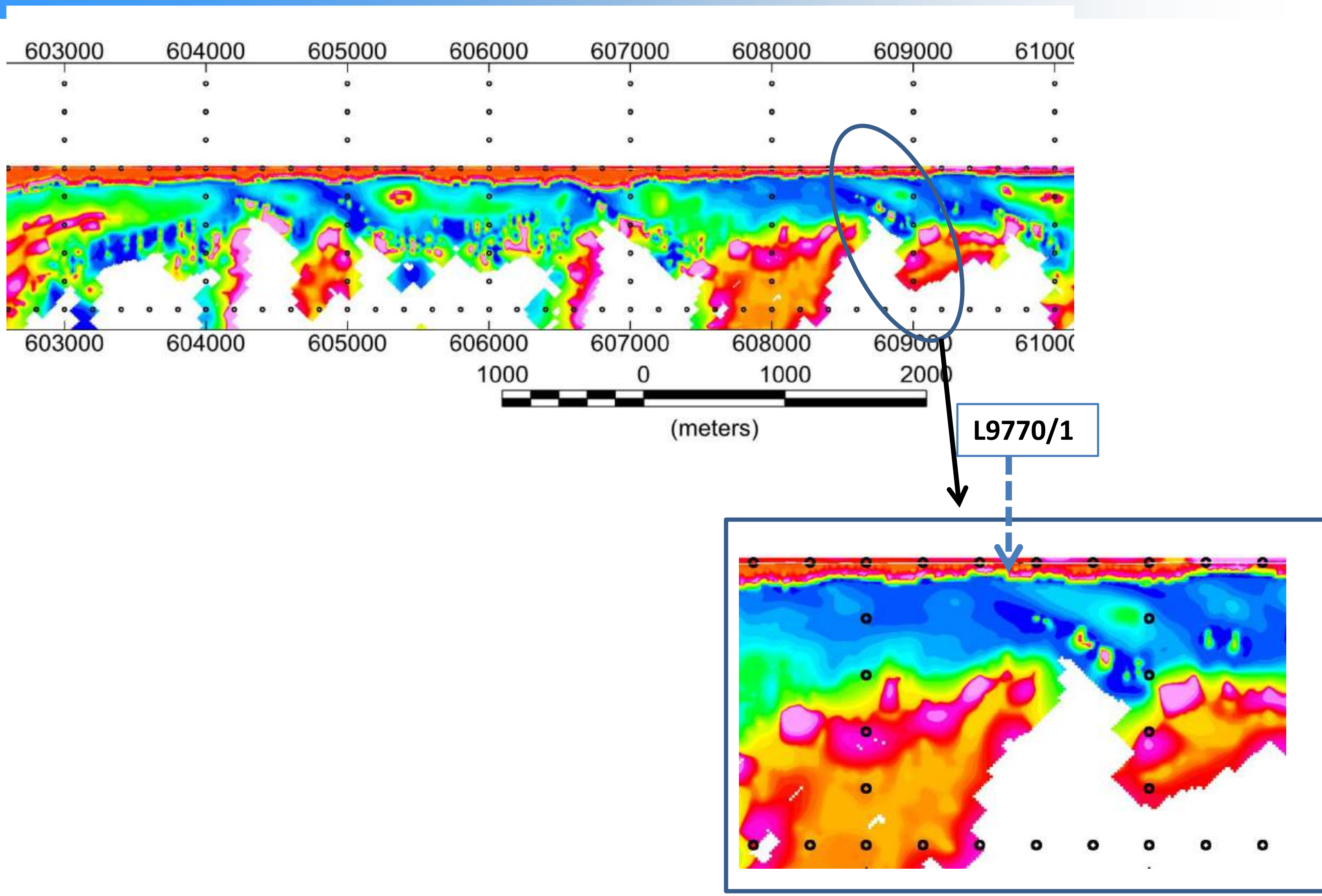




Drill hole L9680/10 intersects mostly pyrrhotite – at some places associated with quartz veining.



Position of a conductor (blue dipping zone) drilled along VTEM survey line L9761. Drillholes 1822D12/3 and L9761/5 intercepted mineralised black shales within the conductor and also some mineralisation of the strata above the conductor.



Conductor drilled along VTEM survey line L9770. Drillhole L9770/1 intercepted mineralised black shales within the conductor .

High resolution ground magnetic survey – ongoing!

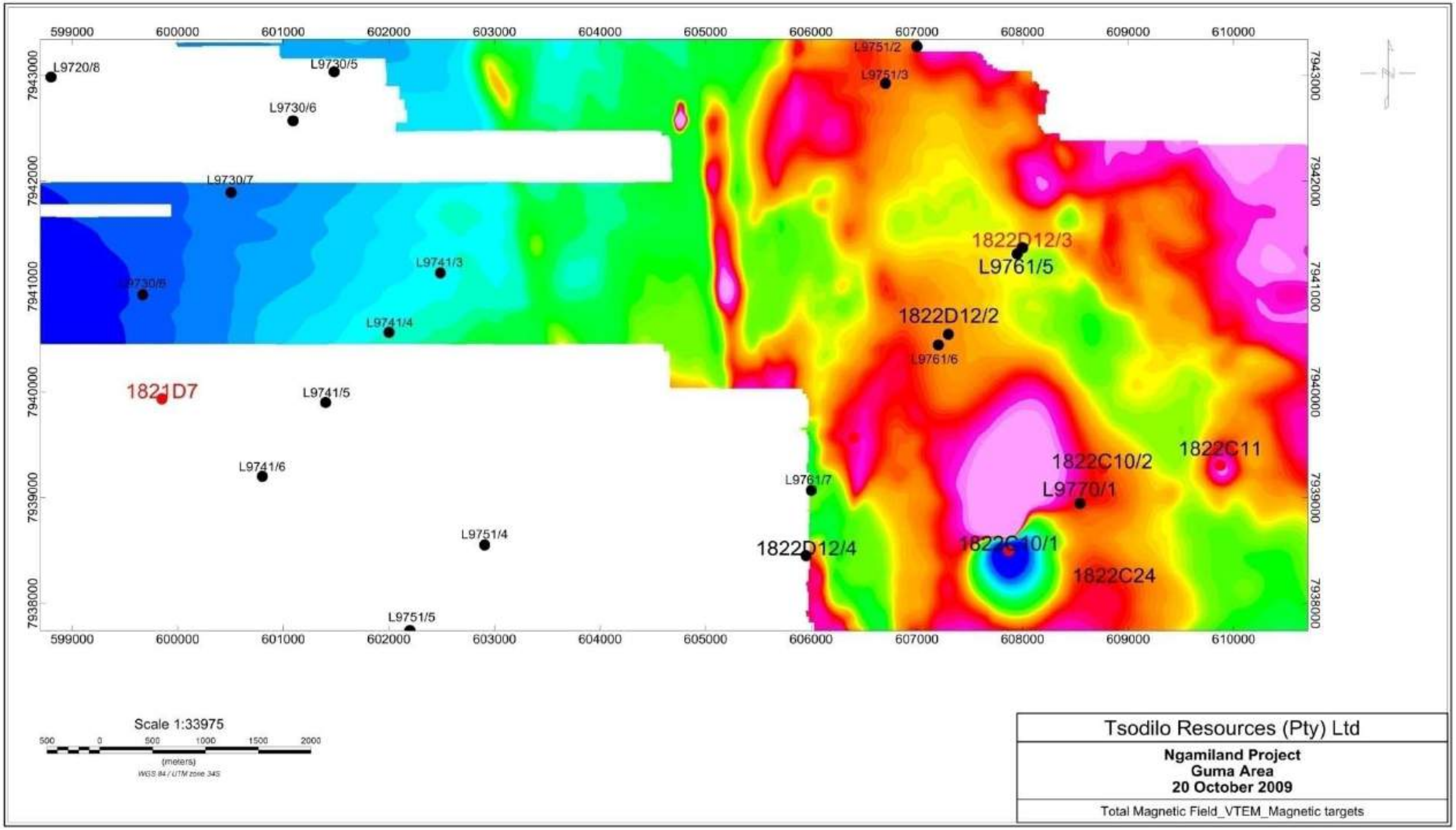
- East-west directed survey at 20m line spacing - reveals more basement structure within the target zones.

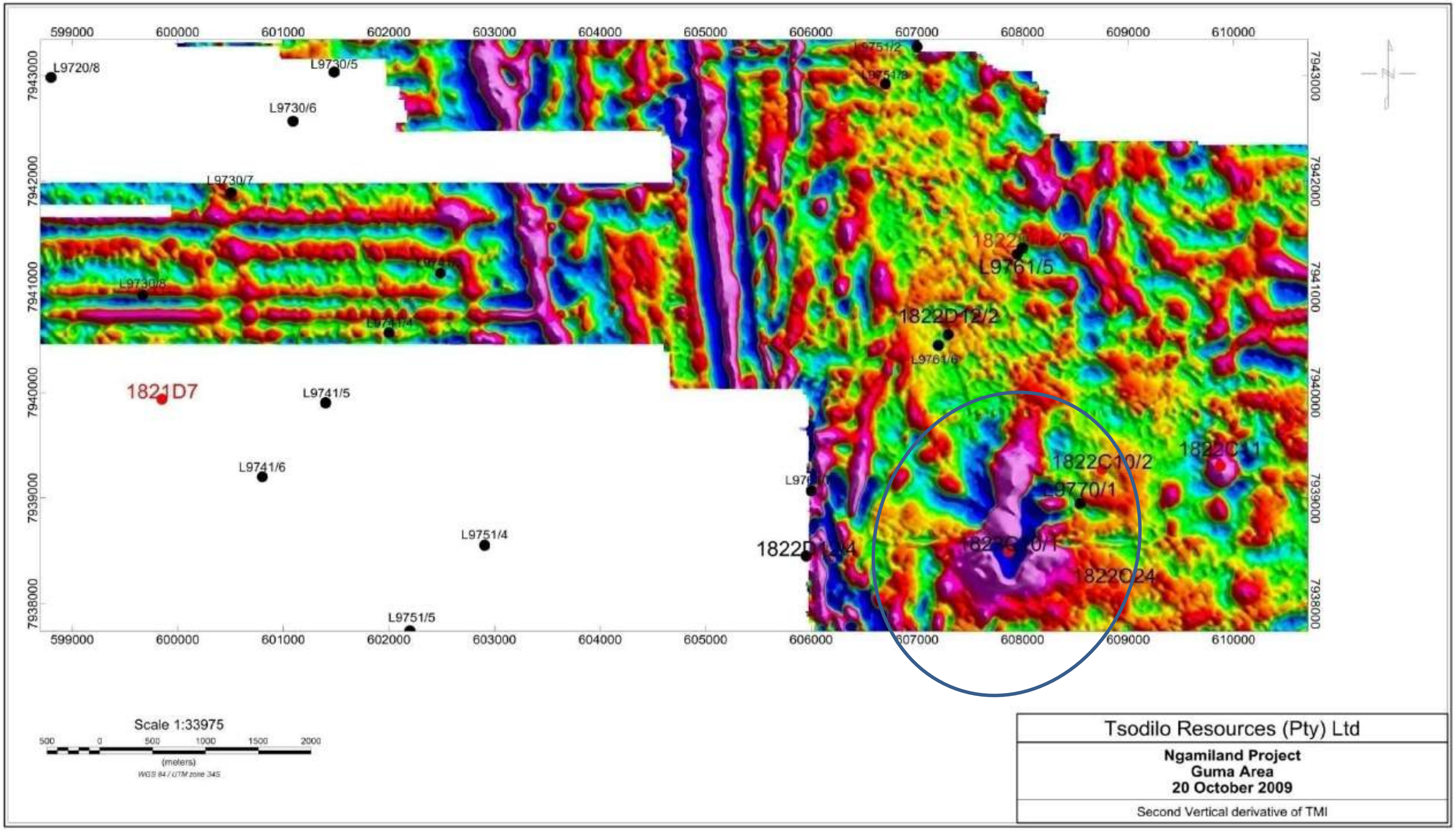
- A closer look at the positions of the top of the conductors shows that they most do not coincide with high magnetic zones.

- The low magnetic zones seen from the analytic signal image coincide with dolomites/marbles.

- The highly magnetic zones could be areas of dominated by schists and may be with magnetite members at some places.

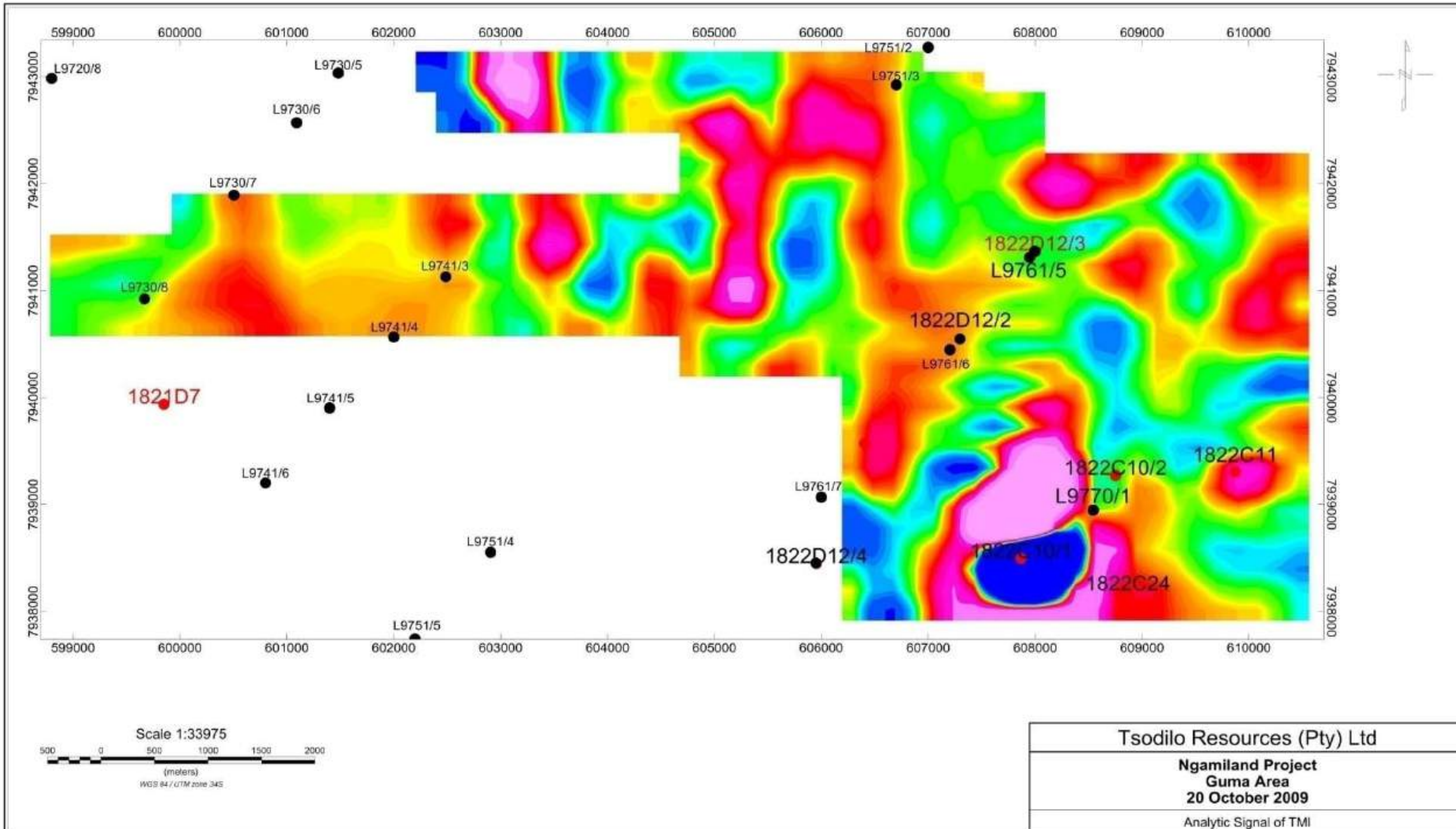
Total magnetic intensity map



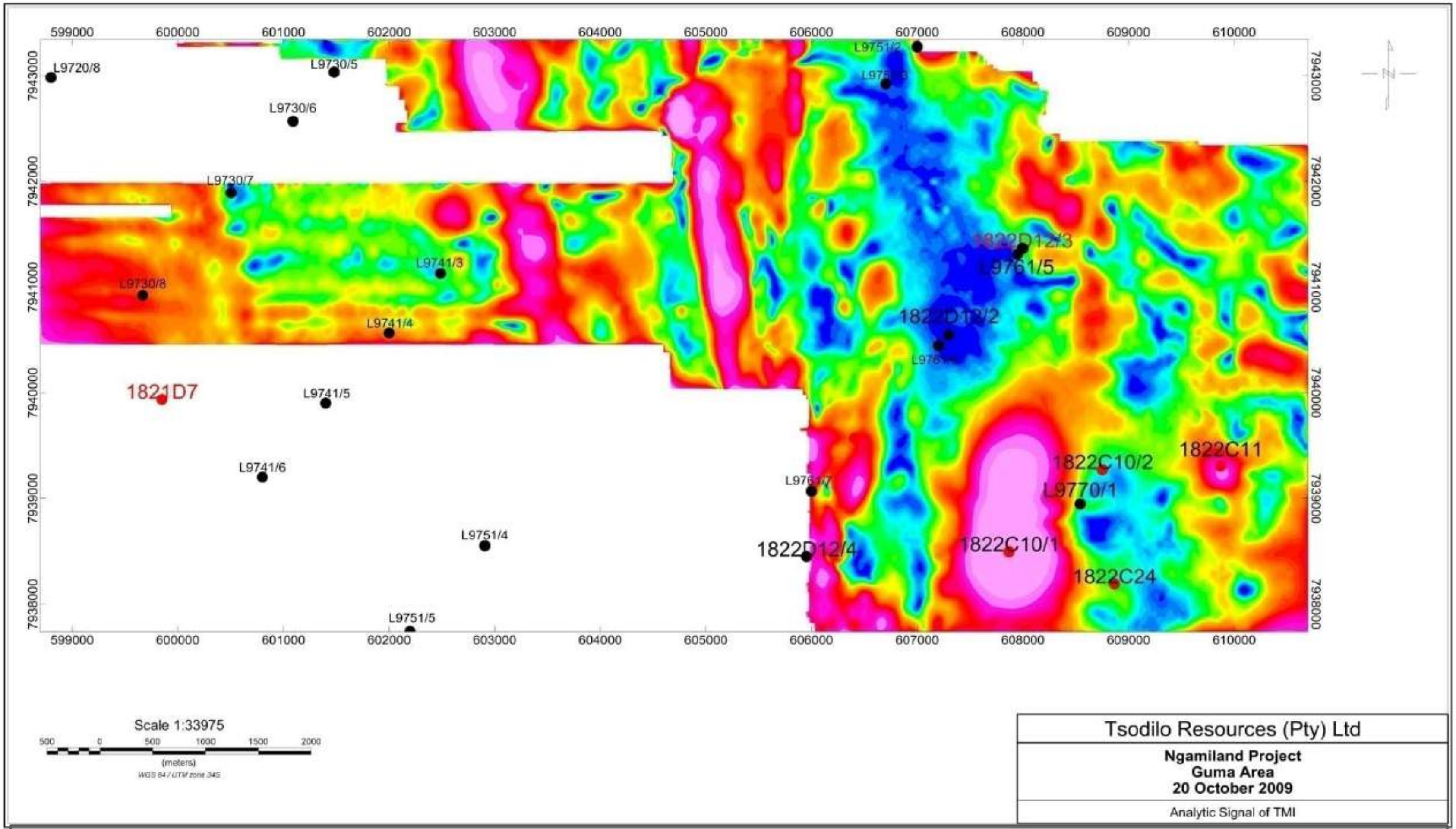


Second vertical derivative image – reveals more structure. Note: corrugation problems in the western side (still to be levelled).

Heavy fracturing around C10,C24 and L9770/1 (eclipsed) – probably enhances mineralization encountered in these drill sites.

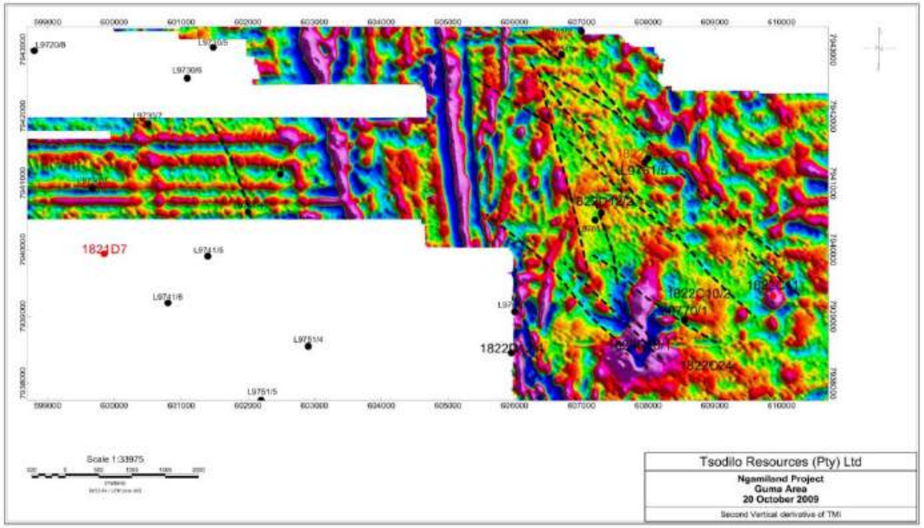


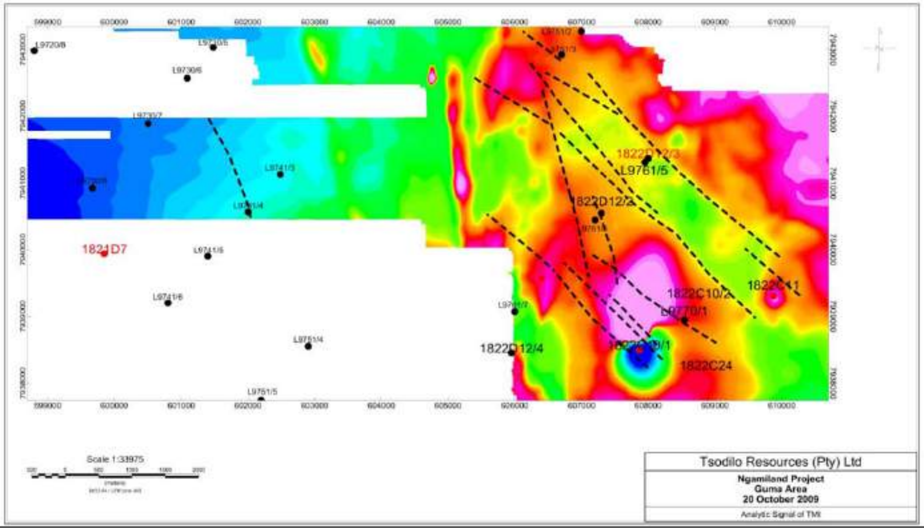
Second vertical derivative from the regional aeromagnetic survey. Note how poorly the basement structure is resolved by this data set compared to the high resolution ground magnetic data.



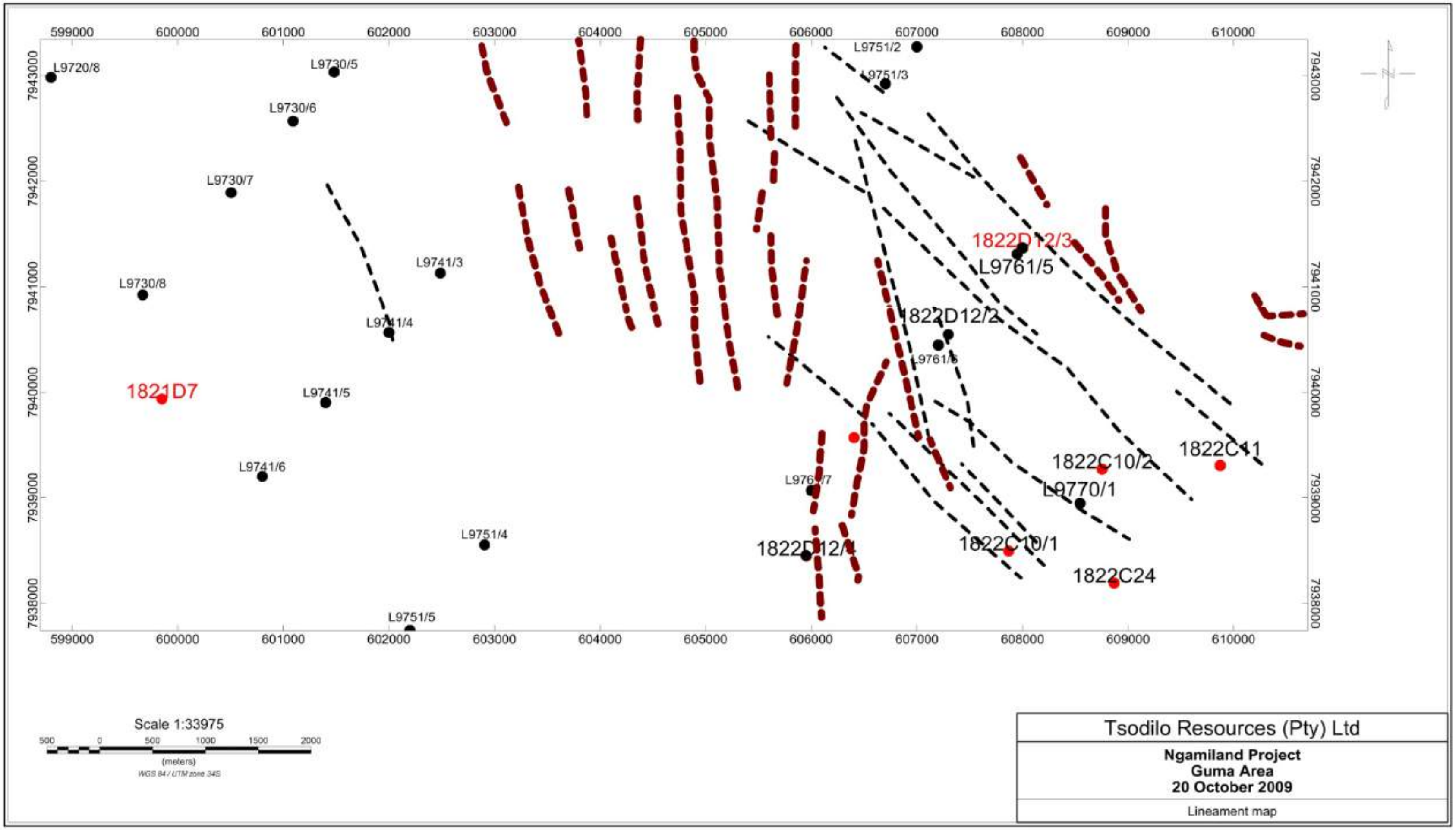
Analytic signal image – drillhole data show that low magnetic zones (blue zones) coincide with massive marbles/dolomites.

Drillhole data show very little mineralization in these dolomites and therefore of not high priority as a target lithology.





Mapping structure from magnetic data. More structure is revealed from the second derivative image although the total magnetic image does capture some of the larger structures.



Lineament map: A conjunctive use of the VTEM data and the lineaments mapped from the magnetics could yield better results – e.g going for VTEM targets close or on fault lines.

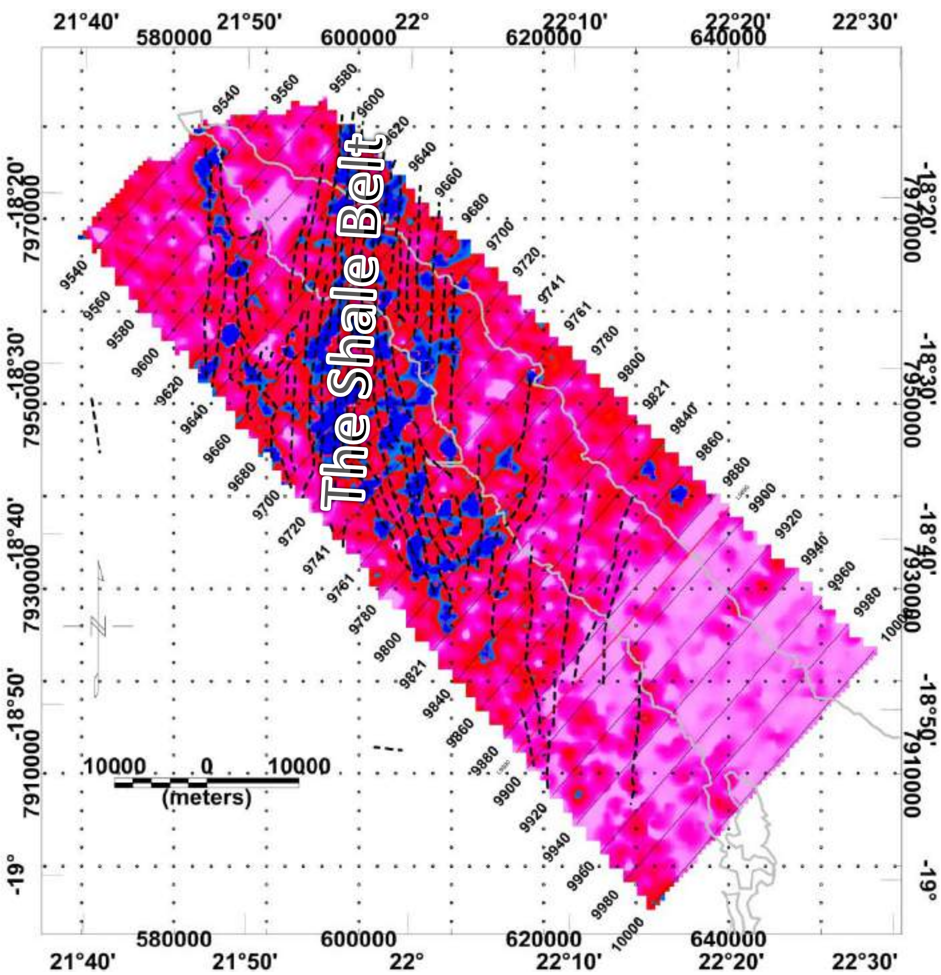
Main Discovery:

•Delineation of The Shale Belt within the Damara sequence in Botswana.

•The shale belt is mineralized with both pyrite, pyrrhotite and chalcopyrite.

•The occurrence of pyrrhotite is particularly interesting since it is often associated with Ni-Co mineralization.

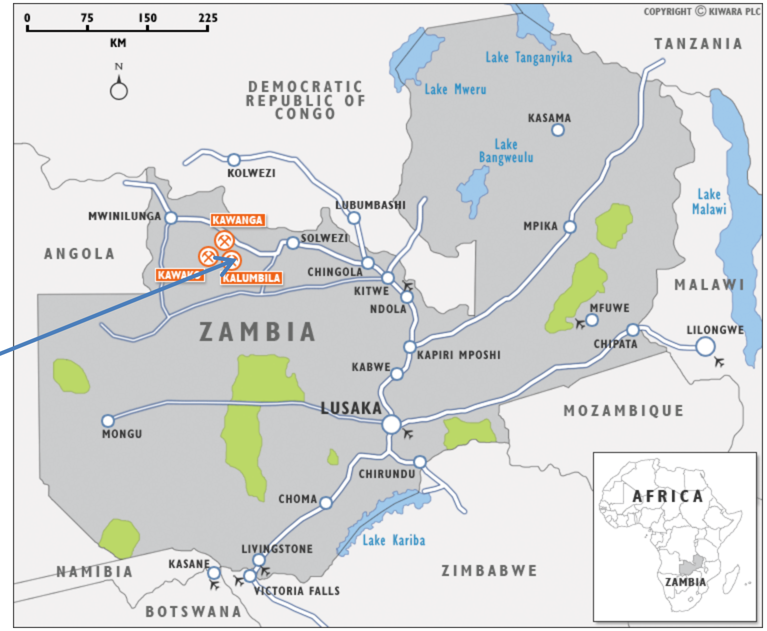
• A strong resemblance of our core and that in Kiwara (Zambia) might suggest Ni-Co (minor Cu) mineralisation.



- A strong resemblance of our core and that in Kiwara (Zambia) might suggest Ni-Co – Cu mineralisation.

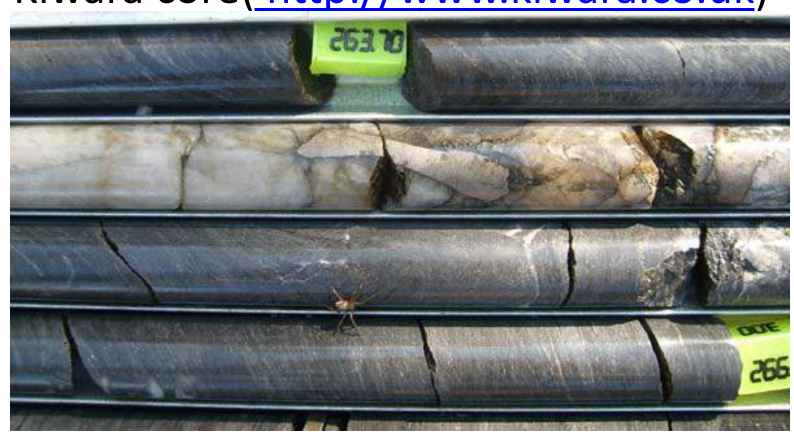
- This mineralisation is hosted within carbonacious shales and meta-pelites; the very same units that we have in our area.

- The carbonacious shales in the Kiwara Deposits are correlated with the Ore Shale of the Zambian Copper Belt (http://www.kiwara.co.uk, N. Steven, 2003)



Tsodilo core

Kiwara core(http://www.kiwara.co.uk)



Planned work:

•Drilling to continue in the northern part (red targets)

•Continue the high resolution magnetic survey towards VTEM survey line L9840 and then shift up north to cover the red targets.

•Evaluate both drilling results, magnetic, VTEM and geochem data sets to come up with a geological model.

•Follow up drilling in a more systematic manner based on assay results.