



3D Seismic

ROSEBERY TASMANIA 2012

June 2013

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TABLE OF CONTENTS

1 INTRODUCTION	5
1.1 Scope/Rationale	5
1.2 Aims	6
1.3 HiSeis	6
1.4 Flow Chart	7
1.5 Local Geology	9
2 PETROPHYSICAL STUDY	11
2.1 Summary	11
2.2 Acoustic Impedance	11
2.3 Methods	12
2.4 Results	13
3 VSP	15
3.1 Summary	15
3.2 Methods	15
3.3 Results	16
4 LINE GRIDDING AND TRACKWORKS	17
4.1 Summary	17
4.2 Methods	17
4.3 Results	18
5 SOURCE HOLES	18
5.1 Summary	18
5.2 Methods	19
5.3 Equipment and Suppliers	21
5.4 Conclusions and Recommendations	22
6 SEISMIC ARRAY	23
6.1 Summary	23
6.2 Methods	23
6.3 Results	24
6.4 Conclusions and Recommendations	24
7 POINT SURVEY	24
7.1 Summary	24
7.2 Methods	25
7.3 Results	26
7.4 Recommendations	26
8 EXPLOSIVES	26
8.1 Summary	26
8.2 Methods	27
8.3 Recommendations	29
9 ACQUISITION	29
9.1 Summary	29
9.2 Survey Parameters And Instrumentation	30
9.3 Methods	30
9.4 Recommendations	32
10 PROCESSING	32

10.1	Pre-Processing	33
10.2	AGC Data Processing	33
10.3	Stacking and Fold	34
10.4	Velocity Analysis	36
10.5	Migration	37
10.6	Amplitude Consistent Processing	38
10.7	Padded Migration	39
10.8	Seismic Attributes	40
10.8.1	Instantaneous Phase	40
10.8.2	Perigram * cosine of phase	40
10.9	3D Presentation	41
11	RESULT AND INTERPRETATIONS	42
11.1	Interpretation Process	43
11.2	Regional Structure	43
11.3	Bright Spot Reflectors	46
11.4	Local Structure	47
12	Conclusions/Recommendations	48
12.1	VSP Recommendations	48
12.2	Future Exploration Tool	49

LIST OF TABLES

Table 1:	Drilling equipment and supplier	21
Table 2:	Potential Explosive Products	27
Table 3:	Survey Parameters	30
Table 4:	Minimum requirements for field and maintenance crew	31
Table 4:	Amplitude-consistent Processing Stream	39

LIST OF FIGURES

Figure 1:	Airphoto showing the planned grid layout. Note that the body of water to the North is Lake Rosebery.	8
Figure 2:	Rosebery Stratigraphy	9
Figure 3:	Idealised Cross Section of the Rosebery Mine (Knight, 2011)	11
Figure 4:	Lines of constant acoustic impedance (Z) superimposed on velocity-density fields and Nafe-Drake curve (Grey) for common rocks at a confining pressure of 200 MPa (Salisbury & Snyder, 2007)	12
Figure 5:	Forward Modelling processing work flow	13
Figure 6:	Sample distribution for petrophysical analysis.	13
Figure 7:	Petrophysical summary of rocks sampled from North Rosebery drill holes and K Lens.	14
Figure 8:	A synthetic seismic section derived from a conceptual geological model of the Rosebery mine sequence.	15
Figure 9:	Examples from shot records with VSP string at various depths plus one panel with surface geophones (second last from right). Most of the energy is in tube waves, which appear as diagonal bands of signals.	16
Figure 10:	Zero Offset VSP with string top set at 50m, lowest sensor at 280m (rightmost). The first energy is relatively clear in the high gain presentation (the first blue pulse). A possible major fracture is seen approximately 210-210m downhole. Such fractures are sources of tube wave emission when the p-wave arrives at the fracture location.	17
Figure 11:	Planned versus actual station implementation.	18
Figure 12:	Cobra Combi Drill mounted on travelling backpack.	19
Figure 13:	Steel Extractor	22
Figure 14:	HiSeis employee loaded up with gear that is about to be deployed.	23
Figure 15:	Deploying trunk cable in difficult terrain	24
Figure 16:	A typical example of implementing best survey practice.	25

Figure 17: Actual Grid location viewed from the North. Note the harsh topographic relief.	26
Figure 18: Number of shots per day.	32
Figure 19: The effects of coupling and rain on data quality.	35
Figure 20: Fold geometry for the survey design at a depth slice of 700m. The image shows that at this depth, each block has been imaged approximately 40 to 70 times through the middle, and down to 5 at the limits of the cube.	36
Figure 21: An example of the RMS velocity field from a representative inline that was used for stacking. Velocities generally range from 3700 m/s – 5200 m/s.	37
Figure 22: The migration of the imaged reflector C-D, to its correct location in space C'-D'.	38
Figure 23: An example of the geometric propagation of energy with respect to dipping reflectors.	40
Figure 24: The results of seismic attribute filtering: Instantaneous phase (left) and Perigram * cosine of phase (right)	41
Figure 25: East West slice of AGC seismic cube with drilling overlain.	42
Figure 26: Depth section taken from the padded migration results, showing the convergence of the Rosebery and Mt Black Faults	44
Figure 27: Viewed from the South West, the Rosebery fault in Green and the Mt Black fault in purple. Background cube has undergone AC processing, and the 2D slice AGC.	45
Figure 28: A clipped section from the preliminary results of HiSeis' padded migration process	46
Figure 29: Isosurfaces showing coherent amplitude reflectors in the AC dataset.	47
Figure 30: 3D image, viewed from the South East, showing the hypothesized shear zone, wireframed in orange.	48

APPENDICES

Appendix A: Images from Kyen Knight's Thesis	50
Appendix B: HiSeis Acquisition Report	51
Appendix C: HiSeis Processing Report	52
Appendix D: HiSeis Interpretation Report	53
Appendix E: PDA Survey Report	54
Appendix F: References	55

1 INTRODUCTION

1.1 SCOPE/RATIONALE

Traditional exploration techniques for base metal deposits such as Rosebery are commonly limited to potential field and electrical methods. These methods have low spatial resolution at depth and are typically limited to directly targeting shallow targets (<500m). Although used extensively in petroleum exploration, until recently, seismic reflection methods have been considered to be of limited use in the complex, hard rock metalliferous environments of the Mt Read Volcanics, due to the complexity of the geology, high velocity lithologies, massive heterogeneous regolith and the presence of confounding elements such as shear zones and dykes. Logistical issues such as remote access, harsh topography, and environmental restrictions also have a significant effect on the cost of data acquisition.

Although 3D seismic as an exploration tool has rarely been used in Tasmania, there are well established examples of its success in the mining world. In the late eighties, 3D seismic surveys were used to image the horsts and anticlines which bring the gold and uranium bearing strata of the Witwatersrand basin in South Africa within mineable depths. Platinum mines in the Bushveld complex of South Africa have used it to map three dimensional geological structures and to assess the characteristics of mineable blocks within known mineralisation for mine planning purposes. Traditionally, as in the previous examples, the primary aim of surveys has been to map structures or contacts between lithological units where ore bodies are likely to exist. Over time, technology has shifted from structural mapping towards the analysis of 'bright spot' reflectors, which could be representing sulphide accumulations (L'Hereux Et. Al, 2005).

In 2011 MMG initiated a study of the petrophysical properties of the Rosebery lithologies, and through forward modelling assessed the potential of seismic methods in this environment. The favourable results of this project led to the decision to proceed. The rationale behind the program was that;

- Current exploration in the area is limited to deep directional drilling on 200m sections with the average drill fan costing ~500K;
- Due to presence of overlying pyrrhotite-pyrite mineralised black shales, downhole EM is not successful;
- No other geophysical method can test a large surface area to adequate resolutions at depth (1km+)
- The consistent dip of the geology (~45°) is considered amenable to seismic reflection
- The stratigraphy is well known and provides adequate acoustic impedance contrasts between the different lithologies (Knight, 2011);
- The trend of the Rosebery and Mt Black faults to the north of the existing development is poorly understood;

- The survey could assist in the understanding of the structural architecture of the region, possibly enhancing drill targeting; and
- There is a need for a transformational discovery at Rosebery

This report is structured to give a technical overview of the logistics of data acquisition, and importantly, the significant key learnings, the data processing stage and then a brief insight into the interpretation of the data (ongoing at time of report). The report will also summarise the background to the survey including Kyen Knight's 2011 Honours thesis and the field testing done prior to the actual survey.

1.2 AIMS

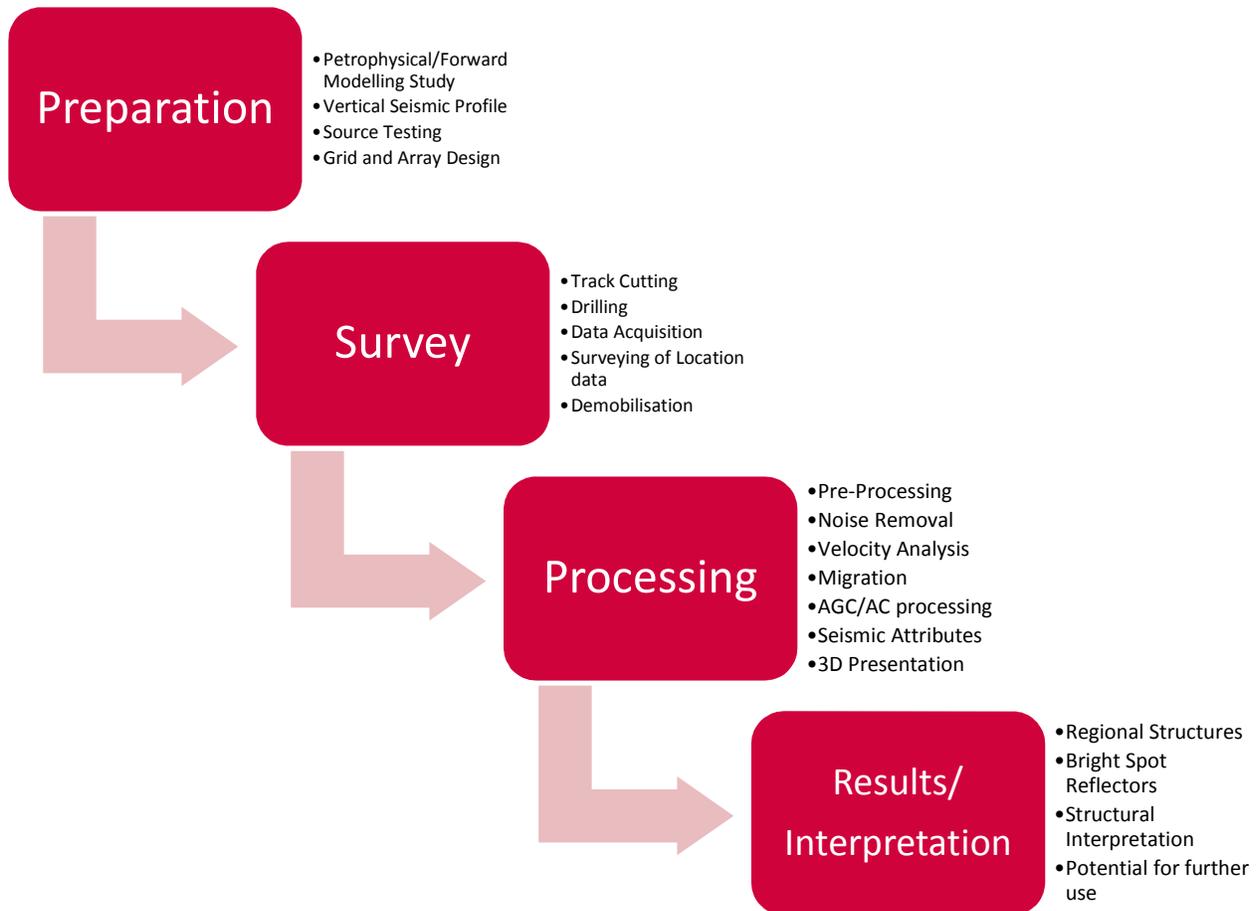
The main aims of this survey were:

- To gain a more detailed understanding of the main faults in the region (Mt Black and Rosebery) and their nature, particularly any indications of their attitude to the North where information is sparse.
- To look for any 'bright spot reflectors'. A bright spot reflector is a discrete, high amplitude response which may represent accumulations of massive sulphide.
- To draw information about the structures and fabric that might have an effect on ore distribution.
- To evaluate whether 3D seismic could be an effective tool for MMG into the future, in other similar terranes.

1.3 HISEIS

MMG contacted HiSeis Pty Ltd to undertake the survey at Rosebery. HiSeis was formed three years ago by Curtin University, to commercialise the hard rock seismic technology developed by its geophysicists. HiSeis, although relatively new, has done work for companies such as BHP, First Quantum, and AngloGold Ashanti. Seismic surveying conducted at Lundis Mining's Neves-Corvo mine in Portugal, revealed a previously unknown southern extension of its 900m deep Semblana deposit. Subsequent drilling confirmed the interpretation, with results including a 5m interval of massive copper sulphides averaging 4.6% copper.

1.4 FLOW CHART



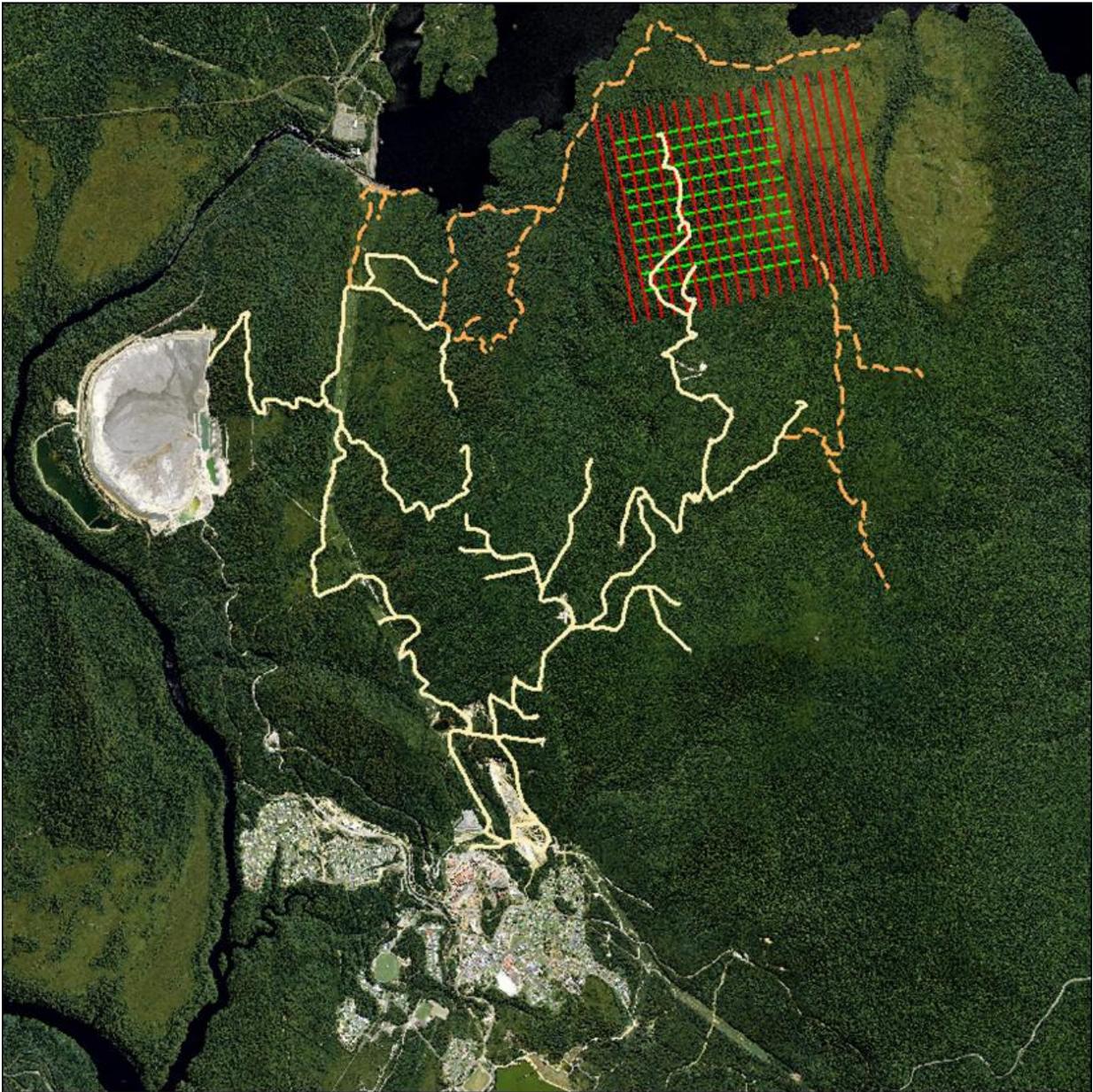


Figure 1: Airphoto showing the planned grid layout. Note that the body of water to the North is Lake Rosebery.

1.5 LOCAL GEOLOGY

Summarised from Martin (2002) and Knight (2011)

The Rosebery massive sulphide deposit is located within the Central Volcanic Complex, an element of the Mount Read Volcanics on the West Coast of Tasmania. The Mount Read Volcanic belt is ~20km in width and ~200km in length and was emplaced along the Dundas Trough during the Middle Cambrian. The belt itself is made up of an eastern-central zone dominated by volcanic and intrusive rocks, and a broader western zone composed predominately of volcano-sedimentary sequences. The Central Volcanic Complex (CVC) is a sequence of predominately feldspar-phyric volcanoclastic rocks, with abundant rhyolite-dacitic lavas, pumiceous volcanoclastic rocks and massive dome like lava bodies. The presence of hyaloclastites and extensive subaqueous pumiceous mass flows indicate that the sequence was dominated in a subaqueous environment.

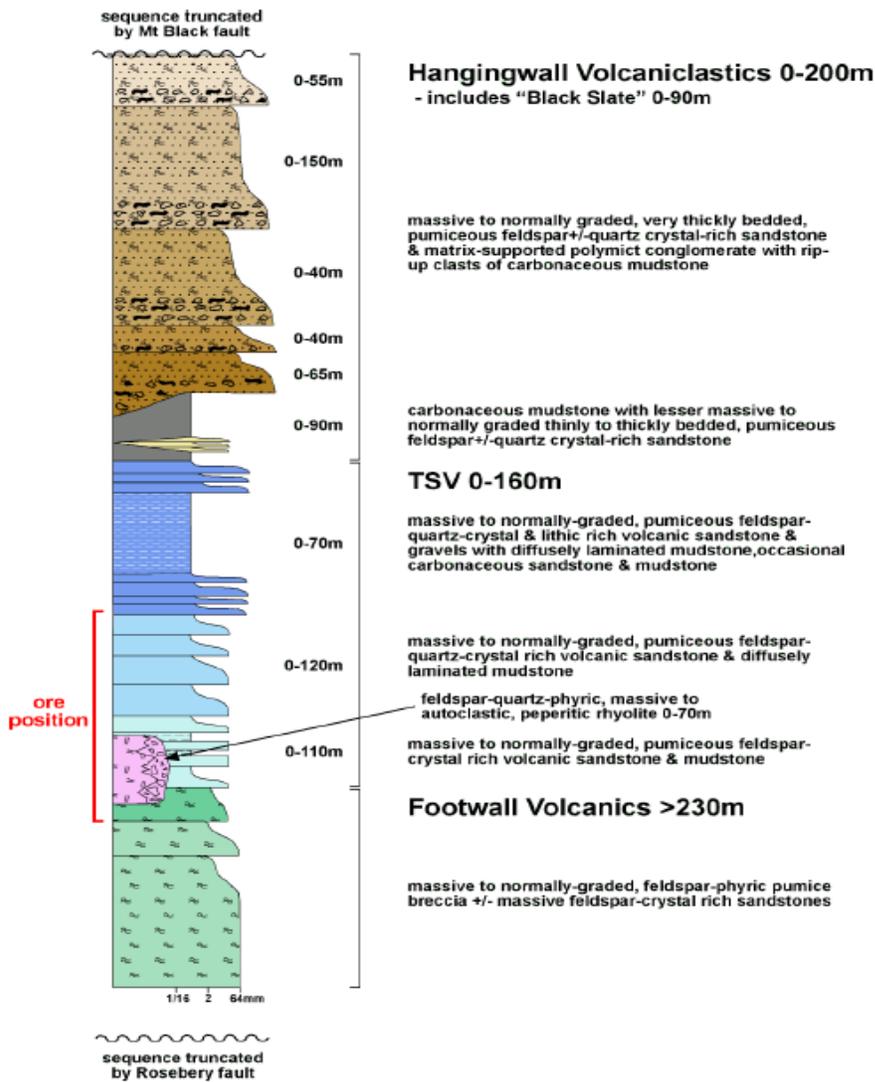


Figure 2: Simplified Rosebery Stratigraphy

Mineralisation is hosted within a sequence of massive to normally graded pumiceous feldspar-quartz crystal rich volcanoclastic sandstones and mudstones, intruded by peperitic rhyolites. This sequence is typically capped by a black shale which represents a period of ambient anoxic, carbonaceous sedimentation, not long after the host horizon was deposited. This unit can be used as a relatively consistent marker bed throughout the Rosebery mine leases. Deposited on top of this unit is the Rosebery Hanging Wall sequence, which is composed of interbedded pumiceous, feldspar-quartz rich crystal rich volcanoclastics with lenses of black mudstone. This unit is truncated by the Mt Black Fault, and overlain by the Mt Black Volcanics, a series of rhyolitic to dacitic, massive flow-banded and autobrecciated lavas dome and syn-volcanic sills.

Throughout the Rosebery mine region, bedding is variably preserved, upwards facing and dips from 40° to 60° with a strike of approximately 350° AMG. There are three cleavages recorded in the sequence, S1 and S2 are early and weak, whilst the dominant cleavage, S3, is a roughly bedding parallel and is a prominent shear foliation with cataclastic brecciation, silicification and quartz-carbonate +/- sulphide veining. The two regional structures in the region are the Mt Black and Rosebery faults. The Mt Black Fault is a large, east dipping (~45°) Cambrian age Structure, which in the mine area forms a faulted contact with the Hanging wall volcanoclastic sequence, and the Mt Black Volcanics. In places, the fault has a brecciation zone measuring up to 10m, but can get as thin as 20cm and is variably overprinted by intense silica – sericite alteration.

The Rosebery fault is a regionally extensive east dipping (~45°) Cambrian age Structure that truncates the lower portion of the Footwall member and is commonly thought to form a faulted contact with the Stitt Quartzite and the Whitespur formation. The Rosebery fault is characterised by a brecciation zone up to 4m thick, cataclastic breccia and/or quartz tourmaline veins with minor disseminated pyrite or pyrrhotite.

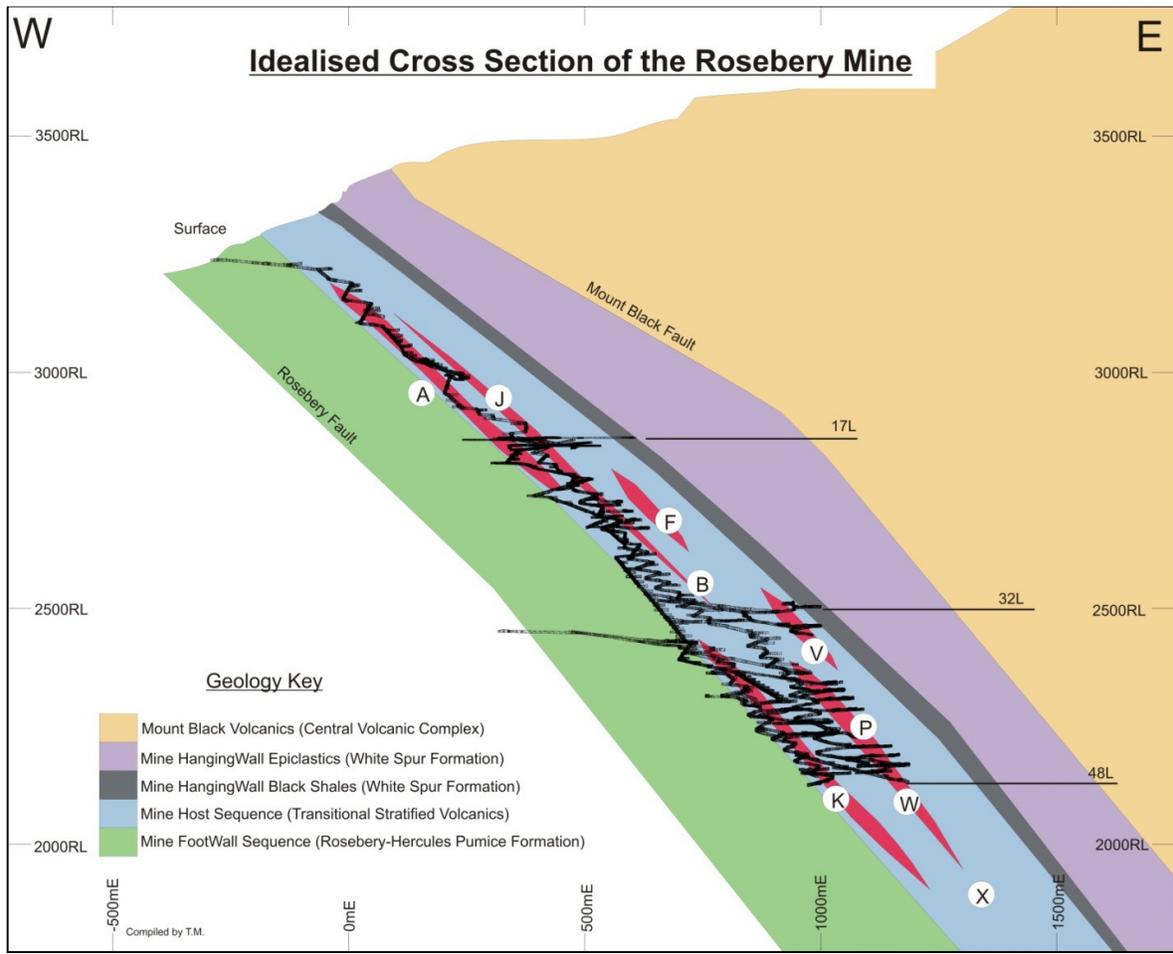


Figure 3: Idealised Cross Section of the Rosebery Mine (Knight, 2011)

2 PETROPHYSICAL STUDY

2.1 SUMMARY

An investigation of laboratory-scale petrophysical properties of the north Rosebery mine area was undertaken to establish a petrophysical database of the Rosebery ore body and host environment. A suite of samples were collected from an area of active exploration, north of the mine, containing relatively simple geology and away from the influence of granite alteration. Sampling was focused on mine sequence rocks (Host Rocks, Hangingwall, Footwall), with samples also taken from the overlying Mount Black Volcanics and associated intrusive units, the White Spur Formation and from the margins of the Mount Black Fault and the Rosebery Fault. High grade ore samples were taken from underground drilling through K Lens, the highest grade lens at Rosebery. These petrophysical parameters were then used to generate forward models with synthesised datasets to assess the potential of seismic techniques to the Rosebery Environment.

2.2 ACOUSTIC IMPEDANCE

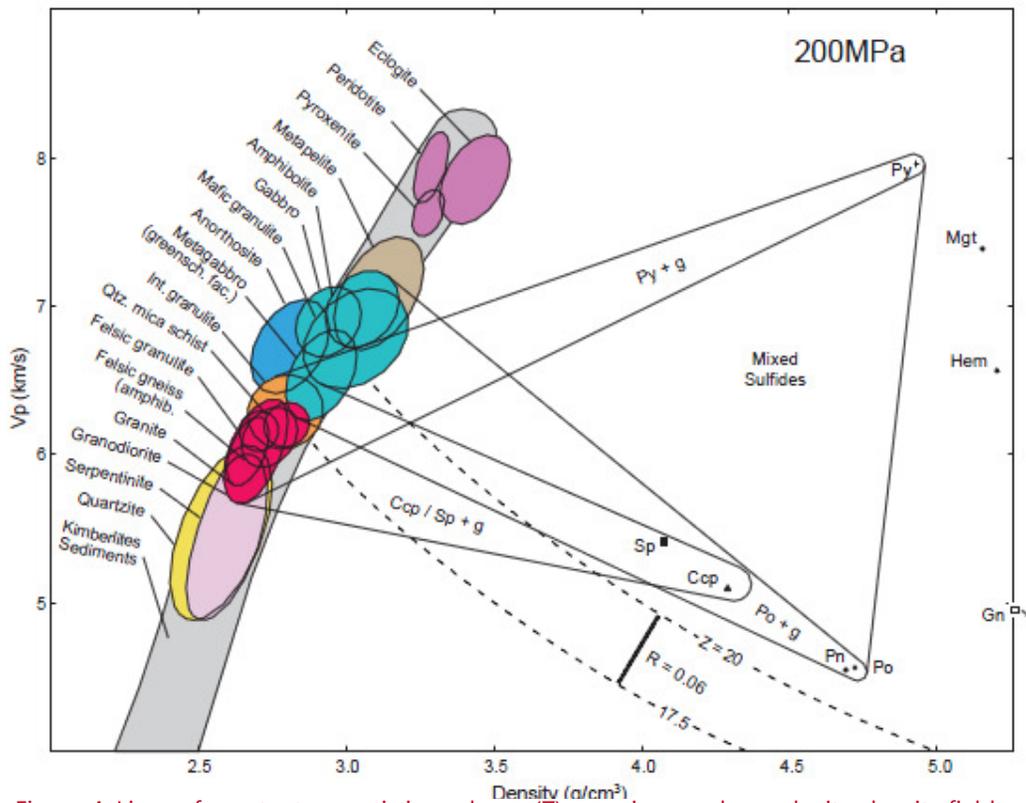


Figure 4: Lines of constant acoustic impedance (Z) superimposed on velocity-density fields and Nafe-Drake curve (Grey) for common rocks at a confining pressure of 200 MPa (Salisbury & Snyder, 2007)

Acoustic impedance is the defining petrophysical characteristic for a seismic survey. By definition, the acoustic impedance of a rock is the product of its density multiplied by the seismic velocity. When a seismic wave travelling through the subsurface encounters a change in acoustic impedance, some of the wave energy will reflect off the interface and some will refract through. By measuring the returning energy at the surface, information about the sub surfaces lithologies can be gained. Figure 4 was extracted from Salisbury and Snyder and shows the acoustic impedance distributions of typical rock type (2007).

2.3 METHODS

252 drill core samples and 12 high grade ore samples, from 8 rock types and two fault structures were analysed for density, porosity, acoustic velocity, resistivity, chargeability and magnetic susceptibility. Forward seismic modeling of synthetic geological models was performed using the petrophysical data to assess the typical response of ore in the host environment, as well as the other lithological components. Synthetic velocity and density models were developed within the GIS software package, ArcGIS (ESRI) and then rasterized into grids representing density and velocity. The forward modeling processes was undertaken using Seismic Unix (CWP, Colorado school of Mines). An example of the processing workflow is shown below in figure 5.

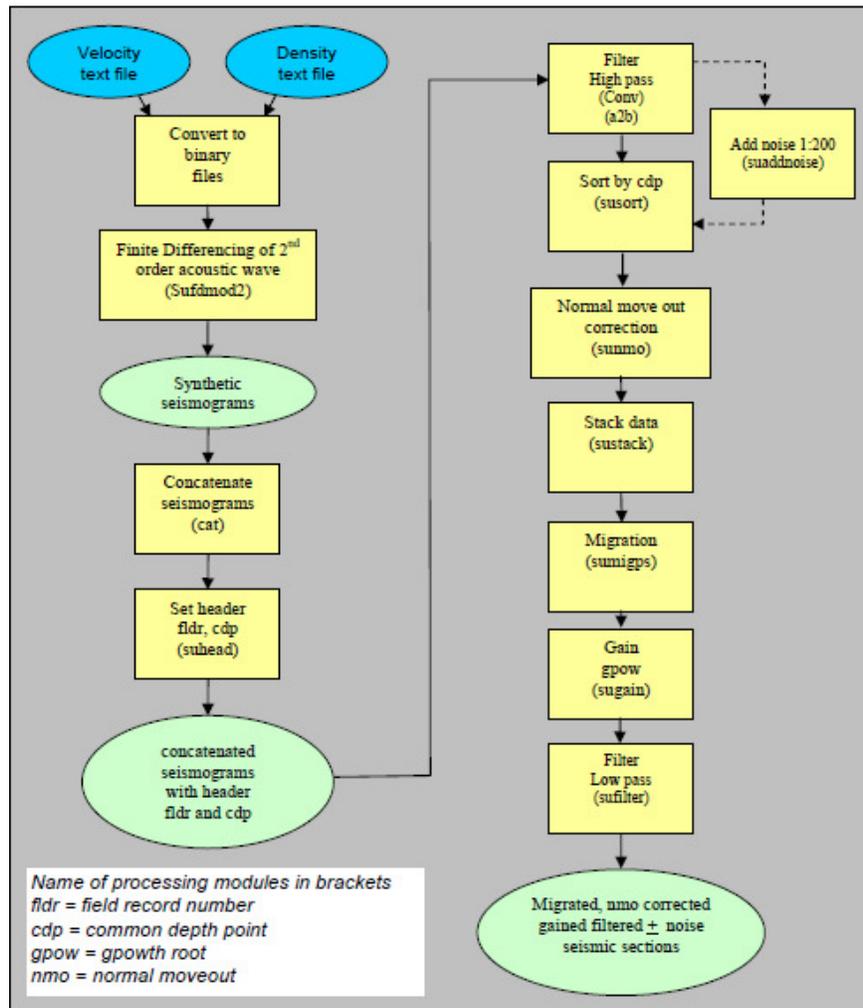


Figure 5: Forward Modelling processing work flow

2.4 RESULTS

Table 3.4: Summary of sampled rock units

DDH code	Total	316R	316R-D1	317R	319R	337R	345R	361R
Rock units/ structures								
Black Shale	24	-	2	6	1	2	7	6
Footwall	20	2	6	3	1	5	1	2
Footwall transition	11	-	2	-	2	3	-	4
Granodiorite	12	-	-	-	-	-	12	-
Host	65	12	15	5	12	14	5	2
Hangingwall	48	7	1	4	3	2	12	19
Mount Black Volcanics	41	11	-	12	5	-	13	-
Mount Black Fault	12	2	-	2	4	-	4	-
Rosebery Fault	8	-	5	-	-	3	-	-
White Spur Formation	11	-	4	-	-	7	-	-
Total no. samples	252	34	35	32	28	36	54	33

Figure 6: Sample distribution for petrophysical analysis.

Petrophysical results from rock samples collected in the north Rosebery area are variably dense, tight (low porosity), display a wide range P-wave velocities, P-wave amplitudes and acoustic impedances. This study showed that mineralised Host Rocks of the Rosebery mine sequence are petrophysically distinct from other rock units in the mine environment. Host Rock samples with massive mineralisation have high densities. Variability of P-wave velocity in high-grade ore rocks has been shown to be associated with sulphide mineral composition, with pyrite rich ore rocks having the highest P-wave velocity and galena rich ore rocks having the lowest recorded P-wave velocity.

Formation	Lithology	No. of samples	DBD (g/cc)	Pa (%)	P wave Vel (km/sec)	P wave Amp _{app} (V)	Res (Ωm)	IP (%)	Mag sus (x10 ⁻² SI)	Impedance (x10 ⁵ g/cm ² s)
White Spur Formation	Qtz fspar-phyric volcanics	14	2.76	0.3	5.5	167	16570	3.7	0.1	15.3
Hangingwall Volcaniclastics	Qtz-fspar-phyric mass flow	48	2.71	0.1	5.7	274	24170	2.4	0.1	15.4
	Carbonaceous black mudstone	25	2.76	0.2	5.1	66	22580	10.3	3.5	14.1
Hercules Pumice Formation	Mn Carbonate	7	3.17	0.5	5.5	144	5410	5.0	3.0	18.1
	Massive ore sph, gln, py	16	3.66	0.4	5.6	215	2110	11.3	2.7	20.3
	Disseminated-Trace ore	32	2.76	0.3	5.2	140	13850	3.5	0.2	14.2
	<i>(Host rock member)</i> Transitional stratified volcanics	24	2.74	0.2	5.3	205	47290	3.9	0.3	14.6
	<i>(Host rock – Footwall member)</i> Footwall Transition zone	10	2.73	0.2	5.0	154	54000	2.0	0.2	13.7
	<i>(Footwall member)</i> Pumice breccia	22	2.70	0.1	5.5	188	80610	2.6	0.1	14.9
Mount Black Formation (Mount Black Volcanics)	Dacite/rhyolite breccia	34	2.74	0.1	5.7	314	29960	2.1	0.2	15.6
	Carbonate (Banded and breccia)	5	2.74	0.4	5.2	47	11860	2.6	0.1	14.4
Intrusives	Mafic fspar-phyric dykes	10	2.85	0.1	6.0	334	23730	3.4	1.8	17.0
	Granodiorite-diorite	11	2.81	0.2	6.2	344	69090	2.7	0.3	17.4
K lens high-grade Ore samples	Massive gln-sphl	2	4.69	0.7	4.4	177	10	143.5	0.1	20.5
	Massive sphl-gln	5	4.20	0.2	4.9	45	20	38.2	0.1	20.7
	Banded py, sphl	3	4.44	0.1	6.3	216	5	98.0	0.1	27.6
	Banded sphl, py	2	4.12	0.2	5.1	80	20	44.4	0.1	21.2

Figure 7: Petrophysical summary of rocks sampled from North Rosebery drill holes and K Lens.

Forward modelling of synthetic geological models show fault rocks as high amplitude reflections, with low amplitude reflections caused by the Black Shale and the Footwall rocks. Rock units with low velocities and low densities commonly show high amplitude low frequency reflections. As figure 3.4 shows, two strong reflections related to the Mt Black fault and the Rosebery fault are clearly resolved in the synthetic seismogram. Weak reflections due to the mine sequence rock units (Black shale, Host rocks, footwall sequence). Reflections due to carbonate horizons in the Mt Black Volcanics are able to be resolved, however the high density and velocity intrusive units are not.

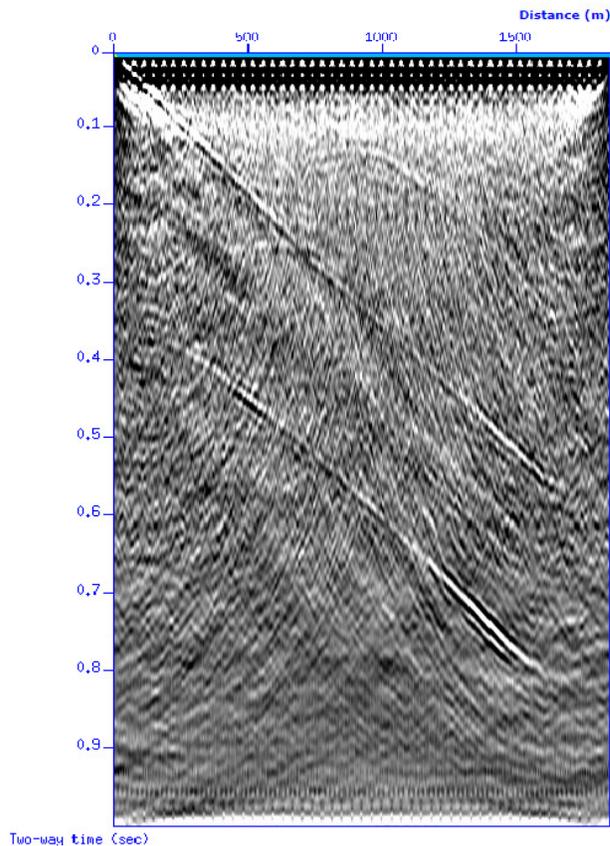


Figure 8: A synthetic seismic section derived from a conceptual geological model of the Rosebery mine sequence.

3 VSP

3.1 SUMMARY

Prior to the commencement of the survey, a Vertical Seismic Profile (VSP) was attempted in hole 402R in conjunction with a surface array spread. The aim of the testing was to check the viability of a small explosive source for imaging the Rosebery geology. This was to be achieved by recording the post-blast ground waves with geophones on the ground and a hydrophone in the newly drilled borehole. A secondary aim was to collect data to be used later to constrain time/depth relationships.

3.2 METHODS

The data was all collected in a single day, on the 20th November, 2011. Detonator and trigger tests were performed the previous day. Once tests to ensure that the geophone string was working correctly were complete, the VSP tool was lowered by 200m increments with 4 elements of overlap between "drops" of the array. Before shooting, the array was allowed 5-10 minutes to settle with respect to hydrostatic pressure in the hole.

The first record was taken with the hydrophone array at 50m (top sensor element position), then deployed at 250, 450, 650, 850, 1050, and lastly 1230m to avoid the hole bottom at about 1470m for the lowest sensor. At a depth of 850m, extra channels of surface geophones were added.

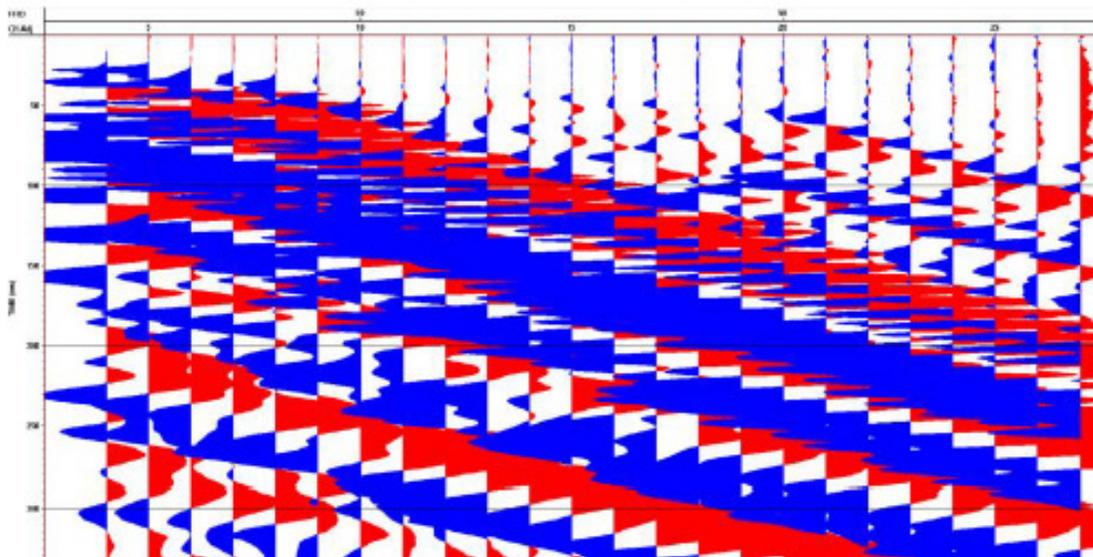


Figure 9: Examples from shot records with VSP string at various depths plus one panel with surface geophones (second last from right). Most of the energy is in tube waves, which appear as diagonal bands of signals.

3.3 RESULTS

Unfortunately, the VSP failed to provide the velocity with depth profile to the target depth because the direct waves were either too weak to be detected, or the sources of noise too strong. The hydrophone string appeared to be fully functional and was deployed with no significant issues, but the relative strength of direct arrivals versus ambient noise was too low to pick the early, direct arrivals. It is possible that noise from the nearby drill rig and even the mine, appeared to be a significant issue. Tube waves in the hole were found to propagate and maintain their signal intensity, thus trapping the weaker signal response from the direct waves with the trapped noise energy. These can be observed in figure 10 as the diagonal reflections down the hole.

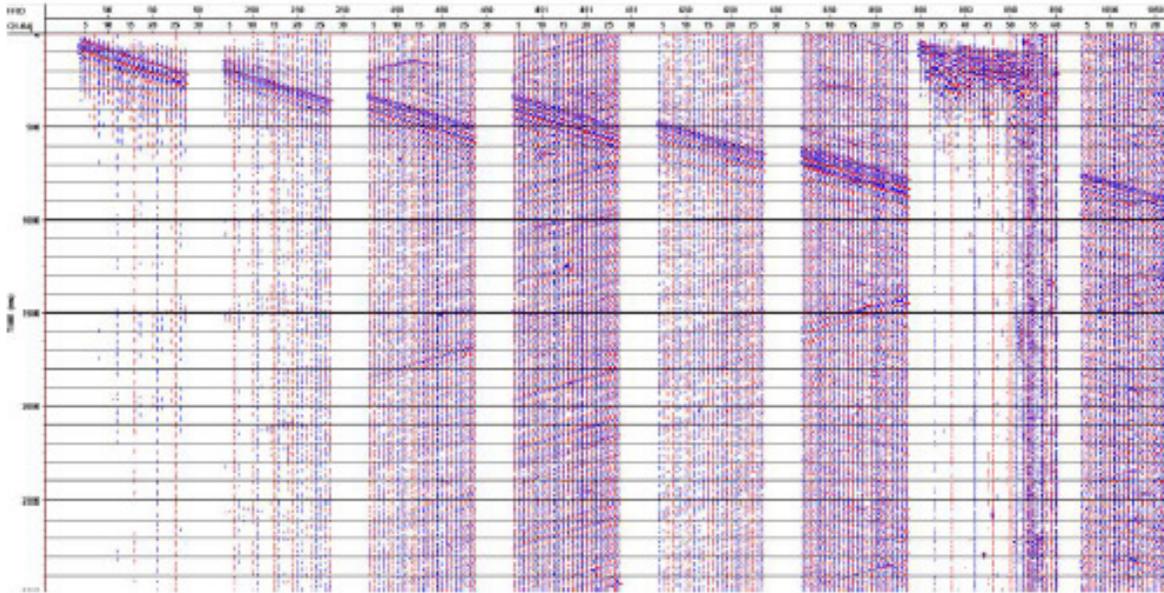


Figure 10: Zero Offset VSP with string top set at 50m, lowest sensor at 280m (rightmost). The first energy is relatively clear in the high gain presentation (the first blue pulse). A possible major fracture is seen approximately 210-215m downhole. Such fractures are sources of tube wave emission when the p-wave arrives at the fracture location.

4 LINE GRIDDING AND TRACKWORKS

4.1 SUMMARY

The location of the 3D seismic grid is north of the Rosebery mine and hosted in thick temperate rainforest. A pre-existing North-South drill access road was used as a main access with hand cut grid lines needed for the received and source locations. The initial estimates were for approximately 36 line km of hand cut track.

4.2 METHODS

Rodgers Exploration Services (RES) were contacted initially to complete the survey. Initial estimates were for 500-600m of walking tracks to be cut per day. When the survey deadline was brought forward, a second track cutting crew were sourced. JK Exploration services hired for this job. Both crews worked hard and generally stayed well ahead of any other works as drilling had begun, but at times bottle necks existed in the drill program due to a lack of cut tracks. Extra tracks were also needed to be cut, to provide easier drill access to the eastern most source lines.

Further into the program changes in drilling technique meant that extra vehicular access would be required. These tracks had to be hand cut for the initial flora and fauna survey. The flora survey outlined that areas of the existing track in high altitude areas had King Billy Pine saplings beginning to grow. Environmental approval was given but it was required to relocate these saplings before any heavy excavation was to begin. Solly Investments were contracted to open up two existing tracks, The Northern track which was previously known as the Innes Track and

old drill access track to the south east (figure 11). The new drilling technique also required the middle receiver line to be widened to enable better access for the main air line.

4.3 RESULTS

Overall the track work took about 2.5 months to complete. The main increase in cost was a result of an extra 7kms of hand cut track being added and 3km of vehicle track. Figure 11 shows the planned and final surveyed grid. The track cutting was done as optimally as was possible at the time, however, if it was finished prior to the commencement of drilling it would have been beneficial. Limited manual handling should be a high priority, therefore having the vehicle lines cut before the survey would have provided a safer route for transporting heavy equipment.

5 SOURCE HOLES

5.1 SUMMARY

A hole into the earth is required to contain the explosive source and force the energy into the ground. Initial requirements were for 1975 holes, 1.5m deep by and a minimum of 33mm wide, preferably into solid rock. Initial trials during the VSP study used a pneumatic Sig drill which was loaned from mining contractor Barmenco. Holes were successfully drilled into moderately weathered rock in a nearby road cutting. This formed the base requirement for drilling and was used for initial timeframe estimates.

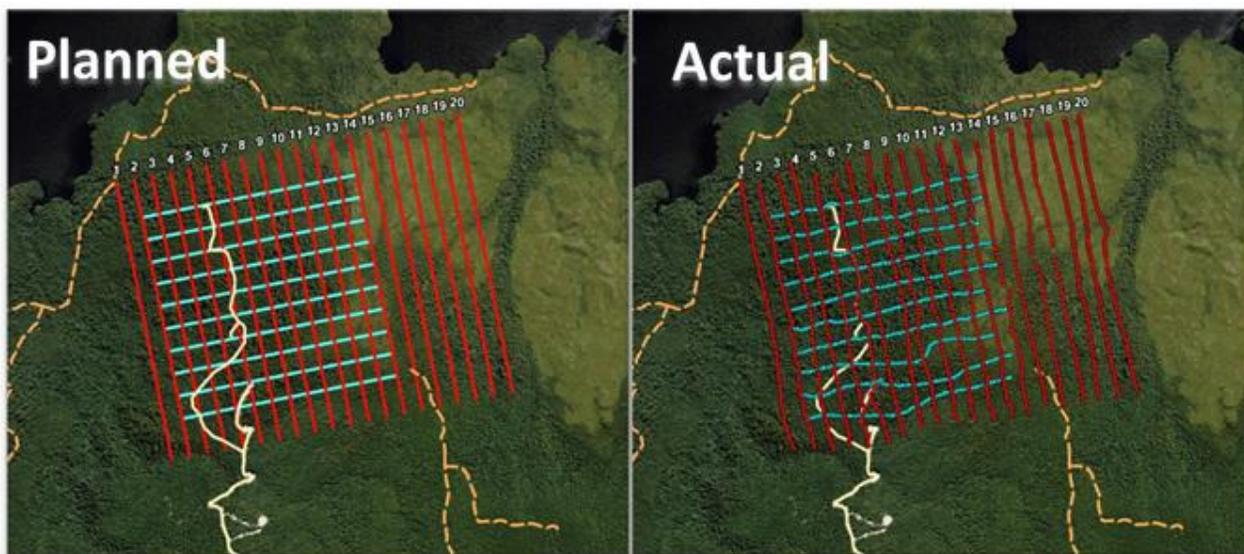


Figure 11: Planned versus actual station implementation.

Environmentally, open holes cannot be left in the ground as they may become pitfall traps for native fauna. To negate this risk a collar must be inserted into the top of the hole which would protrude at least 100mm. This collar should also reduce the risk of the hole collapsing after rain.

The grid design included 1975 source locations over variable terrain with some locations up to a kilometre away from vehicle access. For this reason pneumatic drilled was initially deemed logistically unfeasible due to the limited timeframe and the additional manual handling of air hose.

5.2 METHODS

Initial research indicated two possible options that were man portable and gas powered. One option was from China but had a two month delivery lag and the other option was the Atlas Copco Cobra Combi Rock Drill, from Brisbane. The Cobra was chosen due to time frame limitations and that it was easily man portable with a backpack (figure).

Drilling using this type of drill has to be staged due to the depth of the hole and to reduce the chance of steels getting jammed. A three stage drilling system was proposed. Initially a 400mm (long) x 41mm (wide) steel was used, followed by an 800mm x 40mm and then finally a 1600mm x 33mm. Although these steels are standard sizes numerous issues arose. 41mm is the largest diameter made which proved to be important when trying to determine collar pipe dimensions as standard pipe sizing's did not conform.



Figure 12: Cobra Combi Drill mounted on travelling backpack.

The initial risk of hole collapse formed the basis that the collar should be inserted after the first steel went down. Poly tube was chosen as it should not shatter when a drill steel is put down after it. Zetz Ltd (poly pipe manufacturing company based at Wynyard) were approached to manufacture the custom diameter poly for us which was cut before being rolled and bundled into lots of 10 for easily handling. This was completed within a week.

To further reduce the risk of the hole collapsing, 33mm wooden dowel was planned to be put down the hole. Unfortunately due to time constraints and costs, sourcing that amount dowel was nearly impossible. Instead, square wooden stakes were ordered to be placed down the hole. Although not an ideal fit, it was thought a 1.8m stake could be used. These also had to be custom made to a suitable width. The top of each peg was painted white to enable the location to be written on them.

At this stage time estimates for the drilling program were approximately 3 months. Due to the short time period before winter, it was decided to employ a second drill crew. This issue was brought up with HiSeis and they offered an experienced 5 man crew to man a second drill. Numerous logistical obstacles had to be overcome in a short timeframe to get a second crew running including; difficulties in finding accommodation, vehicles for traveling on the mine lease and a second drill was needed from Atlas Copco but was expected to be delayed by two weeks as it was ex Sweden.

At the initial stages we only had one drill on site so the HiSeis crew was to utilise this until the second drill arrived. Drilling began slowly and only about 10 holes per day were being achieved. Drill steels were regularly being jammed and we were losing about 3-4 per day so more steels needed to be ordered. At this stage an emerging issue had come to fruition that although the steels were standard they were not commonly used anymore and had to be sourced ex Sweden also. Due to communication issues MMG staffs were only notified of lack of steels at the last moment which made it incredibly difficult to keep a constant supply. Success was quite variable, and strongly dependent on ground conditions. A lot of time and effort was being spent on retrieving jammed drill steels and in the end there was no technique that was found to be 100% successful as the ground was so variable.

Sthil augers were trialled to drill the collars in soft ground to reduce the likelihood of the steel jamming. The Auger bits diameter could not be too large otherwise the fines from the rock drill would just fall back down the hole and jam the steel. Luckily Sthil were the only company that made 40mm auger bits, however, due to the size the bits did not have tungsten tips which led to rapid erosion and the need to be replaced. The used auger bits were taken to Dennis Welding in Camdale to see if they could be rejuvenated. It was determined that if limited wear was allowed, tungsten impregnated powder could be welded onto the leading edges and this quadrupled their life. Whilst most were able to be fixed, communication between the contractors and MMG continued to fail and Auger bits that were returned were unable to be repaired.

By the end of week 3, the rate of drilling had not increased and a total of only 150 holes had been drilled. The second drill, which was required to run two crews, was lost in Customs and underwent significant delays. Temporarily, it was thought that the shot firer hired from Victoria would be able to bring a second hand Cobra with him to assist. Unfortunately, due to extenuating circumstances (outlined in section 8.1), the drill and the operator became unavailable. This problem was compounded by the existing Cobra drill failing, with no replacement parts stocked in Australia. At this critical point, the decision was made to switch to pneumatic drilling techniques. Initially the pneumatic Sig drill and compressor was re-hired from Barmingo and an order for two Atlas Panther Drills was made. The logistics behind this were considerably more difficult than the Cobra, however, at the time there were no other options available.

The next challenge was, how we supply air to the drill 1km away? A typical underground set up uses 20m lengths of 1" rubber hose with mince up fittings, with each hose weighing up to 15kg and costing \$150 per length. The second issue to consider was the volume of air to the drill, and whether it was sufficient to use 1" hose over 1km. An engineer from a hose manufacturing company was contacted to calculate the hose diameter needed to provide the pressure and volume of air to Panther drill up to 1km from the compressor. The engineer calculated that 2" pipe would be needed if drilling more than 600m distance from the compressor. Rubber hosing sourced from Barmenco was used at the beginning of the process, but the extra weight created unreasonable manual handling issues. After receiving advice from experienced miners, it was decided to use high pressure poly pipe. An initial design was outlined using a 2" poly main line with 1" poly offshoots. Irrigation Tasmania Burnie was contacted to supply all the poly and fittings and was highly professional in their service.

Although the use of poly pipe solved some problems, it also generated some of its own. 200m roles of 1" poly are very hard to handle and it was determined that each roll would be cut into 20m lengths and connected with high pressure joiners. The issue with disconnecting and reconnecting pipe was eliminated by having a shut off valve at the main line which would be shut off and depressurised each time a new piece of poly was connected. This worked effectively but one person had to stand at the valve all day. With the new drill the average holes doubled to approximately 20 per day. This requirement for extra staff limited the ability to start a second crew and more staff needed to be arranged. These extra team members were sourced from JK Explorations and Mancala.

The Mancala personnel were more experienced in using Panther drills and on their first day they stripped their drill to a bare minimum which enabled more air flow and cleared the holes more effectively. Just over 1200 holes had been completed when the second crew begun and once personnel became stable, drilling begun to ramp up. When teams were working a significant distance from each other, it was found that the air pressure from one compressor was not enough for both drills. A second air compressor was hired which allowed the second crew to work independently and provided a backup with one broke down. Once these problems were resolved, the drill rate doubled to 40 holes per day.

5.3 EQUIPMENT AND SUPPLIERS

Table 1: Drilling equipment and supplier

EQUIPMENT	SUPPLIER
Cobra Combi gas powered rock drill	ATLAS-COPCO Construction
Integral Drill steels	ATLAS-COPCO Dynapac
2x BBD 94W (Panther) pneumatic rock drills	ATLAS-COPCO Construction
900mm x 40mm Poly collars	Zezt Ltd Wynyard
Drill Servicing (spare aftermarket panther parts)	RFG Sales Burnie
Poly hose, rubber hose and fitting	Irrigation Tasmania
2 x Air Compressor. >400 CFM	Coats Hire and Barmenco
Power heads and Augers (and servicing)	North West Mowers Burine

5.4 CONCLUSIONS AND RECOMMENDATIONS

Out of 1975 planned holes nearly 1956 were completed to a serviceable standard. The drilling of the source holes was the single most expensive part of the 3D seismic program. The high costs were most likely due to the combination of high cost equipment rental and delays caused to the extreme difficulty in drilling the holes by hand.

Although drilling was an expensive part of the 3D seismic program, it would also be the easiest part to reduce cost significantly.

- HiSeis’s work ethic and commitment was outstanding, however the cost of having the seismic gear onsite during the drill period was extremely high. For future surveys if this cost is negated it would enable the opportunity for leave days and lower the requirement for large field crews. This would lead to less fatigue amongst the field crews. Lack of communication between the contactor to MMG should also be of note which did cause some delays.
- Mancala staff recommended using a pneumatic drill steel extractor to remove jammed rods. (Mancala). Unfortunately, one could not be sourced within the time period required, however they could be purchased from a Canadian provider. This would be highly recommended for future surveys (Figure).



Drill Steel Extractor	Machine Type	Cylinder Diameter
For usual drill steels up to approx. 18 feet long	11-689	2.5"
Blow per min. at 70 lbs./in.	Weight	Air Consumption Cu. ft./min. at 70 lbs./in.
1,580	35 lbs.	67

Figure 13: Steel Extractor

- This survey was in rugged terrain but if the extra vehicular access was in place from the beginning it would have dramatically reduced manual handling and thus time when using the pneumatic drills. It would also enable the compressor to be located closer to the drills to give them more power and flushing potential (A maximum of 800m from the compressor would be ideal).
- Atlas Copco Panther drills are designed to drill in all directions but are typically designed to sit on an airleg. The drills used on the survey were modified with T handles rather than the standard D handles to become more ergonomic to help reduce fatigue and extra manual handling. Other model drills are available that are lighter and specifically designed to drill vertical holes. At the time these were not chosen due to the fact they had smaller air volume and power but would be worth trailing for future surveys.

Future surveys could expect an overall a cost reduction of 50-70% as costs with staffing and equipment should be reduced.

6 SEISMIC ARRAY

6.1 SUMMARY

1000 seismic receivers (geophones) were required to be positioned over the receiver grid. These must be powered by a series of gel-cell batteries which were recharged by a network of cables connected to power stations (generators and lead acid battery banks). Due to the rough terrain a repeater tower would also be required to relay the source initiation signals to the recording box. The weight of the equipment in total would be many tonnes and the majority of setup and demobilisation was completed manually, thus manual handling was an important consideration.

6.2 METHODS

The majority of HiSeis's gear was taken up to the 3200mN drill pad prior to deployment. Boart Longyear's 4WD fork and truck was utilised to unload the heavy pallets at the drill site. JK exploration services were retained to assist in the array set up and the acquisition period.

Initially the 3200mN line was laid out for the VSP survey. This line stayed out for the majority of the drilling and it was expected that we may get damage from animals and water. For this reason no extra lines were laid out in advance. When the time came to set the rest of the array out this line was re-powered and tested. Surprisingly it powered up with little issues. The rest of the array was laid after the drilling was completed. The control station (Dog Box) was set near to the highest location on the grid. This was a 3x4m steel shed that was constructed during the drilling by VOS. This was needed to store the computers and equipment to keep them dry while the geophysicist recorded the data. In all, it took approximately one week to setup the array (with 10-12 people) and another week before testing confirmed the array was stable enough to begin acquisition.



Figure 14: HiSeis employee loaded up with gear that is about to be deployed.

Once the acquisition was complete it was imperative to remove the gear off the mountain. The main focus was on the gear we were renting and with all staff making a concerted effort it only took 3-4 days. As each geophone was accurately surveyed it was a requirement that pin flags were placed in the exact location of the geophones as a precautionary measure.



Figure 15: Deploying trunk cable in difficult terrain

6.3 RESULTS

Generally the layout was completed effectively and efficiently. There was some conjecture over the installation of geophones (highlighted by the surveyors) where geophones were not positioned effectively into competent ground or into soft logs. This was raised with HiSeis and the geophones were rechecked.

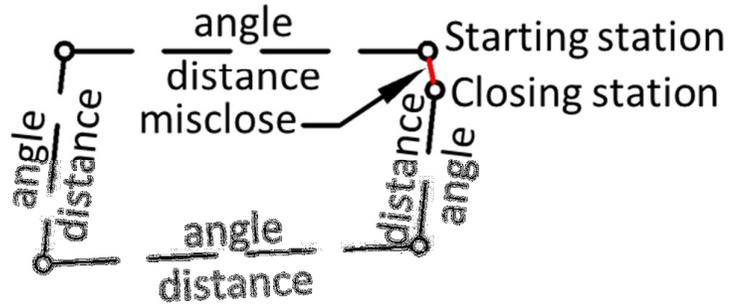
6.4 CONCLUSIONS AND RECOMMENDATIONS

- In general, the larger the field crew, the quicker this process can be completed.
- Care must be made to ensure that all geophones are installed correctly.
- Access is key to reduce manual handling and time inefficiencies.

7 POINT SURVEY

7.1 SUMMARY

In a 3D seismic program it is important to locate the receivers and sources to high accuracy. Each receiver location needed to be located at +/-10-20mm with similar accuracy need for source locations, +/-30mm. To achieve this accuracy in dense terrain differential GPS would be insufficient so different techniques needed to be explored.



7.2 METHODS

Information was sought on other techniques including remote sensing and GPS technology but in the limited time available for determining a survey method that would be quick, cheap (if possible) and accurate the only option that remained was to manually survey the positions using total stations.

Peacock Darcy and Anderson Survey (PDA) were approached as well as Mancala. Both provided quotes, but PDA's ability to provide up to 10 surveyors if needed and the likelihood of superior processing ability led to them being chosen for the project.

Initially differential GPS markers were placed in open areas where surveyors could rely on their location to open and close loops. Teams of two surveyors were used (up to 5 teams per day) and they quickly caught up to the shot



firers and completed the whole survey in just over a month and a half (onsite approximately 50% of time).

The acquisition of the location data was extremely difficult and was made even harder due to soft peat on the ground in areas. To overcome the soft ground issues the total stations were positioned on trees and rocks to limit their movement (figure 16).

Figure 16: A typical example of implementing best survey practice.

The final processing of the data involved reducing errors in miss-closes. To reduce the residual error in the data PDA implemented a least squares technique. This technique determines the best possible result by distributing any errors throughout the network traverse. This was the largest least squares calculation ever performed by PDA.

7.3 RESULTS

The result was 1963 shot holes and 961 geophones located. This was obtained by taking 1266 traverse stations over 32+ kilometers of traverse and 9270 adjusted observations (figure 17).

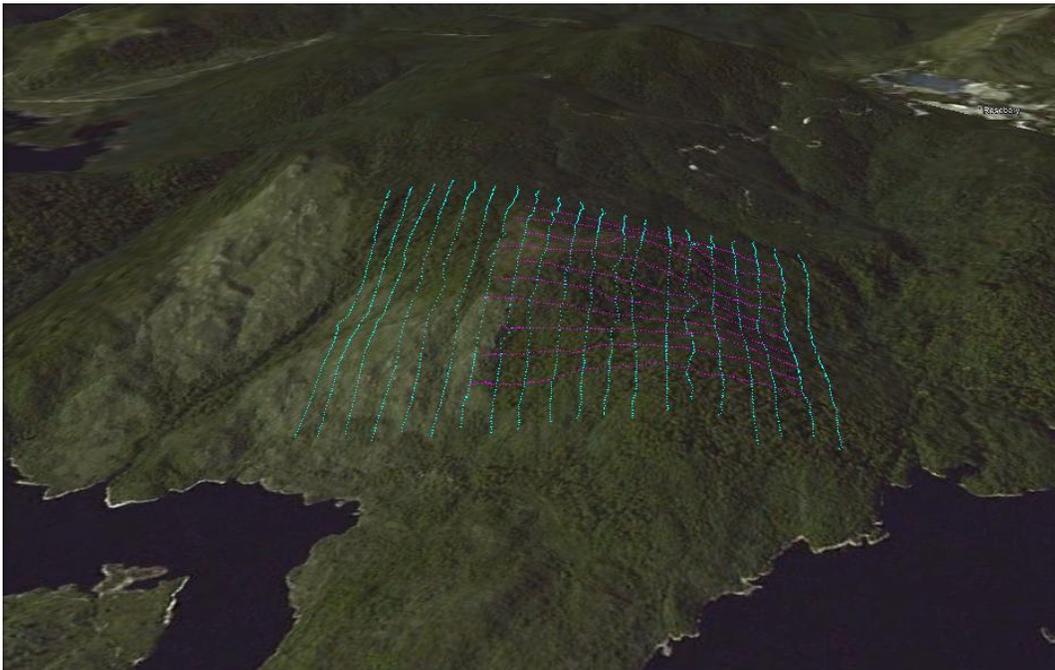


Figure 17: Actual Grid location viewed from the North. Note the harsh topographic relief.

7.4 RECOMMENDATIONS

Overall MMG was extremely happy with PDA's professionalism and expertise but they certainly were not a cheap option. Time was the limiting factor in determining other viable options, however there might be value in investigating the use of a remote sensing technique.

8 EXPLOSIVES

8.1 SUMMARY

The logistics and decision making behind choosing the most suitable and available explosives, and a qualified shot firer to detonate them, were significantly more complicated than expected. The main issues to consider for a source explosive are the size (will it fit down the hole) and the type (explosive velocity) and strength of the explosive product (will the signal be suitable). Initial talks with HiSeis indicated that Pentex or cast boosters would be the most suitable product and that powergel would most likely have a poor signal.

The technique that HiSeis uses requires an optical fibre to trigger the recording; this is a crude but effective technique and allowed us to use less expensive explosive product rather than a super-fast initiating seismic specific products. Tasmania being separated from the mainland means that special conditions need to be considered when

importing explosives. Generally explosives are only shipped on a certified freight liner approximately every 6 weeks. The only other option is to charter a plane at a cost of approximately \$15K but only a certain amount of product can be transported this way. There is also a significant cost in the removal of unwanted or unused explosive as the closest authorised explosive disposal site is in South Australia.

To determine the appropriate explosive, potentially suitable products were shortlisted. These included:

Table 2: Potential Explosive Products

PRODUCT	SUPPLIER AND DETAILS
Pentolite (Mighty Atom) 	Johnex Explosives 75gm 32mm diameter Plastic outer casing for strength
Pentex G Booster 	Orica Explosives 110gm 31mm Cardboard outer coating (can be removed for tight holes)
Cordtex 70P 	Orica Explosives 70gm/m Can be cut to suit any size hole. Potentially messy and time consuming
Senatel Magnum (powergel) 	Orica Explosives 115gm This product was identified early as a poor candidate but suppliers and shot firers insisted we should try it.

Storage for the explosives had to be considered as well. Currently there are no surface magazines located on the West coast of Tasmania so they would have to be stored underground in the mine magazine. Because of this it was imperative that the Magazine manager was kept up to date with our dealings with explosives.

8.2 METHODS

The initial VSP survey used 30-90gm of Pentex (1-3 30gm boosters) sourced from the mine stores. Individually these boosters were deemed too small to be used, but when used together, provided a much better signal. One issue with this though, was that each booster does not initiate at exactly the same time, creating some noise in the data.

Forze Explosive Services (Forze) were approached early in the planning stage, to conduct the shot firing. By the end of the first month, it was obvious that the program was running behind schedule. The results of the original VSP had also been received and these indicated that the explosives previously used were insufficient and due to tube waves another VSP should be attempted. The repeating of the VSP was not only a good opportunity to develop the velocity model, but to increase the confidence in the explosives source through additional testing. Forze were contacted and informed of this delay, and that an additional VSP survey was required prior to commencement. Forze later withdrew from the project, less than two weeks before the scheduled start date with manning issues blamed.

With the closure of Beaconsfield mine, Johnex products became unavailable as the company decided to stop exporting explosives to Tasmania all together and the next Orica shipment did not comply with our shooting schedule. This would mean that test explosive would most likely have to be flown over by plane. With this news, the Victorian company Southern Cross Explosives (SCE) were contacted and appeared to be able to provide suitable explosive, shot firers and the bonus of owning reconditioned cobra drills which could assist the drill program. Unfortunately, there was a protocol breach (failure to lodge a one page document) by the supplier during the airborne transport of the explosives which led to Worksafe Tasmania intervening. It was decided that even though there were no repercussions for the error, it would be in the best interest of MMG to terminate the relationship. The resultant outcome was that Orica were the only company who could provide explosives, so we had to work within their schedule.

Unfortunately there were additional problems in sourcing and storing explosives from Orica. After the delay with SCE, Orica were contacted and luckily they still had some of the G boosters still available. But in the time it took MMG to get the approvals they had sold our explosives to another party, even after a verbal confirmation had been made. Luckily we were able to retrieve a box from the other party to conduct our trial but on the day MMG shot firers were unable to locate the stock in the magazine. In the end it didn't matter as much because on the day of the survey the winch was deemed unserviceable, meaning that only basic source testing was completed using powergel.

The delay caused by Southern Cross Explosives also forced a renegotiation with Forze and they agreed to take on the project for the second time. This agreement was only short lived as again they withdrew but this time due to a more lucrative offer. This decision was deemed by MMG as very unprofessional on Forzes behalf.

At this stage options were running out quickly and the window of opportunity for a bulk explosive order was closing. As testing had been limited, it was decided to use 2 G-Boosters per hole and to minimise the noise caused by boosters triggering at different times, each booster would be given its own det. The equivalent 70p det cord was also planned as a backup as it could be manipulated to fit into tight holes. Another consideration was that any unused explosive has to be used up by the mine otherwise it would have to be sent back to mainland to be

destroyed at our own cost. G-boosters could be used by the mine but 70p Det cord was not. This risk was quickly negated as 70p det cord was then decommissioned by Orica 3 days before the order going through which left G boosters as the only option. Dummy G-Boosters were made out of dowel to double check the hole diameters and the reliability of insertion seemed reasonable. With this new decision, additional problems were also encountered as storing the 4000 G boosters, and 4000 dets in the MMG magazine would put it over the licenced volume of product. Fortunately, an application was made to Worksafe Tasmania and they approved the additional stock for the period of the survey.

At this stage a deadline had been given by Orica for orders so our main focus was on finding shotfirers. We were able to come to an agreement with Mancala to supply two shot firers on a weekday basis. This was not ideal as there would be standby costs from HiSeis associated with no work on the weekends.

Finally an order was ready to go through to Orica with a day to spare. Unfortunately Orica failed to inform anyone that the shipment had been scheduled two day earlier. But luckily again they had 1200 G-boosters in their store from a previous shipment. A verbal agreement was made with Orica to hold the product until the purchase order could be raised. Unfortunately this was not communicated properly by Orica staff and when the purchase order came through they informed us that it has been sold the day before. MMG were extremely disappointed in for this to happen a second time after being assured by Orica. Luckily a stock back was negotiated and shooting could begin, with a second shipment on order to arrive half way through the program.

8.3 RECOMMENDATIONS

- Testing of sources is vital, as the data quality of the survey is dependent on getting good signal into the ground.
- Ensure contracts are established and product guaranteed as early as possible in process.
- Rent a portable surface magazine. (These are commonly converted shipping containers)
- Stringent control on all documentation and processes related to the transport and storage of explosives needs to be in place. Do not rely on contractors to adhere to the standard required by Worksafe Tasmania and MMG.
- Trust nobody

9 ACQUISITION

9.1 SUMMARY

Acquisition refers to the physical collection of seismic measurements through the production of seismic waves from the explosive source (shooting) at various locations throughout the survey area. These manufactured waveforms that are then measured by the active geophone array (live patch).

Shooting began when the entire geophone patch was laid out, connected, powered-up, and error-checked to be ready to record data. Due to there being a single live patch, daily acquisition was planned based on line accessibility, weather and radio coverage. During acquisition, radio repeaters were moved a number of times to ensure adequate radio coverage for both triggering and communications.

9.2 SURVEY PARAMETERS AND INSTRUMENTATION

Table 3: Survey Parameters

Parameter	Final
Total Acquisition Area	2km ²
Number of Receiver Lines	10
Live Channels/Patch (Nominal)	960
Live Receiver Lines/Patch	10
Live Channels/Receiver Line	96
Receiver Internal (In-Line)	10m
Receiver Internal (X-Line)	100m
Nominal Receiver Density	1111.1 per km ²
Total Source Points	1975
Total Unique Source Locations	1776
Nominal Shot Point Density	397.2 per km ²
Number of Source Lines	20
Source Interval (In-Line)	10m & 20m
Source Interval (X-Line)	80m
Record Length	3 s
Sample rate	2 ms
Source Type	Explosives

9.3 METHODS

Shooting consisted of two teams, the source crew and the recording and maintenance crew. Due to staff constraints the field crew sizes varied and it was quickly established that there were minimum requirements for crew sizes and equipment. These are outlined in table 4.

Table 4: Minimum requirements for field and maintenance crew

RECORDING AND MAINTENANCE CREW		
Task	Minimum	Recommended
Geophysicist	1	1
Electrical Technician	1	1
Patch Technician	1	2
SOURCE CREW		
Shot firer	1	1
offsider	1	1
Signaller	1	1
Water Carrier	1	2
Spare	1	1

During the initial trial of explosive insertion using the dummy probe it was realised that some of the holes had silted up which made insertion difficult at times. Unfortunately the smallest auger bit on the market is 40mm so a 32mm auger was developed using a 32mm masonry bit with large flutes (Dewalt brand), welded onto a Stihl auger extension. This bit worked well and was carried by source crew.

Holes were to be stemmed with water to increase coupling, but we knew carrying water over the grid would be difficult. Small bilge pumps were purchased to pump out of the many small streams that were present on the grid. This system seemed to work well and reduced a significant amount of manual handling.

Shooting begun slowly as expected and teething problems with the radio signalling were evident. Initially this was put down to the steep terrain. Slow rates continued for a few weeks until a specialist radio technician was bought in. He calibrated the radios and signal issues were almost redundant from there on.

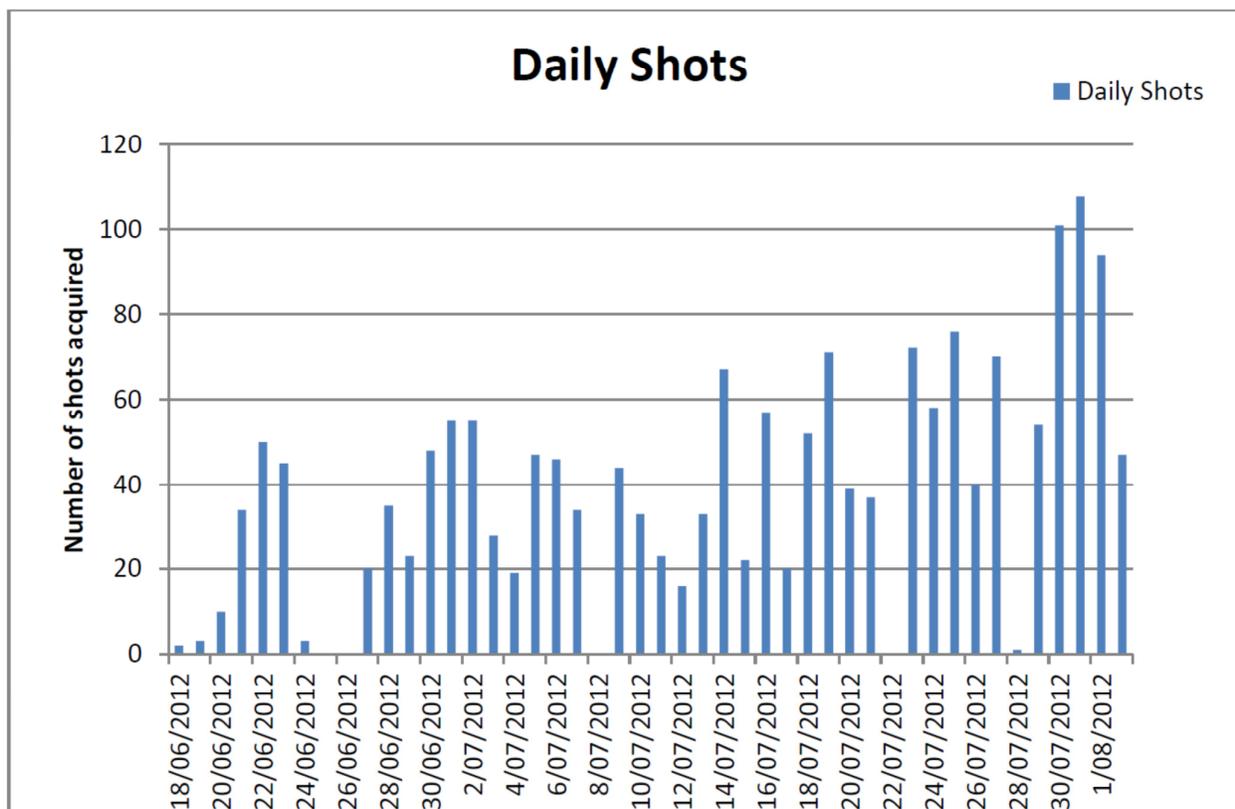


Figure 18: Number of shots per day.

It was later determined that for the first week of shooting, HiSeis had begun the acquisition with only 9 out of the 10 grid lines (and sometimes 8/10) in service. HiSeis informed us that the net effect on the image fold (effectively illumination) of our line use will be less than a 1% decrease from that planned. The delay in MMG discovering this information indicated the communication was an issue between the contractor and the MMG team on site.

9.4 RECOMMENDATIONS

- Proper communication between the contractor and project owners is essential.
- Future surveys may benefit from the additional of a individually contracted experienced “spotter” to oversee the data acquisition stage. Due to a common lack of experience, it can be difficult for the non-seismic staff to notice things that have been done incorrectly or inefficiently by the acquisition contracting company.

10 PROCESSING

Processing of the raw data was performed by HiSeis in Perth. Due to the target structures and stratigraphy being steeply dipping, deep, and towards the edge of the survey area, the main processing effort was put into the testing of various migration algorithms. In addition to this, considerable effort was put into noise removal i.e. rain drops.

Two main processing streams were used on the data: Automatic Gain Control (AGC) and Amplitude-Consistent processing (AC). In addition to this, several seismic attributes were calculated to try and highlight particular features of the data set. As of May 18th, 2013, HiSeis processors were working on a padded migration cube, which attempts to position the energy into its correct location outside of the original imaged cube.

10.1 PRE-PROCESSING

Prior to the actual process, the data are required to be 'cleaned', which predominately is the removal of bad traces. This phase of the processing is time intensive, and particularly so for the Rosebery Dataset. Below is a summarised version of the process:

- Observer's logs that provided a hard copy of every shot record, geometry and field issues were read and incorrect data removed
- Geometry was manually assigned to each channel. Each trace received coordinate information and the relation between source point and receivers was established.
- Bad or noisy traces which might lower the overall signal to noise ratio were removed. In this dataset the largest source of noise was rain. Noise-spike removal algorithms helped to identify and remove traces affected by raindrop noise.
- First break picking was carried out to facilitate the calculation of refraction statics. In this process, all of the shots need to be individually picked to allow for time delays due to the weathered zone to be calculated. This is aimed to remove the velocity variations in the data caused by heterogeneous regolith. In the case of Rosebery, it was found that the main source of error was actually the severe topographic relief. In the survey area the topography varied from 262m to 556m ASL. For this reason the data was referenced to a set datum of +600m ASL.

10.2 AGC DATA PROCESSING

Automatic gain control (AGC) is a processing system used to improve the signal strength of late- arriving events in which attenuation has caused the signal to decay. The benefits of this are increased resolution at depth of weak reflectors; however this comes at the cost of noise also being amplified. Whilst subtle responses are enhanced, strong responses will be muted meaning that bright spot reflectors may be hard to distinguish from background. Conversely, reflectors will appear more consistent, aiding structural interpretation.

Table 4: AGC Processing Stream

Automatic Gain Control Processing Stream
1. Binning (10 m x 5 m)
2. Trace editing and noise-spike removal
3. Refraction static computation (Delay time and diminishing residual matrix) and second edit of first break picks
4. Quality control (QC) of the refraction static solution (on shot records, every 20th shot)
5. Application of refraction statics
6. Window design for amplitude compensation and deconvolution
7. Tests for: amplitude compensation, band-pass filter, Multi-channel filtering (F-K/ · -p), autocorrelation and

deconvolution
8. Application of ensemble balance and spherical divergence correction
9. Application of spiking deconvolution – zero phase spiking, 80 ms operator, 0.1% white noise
10. Surface wave noise attenuation: 2200 m/s
11. Airblast attenuation: 330 m/s
12. Application of band-pass filter: 8 – 14 – 125 – 200 Hz Ormsby
13. Constant velocity stacks (CVS)
14. NMO application
15. Brute stack
16. Computation of surface consistent residual reflection statics (QC check)
17. Application of residual statics
18. Residual stack I
19. Second pass velocity analysis (CVS)
20. Residual stack II
21. PSTM: 80% stacking velocities, maximum dip 50 degrees, absolute offset of first bin centre 20 m, bin size 40 m, maximum offset 1786
22. Inverse TAR applied
23. Stack
24. Seismic attribute cubes calculated
25. Time/depth conversion
26. SGY files to specification

10.3 STACKING AND FOLD

Noise is any signal which is measured by the geophones but not due to variations in the geological subsurface. The main sources of noise in the Rosebery survey were due to rain and poor coupling in peaty ground. One of the limiting factors in the survey was a maximum drill depth of 1.5m to position the explosive source. This meant that in some locations, where regolith was greater than 1.5m, the explosives were detonated in peaty regolith. Figure 10. X shows the different in data quality between a well coupled explosive and source and a peaty one, as well as the negative effects of rain.

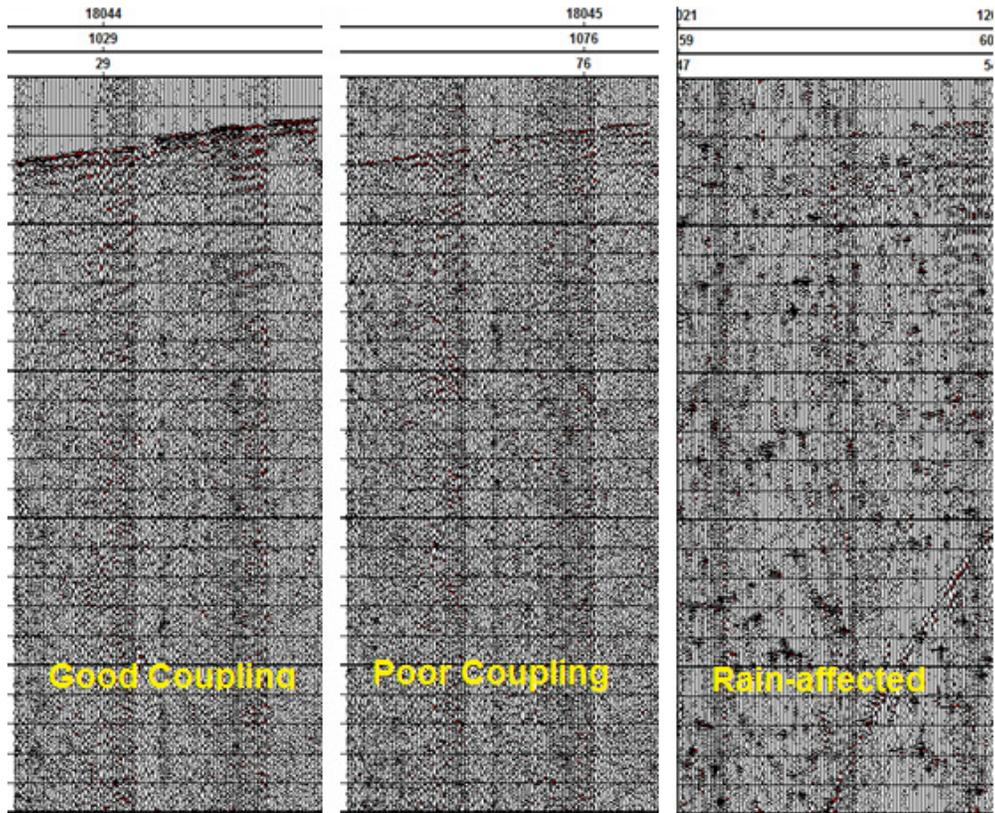


Figure 19: The effects of coupling and rain on data quality.

The most powerful and simple technique there is for enhancing the primary signal is stacking. Stacking is the summation of a number of traces which contain signal and originate from the same depth point for various source-receiver separations into a single trace. The fold of the survey, is how many stacks you have created, and generally speaking by increasing the fold, you increase the signal to noise ratio. Fold is defined as the number of midpoints which are stacked within a common mid-point bin and is depth varying, because, as the offset distance increases, deeper reflectors are included in the stack. Therefore, reflectors imaged from deep in the cube, have been imaged by significantly traces than shallow events. Below is an example of fold geometry in the Rosebery grid (Figure 10.x).

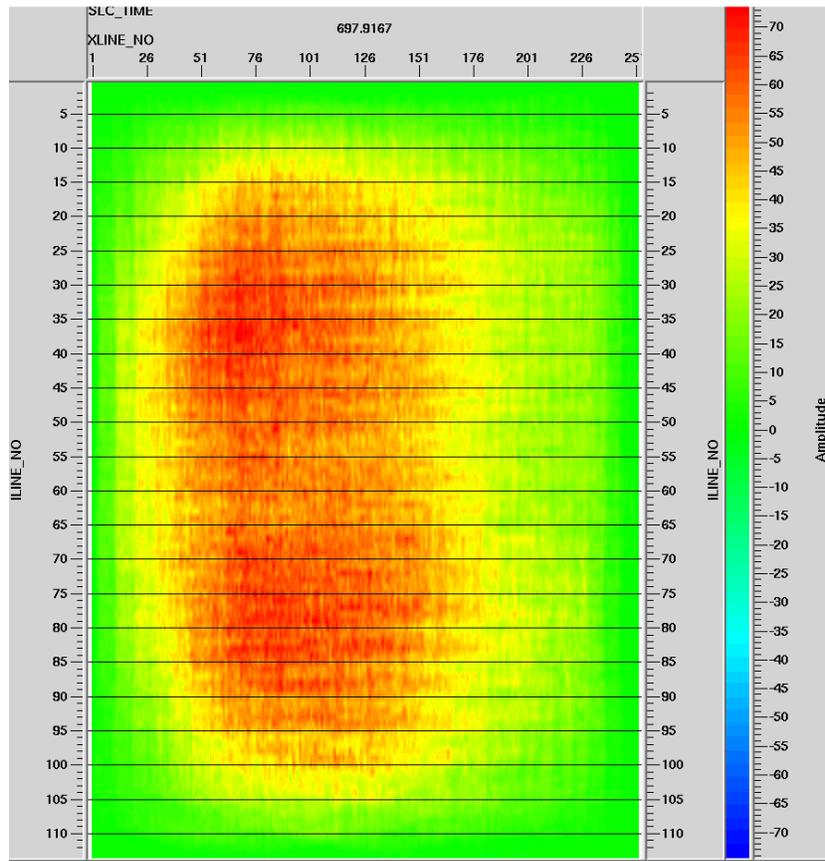


Figure 20: Fold geometry for the survey design at a depth slice of 700m. The image shows that at this depth, each block has been imaged approximately 40 to 70 times through the middle, and down to 5 at the limits of the cube.

10.4 VELOCITY ANALYSIS

Traditionally, oil and gas soft rock seismic processors will use a system called interactive velocity analysis (IVA) as a standalone velocity analysis tool. Due to the complex geological environment and the lack of signal, the IVA technique was deemed ineffective for this data set. Instead, the initial velocity analysis was carried out using Constant Velocity Stacks (CVS), with further refinement by IVA. For the CVS technique, a preliminary understanding of the rock properties must be known. CVS works by stacking common depth points (CDP) using a varying single velocity. When compared to other CDPs, some events will be shown more prominently than others. This indicates that a particular velocity is a better approximation of the subsurface, and the velocity-time pair for this particular CDP can be established. Once the velocity function has been established, it can be used to create a stacking velocity field from which the brute stack will be created (figure 10.X).

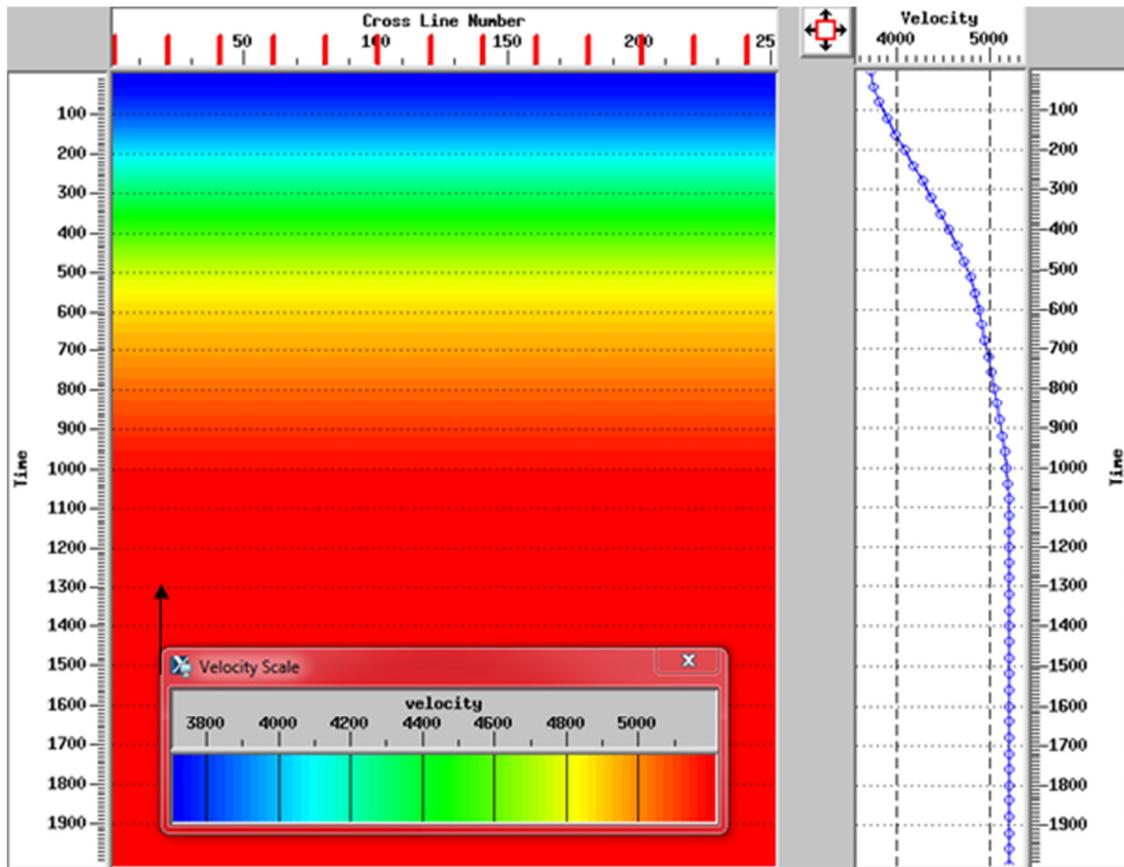


Figure 21: An example of the RMS velocity field from a representative inline that was used for stacking. Velocities generally range from 3700 m/s – 5200 m/s.

10.5 MIGRATION

Seismic migration is the process in which seismic events are relocated in space or time to more accurately reflect its subsurface location, as opposed to the location it is recorded at the surface. Migration works by moving dipping reflectors to the correct location and collapsing diffractions, leading to a higher resolution and more accurate image.

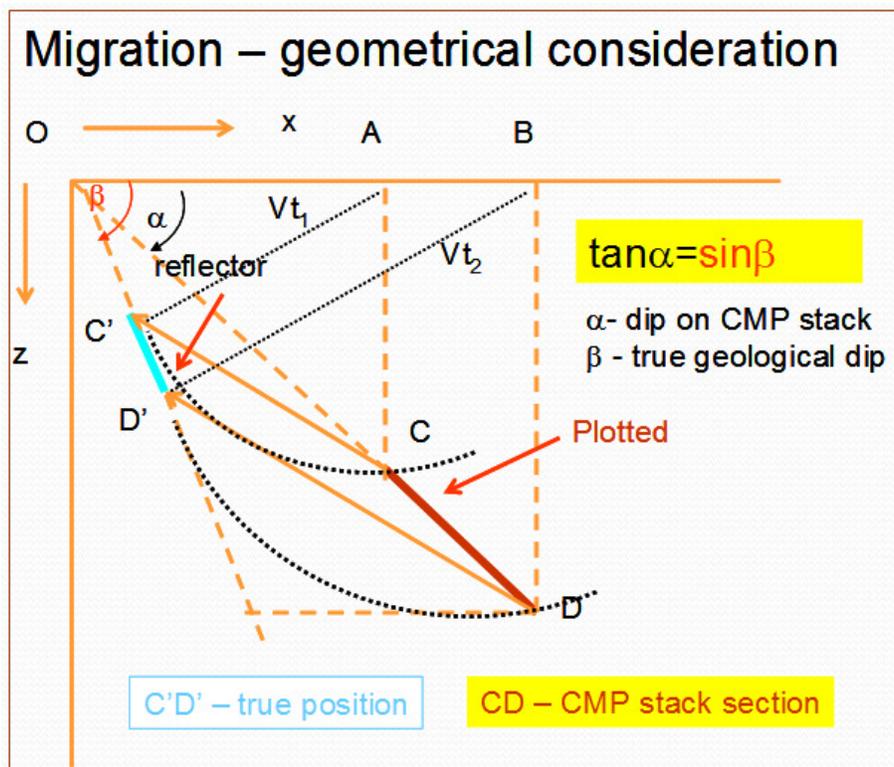


Figure 22: The migration of the imaged reflector C-D, to its correct location in space C'-D'.

A number of different migration algorithms were used to assess the most suitable for this dataset. Initially, a post stack migration was applied but obtained unsatisfactory results. The algorithm used in this process is sensitive to the velocity model, and with the failure of the VSP, this negatively impacted the quality of the data. In light of this, a Pre-Stack Time Migration (PSTM) was attempted. This is a significantly more rigorous migration algorithm, and produced far superior results compared to the post migration stacked cube. An 80% scaling factor of migration velocities was required to give the target area the best chance of being imaged within the limited extents of the survey area. The downside of this is that there may be inaccuracies when attempting to reconstruct the true dip of geological events.

In the absence of a VSP to constrain the velocity variation with depth, a time-depth conversion velocity field was created from the migration velocity field as a smooth average function. This was found to be within 10% of the mapped structural surfaces provided to HiSeis by MMG and was scaled accordingly.

10.6 AMPLITUDE CONSISTENT PROCESSING

The benefit of using AGC processing is that it normalises the response from a reflection, hence amplifying late arrivals and dampening near surface events. The negative of this is that subtle, discrete 'bright spot' anomalies can be lost in the processing. To correctly analyse the behaviour of a particular reflection, it is important to remove

any disturbances in the signal from else-where, such as those caused by near-surface layers and from the energy source and field recording system. Surface consistent factors can be divided into source, receiver, offset and subsurface components. Put simply, surface consistent corrections look at all source-receiver paths for a particular station and calculates an average based on all these pairs, with the aim being to preserve the nature of the reflection and remove alternative sources of noise.

Table 5: Amplitude-consistent Processing Stream

Amplitude-consistent processing flow	
1.	Binning (10 m x 5 m)
2.	Trace editing and noise-spike removal
3.	Refraction static computation (Delay time and diminishing residual matrix) and second edit of first break picks
4.	Quality control (QC) of the refraction static solution (on shot records, every 20th shot)
5.	Application of refraction statics
6.	Ensemble balance
7.	Surface consistent amplitude recovery – computation
8.	Surface consistent amplitude recovery – application
9.	Surface wave noise attenuation: 2200 m/s
10.	Surface consistent deconvolution – spiking 80 ms gap, 0.1% white noise operator
11.	Airblast attenuation: 330 m/s
12.	Application of band-pass filter: 10 – 15 – 120 – 160 Hz Ormsby
13.	TFD noise rejection – window 20 ms, aperture 5, threshold multiplier 3
14.	NMO application
15.	Brute stack
16.	Computation of surface consistent residual reflection statics (QC check)
17.	Application of residual statics
18.	Residual stack I
19.	Second pass velocity analysis (CVS)
20.	Residual stack II
21.	PSTM: 80% stacking velocities, maximum dip 50 degrees, absolute offset of first bin centre
20	m, bin size 40 m, maximum offset 1786
22.	Inverse TAR applied
23.	Stack
24.	Seismic attribute cubes calculated
25.	time/depth conversion
26.	SGY files to specification

10.7 PADDED MIGRATION

Seismic energy from a shot source will travel through the earth with a hemispheric wave front. When the wave front interacts with a reflector will return at an angle proportional to the acoustic impedance. Therefore, as figure 23 shows, reflectors imaged from outside the 3D cube, are still recorded in the full dataset. The geometry of the original cube is based on the midpoints of the source – receiver arrays, therefore, although the reflection event is in the recorded CDP data, the migration process will move it back towards its true spatial position. In an attempt to image this migrated energy, the cube was padded out significantly with additional blank traces before the migration processes were run. As with the previous models, Pre Stack Time Migrations were used in conjunction with amplitude consistent processing.

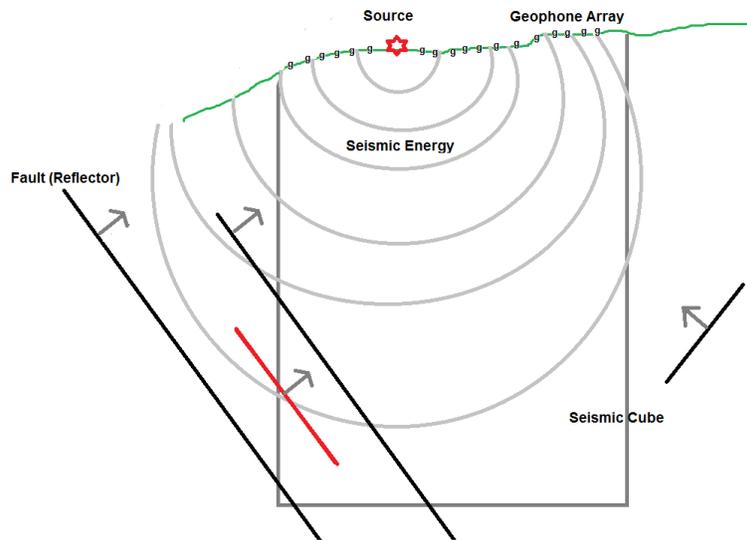


Figure 23: An example of the geometric propagation of energy with respect to dipping reflectors.

10.8 SEISMIC ATTRIBUTES

In order to aid in the interpretation of the seismic data, a number of seismic attributes were generated. These are analogous to the various filters commonly applied to magnetic data, such as 1VD.

10.8.1 Instantaneous Phase

Instantaneous phase is obtained by taking the derivative of the complex trace. It is used to enhance the lateral continuity of reflectors, particularly in noisy data, and is particularly useful for picking faulted boundaries and geometrical relationships between reflectors.

10.8.2 Perigram * cosine of phase

This filter is particularly useful in picking structural boundaries. A low-pass filter is applied to the reflection strength and is then multiplied by the reflection continuity. It therefore is used to highlight the lateral continuity of strong events.

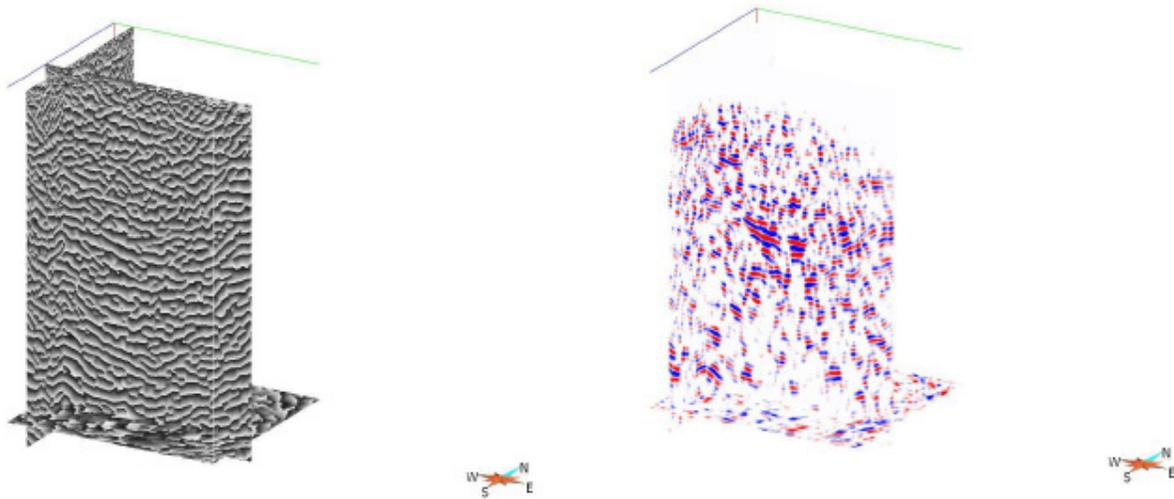


Figure 24: The results of seismic attribute filtering: Instantaneous phase (left) and Perigram * cosine of phase (right)

10.9 3D PRESENTATION

Data was imported from seg-y format into geosoft voxel format to aid with interpretation. Series of 2D voxel sections were generated for both the AC and AGC data. Using these sections, manual picking of reflectors was undertaken and compared to both drilling and existing surfaces. 3D isosurfaces were then generated from this picking.

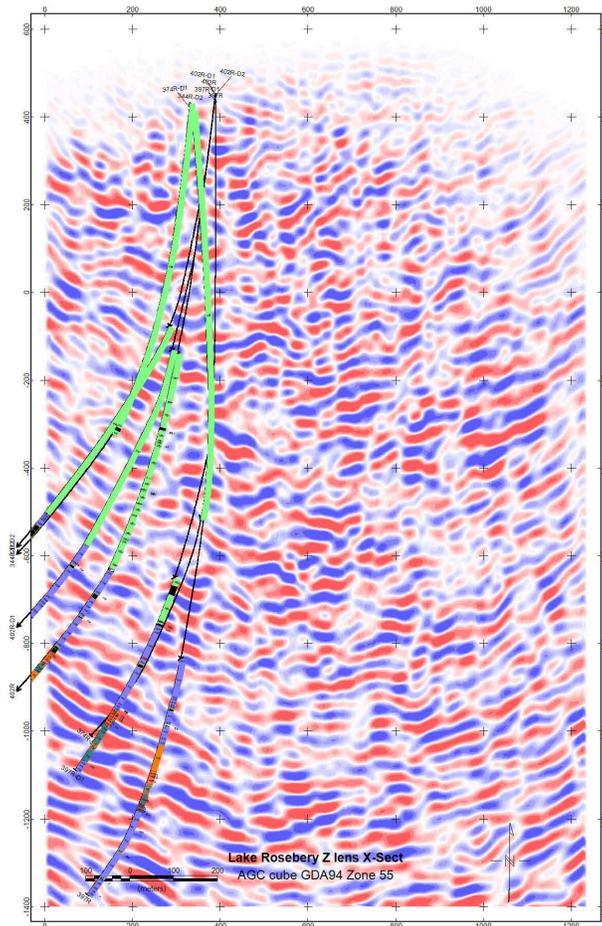


Figure 25: East West slice of AGC seismic cube with drilling overlay.

11 RESULT AND INTERPRETATIONS

HiSeis presented the information to MMG representatives in the Melbourne office in Early May 2013. In this presentation they displayed some basic interpretations that had been done by their structural geologist and explained the process behind them. These basically showed the picking of the Rosebery and Mt Black faults, and Z Lens. The next step for MMG after been given the data was to do a more thorough interpretation, using the drilling as a guide. The expectations from this interpretation were:

- A more detailed understanding of the main thrust faults and their nature, particularly any indications of their attitude to the North where information is sparse;
- To draw information about the structures that might have an effect on ore distribution;
- To look for any 'bright spots' which may represent potential ore horizons;
- To evaluate whether 3D seismic could be an effective tool for MMG into the future.

11.1 INTERPRETATION PROCESS

At the time of the writing of this report, the MMG interpretation is still ongoing, but below is the simplified work flow being followed:

- Form lines are drawn on along reflectors
- Breaks and discontinuities in form lines are assessed and if continuous along dip are digitised as faults/shears
- The major faults are mapped, typically as significant changes in dip and amplitude. The Rosebery Fault typically appeared to give a strong reflector response, whilst the Mt Black was more subtle and interpretation relied on reflection terminations and changes in dip.
- Form lines and breaks were analysed for fabrics and patterns. Possible fabrics such as riedel shearing are digitised in
- Interpretations are checked against drilling
- Drillholes are then used to pick reflector patterns at significant boundaries
- In general, the AGC data has been used to pick structural information, and the AC data for locating and evaluating 'bright spot' reflectors
- Reflector lines, drill hole data, existing surfaces and interpretations are then used to construct a 3D model.

11.2 REGIONAL STRUCTURE

One of the main aims of the survey was to establish the nature and relationship between the Rosebery Fault and the Mt Black Fault to the north. Initial results indicated that while the Mt Black Fault is not always readily observed in the data as a strong reflector, it is quite easy to pick its location by the change in dip of reflectors. The Rosebery Fault appears to be a strong reflector, particularly up dip in the preliminary padded migration results. It appears as a high amplitude, coherent reflector, consistent with drilling. These results are consistent with the forward modelling which predicted that the petrophysical contrast between the rocks on either side of the fault, combined with the fault itself, should be sufficient to produce a reflection (Knight, 2011).

One of the main aims with regard to the two major faults, was to determine their nature with respect to each other going North. As figure 26 shows, there is a probable convergent trend showing the Mt Black fault disappearing into the Rosebery Fault. This would indicate that the host horizon is closed off completely to the North, and doesn't open up again, as hypothesized (McGilvray 2011). The cause of the response would be likely due to the decreasing amount of black shales as the host horizon is cut off.

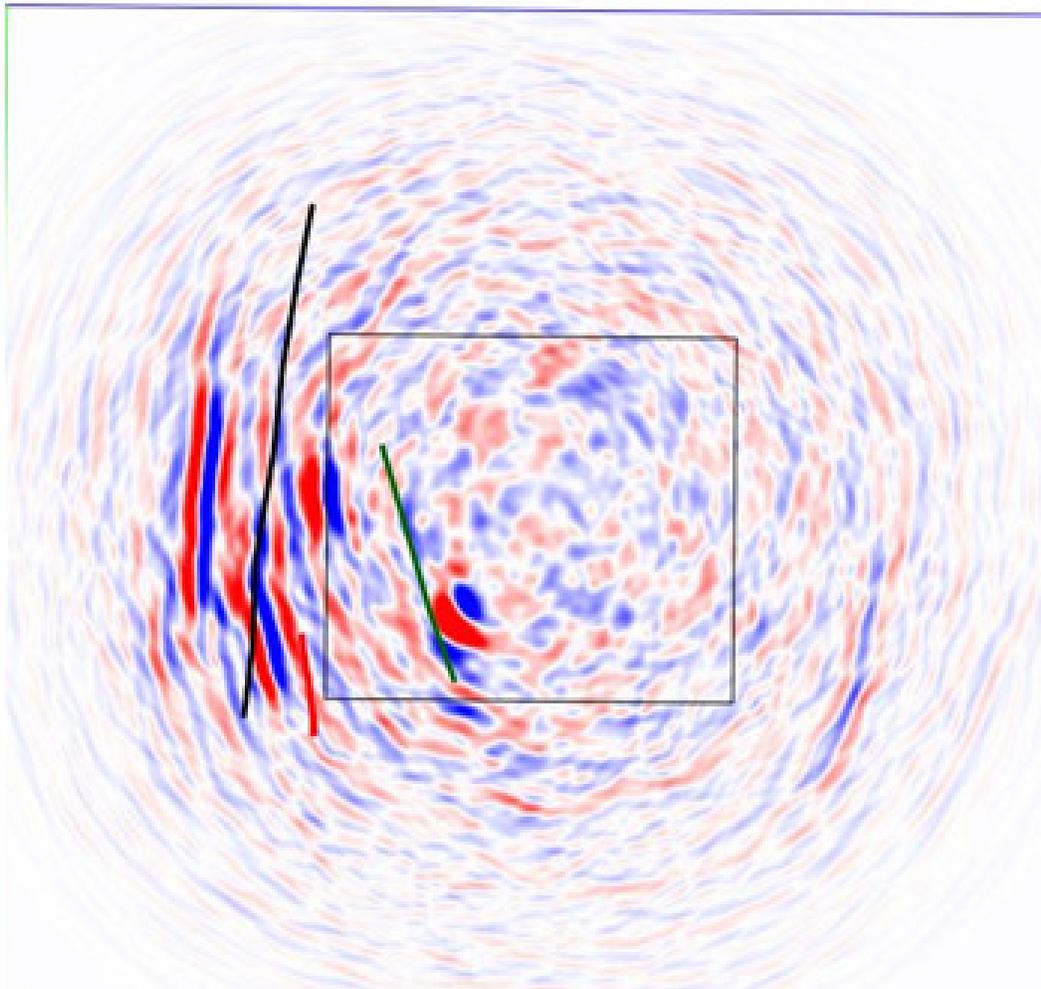


Figure 26: Depth section taken from the padded migration results, showing the convergence of the Rosebery and Mt Black Faults

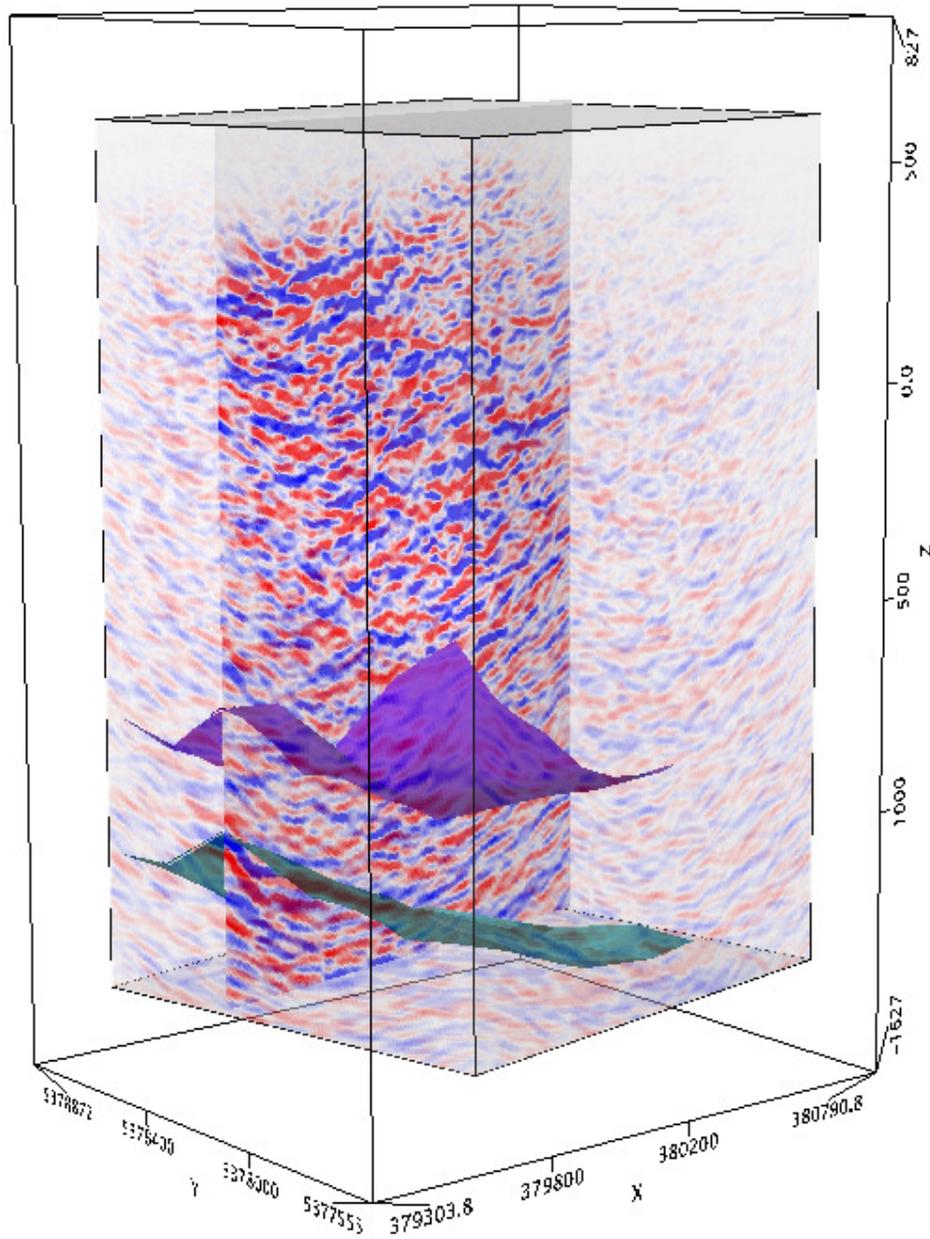


Figure 27: Viewed from the South West, the Rosebery fault in Green and the Mt Black fault in purple. Background cube has undergone AC processing, and the 2D slice AGC.

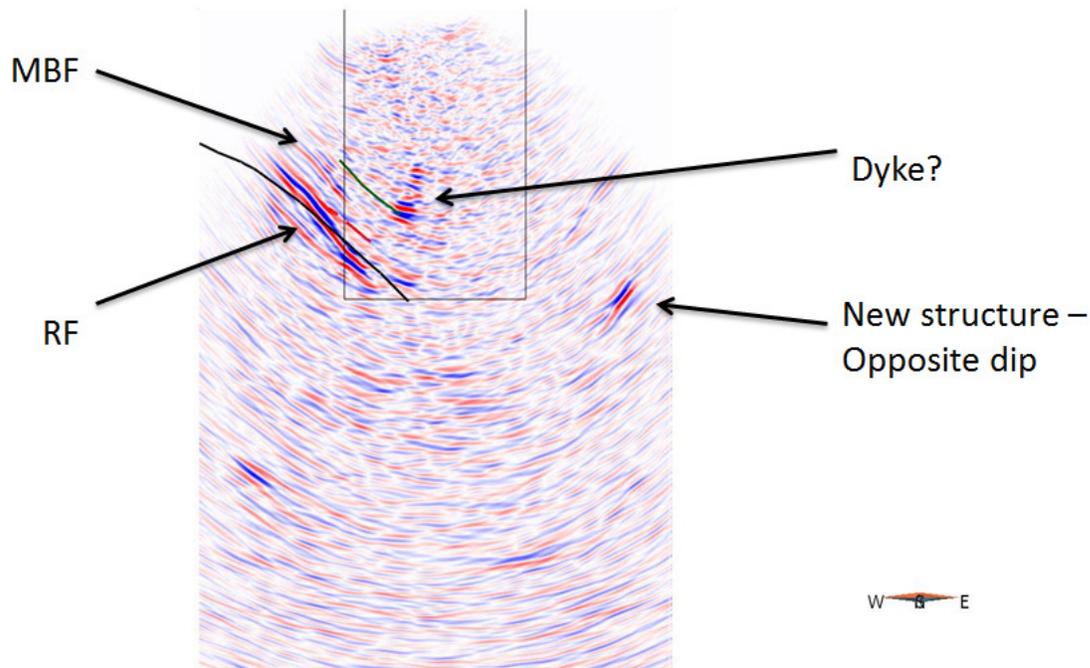


Figure 28: A clipped section from the preliminary results of HiSeis' padded migration process

11.3 BRIGHT SPOT REFLECTORS

The survey array was designed so that the southern extent of the cube would potentially image Z lens. This was implemented as a control, as even though Z lens is only a disseminated sulphide lens, if it was able to produce a reflection, it could be used as a proxy to help interpret other reflectors of similar nature. As an additional benefit, if Z lens could be imaged under these challenging conditions, it would indicate that the technique might have significant application for future exploration. Initially when the data was processed using the AGC technique, it didn't appear that there were many strong reflectors at all, especially not around the location of Z lens. However, HiSeis obtained promising results using their AC technique, and managed to generate a number of 'bright spots', including one which corresponded with Z Lens (Figure 29).

One consistent reflector was identified at approximately 3700N N (Mine Grid), which appeared to have a similar nature as the Z lens response, however was approximately twice the size (Figure 29). This reflector, (R1 in figure 29), is down plunge and dip of Z lens. Geologically, it correlates with the host horizon and potentially could be from a sulphide horizon. Thallium geochemistry results from nearby drilling do not indicate that they were proximal to any mineralisation however, which would indicate that the response could be from a black shale unit.

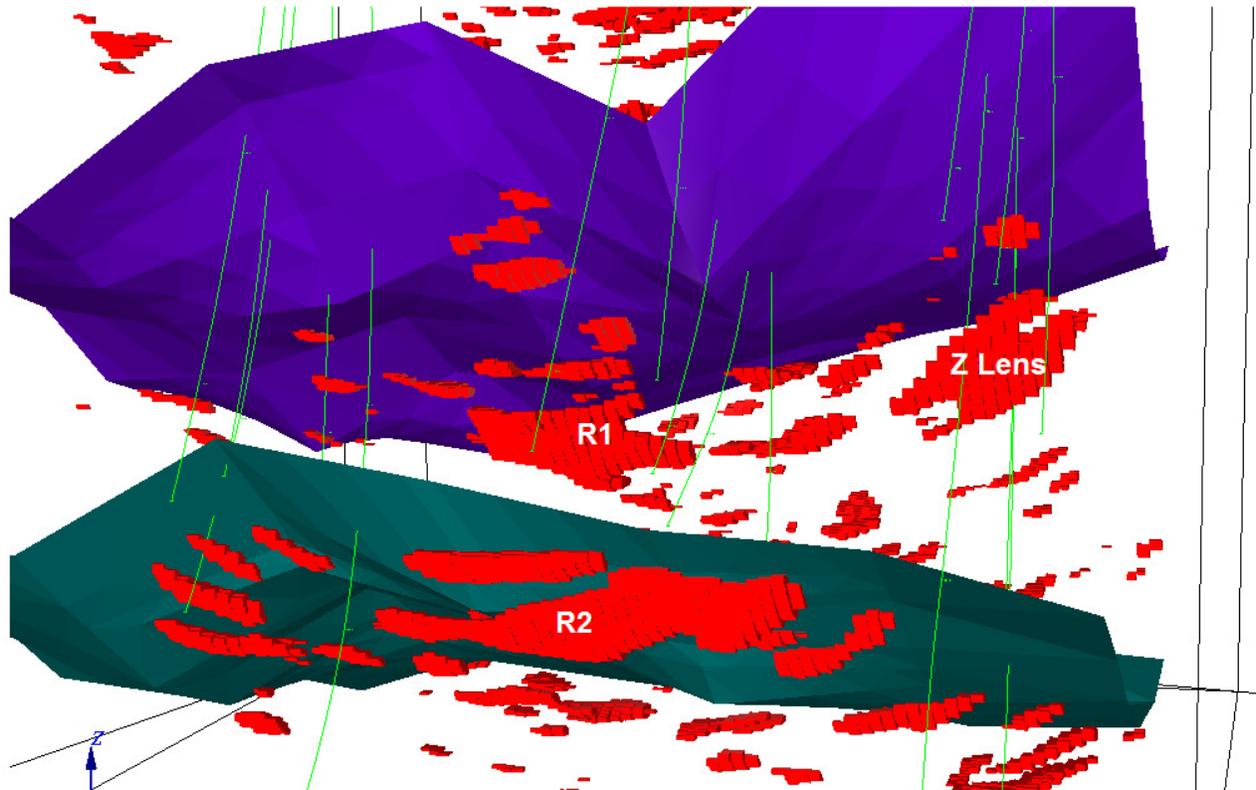


Figure 29: Isosurfaces showing coherent amplitude reflectors in the AC dataset.

Interestingly, there are a number of significant responses in the AC processed cube under the Rosebery Fault, in particular the consistent, high amplitude response shown in figure 29 as R2. These are evident in the original cube, and are strongly evident in the padded migration cube. According to HiSeis geophysicists, the minimum thickness which can be resolved at this depth is 30m, which indicates that any reflectors more than 30m below the interpreted fault reflections are likely to be from separate geological events. This is consistent with recent drilling results which have intersected sulphide mineralisation below the interpreted position of the Rosebery Fault. It is the belief of the author that this reflection is the most prospective drill target for base metal mineralisation; however the depth is quite significant.

11.4 LOCAL STRUCTURE

Aside from the main regional faults, any additional information which could be interpreted from the data regarding structural fabrics or local faulting is beneficial for local and regional interpretation. In particular, any structural information explaining the distribution of ore at the Rosebery mine and other deposits in the region could be used to focus drill programs in the future.

The most evident structures in the AGC data are vertical to sub-vertical faults which appear to truncate and off set reflectors. These most likely causes of these truncations are approximately E-W normal faults, causing local scale disruptions in the stratigraphy. Similar style faulting has been mapped underground by geologists.

A consistent change in dip and seismic character was interpreted between the two faults and wireframed. This boundary shows a change from reflectors with dull response to sharper high amplitude returns. The pattern could be due to the change from Whitespur type hanging wall lithologies into the host horizon (with more common shale units). The nature of this boundary is interesting as it is quite consistently of a "S" shape which may indicate parasitic folding of the contact (figure 30). If detail of this level can be obtained, then it could be possible to more accurately target hinge zones in these folds where mineralisation may be thickened (Neilson, per. Comms. 2013). It also might be an indication that the prospective host horizon is also cut off at depth by the Rosebery fault.

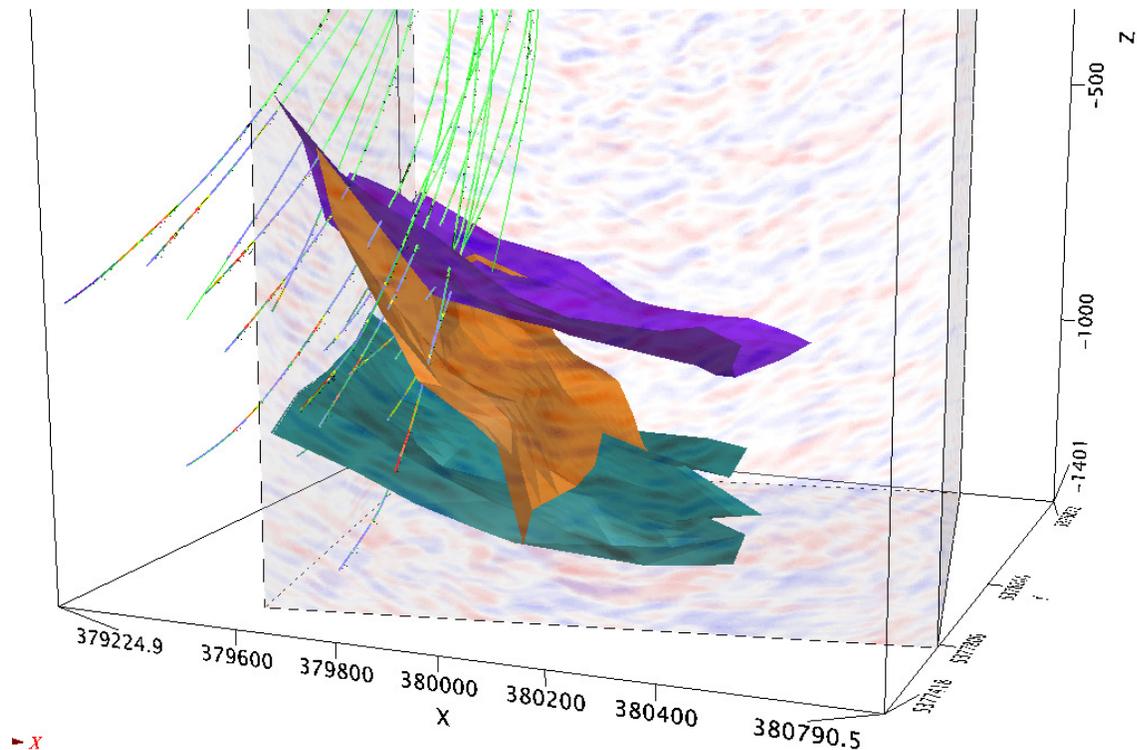


Figure 30: 3D image, viewed from the South East, showing the hypothesized shear zone, wireframed in orange.

12 CONCLUSIONS/RECOMMENDATIONS

12.1 VSP RECOMMENDATIONS

- VSP is repeated with downhole baffles to dampen the effect of tube waves.
- Use a better downhole winch and pulley system. The existing system was at times hazardous and unwieldy to use.
- Shut down/ Move all drill rigs working in the vicinity.
- Complete survey as far from mine as possible.

12.2 FUTURE EXPLORATION TOOL

The significant benefit of seismic exploration is that compared to potential field methods, it does not lose significant spatial resolution with depth. Additionally, it does not suffer from the problems with conductivity problems that EM techniques do. Until recently, the main prohibiting factor in a lack of 3D seismic as a tool is a lack of understanding and research in its application in metalliferous environments, as well as high costs for relatively small surveys. One of the focuses of this program was to establish whether or not seismic techniques were amenable to the Mt Read volcanics environment on the West coast of Tasmania. If the results indicated that the technique was a cost effective way or targeting ore horizons, it would give MMG a competitive advantage, and would open up new areas of ground. Therefore, the two vital things being investigated were cost and effectiveness.

Analysing the success of the survey was confounded by the lack of massive sulphides in the region. A true test of its potential for belt wide use would have been to image over an area of known and well mapped massive sulphide mineralisation. Due to the significant costs involved however, a trade off was reached where Z lens was included as a test and a calibration and the area to the north of it was under explored. Therefore, the lack of a significant "bright spot" reflector could be determined as a failing in the survey when it could simply be that there was nothing there to image.

With the exception of direct sulphide detection, the survey achieved its aims. The regional faults were relatively clearly imaged, and a significant amount of internal structure was delineated. One issue however is that this survey was completed in a region with relatively well known geology and was constrained by existing and recent drilling. In a greener terrane interpreting the results would be considerably more challenging. The technique is definitely more suited to brownfields exploration where some constraints can be added, however in green areas where massive sulphides are expected, 3D seismic could be a powerful, yet expensive, direct detection tool.

The learning's from this survey for MMG and Hiseis were significant, in particular in relation to lag times prior to the actual surveying, survey design, processing and interpretation. If the survey were to be repeated MMG would do the preparation work themselves and not bring the seismic crew in until the latest possible minute. It is recommended that the common soft rock practise of using a separately contracted spotter to oversee the survey would be of great benefit. Using 3D seismic experts who are separate from the acquisition company to process and interpret the data would be of great value as well, and may still be an option for this survey. Future surveys by MMG would come at greatly reduced cost for superior results due simply to an increased understanding by the company.

APPENDIX A: IMAGES FROM KYEN KNIGHT'S THESIS

APPENDIX B: HISEIS ACQUISITION REPORT

APPENDIX C: HISEIS PROCESSING REPORT

APPENDIX D: HISEIS INTERPRETATION REPORT

APPENDIX E: PDA SURVEY REPORT

APPENDIX F: REFERENCES

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