3D Modelling of a deep massive sulphide body at Norman West

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Introduction

The aim of the project was to better define a deep Cu-Ni footwall deposit at Norman West beyond that achieved by traditional thin ribbon plate modelling.

MGEM – MultiGrid EM - a full volume 3D modelling tool using a multi-grid finite difference solution was used. MGEM technology was previously demonstrated in the modelling of the Ovoid deposit at Voisey's Bay.

Glencore geologists produced a detailed geological ore model of the deposit developed from drill cores combined with separate EM interpretation of 17 boreholes (BHUTEM). The conceptual model of the body was represented as 32 horizontal slices of 10m thickness starting at a depth below 2200m. Each slice consisted of an inner zone of massive sulphides surrounded by an outer zone of less conductive semi-massive or stockwork sulphides.

The question being: whether the shape and size of the model did in fact render well the borehole EM data collected in the 17 holes or whether significant changes in the model were needed to render the drill hole data?

Figure 1: The model slices for both outer and inner zones were drawn using Gridplot which generates a conductivity mesh as the polygonal boundaries are drawn.

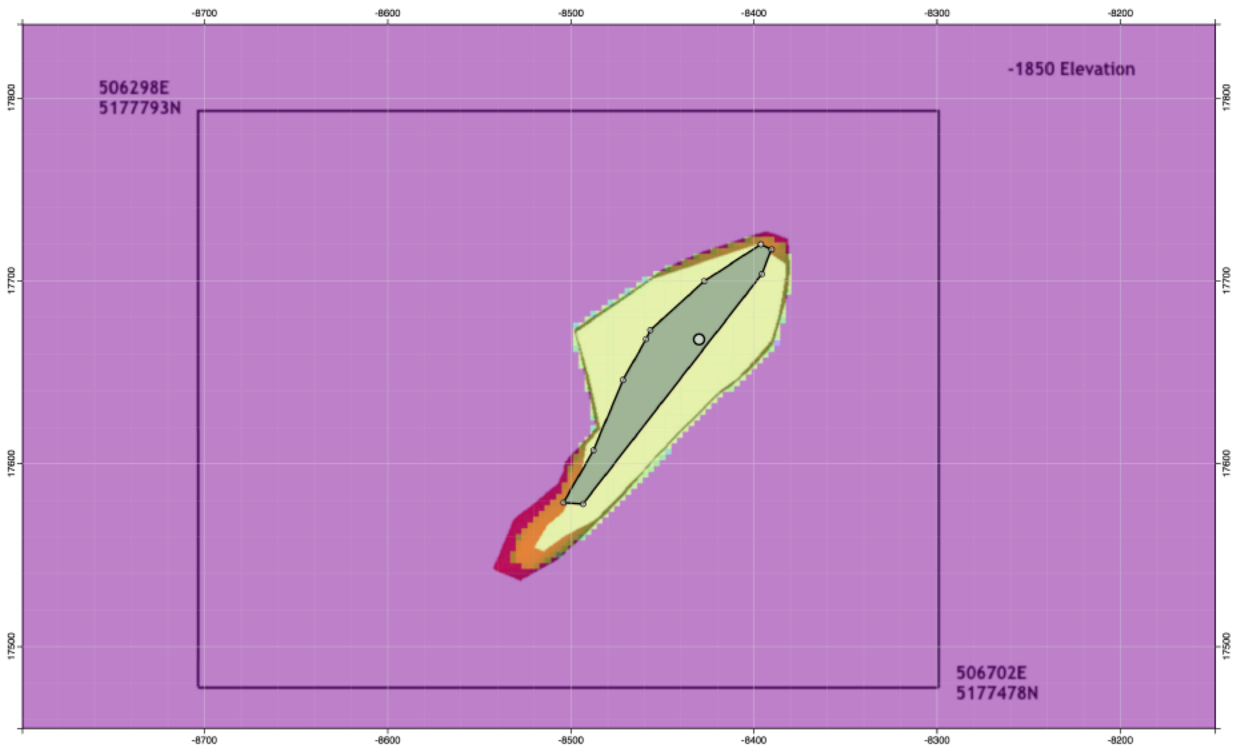


Figure 2: NS section view of the MultiGrid conductivity mesh with one slice of the inner zone highlighted. (same scale)

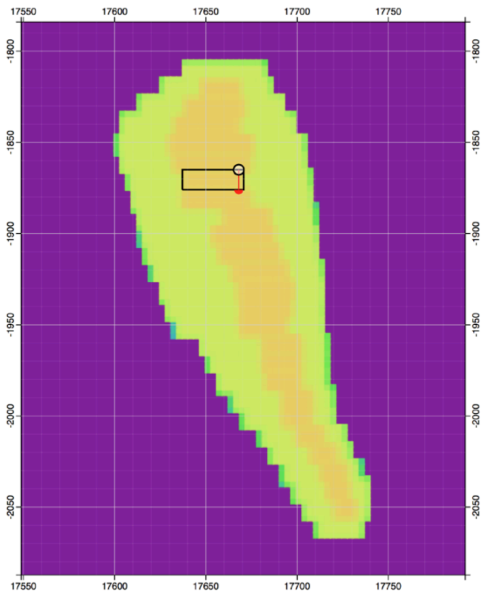


Figure 3: 3D perspective view from the south of the objective model with the outer zone shown in translucent green and the inner zone as opaque.

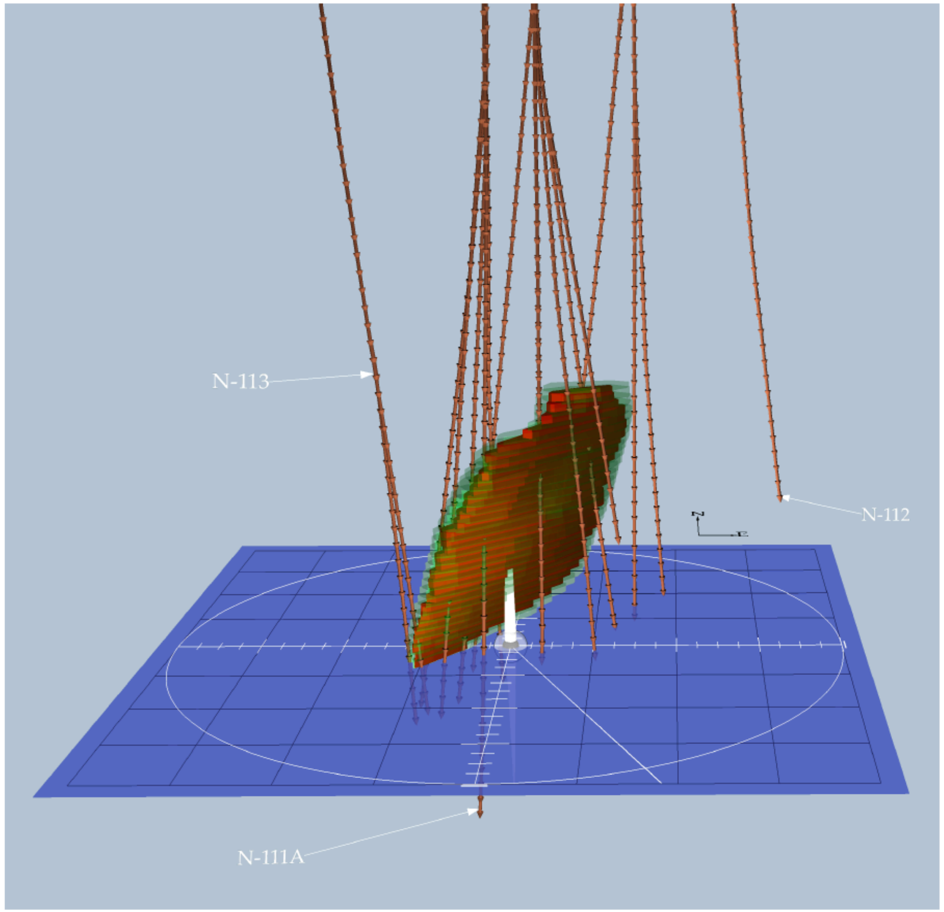


Figure 4: Plan view of the study area showing the loops, holes, objective zone and reference grid.

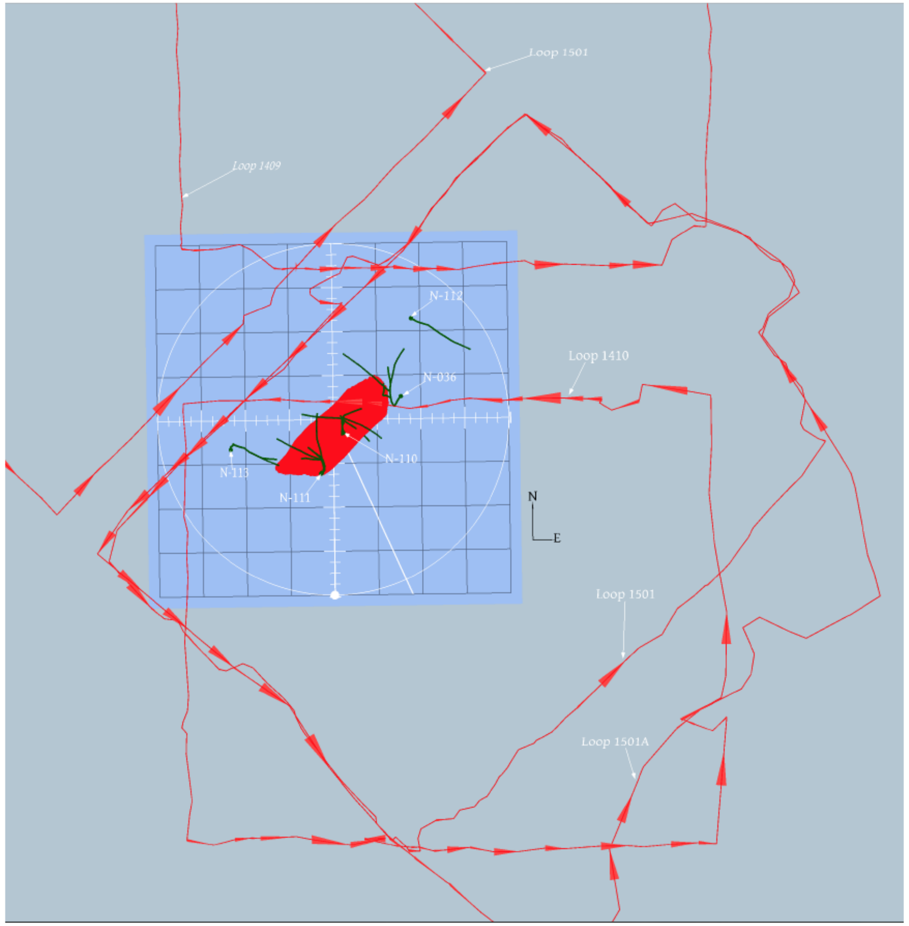
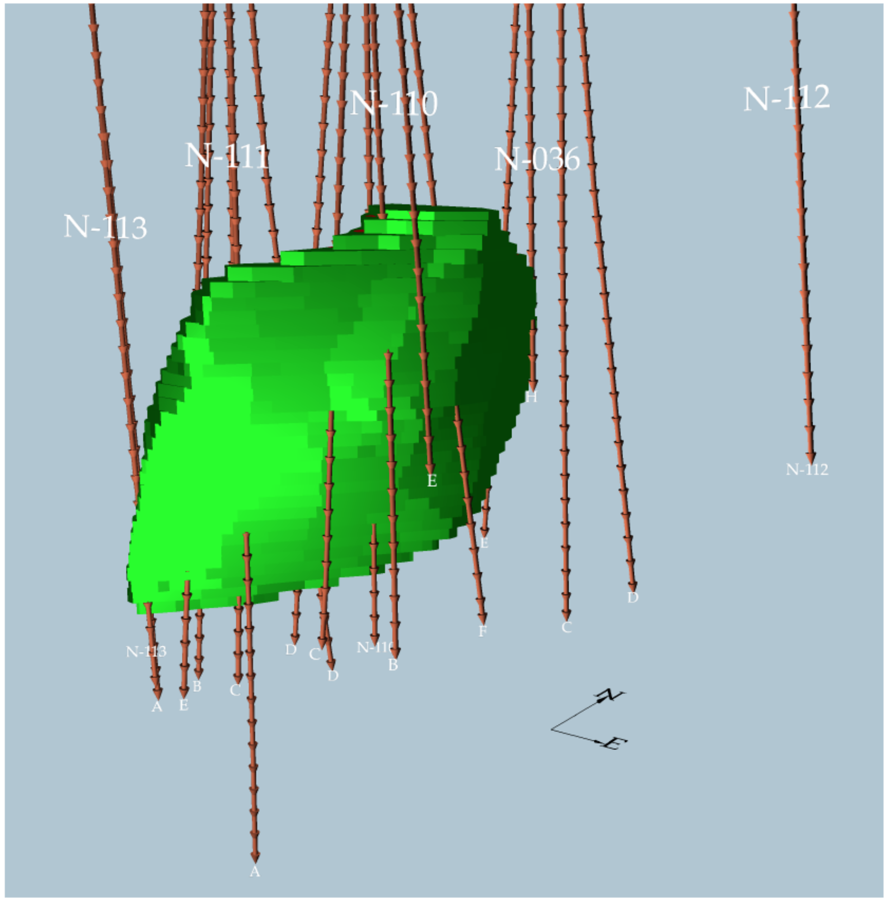
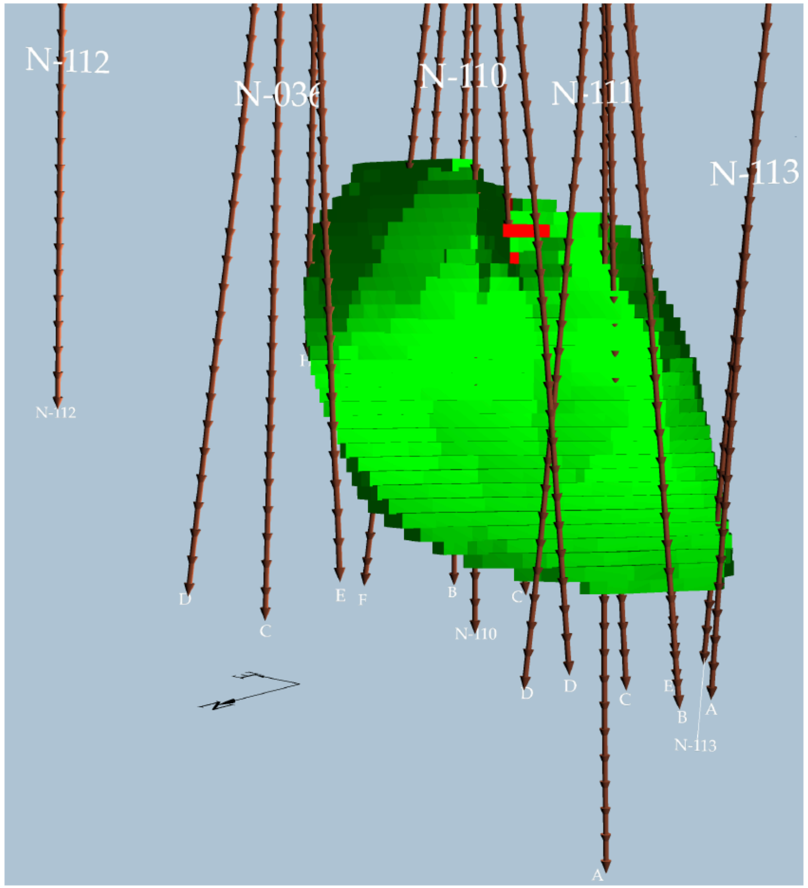


Figure 5: View from the SE of the objective body and borehole branches

Figure 6: View from the NW of the objective body and borehole branches





The MGEM modelling process

In the study MGEM calculated the step response everywhere in all volumes and at all eight mesh levels over 54 time steps ranging in delay times from 12.5 μs to 22 s.

The multi-grid calculation consisted for each time step of solving a system of linear equations using an iterative method (Full MultiGrid, or FMG) by which solutions on coarse meshes are used to speed up the solutions of finer meshes.

In the first four models considered there were 17 million unknowns to solve for. The largest model was run on a mesh with 33 million unknowns.

After each time step the 3-axis response was interpolated at 10 m intervals in all holes and saved to 3-axis output files.

Modelling sequence

The plan for 3D modelling at Norman West was to proceed in two phases.

Phase 1:
consisted of comparing the response of the objective model shapes to measured data while adjusting the conductivities to fit the general decay times of the observed response.

The main question was how well did the objective model explain the data?

Phase 2:
was considered a separate modelling exercise involving the addition of other conductive bodies and or revising the original model.

Model Prefix	Outer Zone Conductivity S/m	Inner Zone Conductivity S/m
B	20	4000
C	2000	2000
D	1000	6000
E	250	6000

Figure 7: The modelled 12Channel/4Hz response excited by Loop 1501 in Hole N-111A plotted as total field response.

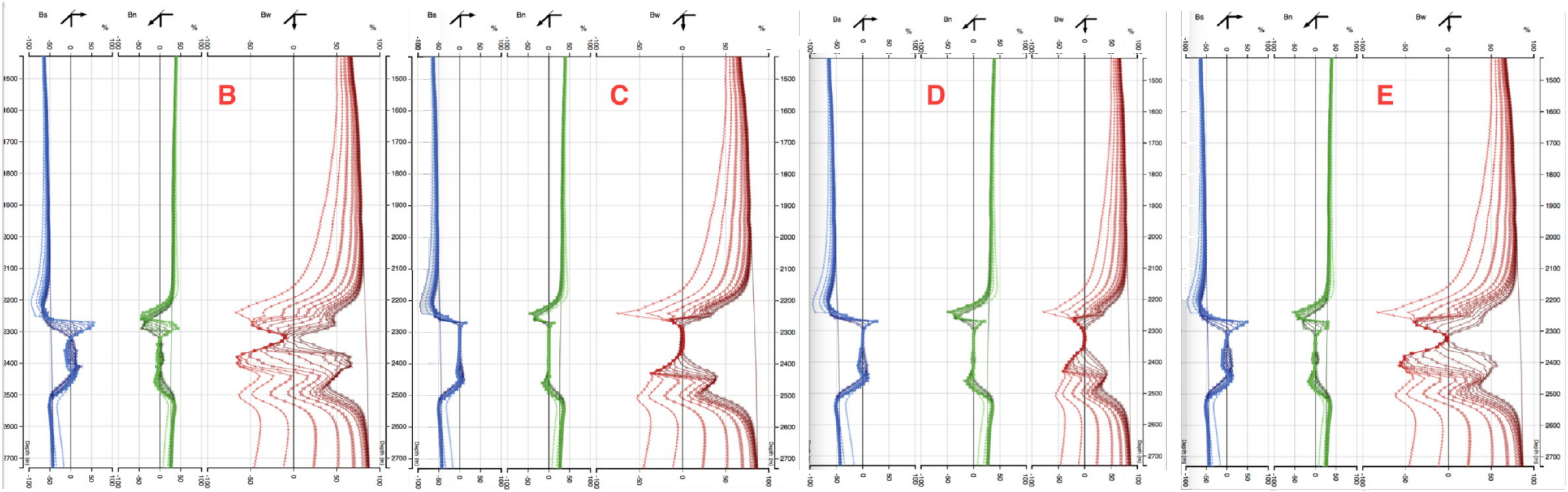


Figure 8: The observed response in Hole N-111A measured at 4Hz with Loop 1501

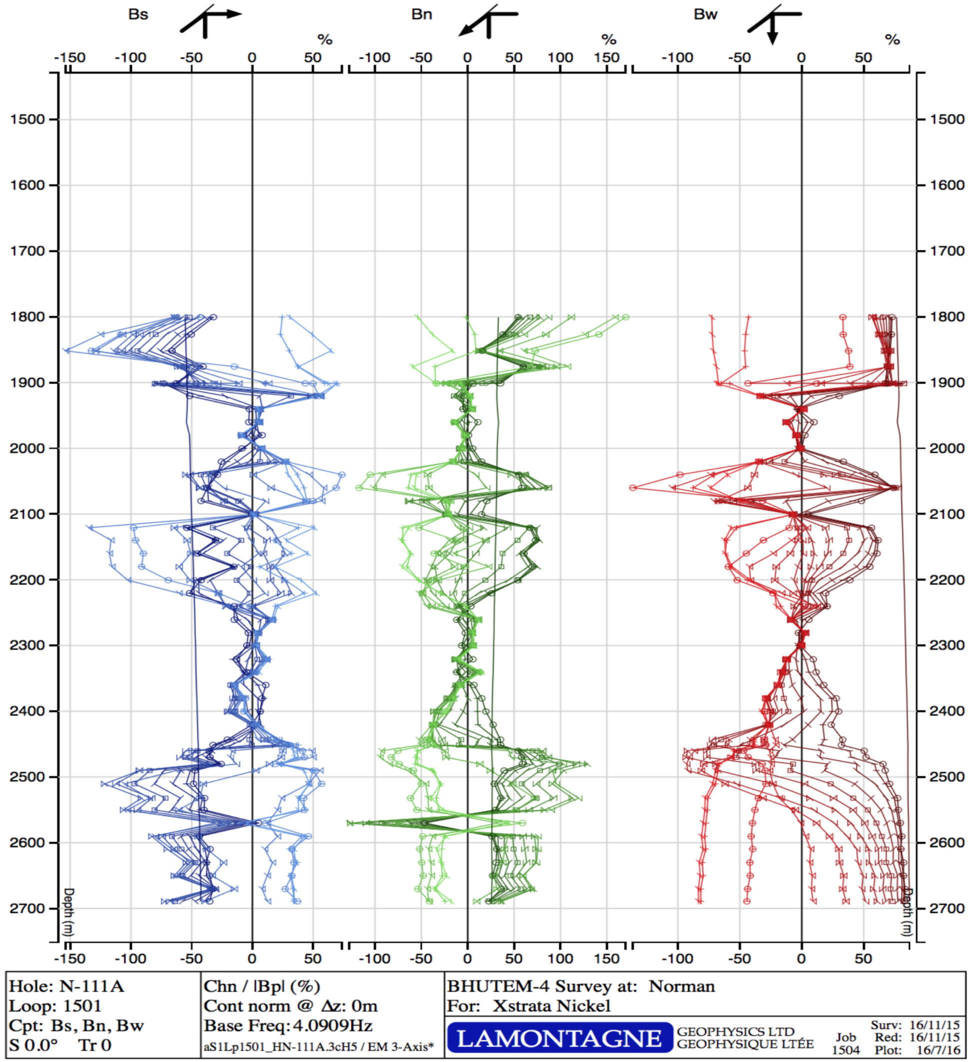
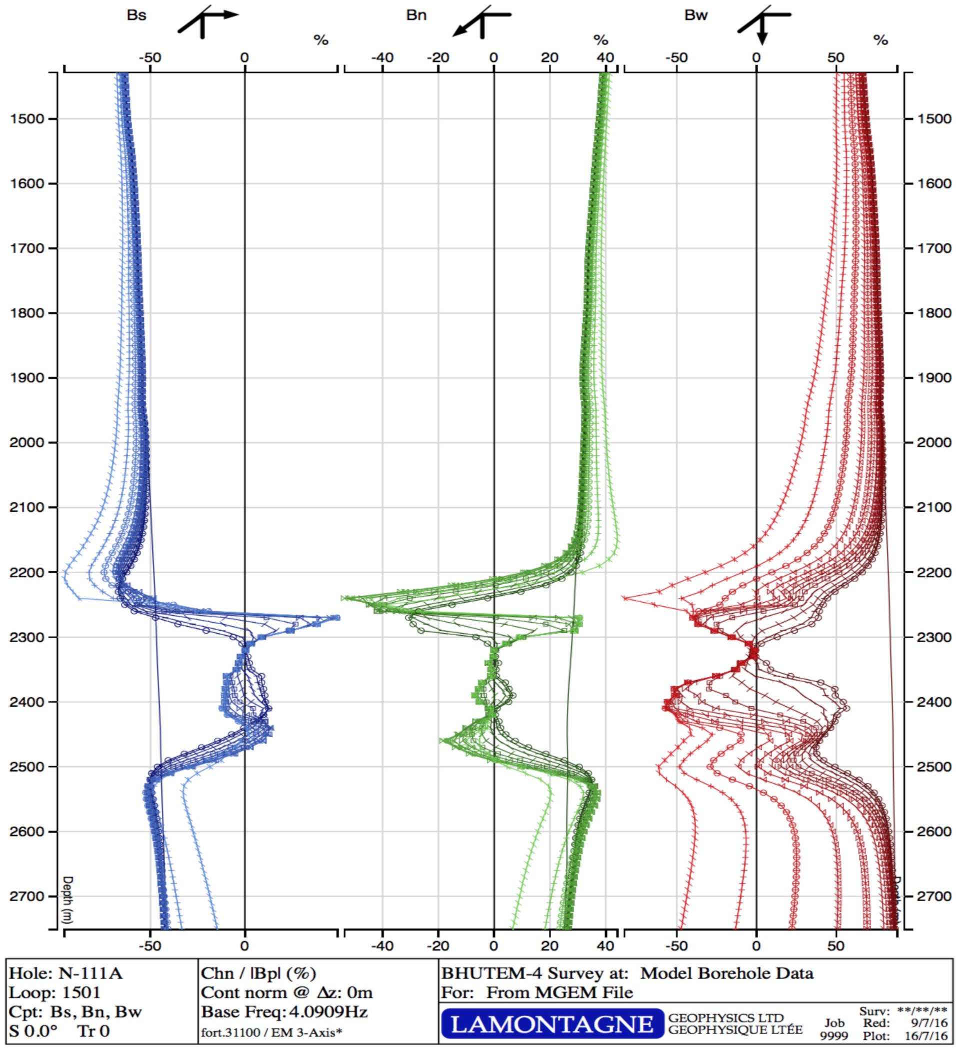


Figure 9: Modelled total field 4Hz data in Hole N-111A with Loop 1501 using model E (Outer/Inner 250/6000 S/m).



Phase 1 - Conclusions

The modelling results obtained in Phase 1 confirm the general correctness of the objective model but indicates a lower conductivity than expected for the outer zone (250 S/m) and a higher conductivity for the inner zone (≈10 000 S/m).

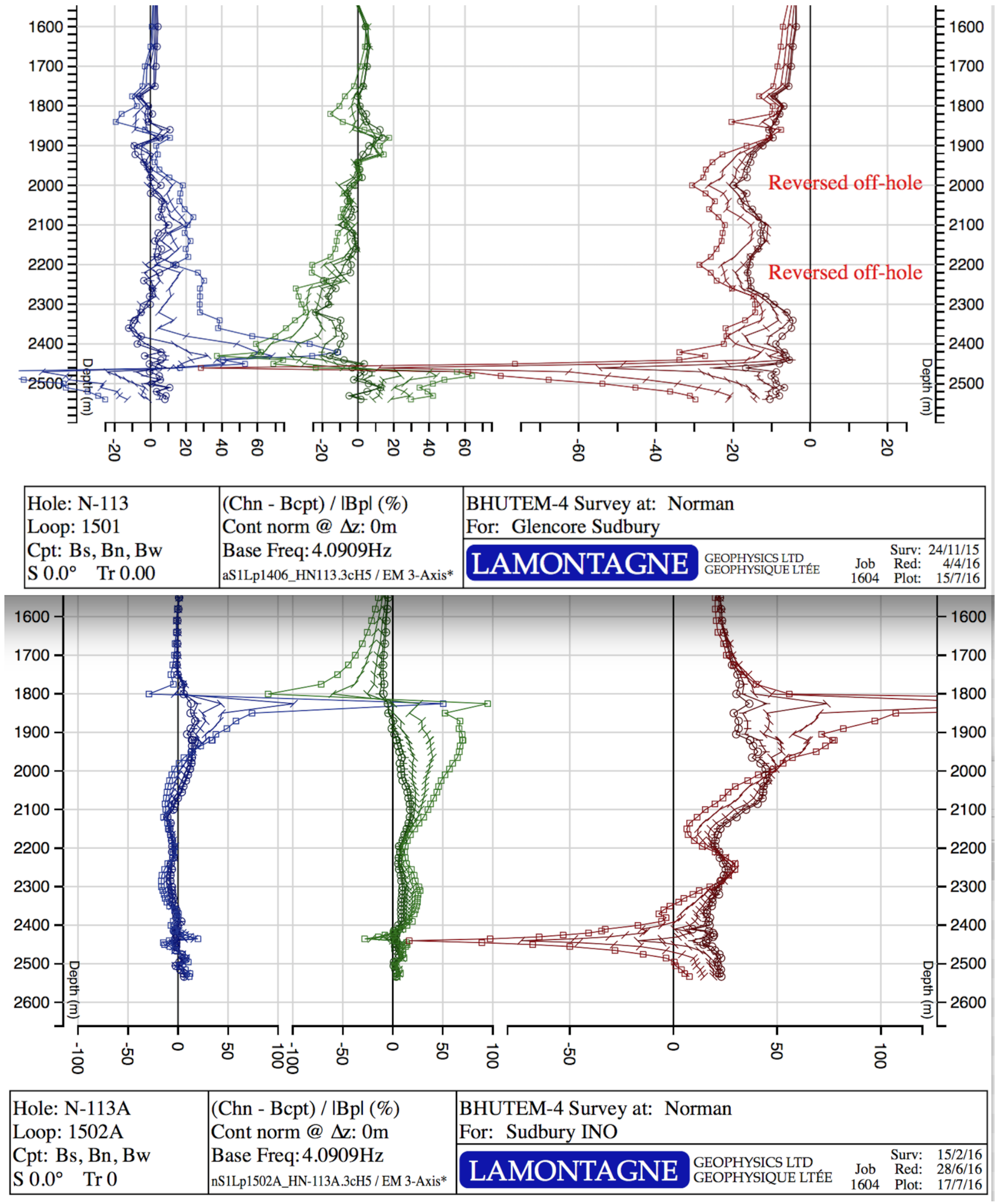
Three main responses are unexplained by this model:

1) The background response which appears due to the known contact zone intersected around 1800-2000m depth in almost every hole. In hole N-110D this zone is mainly off-hole. In hole N-113, a poorly conductive extension of the zone is off-hole east of the hole @1825m depth giving rise to a huge short decay-time anomaly.

2) The response of the known “contact zone” around hole N-112 which is indicative of much higher conductivity than in (1).

3) The apparent late channel off-hole responses observed in hole branches N-113 and N-113A. These responses in N-113 are shown on Figure 10.

Figure 10: Two anomalies seen in the Hole N-113 Loop1501 response that appear to be reversed coupled off-hole responses with Loop 1501 and forward coupled with Loop 1502A.



Interpretation of variance in the modelled/measured responses showed that the conceptual model was incomplete and possibly two separate conductors to the southwest were required.

The **Phase 2 modelling** was implemented in an attempt to define the missing conductors. 2 Suites of Modelling were completed:

Prefix	Outer Zone	Inner Zone	Off-hole A1	Off-hole A2	Off-hole B
HA	-	-	167 S/m 9m	330 S/m 18m	5000 S/m 20m
HB	250 S/m	6000 S/m	50 S/m 15m	500 S/m 24m	3333 S/m 30m

Results indicated that the new zones needed to be electrically isolated from the known ore zone and consisted of two zones, a shallower zone and a deeper zone with a higher conductivity.

Subsequent **drilling** has located and verified these zones but with a more complex shape than in the MGEM models.

Figure 11: Model HB. Two conductive zones added to the objective model E. Zone A1 (50S/m) in blue and A2 (500S/m) in light green. Zone B (3333 S/m) is in orange. The reference plane protractor is @2275m depth (-1905 elevation).

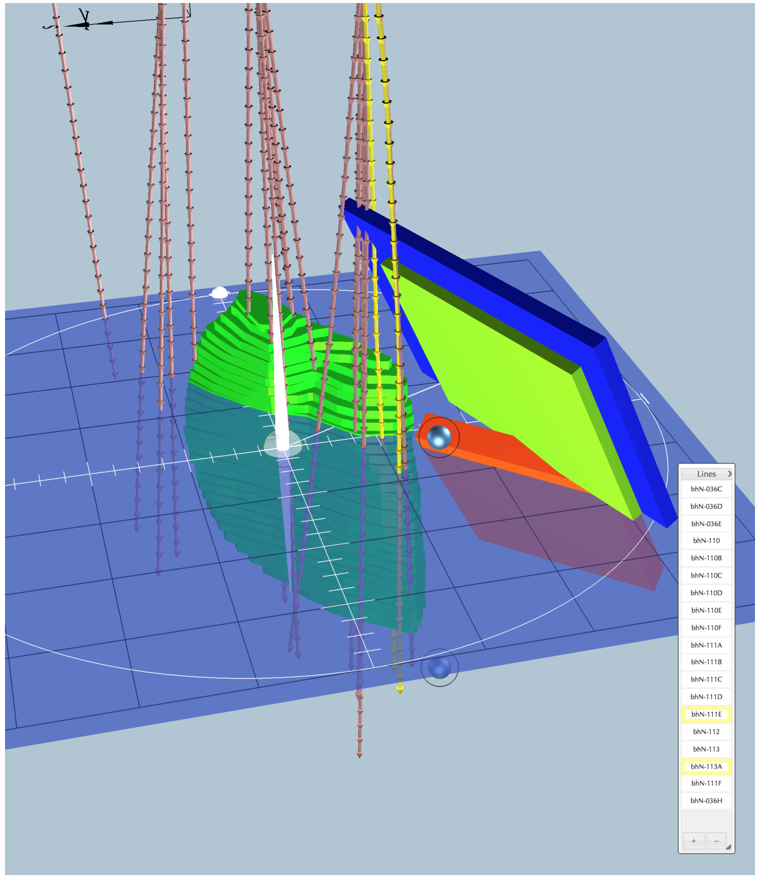
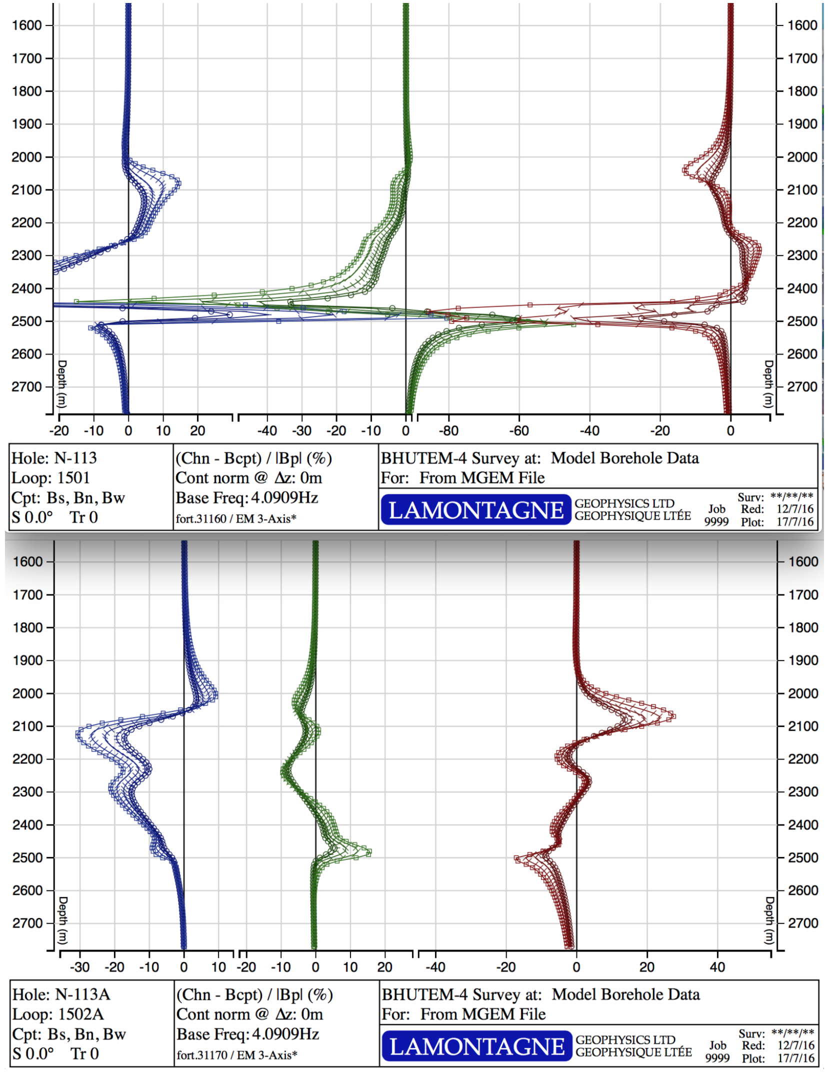
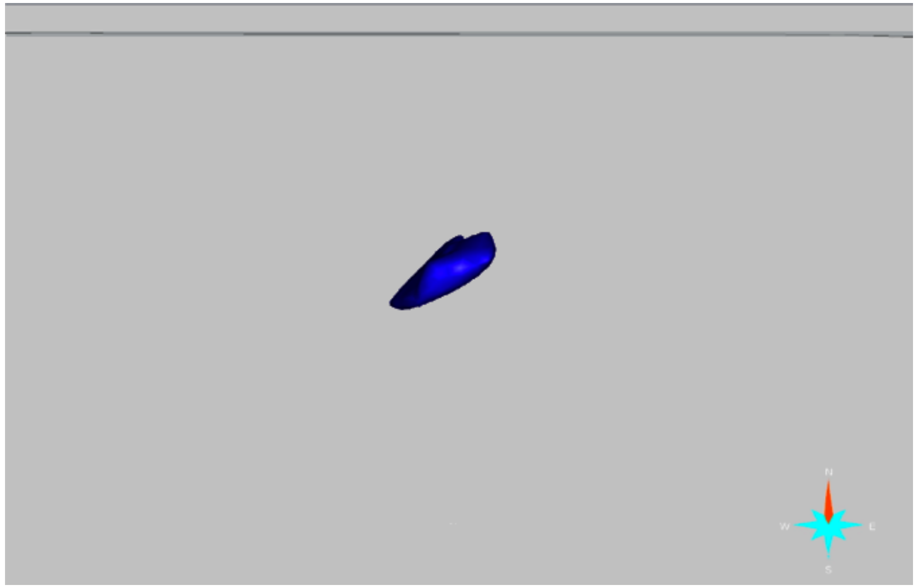


Figure 12: HB model response in N-113/N-113A for Loops 1501 and 1502A. Holes N-111E and N-113 highlighted in model.

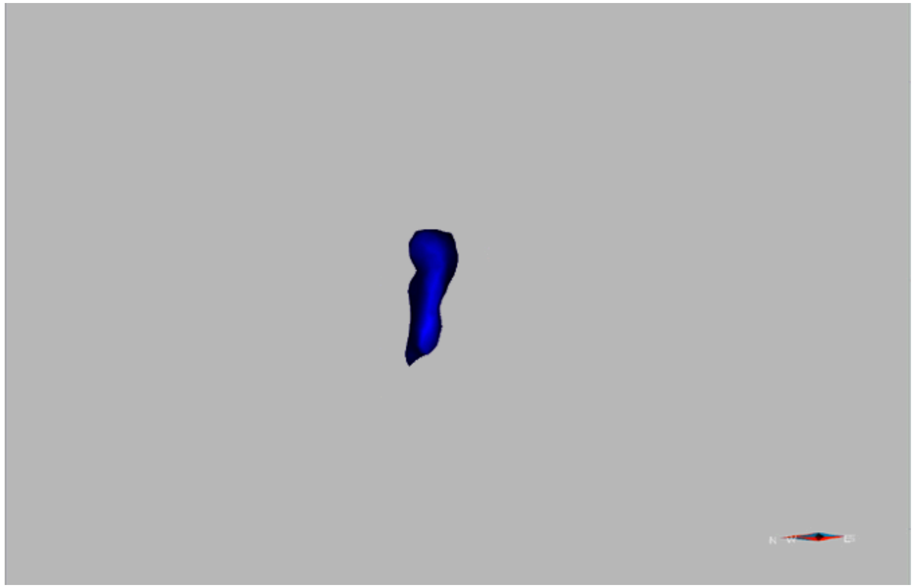


Footwall Main Zone 2016

Plan View

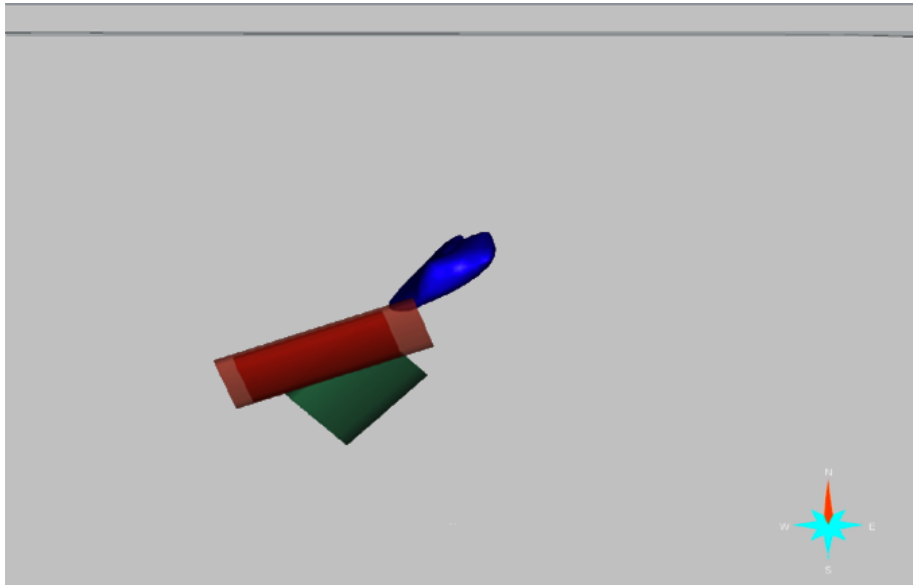


Side View looking North



Footwall Main Zone 2016
with residual thick plates (slabs)

Plan View



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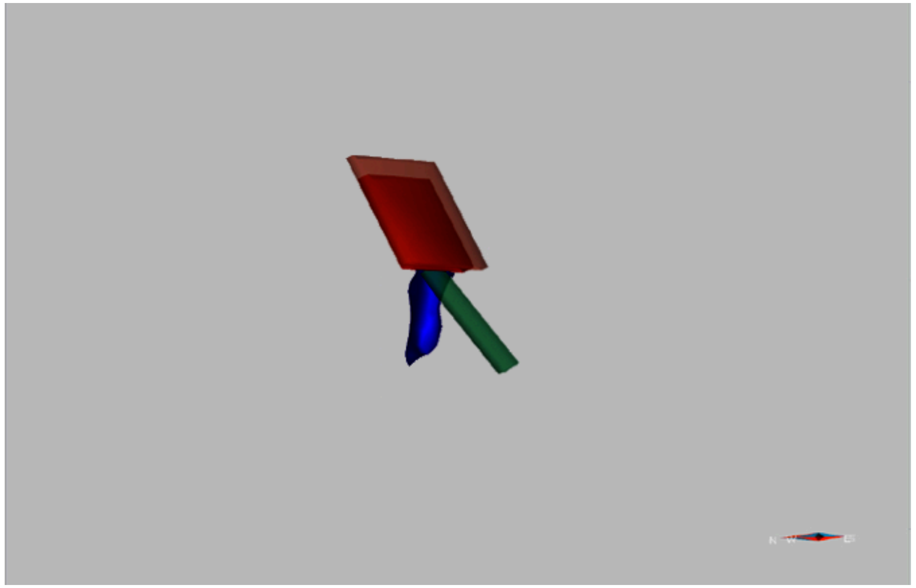
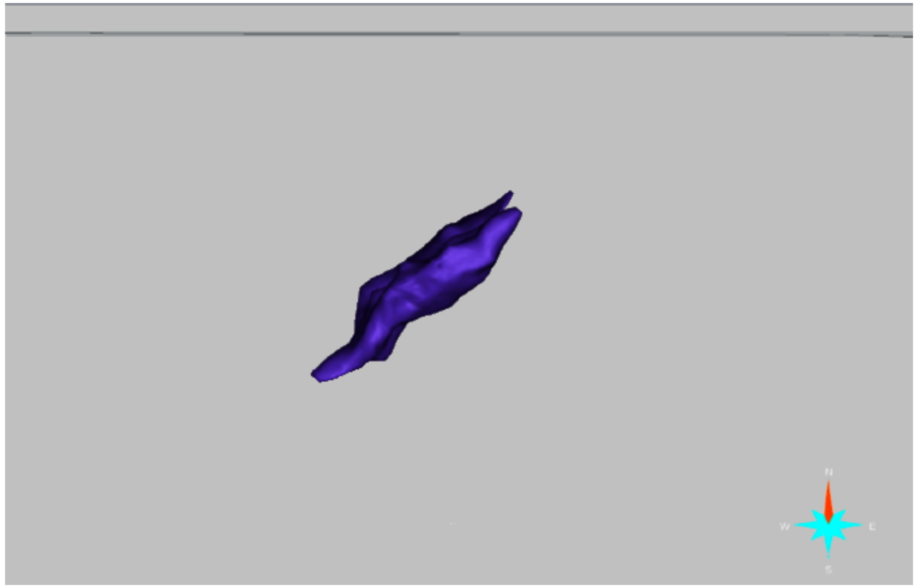
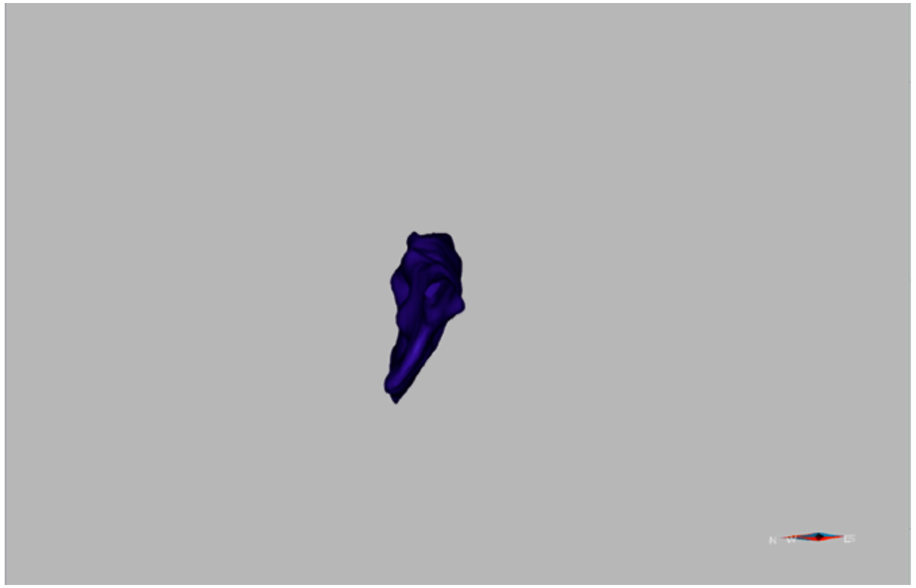


Footwall Main Zone 2019

Plan View

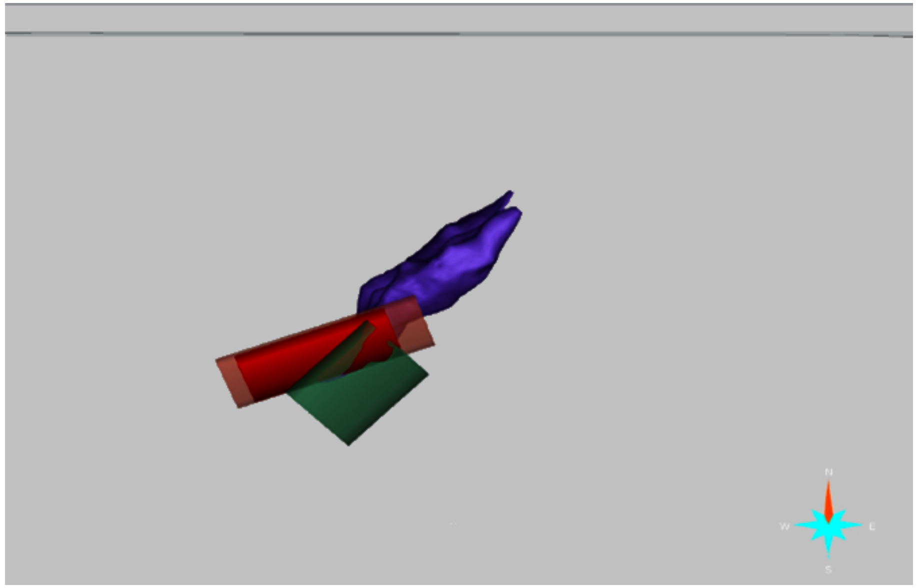


Side View looking North



Footwall Main Zone 2019
with residual thick plates (slabs)

Plan View



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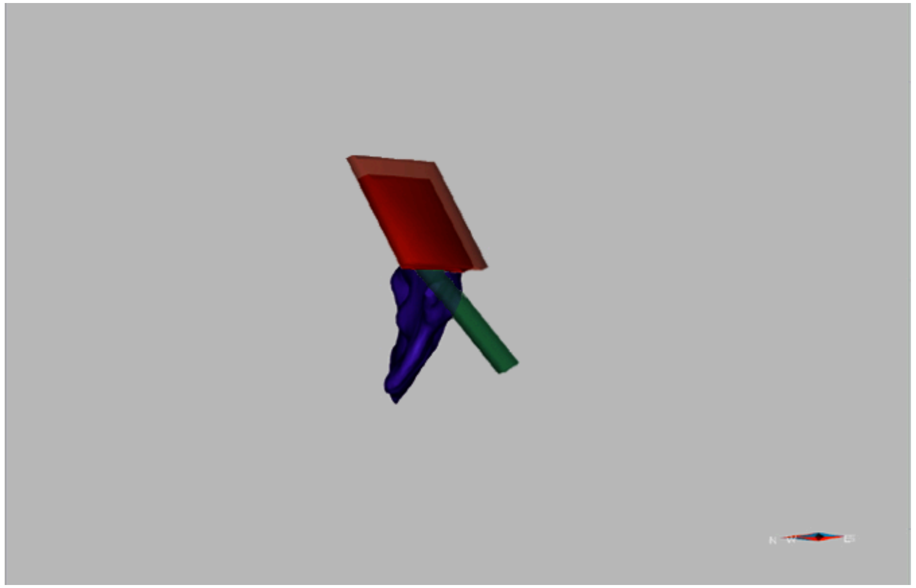
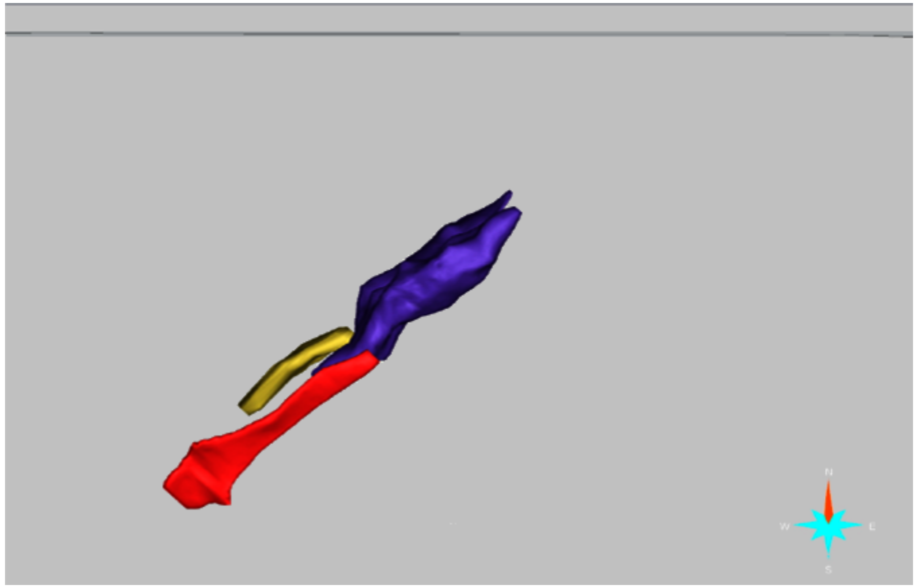


Footwall Main Zone FW1 2019 (purple)
Footwall Zone 2 FW2 (yellow)
Contact Zone 2 C2 (red)

Plan View



Side View looking North

Footwall Main Zone FW1 2019 (purple)
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Contact Zone 2 C2 (red)
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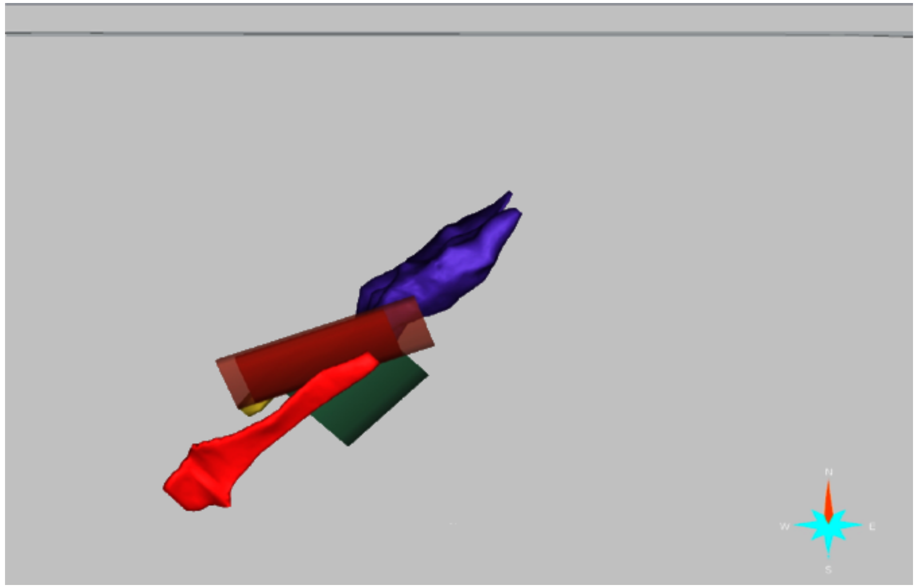
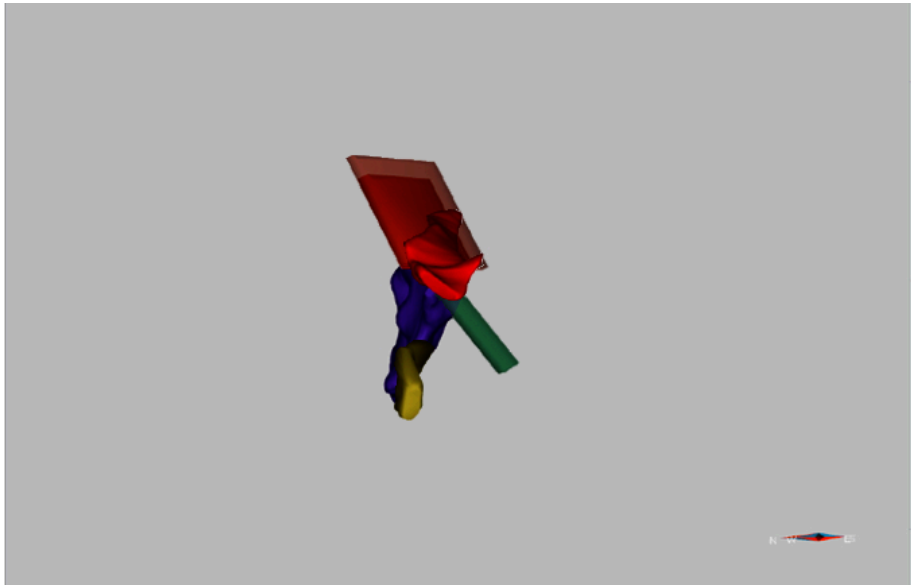
Plan View

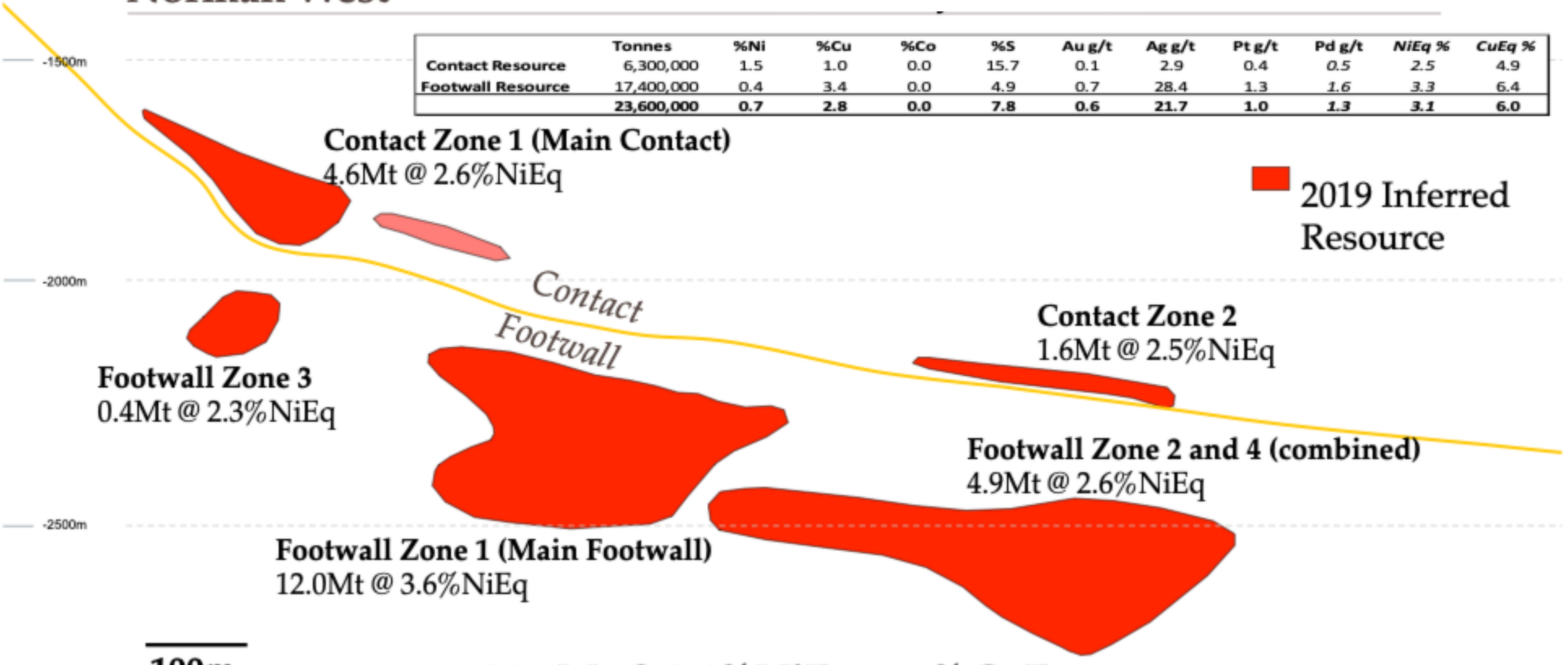


Side View looking North



Norman West

	Tonnes	%Ni	%Cu	%Co	%S	Au g/t	Ag g/t	Pt g/t	Pd g/t	*NiEq %*	*CuEq %*
Contact Resource	6,300,000	1.5	1.0	0.0	15.7	0.1	2.9	0.4	*0.5*	*2.5*	4.9
Footwall Resource	17,400,000	0.4	3.4	0.0	4.9	0.7	28.4	1.3	*1.6*	*3.3*	6.4
	23,600,000	**0.7**	**2.8**	**0.0**	**7.8**	**0.6**	**21.7**	**1.0**	***1.3***	***3.1***	**6.0**



23.6Mt @ 3.1%NiEq, 6.0% CuEq

Norman West Long-Section Looking SE

SUDBURY INTEGRATED NICKEL OPERATIONS
A GLENCORE COMPANY

Norman West

	Tonnes	%Ni	%Cu	%Co	%S	Au g/t	Ag g/t	Pt g/t	Pd g/t	*NiEq %*	*CuEq %*
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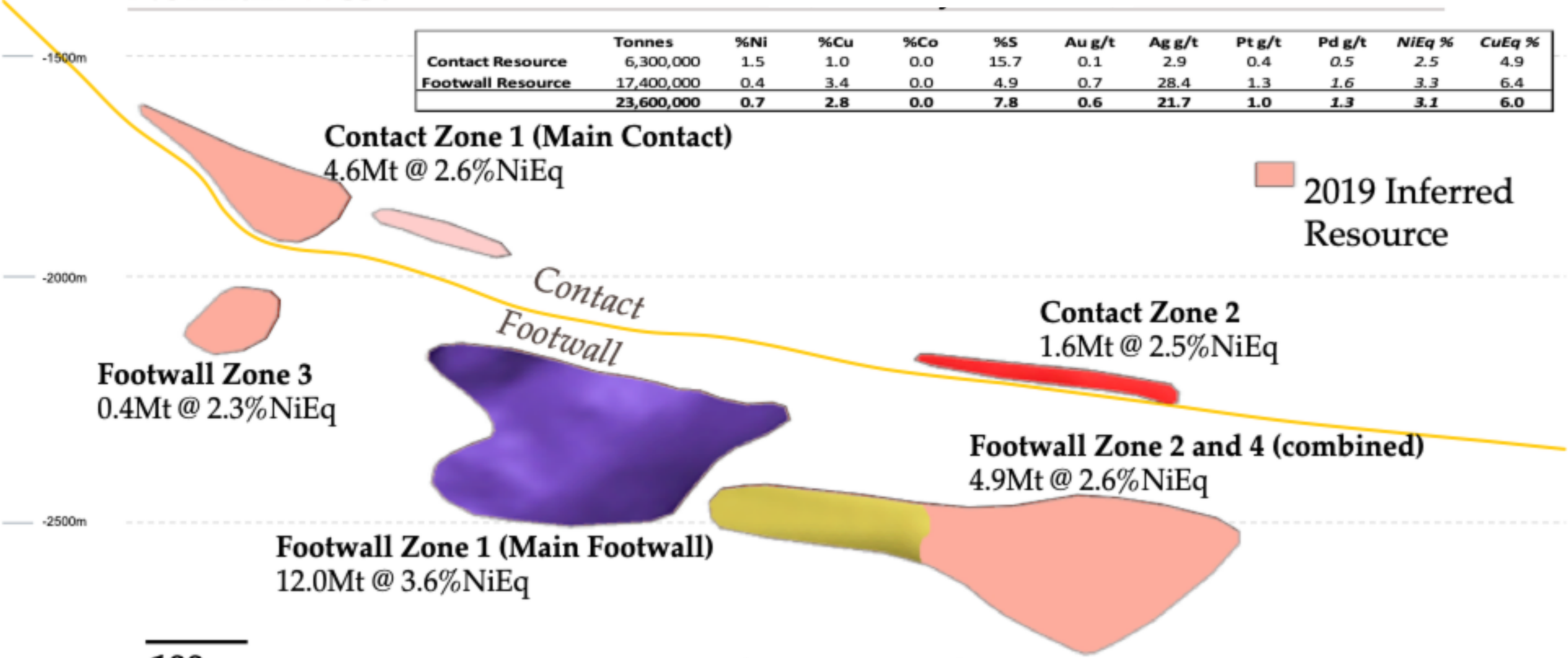

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Norman West Long-Section Looking SE

SUDBURY INTEGRATED NICKEL OPERATIONS
A GLENCORE COMPANY

Summary

The success of plate modelling of BHUTEM data has been requisite for finding new Ni, Cu deposits in Sudbury. At Norman West, direct integration with the geological ore model was becoming very time consuming and more than difficult. Drilling at depths greater than 2km is expensive especially with a such a complex footwall body. More ore needed to be found but where to find it?

The catalyst/innovation was the use of MGEM to model the main footwall zone accurately in 3D for better agreement between the geological model and the geophysics - same time/same environment. Phase 1 was completed in 2016.
The addition of targets to chase to the SW increased focus. Exploration confidence rose as the model was verified - drilling increased size of FW-1 and confirmed success with new ore bodies found. Ore tonnes increased from 9Mt to 23.6Mt (~260%).

Recommendation

MGEM modelling be undertaken on geological models updated with the last 3 years of drilling to provide further exploration guidance and, potentially, additional targets.

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