Waihi subsidence assessment

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Frontispiece The iconic Cornish Pumphouse on the move past the end of Gilmour St. to site 4A, late October 2006

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EXECUTIVE SUMMARY

This study has been progressing, in stages, over approximately two years. It builds on earlier work by GNS Science (GNS) in 2002 and 2003, and uses results of more extensive, detailed investigation and analytical work carried out subsequently by Newmont Waihi Gold (NWG) and their technical consultant PSM.

The August 2002 GNS report formulated a method for estimating the hazard of a sink-hole subsidence reaching the surface from the abandoned underground Martha Mine workings at Waihi. Based on the assessment of risk in the August 2002 GNS report, occupied parts of Waihi located in hazardous areas above the Royal and Empire stopes of the old underground mines, were evacuated. Subsequent sub-surface investigations in the Edward South stope area established that the rock mass is of good quality and the sink-hole subsidence hazard appears very low (GNS 2003).

Since public release of the GNS report in 2002 and the Addendum Report covering investigations and hazard in the Edward South area (GNS 2003), major works in the open pit have included:

- Completion in 2007 of mining at the bottom of the open pit;
- Shifting the Cornish Pumphouse - following slope movements and concerns for the long-term stability of the southern open pit wall, the Cornish pumphouse has been shifted to a safer site closer to Waih;
- Commencement of the stabilising “south wall cut-back” – once the Cornish pumphouse was moved. The south wall cut-back decreases the slope angle of the south wall and is designed to improve its long-term stability. In its later stages, the cut-back excavation also allows the recovery of additional ore from the open pit. To assist with understanding the stability behaviour of the open pit walls, NWG have installed a comprehensive system for the continuous measuring and monitoring of slope deformation, both within and around the perimeter of the open pit.

This report reviews the sink-hole subsidence hazard assessment methodology used in the August 2002 GNS report and applies it to the “Martha” lodes located in the north-east quadrant beyond the perimeter of the open pit. The “Martha” lodes (North Branch, Mary, No. 2 and Martha lodes) were specifically not included in the 2002 subsidence assessment. High, medium and low sink-hole subsidence hazard zones have now been established above these parts of the old underground mine. An evaluation of risk suggests that transient movements, such as vehicle, cycle and pedestrian access are acceptable on roads or tracks established through all the high sink-hole hazard areas. This report also assesses the known creep deformations that have occurred in Waihi since the 2002 GNS reports.

Where the August 2002 GNS report focused on the risk of sink-hole collapses, this report recognises the additional possibility of low hazard, long-term creep movements associated with underground and open pit mining. While it is likely that such creep deformations may occur in parts of Waihi adjacent to the mines, without accurate monitoring information it is not possible to establish if, how much, or over what area the creep movements are actually occurring

Prior to, and while this report has been in progress, ground cracking (a slow creep deformation) has been observed outside the mine area along a lineament in Seddon and Haszard Streets, in part outside the hazard zones outlined by GNS in 2002. These areas of ground cracking are now included in the regular movement monitoring being carried out by NWG.

Slow creep movements are influenced by subsurface rock mass properties and by through-going rock mass defects such as shears and faults, which can weaken with time due to strain softening. As a first approximation, we estimate that the creep movements may possibly extend in the poorer rock mass on the southern and eastern sides of the open pit as far as the angle of draw (~30º from the vertical) from the deepest underground mine workings, and/or as far as the open pit depth from the pit rim. Whichever of these extends the furthest from the mine workings is taken as the probable limit of creep deformation.

Currently it is not possible to determine whether active cracking is due to collapse into stopes, pit wall instability, or a combination of both. It is important for future management of the hazards posed by this movement that its magnitude and trend over time be adequately understood. Complicating interpretation of this movement within the town streets is the fact that chimney caves found during the current Pit 64 cutback appear to lie directly above the stopes rather than aligned along the inferred 30° angle of draw.

The observed ground cracks being formed by lateral and vertical creep movements are small and are presently causing deformation along roads, footpaths and to some properties near the mine on its southern side. In places these movements have required repair and are outside the underground mine low subsidence hazard zone outlined by GNS in 2002. Should the movements continue as they are, or increase and become more widespread with time, the HDC and others will require accurate survey monitoring information to evaluate and assess what actions they may need to take. Survey monitoring is recommended to determine the actual rate and extent of creep movement as it occurs, information that is needed to assess potential damage to buildings and services.

Within the wider Waihi township there are also small, non-damaging, vertical ground settlements due to ground water lowering for the mine pit excavation. These settlements are being monitored by six monthly levelling surveys.

A key recommendation of this report is the establishment of accurate lateral and vertical monitoring in areas of Waihi near the pit. It will assist with better understanding the ground deformations associated with subsidence of the old underground mine workings and movements outside the mine close to the southern highwall. The monitoring system recommended is to install and survey regularly spaced metal pins along lines extending out from and around the cut-back southern, and the eastern pit rim, and adjacent to the underground mine stopes. Survey monitoring is not recommended beyond the northern and western walls of the open pit where pit wall monitoring by NWG shows there are no significant movements.

We recommend accurate survey monitoring along a series of points, initially established along road kerb lines to allow easy access for regular re-surveying. We recommended including in the new survey lines as many as possible of the points that are used for the six monthly settlement monitoring surveys in Waihi. The accurate surveying is required to determine both vertical and lateral creep movements. A similar ground deformation survey in Taupo has achieved good accuracy by using precise levelling for vertical monitoring in combination with an RTK GPS survey for lateral movement monitoring, along lines of points. It is a model which should provide input data of sufficient accuracy from which evaluate creep movements that may occur in Waihi.

It is recommended that the survey monitoring points are established without delay, so that changes in movement rates which could be associated with on-going works, such as the south wall cut back, or to later filling the recreational lake, are recorded. Once an initial network of points is established and re-surveyed, the deformation monitoring frequency and extent can be reviewed and adjusted to suit the locations and movement rates being observed.

1.0 INTRODUCTION

1.1 Mining Background

The Martha mine at Waihi was one of the great gold mines of the world. Underground mining at Martha Hill began in 1882 and by the time the mine closed in 1952, some 12 million tonnes of ore had been mined to yield 1,082 tonnes of gold-silver bullion. Underground mining extracted ore from four main sub-parallel lodes (the Martha, Welcome, Empire and Royal) together with numerous branch and cross lodes e.g. (the Edward). The lodes are sub-vertical or steeply dipping and are quartz/ore infillings of extensional faults and fractures. Early mining in stopes was by the cut and fill method, but after 1908 this method was largely replaced by shrink stoping. After 1914 the shrink stopes were generally not backfilled, but left open. Although late in the retreat mining phase of the mine life, some stopes were apparently back-filled to remove the crown pillars, without this information being entered onto the mine records. Overall the workings reached a total depth of 575m on sixteen levels with access by seven main shafts, although many other shafts were developed for ventilation and exploration.

Exploration drilling between 1980 and 1984 proved large reserves of lower grade ore which could be mined from an open pit located within the underground mine area. In 1988 mining recommenced and in 1997 the open pit was extended to target deeper reserves. The pit was scheduled to close in 2006, but the south wall cut-back, designed to improve the long-term stability of the south wall, will now keep the open pit mining operations running for about four more years until 2010. At completion the pit will be an oval shape about 640m wide, 950m long and 250m deep. After closure a recreational lake is proposed for the open pit.

1.2 Mining Subsidence Review

The sudden formation of ground collapse craters near Upper Seddon Street in 1999 and the similar, highly publicised Barry Road subsidence in 2001, dramatically alerted people to potential hazards associated with the former deep underground mining at Waihi. The August 2002 GNS Report on the Stage II investigations of the Waihi underground mine workings, focussed on this type of sudden chimney collapse subsidence crater. That report concentrated on the probability of occurrence and the risk to public safety of the formation of a sudden sink-hole subsidence migrating to the surface from the worked out Edward South, Royal and Empire stopes of the old underground mine.

Although it was recognised in the August 2002 GNS report that slow creep movement of the ground surface is common where underground mining, or the removal of underground fluids such as oil, water or geothermal steam has taken place, this type of subsidence appeared to be of minor significance and risk compared to the sudden collapse craters. Since 2002, the observation of surface creep deformation in the pavements and road surface of Seddon and Haszard Streets (Photos 1 to 7) has raised concern about the causes and potential risks of these ground movements.

Report Objectives. GNS Science (GNS) and URS Corp NZ Ltd. are presently engaged by Hauraki District Council (HDC) to review the 2002 GNS report, and if appropriate to extend the sink hole risk assessment methodology to the Martha Lodes, and to report on the ground cracking now being observed outside the sink-hole subsidence hazard zones outlined in 2002.

Photos 1&2 Cracking in Haszard Street with an unusual north (pit wall) side up and small right lateral component, suggestive of large "block" movement on a through-going rock mass defect.

Photos 3&4 Cracking in Seddon Street appears to be extensional but also has a small right lateral component of movement in the pavement above.

As well as the potential sudden collapse craters, there was recognition in the August 2002 GNS report of the small, relatively predictable surface settlements of up to 260mm due to lowering of the groundwater table affecting the subsurface geology. However, there was a lack of recognition of the possible extent of gradual vertical, lateral and rotational adjustments of the ground due to the earlier deep underground mining, later combined with possible influences from the excavation of the open pit. Gradual ground movements began and were recorded during the era of underground mining, most notably about the “milking cow” subsidence zone on the main Martha lode, but also in the mine shafts and other parts of the underground workings. Early geologists noted that such movements could be concentrated on through-going rock mass defects, such as faults. It is noted that much of the ore mineralisation occurred along faults and shears that were sometimes cut by later non-mineralised faults. In places the creep movements of the deep underground mine era are likely to have been influenced to some degree more recently by the excavation of the large open pit, more apparent in the poorer rock mass of the south wall area of the pit than the better rock mass of the north wall.

The accurate ground surface monitoring recommended below is intended to assist with the assessment and interpretation of the causes, and in determining the extent of the slow creep ground movements that are occurring in Waihi near the mine areas.

1.3 Previous Reporting

Following the ground collapse which formed the 1999 subsidence crater in reserve land near Seddon Street, the HDC assembled the Waihi Underground Mines Technical Working Party (TWP) and assigned it the task of investigating the abandoned mine workings, the likely cause of the collapse events, the implications for Waihi and the possible management of affected areas. In September 2001 GNS was contracted by HDC to compile a GIS dataset of the underground mine workings at Waihi using all available data. Reasonably good records from various sources were used by GNS to build a three dimensional digital model of the mine (GNS Feb. 2002).

The subsidence crater collapse in a developed urban part of Waihi at Barry Road in 2001, heightened the concern regarding the threat to public safety and other issues posed by further similar collapses. The TWP commissioned GNS to assess the causes of the subsidence crater collapses for Edward South, Royal and Empire lodes, determine where further such collapses might occur in the future on these lodes, particularly outside the mine boundary, and to investigate what could be done to mitigate their affects (August 2002 GNS report). The “Martha” stopes were specifically excluded from the August 2002 GNS study, but are included in this study.

Newmont Waihi Gold (NWG) have built up an extensive dataset of the old underground mine workings combined with later drilling investigations, geological records and a large quantity of their “in house” open pit information. This valuable dataset has been utilised and extended by Technical Consultants employed by NWG. In particular there have been comprehensive studies such as the 2002-2003 Geotechnical Investigations (PSM125.R28), Pit Closure Studies (PSM125.R34) and the Pump house Relocation: Geotechnical Risk Assessment of Site 4A (PSM125.L88).

For this present report we have drawn extensively on the previous work, particularly the well documented and detailed studies by PSM and NWG over the last six years.

2.0 SUBSIDENCE CRATER REVIEW

When carrying out their subsidence crater assessment for the 2002 report, GNS could not find an established method for estimating the probability of subsidence craters forming from unfilled underground mine workings and set about developing one. Under the direction of Dr Laurie Richards, an author of the 2002 GNS report, a methodology was developed to do this. In the technical assessment portion of the August 2002 GNS report, rock mechanics methodologies were developed and used to assess the stability of crown pillars in the stopes of the old Martha underground mine at Waihi. The work, which involved several different crown pillar stability assessment methods, is summarised in Figures 28 to 38 of that report. The stability assessments indicate that given certain realistic rock mass and stope parameters, the crown pillars could be unstable and would tend to collapse (i.e. Fig. 35).

The methodology for assessing the subsidence risk is presented in Figure 36. Using the software program @Risk, the report examines the probability of a roof collapse extending to the ground surface using a predefined collapse mechanism assuming that collapse of weak ground occurs as an upward migrating void, which, depending on the rock cover and rock strength conditions, may or may not reach the ground surface as a zone of subsidence. The ability of a stope collapse to reach the ground surface is calculated as the sinkhole index. When the sinkhole index exceeds 100% then subsidence of the ground surface could occur. The probability of the sinkhole index exceeding 100% is assessed in the void migration calculation utilising numerous iterations of a range of stope size and rock mass input parameters within predetermined bounds defined by a frequency versus dimension relationship in the @Risk software. The probability of a void reaching the surface was then tested against those places where subsidence craters have actually migrated to the surface, and was found to be very high. With this deterministic validation of the probabilistic void migration calculation, we were satisfied that our estimates were realistic.

The diagram on the left side of Figure 36 in GNS 2002 was intended to demonstrate the stope parameters used in the void migration calculation. The diagram was not intended to show how a void migrated to the surface. Rather we envisaged in the 2002 report that the voids migrated to the surface using a chimney caving mechanism as indicated in Figure 30, (c) and (d). As shown in Figure 31 of the 2002 report, a conical (chimney) collapse can migrate upwards the greatest distance. As well, the evidence of subsidence craters both outside (in 1961, 1999 & 2001) and inside the mine (summarised in Fig. 5, PSM125.L88 and NWG Geotechnical Summary – Martha Pit 2007/2008 Figures 7 & 8) show that voids tend to migrate by chimney collapse. We considered that in the underground mine, chimney void migration to the surface was most likely to occur upwards from an empty stope cavity along a line of poor rock mass, such as that provided by the intersection of two through going, sub-vertical faults or shears. We know from mine records that steeply dipping, intersecting faults and shears with various orientations are present in the mine rock mass.

In 2004 Trevor Carter, an experienced and well regarded colleague of Dr. Laurie Richards (lead author of the August 2002 GNS report), made an unsolicited review of the August 2002 GNS Report. In his “review”, forwarded by email, Trevor discussed the methodology we had used, and the review of our report by Tony Taig (Appendix 2, GNS August 2002 report), and forwarded two recent papers he had written on crown pillar stability. The comments by Trevor are briefly summarised here because they are the only detailed written evaluation we have received regarding rock mechanics aspects of our 2002 void migration assessment methodology.

Trevor discussed the rock mass parameters we had chosen and the values we had derived for crown pillar critical span, suggesting that the values he would have derived for these items would be for a poorer rock mass and less stable crown pillars – i.e. collapse of the crown pillars would be more likely in his assessment. As well he suggested that in his experience there are two distinct periods when crown pillar collapse is more probable – a two peak event history with early collapses due to bad workmanship (mining too close to the surface or stopes too wide, or both), followed by late collapses due to wear and tear (i.e. long term collapses due to weathering, loss of support from decay of timbers, ravelling, etc.). Trevor also made comments about his experience with open pits excavated near old underground mine workings.

Following this review and that by Tony Taig, which is included in the August 2002 GNS Report, and because there appears to be no viable alternative, we have elected to maintain the consistency and the methodology of our reporting. We have therefore used the same void migration calculation method for deriving the probability of sink-hole collapse for the North Branch, Mary, No. 2 and Martha stopes in this report, as was used in the August 2002 GNS report. By using this consistent approach we can then directly compare the new estimates for the Martha stopes (Table 1) with those for the other stopes in the August 2002 GNS report.

3.0 VOID MIGRATION CALCULATIONS FOR NORTH BRANCH, MARY, NO. 2 AND MARTHA STOPES

We have examined the risk of ground subsidence developing from chimney collapses into unfilled mined out stopes in the lodes that extend away from the northeast quadrant of the Martha Mine. This was carried out using the same methodology i.e. @Risk simulations of sinkhole index probabilities as developed for the study of ground collapse in the August 2002 GNS report. The basic model was calibrated by checking the predicted sinkhole indexes against this previous work.

The input data of stope locations, dimensions and volumes and whether filled or unfilled was provided from the NWG mine model, with a little additional data provided from historical records held by Dr. Bob Brathwaite of GNS. Estimates of maximum and minimum stope widths were developed from the stope volume and surface area data provided. Maximum and minimum stope widths for use in the probability simulations were developed from examination of the previous width ranges used for the Royal, Empire and Edward lodes south of the open pit.

The results are presented in Table 1 and the high, medium and low sink-hole hazard areas are shown on Figures 5 & 5a. The rock cover and % rock cover given in the table are best guess estimates based on the cross-section data through the lodes. Where individual stopes are known to have been filled, i.e. Martha Lode stopes F1, F2, F3 and F4 and No 2 Lode stopes 2, 3 and 4, then these have been omitted from the hazard assessment because they are deemed to pose no risk of surface subsidence. Where the collapse of adjacent stopes could combine to form a bigger collapse feature, then this has been examined by combining stopes together in the assessment. The results are also given in the table.

The assessed current annual probabilities of ground collapse (calculated using the same methodology as GNS 2002) within the influence zones of the unfilled stopes follows:

- Mary Lode – 0.04 or 4.0%
- Martha Lode – 0.04 or 4.0%
- No 2 Lode – 0.01 or 1.0%
- North Branch – 0.04 or 4.0%

These probabilities for the Mary, Martha and North Branch stopes are of the same order of magnitude as determined by GNS in 2002 for the Royal and Empire stopes along the southern boundary of the mine. The sink-hole hazard zones associated with each of the lodes are shown on Figures 5 & 5a.

4.0 PEDESTRIAN SAFETY IN WAIHI HAZARD ZONES

The assessment for traffic risk performed by Professor D G Elms (Letter Report to HDC dated 2 Oct 2002 – Appendix 3) concluded that the likelihood of vehicles being directly impacted by a sudden collapse was significantly (two orders of magnitude) lower than the ambient probability of vehicle accidents on NZ roads. Further, by implication, the level of risk posed to the road-using community would be expected to be acceptable to them in a rational analysis. We expect the same to apply to the use of the potential high probability collapse areas by pedestrian traffic in the event that future land use is for recreational purposes, e.g. as reserve areas having walking and cycle tracks.

Professor Elms assumed a car speed of 50 km/hr. For walkers we could assume 5 km/hr. Thus a pedestrian takes 10 times as long to pass through one of the high hazard zones as a car does. This means that the probabilities for a pedestrian are 10 times those for a car, i.e.

- Edward 2.96×10^{-9}
- Royal 6.14×10^{-9}
- Royal 3.68×10^{-9}
- Empire 20.36×10^{-9}

The annual probability of collapse on the Mary, Martha and North Branch lodes are essentially the same as for the Royal and Edward lodes. Therefore assuming a similar number of pedestrian trips as traffic, we can apply Professor Elms' assessment logic to show that the risk of death to a pedestrian in a high sink hole hazard zone is about 50 times less risky than a person in Waihi being killed in a car accident. Death due to a traffic accident in Waihi was estimated to be about 1 death in 10 years (Appendix 3). This does not mean that the death of a pedestrian (or cyclist) in a high hazard sink hole subsidence zone could not occur. It could, but its probability is very low and is generally regarded as acceptable in the normal scheme of our daily activities.

Waihi Gold Mine

Table 1 Probability of sinkholes above stopes in Martha, Mary, No 2 and North Branch lodes

Job # 42160447

Stopes nos.	Length m	Stope width m Min	Mean	Max	Volume m³	Rock Cover m	% rock	Sinkhole index - bulking 33-50% Mean	% > 100	Risk	Sinkhole index - bulking 15-30% Mean	% > 100	Risk	Probability a stope will not collapse (for bulking 33-50%)	Combined Probability of a Collapse on Lode (see pg 61 of GNS 2002)	Annual Probability of Collapse now (t = 0) (see pg 53 of GNS 2002)	Comments
Mary Stope																	
1	98	0.90	1.31	3.31	2970.0	73	83	65.4	9.6	M	143	73	H	0.904			
6	59	1.80	3.10	5.10	3376.0	185	93	29	0	L	65.2	5	M	1			
7	20	0.30	0.65	2.65	51.0	209	93	3.3	0	L	7	0	L	1			
8	54	1.80	2.30	4.30	1946.0	195	93	19.5	0	L	44.7	0	L	1			
12	102	1.80	3.05	5.05	10256.0	248	94	38	1.2	M	86.6	30	H	0.9876			
14	68	1.20	2.04	4.04	1811.0	302	95	10.4	0	L	22	0	L	1			
1,2	98	1.80	2.57	4.57	8056.0	73	83	116	64	H	264	100	H	0.357			
1,2,3,4	146	###	2.21	4.21	10480.0	73	83	113	57	H	254.6	100	H	0.426	**1.00**	**0.04**	
1,2,3,4,5	169	1.20	2.21	4.21	15118.0	73	83	143	82	H	320.7	100	H	0.183			
6,9	122	###	3.10	5.10	15129.0	185	93	63.8	7.5	M	140.7	79	H	0.925			
6,9,11	122	1.80	3.10	5.10	26706.0	185	93	136	78	H	190	100	H	0.224			
7,8	73	1.80	2.30	4.30	1997.0	195	93	13.7	0	L	28	0	L	1			
7,8,10	73	1.80	2.30	4.30	9264.0	195	93	88	69	H	109.6	60	H	0.306			
12,15	102	1.80	3.05	5.05	10748.0	248	94	41.3	1.4	M	89.7	35	H	0.986			
7,8,10,13	98	1.80	3.54	5.54	16386.0	195	93	88.1	34	H	140	95	H	0.664			
7,8,10,13,16	166	1.80	3.54	5.54	23333.0	195	93	60.4	5.6	M	134.8	70	H	0.944			
No.2 Lode																	
1	87	1.80	3.86	5.86	7751.0	136	90	52.8	4	M	116.9	59	H	0.96			
5	78	###	1.60	3.60	1578.0	302	95	8.7	0	L	17.6	0	L	1	**0.16**	**0.01**	Stopes at No.2, 2, 3, 4 are filled
1,5	87	1.80	3.86	5.86	9329.0	136	90	69	13	H	140.5	82	H	0.874			
Martha Unfilled																	
1	68	1.80	3.29	5.29	7122.0	170	92	64.6	8.2	M	109.7	63	H	0.918			
2	29	0.90	1.43	3.43	154.0	224	94	3.5	0	L	7	0	L	1			
4	29	1.20	2.05	4.05	521.0	278	95	8.4	0	L	18.6	0	L	1			
5	29	0.90	1.31	3.31	440.0	248	94	10.7	0	L	23.5	0	L	1			
6	44	1.20	1.67	3.67	1150.0	273	95	13.8	0	L	31.4	0	L	1			
8	54	1.20	1.83	3.83	1004.0	327	96	7	0	L	15	0	L	1			
11	20	###	1.50	3.50	299.0	380	96	6.7	0	L	59.4	2.7	M	1	**1.00**	**0.04**	
12	29	1.20	1.94	3.94	1864.0	341	96	24.4	0	L	25.2	0	L	1			
13	56	1.80	3.05	5.05	5060.0	131	90	79	23	H	120	78	H	0.771			
1,3	68	1.80	3.29	5.29	13257.0	170	92	111	64	H	119	74	H	0.365			
1,3,7,9	112	1.80	3.15	5.15	16244.0	170	92	87.8	27	H	166	95	H	0.735			
1,3,7,9,10	112	1.80	3.15	5.15	17019.0	131	90	124	62	H	225	100	H	0.384			
13,14,15,16,17,18	88	1.80	4.22	6.22	17830.0	131	90	144	83	H	195.4	100	H	0.17			
1,13	124	1.80	3.29	5.29	12182.0	131	90	65	7.4	M	147	77	H	0.926			
1,13,3,14	124	1.80	4.22	6.22	24765.0	131	90	133	67	H	247	100	H	0.33			
1,13,3,14,15	124	1.80	4.22	6.22	26238.0	131	90	141	72	H	253	100	H	0.279			
1,13,3,14,15,16,7	173	1.80	4.22	6.22	28723.0	131	90	96.3	32	H	212	97	H	0.684			
1,13,3,14,15,16,7,17,9,10	173	1.80	4.22	6.22	34138.0	131	90	119	56	H	256	99	H	0.44			
1,13,3,14,15,16,7,17,9,10,18	173	1.80	4.22	6.22	34849.0	131	90	121	60	H	261.5	100	H	0.396			
Martha filled																	
F5	127	0.60	0.94	2.94	1936.0	248	94	11.3	0	L	22.4	0	L	1	**0.00**	**0.00**	Stopes at Martha Filled, F1, F2, F3, F4 are filled
6,F6	78	1.20	1.75	3.75	1798.0	273	95	10.5	0	L	21.8	0	L	1			
North Lode																	
1	102	1.80	3.07	5.07	7663.0	127	90	52.2	3.3	M	118.6	56	H	0.967			
1,2,3,4,5	122	1.80	3.50	5.50	19337.0	127	90	118	57	H	232	100	H	0.43			
1,2,3,4,5,6,7	122	###	3.50	5.50	31948.0	127	90	213	99	H	284.6	100	H	0.01	**1.00**	**0.04**	
1,2,3,4,5,6,7,8	122	1.80	3.50	5.50	33453.0	127	90	225	99	H	282	100	H	0.01			

5.0 GROUND DEFORMATION AT WAIHI

5.1 General ground deformation near mines

There is an extensive literature on ground surface subsidence, mainly related to underground mining of coal seams, with less information on ground movements near open pits. It is clear that either can cause significant ground surface movements extending some distance away from a mine.

Much of the ground subsidence literature on underground mining relates to coal mining where extensive, sub-horizontal coal seams have been substantially mined out, causing variable widespread subsidence with a mainly vertical downwards component of movement at the surface. This type of subsidence can reach the surface relatively quickly, especially where the mined coal seam is “shallow” and where unsupported, longwall mining methods are used, but is not directly applicable to the situation at Waihi.

In some urban areas affected by underground mine creep subsidence movements, generally from mining coal seams, there are pragmatic restrictions on the type of buildings and services that can be constructed. For example, resilient, sheet clad, timber framed buildings constructed on piles with a crawl space above the ground so that the building can be re-levelled or relocated, are acceptable, whereas brittle brick or concrete buildings generally are not. Although creep movement has not reached this level in Waihi, and may not do so, the accurate monitoring recommended in Waihi, in our view is necessary for long-term assessment and to assist in development of planning measures for building and infrastructure close to the mine.

Chimney subsidence from steeply dipping or vertical voids, such as that occurring at the Martha underground mine, has formed roughly circular subsidence craters and distinctive concentric ground cracking extending some distance away from the “crater”. The width of high, medium and low hazard zones have been set up to encompass the observed ground subsidence and cracking from the 1999 and 2001 events (Figures 5, 8 & 9). However, any unfilled stope voids will tend to close up with time, mainly by lateral movements normal to the void. These movements are likely to be very slow, complex, episodic and may involve block movements which exploit through going rock mass defects such as faults and shears. They would be a combination of small vertical subsidence and lateral movements which may be concentrated on sub-surface rock mass defects such as shears and faults.

In addition to conventional slope failures, the long-term creep ground movements associated with open pits appear to depend on rock mass properties and the size and depth of the pit. Initially movements can tend to be rebound types of movements due to rapid unloading as the pit is excavated. In the long-term these can translate into slow, inelastic creep displacements towards the pit, especially when long-term strain softening is considered. They could also be expressed at the surface as a combination of small vertical subsidence and lateral movements which may be concentrated on sub-surface rock mass defects such as shears and faults. Thus it will require specialist interpretation of detailed measurements to determine whether or not the observed surface movements can be attributed to the open pit, the old underground mine, or a combination of both.

5.2 Terminology

To reduce confusion, we qualify our use of the general term “subsidence” and instead describe the main type of ground movement, where possible following the four descriptions outlined in 5.3 below. In cases where the ground movement may be related to more than one of the four ground movement types listed, we will describe the combination of movement types which we consider are involved.

In engineering terms Risk (R) is defined as the product of the probability (P) of a hazardous event occurring by the consequences (C) if it does occur. i.e.

R = P x C

Consequences are typically defined as damage (economic loss) or loss of life that would likely result if the hazardous event actually occurred. We note that in this definition risk is not the same as probability.

5.3 Deformation at waihi

At Martha Mine where there has been a combination of historical, deep underground mining and more recent excavation of the open pit, there is likely to be a complex interaction of ground movements between the two mines, which may extend some distance from both mines. At this stage there is visible linear cracking in Haszard and Seddon Streets (photos 1 to 4). That in Seddon St. is being monitored by NWG using crack width measurements with proposals to strengthen the monitoring system by recording the total spatial movement of selected points with time. As well there is deformation which is not being monitored, such as that in Haszard Street.

The monitoring in Seddon St. shows total crack width movements in the range 1 to 10 mm in the first six months of 2008. The assumption of a continuing rate of movement would result in 0.2 to 2 m of total movement over 100 years. Movement rates may increase following the start of lake filling as increased water pressures cause declining effective strength within the slope and around stopes, leading to additional movement. The current amount and rate of movement is not life threatening, but is sufficient in time, to damage buildings and services and has already done this. The footpath, kerb and channel (in Seddon Street) and a water main (in Haszard Street) have required repair because of this ground deformation. At this stage there is a lack of accurate knowledge of where else outside the mine boundary, similar or smaller movements may be occurring. Accurate and detailed monitoring is required to determine this, and to pick up possible future movements, if they occur.

In our view there is a high probability that small, long-term creep deformations due to both the old underground and the open pit mines could occur in adjacent parts of Waihi. However, without accurate monitoring information we cannot accurately assess how much and over what area the creep movements might occur. Given that this study is focussed on stope subsidence hazard we have not regularly received or reviewed the monitoring data related to pit wall movement which may assist interpretation of the nature of the movements. In our view, based on the observed cracking, there are insufficient accurate movement data available away from the pit perimeter. Therefore we recommend initially monitoring points in an area above where the open pit and the underground mine stopes are close to each other and could interact. We recommend that a set of survey monitoring pins along lines are established and accurately (± 2mm) surveyed for their x,y,z coordinates on a regular basis (three monthly initially then declining as the behaviour is better understood) within this area to establish movement (or lack of it) over the forthcoming years. Our suggested monitoring lines are shown on Figure 5b and are discussed in Section 5.5 following. They should include as many as possible of the settlement monitoring points already installed and being monitored in Waihi (Figures 7 & 7a).

A network with a similar purpose has been established in Taupo urban area to monitor possible subsidence ground movements related to nearby deep geothermal steam extraction for a proposed electricity generation plant. This network of pins is set into road kerbs, initially at 20m centres, is monitored at 6 monthly intervals, and a movement history has been established prior to any deep geothermal steam extraction from the adjacent Tauhara area. In our view the Taupo monitoring network serves as a working model of what is required in Waihi.

5.4 The types of ground deformation near Martha Mine at Waihi

In brief there are several, possibly complexly interacting forms of ground movement at Martha Mine, all of which can be referred to as “subsidence”. These are:

1. The small, gradual surface settlements of up to ~260mm due mainly to lowering of the groundwater table in the open pit (Figure 7b), but also influenced by rock mass relaxation due to mining and the subsurface geology. The extent of this ground settlement is monitored with levelling surveys and reported annually to HDC. These movements have influenced much of the town and are considered to have a very low impact – see Figure 7, which is Figure 42 from the August 2002 GNS report. Figure 7a shows the location of the levelling survey pins.;

2. Sudden collapse craters into old underground mine workings. The extent of this high risk hazard was assessed by GNS in 2002 for the Royal, Empire and Edward stopes to the SE, South and SW of the open pit. The “Martha Stopes” to the north-east of the open pit have now also been assessed for this form of sudden collapse in this report (Figures 5 & 5a). Recent observations by Newmont during construction of the Pit 64 cutback indicate that as with previous collapses (in 1961, 1999 and 2001) that have reached the ground surface the chimney caves have formed directly above the stopes rather than along the 30° angle of draw. (Ref Newmont Geotechnical Summary – Martha Pit 2007/2008 Figures 7 and 8) This recent observation is consistent with the definition of the location of the high hazard ground subsidence zones directly over the stopes developed during the initial study by GNS in 2002. (GNS August 2002) and continued in this report.

3. Pit wall movement. The movement and stability of the walls for the entire open pit are being continuously monitored and assessed in near real time by NWG using a Geotechnical Management System (Maton 2004 – Appendix 1), which includes measurements from three total survey stations to numerous monitoring prism points. We understand that the results of this monitoring are reviewed regularly for HDC by Open Pit Reviewer Mr John Ashby who advises HDC on pit wall stability.

   The pit wall movement monitoring is used to assess the short and longer-term stability of the pit walls. Concerns over the stability of the south wall have resulted in moving the Cornish pump house so that work can be undertaken on a south wall cut-back to a long-term, stable angle (PSM125.R28 and PSM125.R34 Reports). Following completion of the cutback works, the open pit walls are expected by NWG to be stable with acceptable levels of stability under static, lake filling and earthquake loading conditions, and thus have a low probability of failure. The continuation of total station pit wall monitoring into the foreseeable future provides assurance that slope movement which may possibly lead to a slope failure, would be detected, evaluated and dealt with as it occurred.

It is noted that some of the creep movement cracks in the surface of Seddon Street lie outside the previously defined low subsidence hazard zone and are parallel to the southern high wall rim, in a similar manner to tension cracks associated with slope instability. These cracks are shown in Photos 1 to 7 and their locations are shown in Figure 5. They are discussed in more detail below. Our current knowledge of the movements does not permit reliable differentiation between pit wall instability and stope collapse as the cause(s) of this movement, but their nature, alignment and extent coupled with observations presented by Newmont (Ref Newmont Geotechnical Summary – Martha Pit 2007/2008) indicate that pit wall movement cannot be ruled out at this stage and a precautionary approach to their interpretation is warranted.

4. Gradual vertical, lateral and rotational ground movements caused by creep of large “blocks” of ground as they adjust to the various underground and open pit mining excavations, as outlined by Trevor Maton in Appendix 1. These movements appear to be mainly associated with the southern and eastern perimeter areas of the open pit above the old underground mine workings and where the rock mass is noticeably poorer than in the northern and western walls of the pit. The movements have caused what are at this stage relatively minor surface deformations at several locations. However, there is potential that these ground movements could slowly enlarge over a period of many years to eventually reach more than a metre or so of overall displacement. The known ground movements in Seddon St. are being monitored monthly by NWG using a micrometer distance measurement between two pins. These cracks are generally outside both the extensive pit wall total station monitoring being carried out by NWG and are too complex to be effectively monitored by the annual vertical surface settlement monitoring being carried out to determine the ground response to groundwater lowering for the open pit excavation.

As noted, there are small linearly oriented ground displacements related to type 4 above, extend some distance beyond the open pit and are presently noted in Seddon and Haszard Streets, in places well outside the collapse crater low hazard zone and some 120m from the rim of the open pit (Figure 5). Subsidence and ground cracking is also seen at and near the net ball courts and a few other places. Our present interpretation is that these slow ground movements are low impact (and low risk) and are gradual surface movements, possibly due to adjustments and rotations of large rock mass blocks. They appear at this stage to fall within the general definition for low hazard described in the 2002 GNS report - *“there may be minor surface settlement and ground cracking deformation*” (p35, August 2002 GNS report).

Of these four types of ground movement, types 2 and 3 can in some situations be rapid and thus high impact and risk, while types 1 and 4 are considered to be low risk. Type 4 differs from type 1 by having an unknown level of potential for the deformations to become increasingly large, possibly reaching up to a few metres of total movement in time, whereas at least part of the type 1 deformations may tend to reverse when the open pit is flooded and the groundwater table reaches former levels. The degree of movement from type 4 is potentially damaging to buildings and services, but because of its slow rate of movement, it is not a threat to life. The magnitude of these deformations can be expected to decrease with surface distance from the open pit and from the underground mine stopes. We recommend accurate survey monitoring to measure the magnitude and extent of these possible movements against time.

5.5 Recommended Additional Ground Movement Monitoring

As the possible type 4 gradual ground movements beyond the pit perimeter are not being effectively measured at present, we recommend that systematic on going monitoring, similar to that presently being carried out in Taupo, should commence in Waihi. This monitoring should accurately pick up the extent and directional magnitude of these movements, if any, so that a better assessment of any ground movements can be made. Three dimensional (x, y, z co-ordinate) monitoring of similar accuracy to the total station monitoring being carried out by NWG for the open pit walls would be ideal. Where practicable the open pit monitoring using total stations could be extended into parts of Waihi. However, the lack of suitable vantage points for a total station theodolite to see into all the key parts of Waihi township and the requirement of having numerous prisms close to the ground for this system to be effective, suggests that other options, such as the Taupo model, may be preferable. GNS experience using a total station to monitor on-going landslide movements in near real time in Taihape township, show that the total station survey system with prisms can be effective (see www.geonet.org.nz/landslide/LandslideResources/TaihapeLandslide).

In town areas one disadvantage is that prisms attached to houses, poles and other cultural features may not show the real ground movement when this is small and slow. For example, the actual ground movement of a crack, such as that in Photo 1, where it passes under a house, may not be accurately reflected by monitoring a prism attached to the house. In this case, the ground movement is masked by the house or structural feature. Further these structures can introduce their own spurious movements related to climate (temperature and moisture) changes. Thus for accurate ground movement monitoring, we recommend having a pin or prism attached on or as close as possible to the ground surface. This is the case in Taupo where metal pins are cemented into kerb lines along the edge of roads. Here they give ready access for repeat surveys and for placing additional pins when extension or more detailed monitoring is required. As well this system of pins is low maintenance and does not require a continuous monitoring set-up, as a total station system does.

Initially the monitoring points in Waihi could be set at 20m centres along suitably oriented streets in areas near the underground mine and the open pit rim, with additional points installed either side of visible “cracks” and other known surface deformations. The monitoring frequency of these points could initially be set at 3 months and then adjusted to be more or less frequent depending on the rate of movement being observed. As well there should be regular assessment of the need to adjust the length of the lines or for additional rows and points to monitor new or expected areas of deformation.

We recommend initially the linked monitoring lines shown on Figure 5b.

5.6 Future Ground Movements

5.6.1 Estimating the extent of slow (type 4) ground movements

The slow, type 4 ground movements may be caused by the old underground mine workings, the open pit, or a complex interaction of both combining to affect the adjacent rock mass and its defects, such as shears and faults. The relative contributions from the underground mine and the open pit to surface deformations are likely to vary according to the proximity of each and the prevailing subsurface ground conditions, particularly where through-going crush and shear zones can be exploited.

With reference to Figure 6 (Fig. 41 of the August 2002 GNS report), the angle of draw is defined as the vertical line between the edge of the mine opening – in the case of the underground stopes on the Royal or other lodes, and the line connecting the opening (stope) edge to the limit of significant displacement. The angle of draw is typically in the range 10 to 30 degrees. The cracking in Seddon Street is “linear” (rather than having a circular sink hole appearance) and has an alignment roughly parallel with the open pit rim. It has a maximum angle of draw of about 28 degrees from the base of the Royal stopes, or about 60m from the southern edge of the low hazard zone from the Royal stopes for the 1999 collapse cross-section (see Fig. 8), or extending out 30 to 80m from the edge of the low hazard zone for the 2001 collapse cross-section (Fig. 9). The linear alignment of these cracks roughly parallel to the open pit wall, the direction of their movements and their location outside the hazard zone related to stope subsidence, is suggestive that pit wall movements may be involved with generation of the cracking.

As well as adding complexity to interpretation of observed surface cracking, small, long term relaxation movements of the ground due to the open pit might be expected to extend some distance from the pit rim. Such ground movements would be type 4, low risk ground movements. Using basic rock and soil mechanics estimates, the zero deformation limit could possibly extend to about 250m (the pit depth) from the edge of the pit but would be expected to lie within and may be considerably less than this figure.

In Seddon Street the possibility that the observed cracking is influenced by stope collapse cannot be ruled out. The ground deformations at the NE end of Seddon Street and the Millenium Wall (Photos 4 & 5) appear to be north side down extensional features (Photo 4), possibly related to the 1961 and 1999 collapse craters, the Royal stopes, and/or to the open pit wall movements.

In Haszard Street the deformation movement is “compressional” north side up with a small right lateral movement, indicating a different mechanism, such as graben-type block adjustment associated with a small outward movement of the pit wall, or rotation of a rock mass block towards the open pit wall (Photos 1 and 2).

The recommended survey monitoring is considered to be what is required to accurately determine the extent and type of deformation movement which may be occurring outside the Open Pit. The lines may be helpful in assessing the possible causes of the ground movement, such as whether they are block movements related mainly to the abandoned underground mine workings. As well, the rate and amount of movement may help determine the level of risk. For example an accelerating movement rate may typically indicate that a rapid failure is on the way, whereas movement that reduces with time typically indicates a settling down and an improving degree of stability or reduction in risk. The recommended monitoring is intended to cover all these possibilities and is likely to be required for the medium to long-term future, for many years after mine closure.

At this stage we have no reason to expect that the deformation hazard might increase above the Edward South stopes. The Edward South stopes are relatively small in volume, they are deeper than most of the other areas, and investigation drilling shows that the rock mass above them is of good quality. They are within the low hazard zone established previously (Figure 5). As well, the two inclined investigation holes above the Edward stopes are being regularly monitored by OPUS for down-hole movements. The accurate surface survey monitoring points recommended in this area are an additional assurance method for checking the potential subsidence hazard in this occupied part of Waihi township.

5.6.2 Possible extent of long-term ground movements

Figure 10 illustrates the extent of the Martha and Royal lode excavations below the deepest part of the open pit. On the Figure 10 cross-section, the Martha lode extends at least 250m below the greatest depth of the open pit, while the 250m deep Royal lode excavations are present to the south and stop some 70m beneath the pit perimeter. Given that the Martha lode excavations average about 10m in width and the Royal average 4m, there is a combined total stope width of about 14m which may tend to close up with long-term rock mass deformation. Allowing approximately 40 to 75% of this void space to be unfilled and available for lateral movement, it is possible that there could be a few metres of long-term lateral closing movement of the south pit rim relative to the north, resulting in a narrowing of the north–south pit width. This lateral movement is likely to be variable depending on void space available and subsurface geology. As well it could have associated surface deformation adjustments over a lengthy period, possibly hundreds of years.

5.7 Possible remote sensing DInSAR monitoring

In 2007 GNS employed a remote sensing specialist Dr Sergei Sampsonov. This opened the possibility of using satellite-borne synthetic aperture radar (SAR) images to detect and measure the subsidence movements in Waihi. DInSAR uses two or more SAR images to generate maps of surface deformation using differences in two-way travel times of the waves returning to the satellite. Once the ground, orbital and topographic contributions are removed the interferogram contains the changes of the surface caused by an increase or decrease in distance from the ground pixel to the satellite. One fringe of phase difference is generated by a ground motion of half the wavelength that is about 3 cm for ERS, RADARSAT and ENVISAT satellites and about 10 cm for ALOS. Phase shifts are resolvable relative to other points in the interferogram only, but absolute deformation can be inferred by assuming one area in the interferogram (for example a point away from expected deformation sources) experienced no deformation, or by using a ground control (GPS or similar) to establish the absolute movement of a point.

The advantage of DInSar is that it potentially offers monitoring of ground deformation over a complete area, rather than along lines as measured by surveying. GNS agreed with HDC to trial the DInSAR technique at Waihi (Appendix 4) in April and May of 2008 and this has been done. However, the results are equivocal as it appears any ground movements at Waihi may be too small to be measured using the technique. This is possibly good news for Waihi, but remains to be confirmed by this technique. Better accuracy measurements using DInSAR could possibly be achieved in Waihi if an accurate terrain model, such as Lidar, was available. We are informed that a Lidar (accurate air borne infra-red height scanning measurements) survey has been completed in Waihi by Environment Waikato. Once this Lidar data becomes available, GNS has undertaken to make a further assessment of the potential for using DInSAR for monitoring ground movements in Waihi

Photo 5. Ground cracking due to lateral northward movent and subsidence, evident along the base of the Millenium Wall in Seddon Street, Sept 2008.

Photo 6 View of surface cracking near the open pit rim which is being monitored with wire extensometers. View looking west.

Photo 6 & 7 Open ground cracking with north (pit) side up, close to the pit rim and east of the Judges Kauri.

6.0 SUMMARY AND CONCLUSIONS

1. When GNS was carrying out the work required for their 2002 report, it became apparent that there was no accepted method in use for assessing the risk of subsidence collapse craters migrating to the ground surface from underground mine workings, so a method for doing this was developed and used.

2. A review has been carried out of the methodologies used in the August 2002 GNS report for estimating sink-hole hazard zones above the old underground mine stopes at Waihi. In our assessment, the methodologies used are appropriate and can be tested deterministically in the places where sink-holes have occurred. To date all observed chimney caves have formed over the high hazard zone derived from the model. Therefore for consistency in our reporting, and because there appears to be no viable alternative, the same void migration calculation methods have been used for deriving the probability of sink-hole collapse over the “Martha” (North Branch, Mary, No. 2 and Martha) stopes in this report. The new estimates (Table 1) can therefore be directly compared with those for other stopes (Edward South, Royal and Empire) in the August 2002 GNS report.

3. The risk of ground subsidence developing from chimney collapses into unfilled, mined out stopes in the “Martha” lodes (Table 1) has been carried out using the @Risk simulations of sinkhole index probabilities, as developed for the study of ground collapse in the August 2002 GNS report. The basic model was calibrated by checking the predicted sinkhole indexes against this previous work.

4. High, medium and low sink hole hazard zones have been established over the “Martha” lodes lying in the NE quadrant beyond the perimeter of the open pit (within Figure 5) using the procedures of the August 2002 GNS report. The historical large subsidence craters and the chimney caves found during excavation of the Pit 64 cut back, are all located in the high hazard zones, which supports our hazard model.

5. The risk of sink-hole collapse from the “Martha” stopes was specifically not included in the work brief for the August 2002 GNS report.

6. Risk assessment evaluations suggest that vehicle, cycle and pedestrian access is acceptable on roads or tracks established through high sink-hole hazard areas.

7. The August 2002 GNS report was focused on the risk of sink hole collapses from the Edward South, Royal and Empire lodes and did not fully recognise the possible extent of low hazard, long-term creep movements associated with underground and open pit mining.

8. We expect that creep deformations due to both the old underground and the open pit mines will occur in adjacent parts of Waihi. However, without accurate monitoring information it is difficult to accurately predict the extent of creep movements..

9. Slow creep movements are influenced by subsurface rock mass properties and by through-going rock mass defects such as shears and faults. Using engineering judgement guided by observed ground cracking, we estimate that the creep movements may extend as far as the angle of draw (~30º from the vertical) from the underground

mine workings or as far as the open pit depth from the pit rim, whichever extends the furthest from the mine workings on the southern and eastern sides of the open pit. The creep movements are presently causing relatively small deformation of roads, footpaths and a few properties in Seddon and Haszard Streets and are considered to be low risk, meaning they are regarded as causing some economic damage rather than posing a threat to safety. Should the movements continue, increase or become more extensive the HDC may have to assess the introduction of resilient building and service construction methods in the movement areas.

10. To establish the extent and context of movements, we recommend that movement monitoring survey lines are established in the areas of Waihi that may be most affected by long term creep movements. These monitoring lines extend out from and along the southern and eastern pit rim and from the underground mine stopes. We also recommend that the survey monitoring lines are established without delay so that changes in movement rates which could be attributed to on-going works, such as the south wall cut back and/or lake filling are recorded and assessed. Once lines are established, the survey monitoring frequency can be adjusted to suit movement rates being observed and their locations.

11. Once accurate monitoring data is available from repeat surveys of the recommended survey monitoring lines, it can be used to assess whether the surveys need to be adjusted, either extended or reduced, to suit the actual ground movements being recorded.

12. Pit wall monitoring by NWG indicates that the “northern” pit wall is generally stable and not moving.

7.0 ACKNOWLEDGEMENTS

The assistance of Newmont Waihi Gold with field visits and the provision of reports and mine models is gratefully acknowledged. In particular, the friendly help of Trevor Maton at NWG has been much appreciated.

Our GNS Science colleagues, Drs Warwick Smith and Bob Brathwaite, the TWP and the Open Pit Mine Reviewer Mr John Ashby, have provided helpful comments and review of the report.

We appreciate the assistance and helpful suggestions of Messrs Langley Cavers and Mark Buttimore during preparation of the report.

8.0 LIMITATIONS OF THE REPORT

Our study has approximations and limitations that are inherent in attempting to model and understand complex geological processes and ground conditions. We are attempting to forecast future subsidence movements and are unable do that with any precision. We have applied our engineering and geological judgement to an imperfect knowledge of subsurface ground conditions and past events. The estimated probability of various subsidence events has a relatively high level of uncertainty because of the uncertain nature and properties of the ground in which movements occur and through which voids migrate before they reach the surface. In addition, a lack of accurate knowledge of the processes by which voids migrate increases the uncertainty. However, our model for void migration has been tested and validated against the subsidences that have occurred. We are satisfied that the void migration model gives good indicative and useable hazard assessment results.

The report findings are made on consideration and analysis of the best information available to us.

9.0 REFERENCES

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Richards L, Mazengarb C, Beetham D, Brathwaite B & Smith W, 2002: *Waihi Underground Mine Workings Stage II Investigations (Risk Assessment and Mitigation) 2 Volumes.* GNS Client report 2002/46, August 2002.

Figure 5: Aerial photo of Waihi showing collapse areas, the open pit and probabilistic hazard zones – circles around shafts, elongated areas above lodes (from the August 2002 GNS Report). The Edward South hazard zones were changed in the 2003 GNS report and 'Martha' stopes have been added - this report.

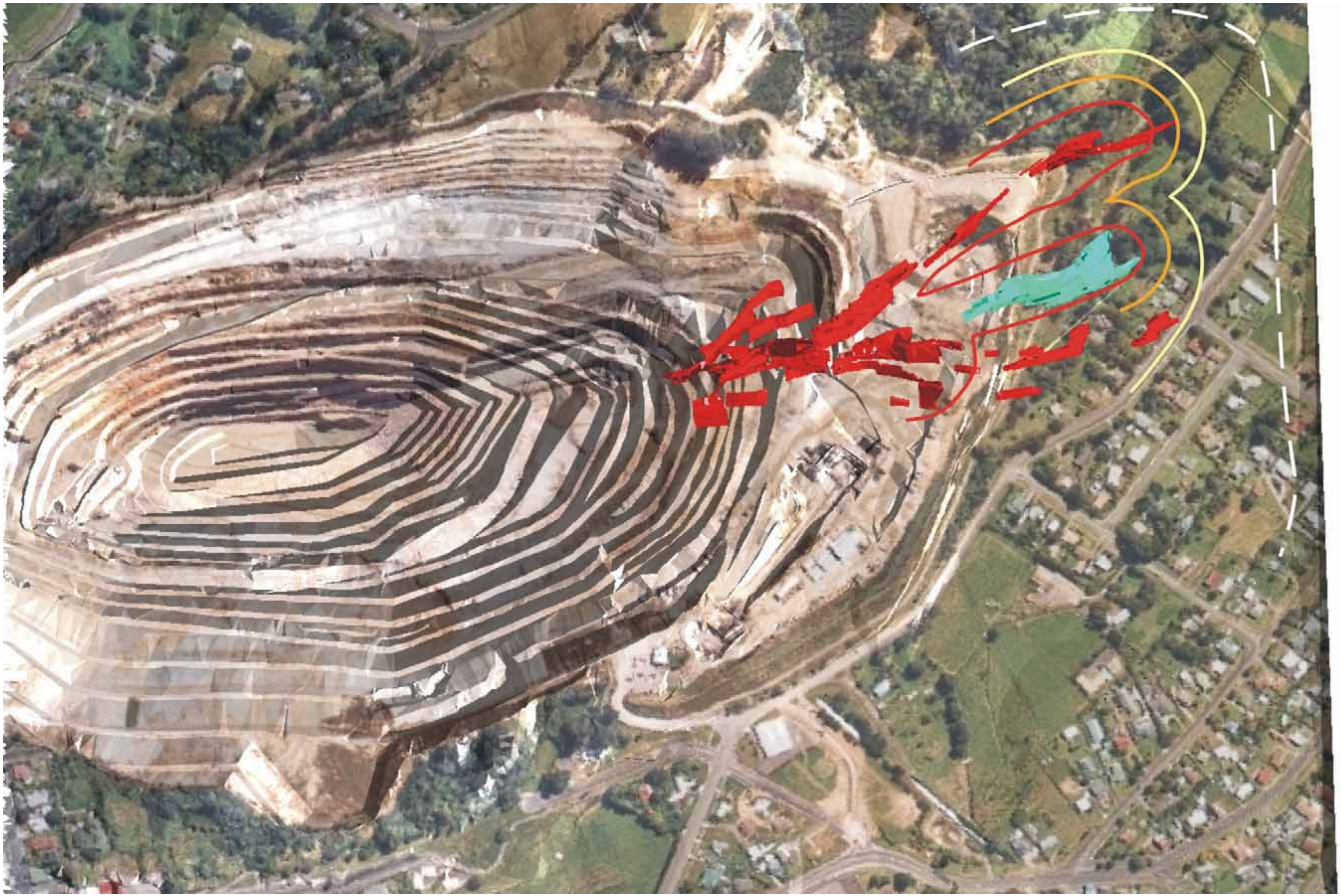
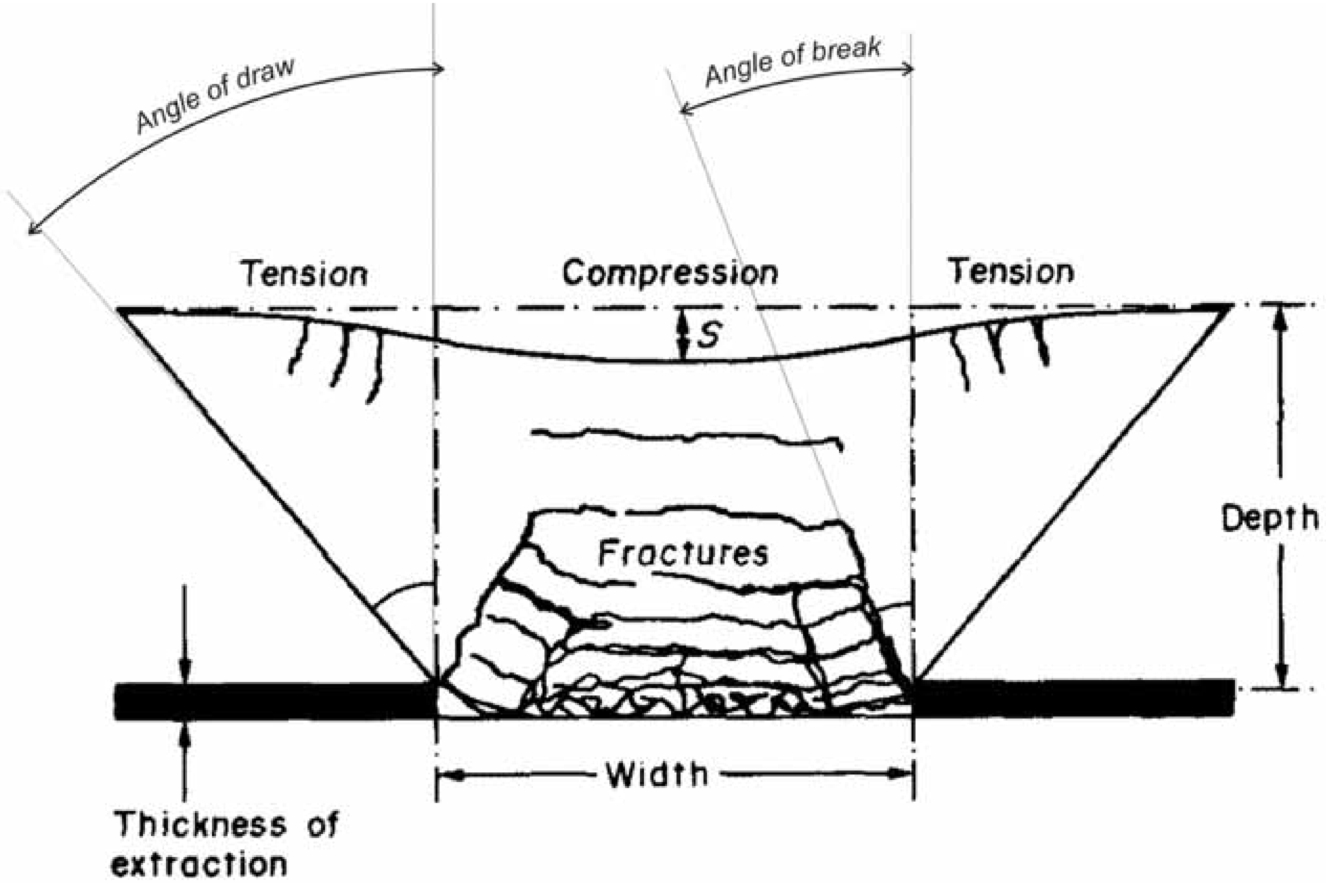


Figure 5a "Martha" stopes showing detailed sinkhole hazards zones

Figure 5b Yellow dashed lines show recommended monitoring lines with points at ~20m spacing and incorporating as many existing settlement monitoring points as possible (Figure 7 & 7a). Orange dashed lines are linking lines using existing points.



The angle of draw is the angle between the vertical line at the edge of the mine opening and the line connecting the opening edge to the limit of significant ground displacement. It is typically in the range from 10 to 30 degrees
The angle of break is the angle between the vertical line at the edge of the mine opening and the line connecting the opening edge to the point of maximum tensile strain at the surface. It is typically 5 to 15 degrees.

Figure 6 Definition of angles of draw and break (As Fig. 41 in the August 2002 GNS report.).

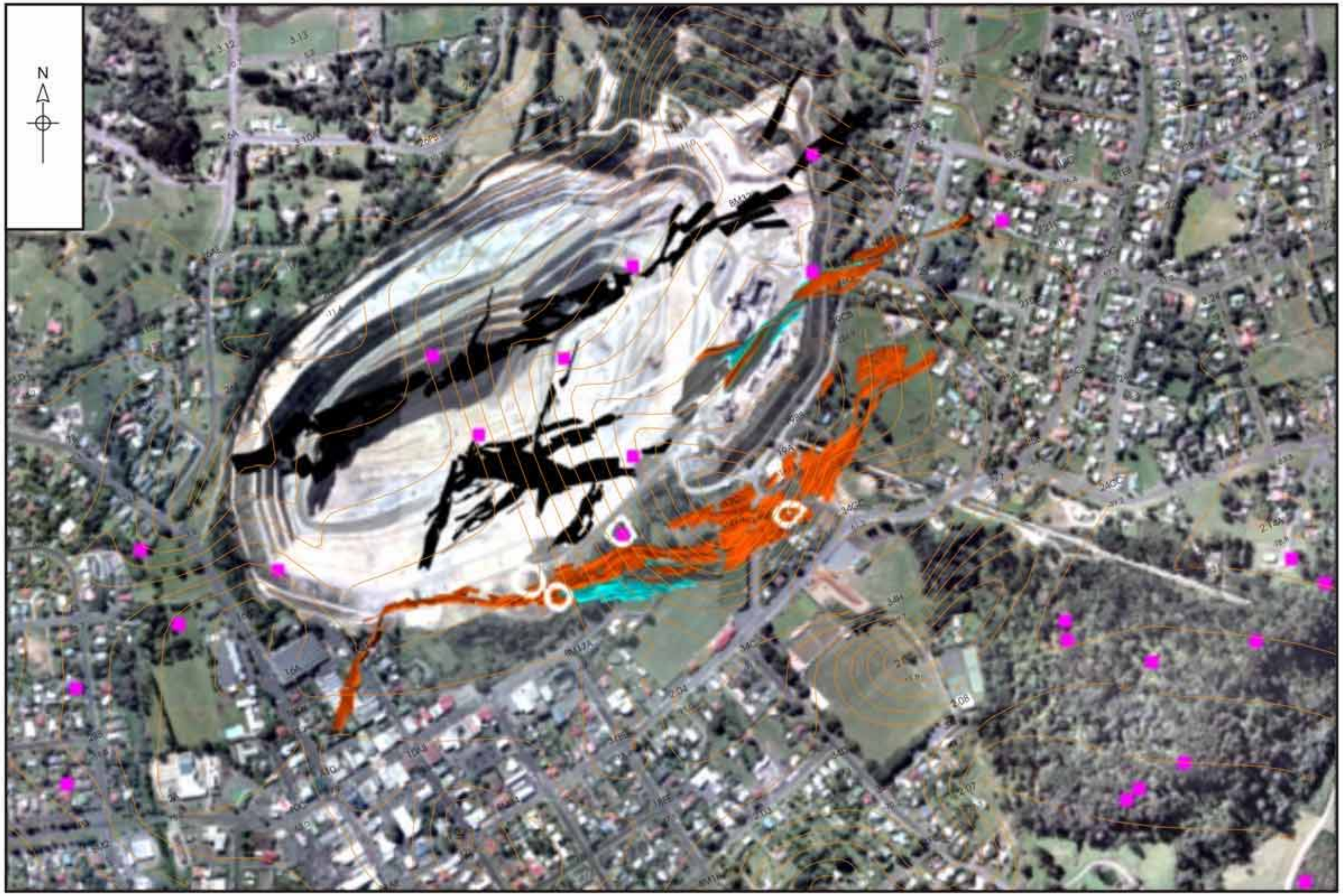


Figure 7 Total ground settlement contours (orange), settlement values (mm) and survey points, with stopes, shafts and collapses (white) (As Fig. 42 in the August 2002 GNS report.).

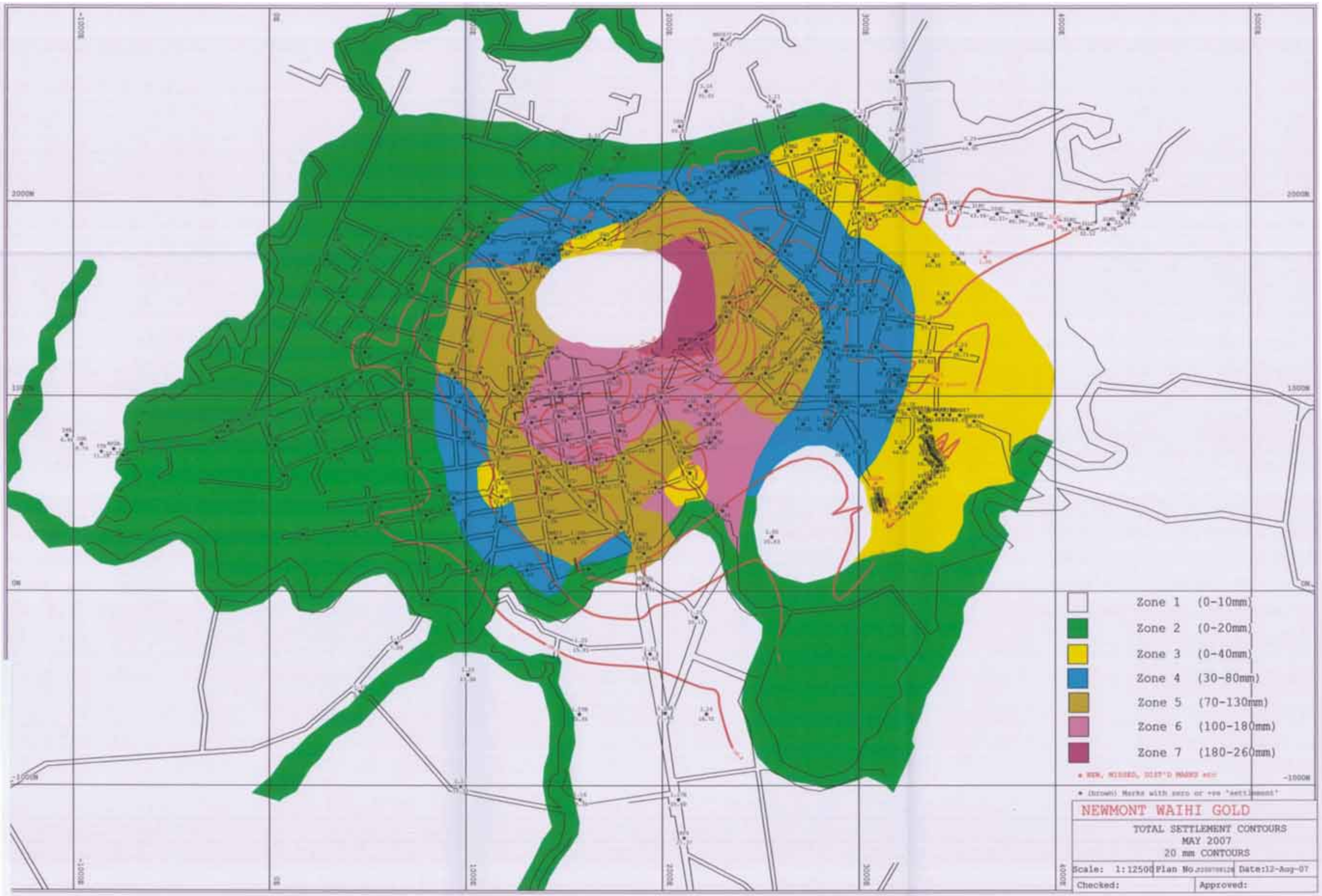


Figure 7a. Existing settlement monitoring points in Waihi with settlement zones due to dewatering. The points are monitored only for vertical movement. Those incorporated in the monitoring lines also need to be accurately surveyed for lateral movement.

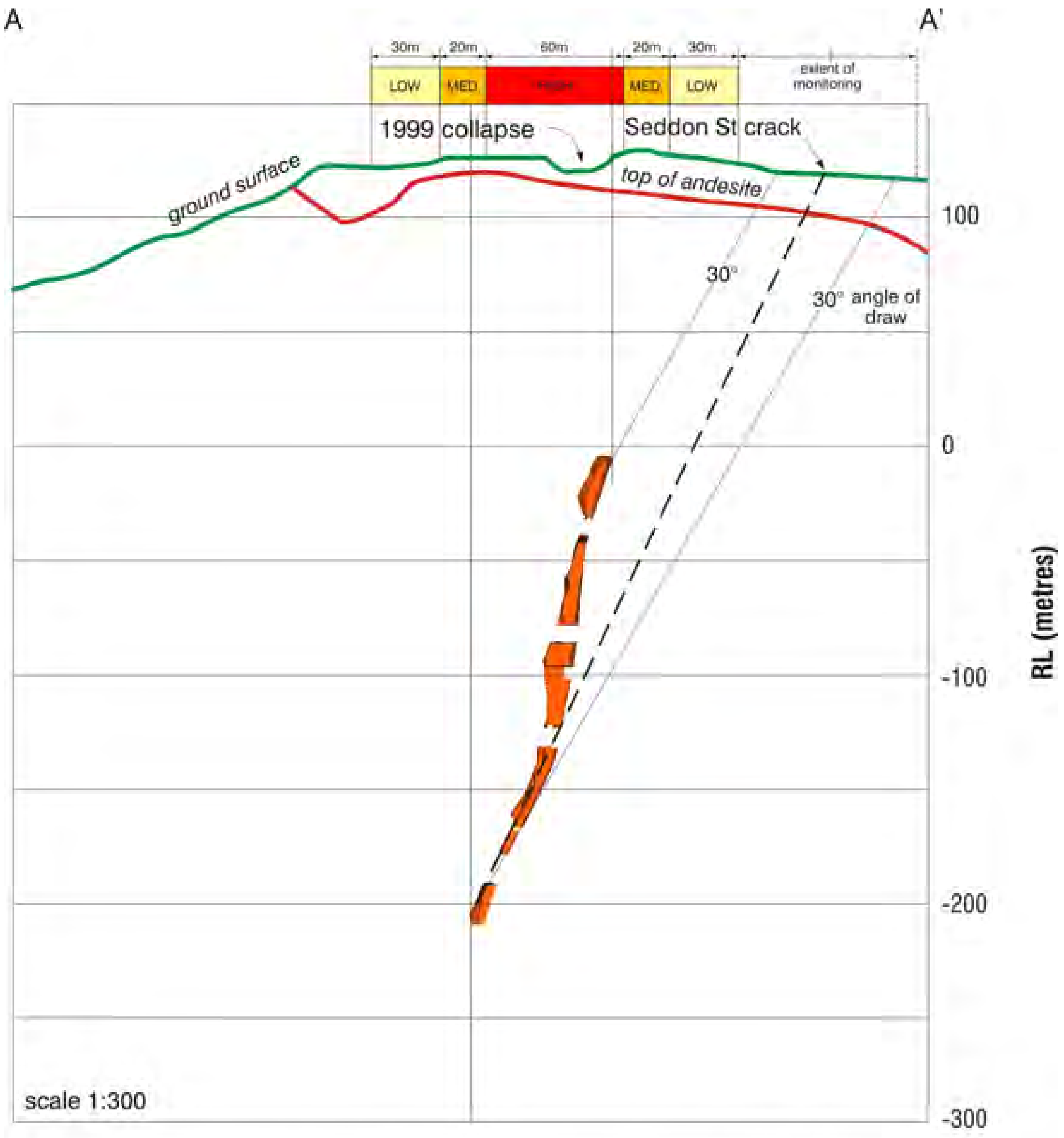


Figure 8 (From Fig. 11 in the August 2002 GNS report.) Cross-section A-A' through the Royal stopes at the 1999 collapse. Probabilistic hazard zonation is shown illustrating buffer technique employed in this study.

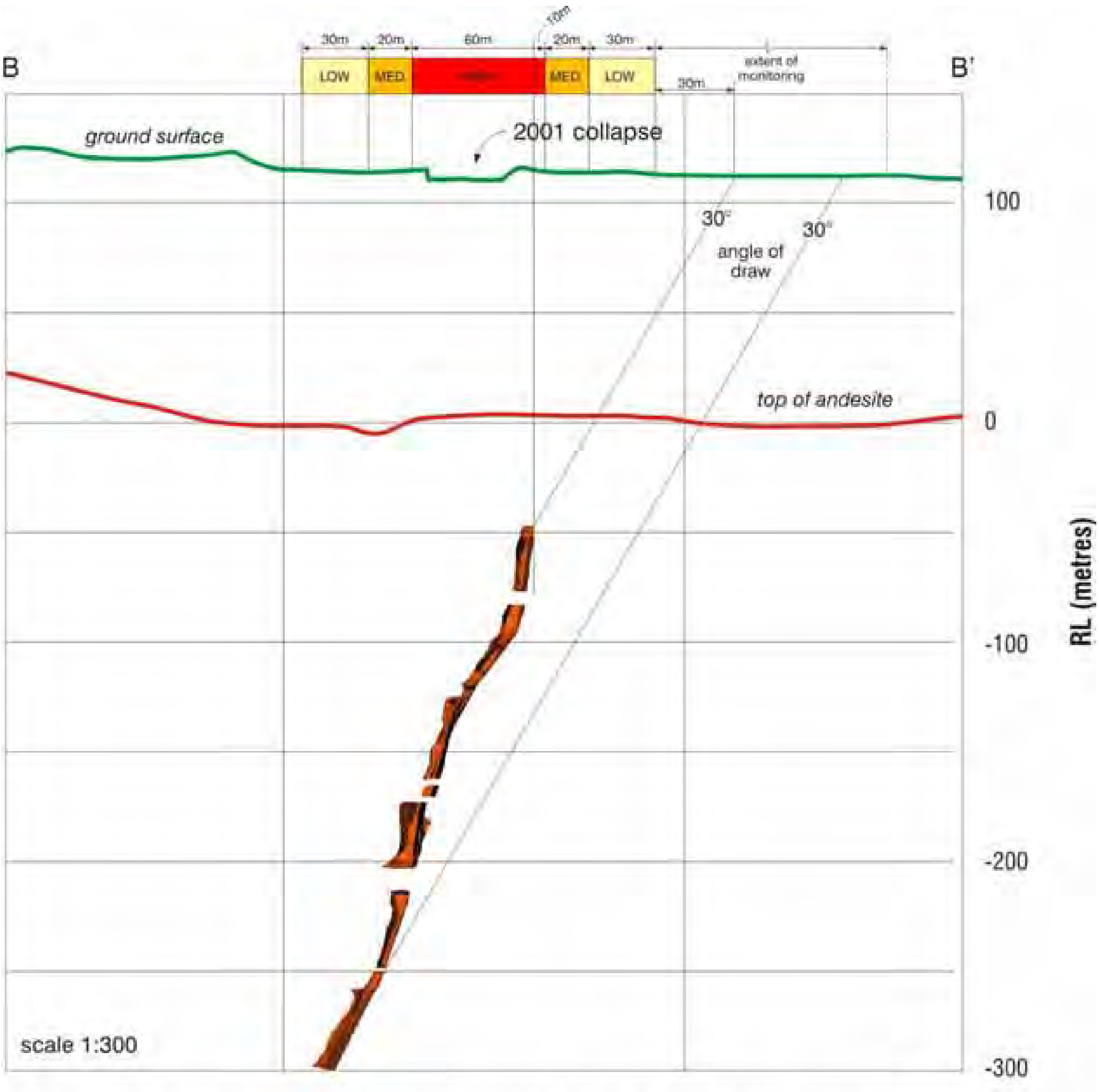


Figure 9 (From Fig. 12 in the August 2002 GNS report.) Cross-section B-B' through the Royal stopes at the 2001 collapse. Probabilistic hazard zonation is shown illustrating buffer technique employed in this study.

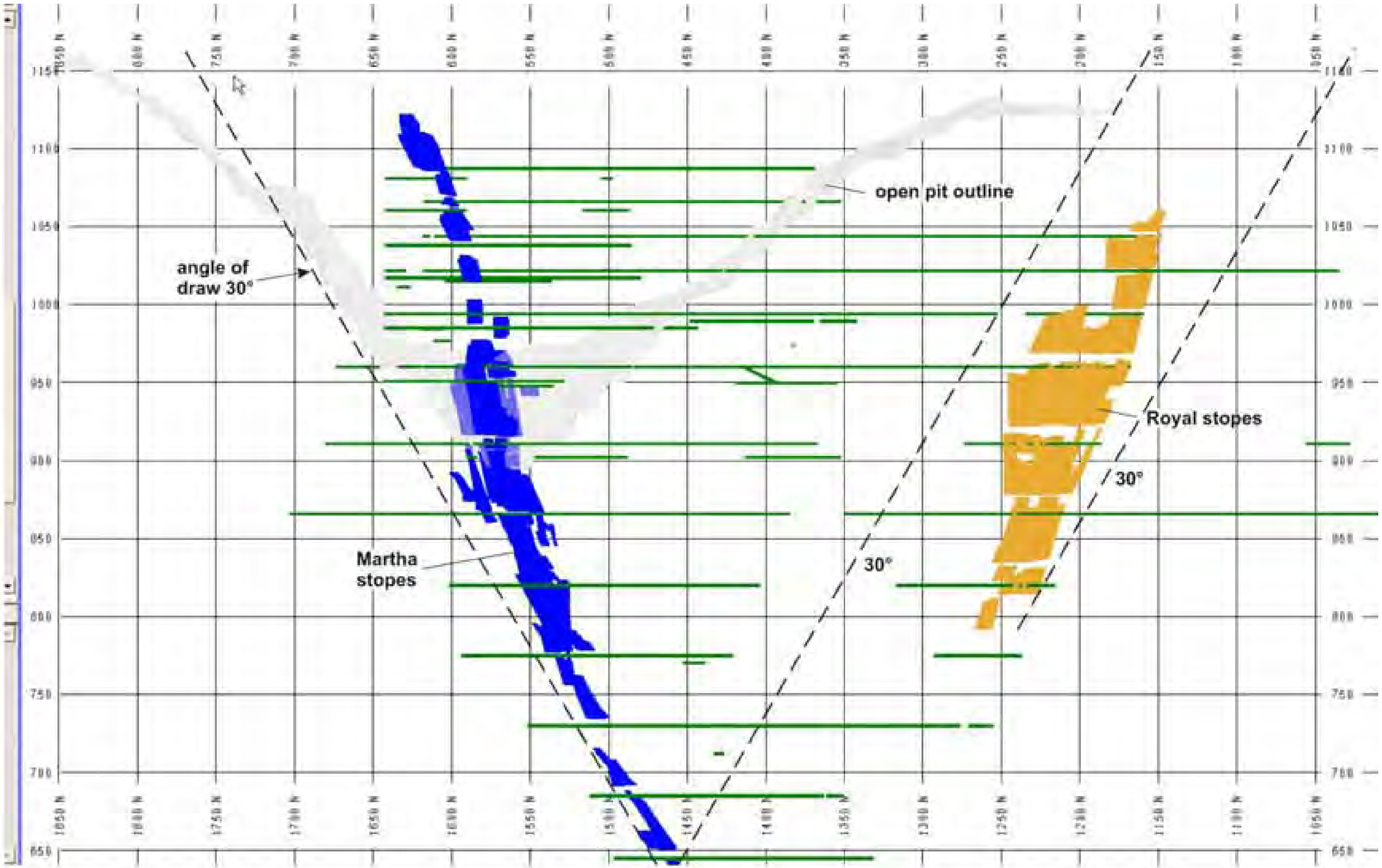
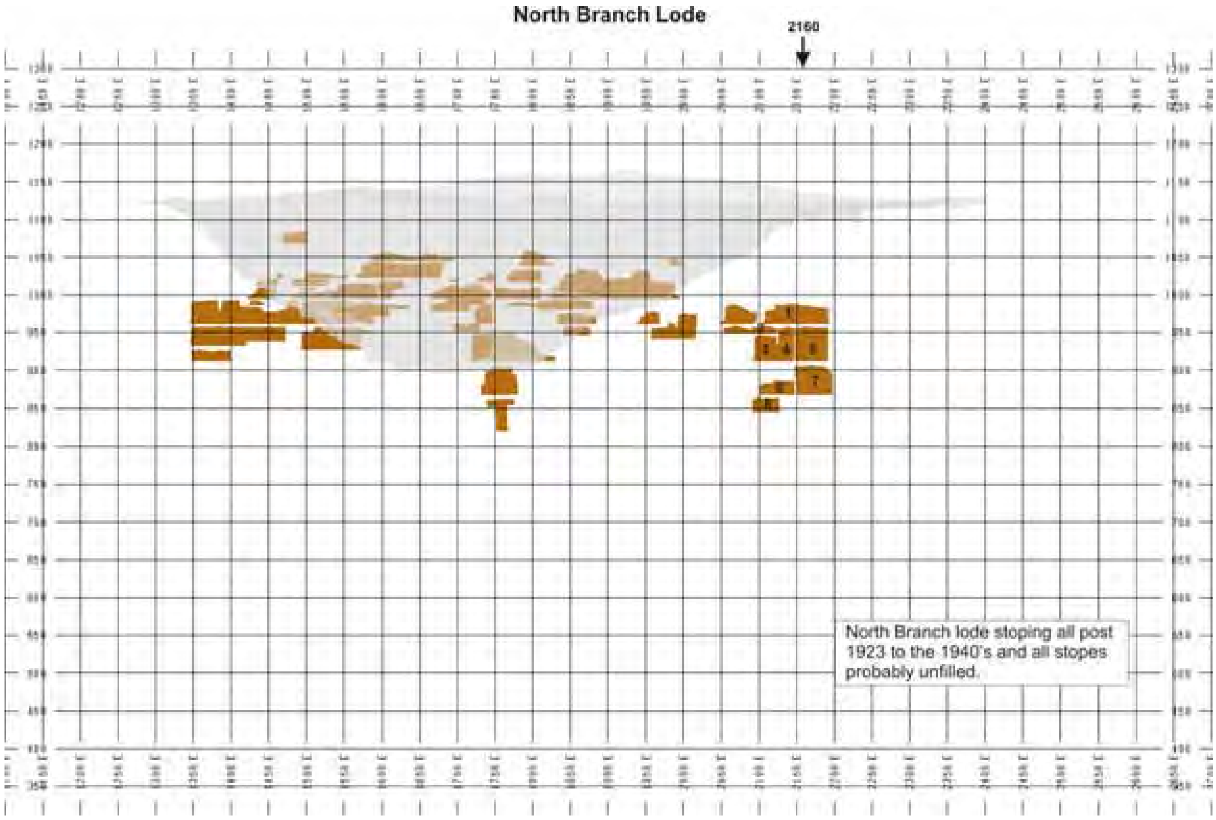
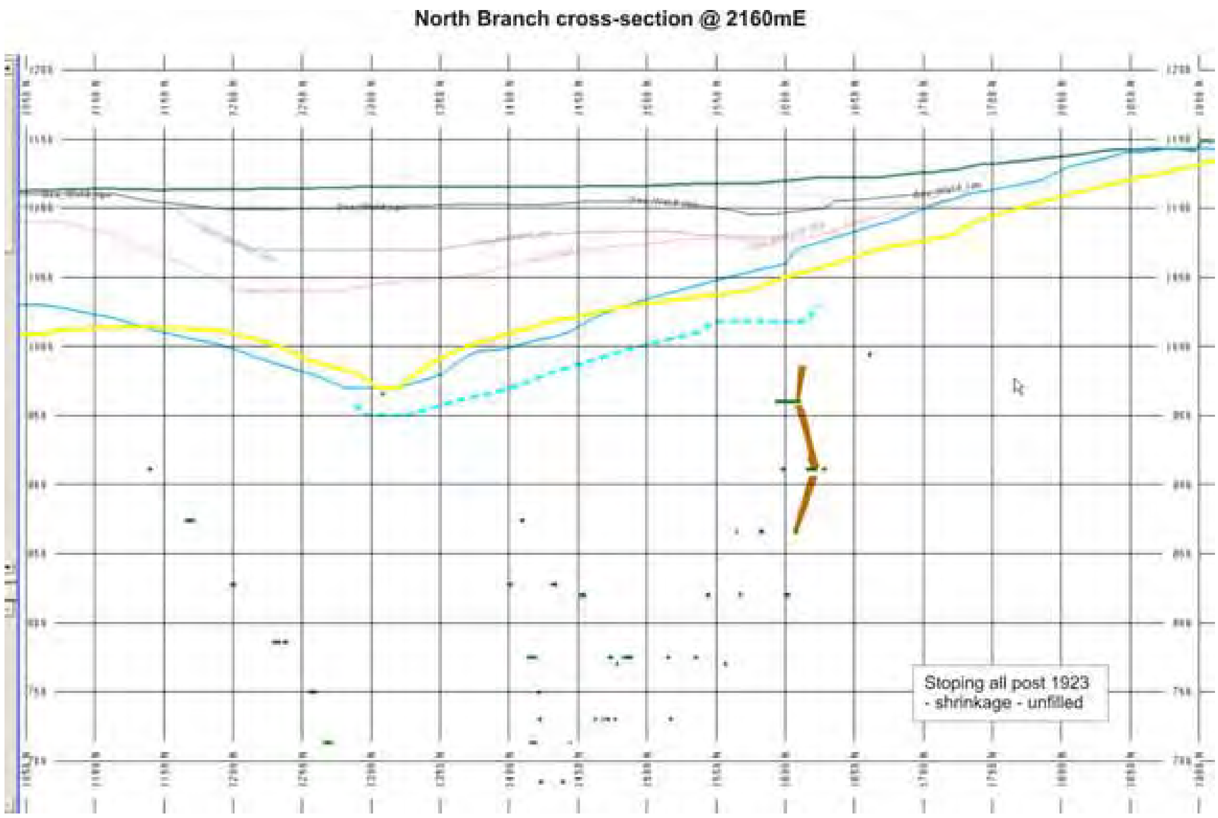
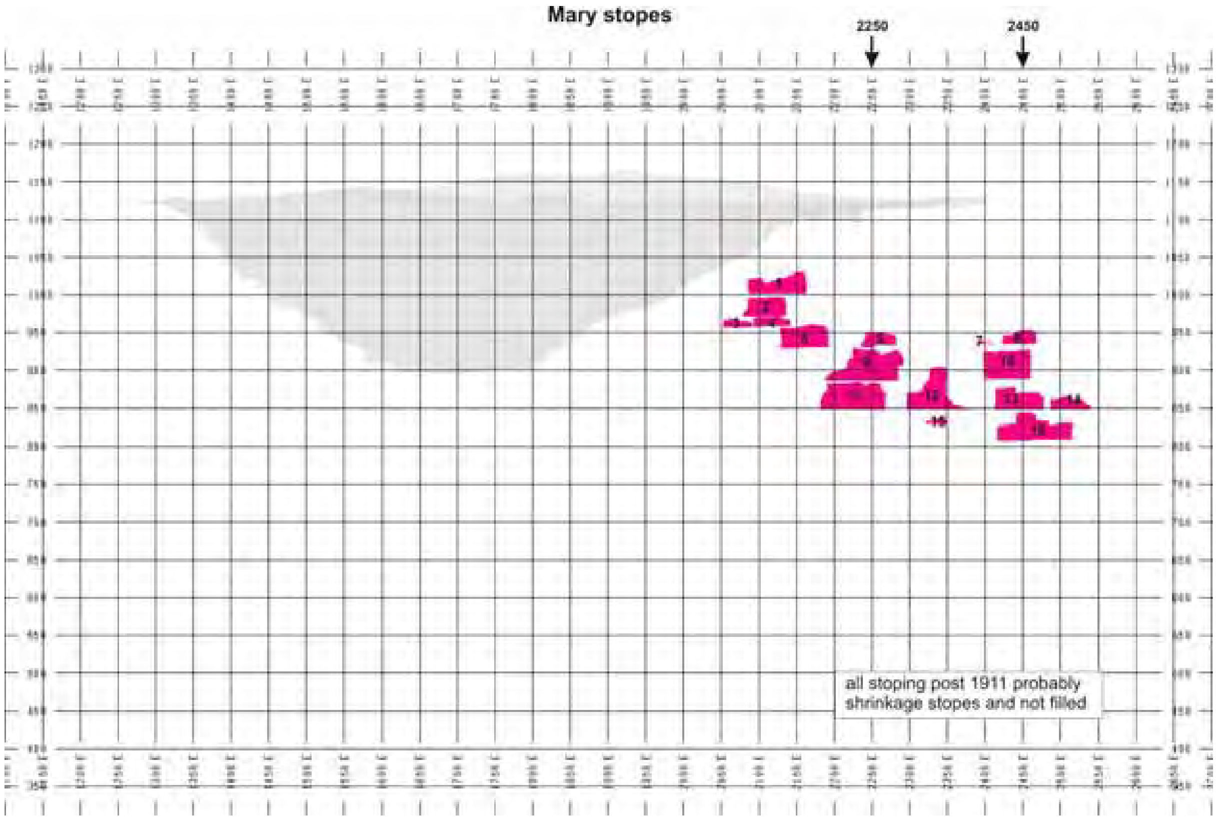


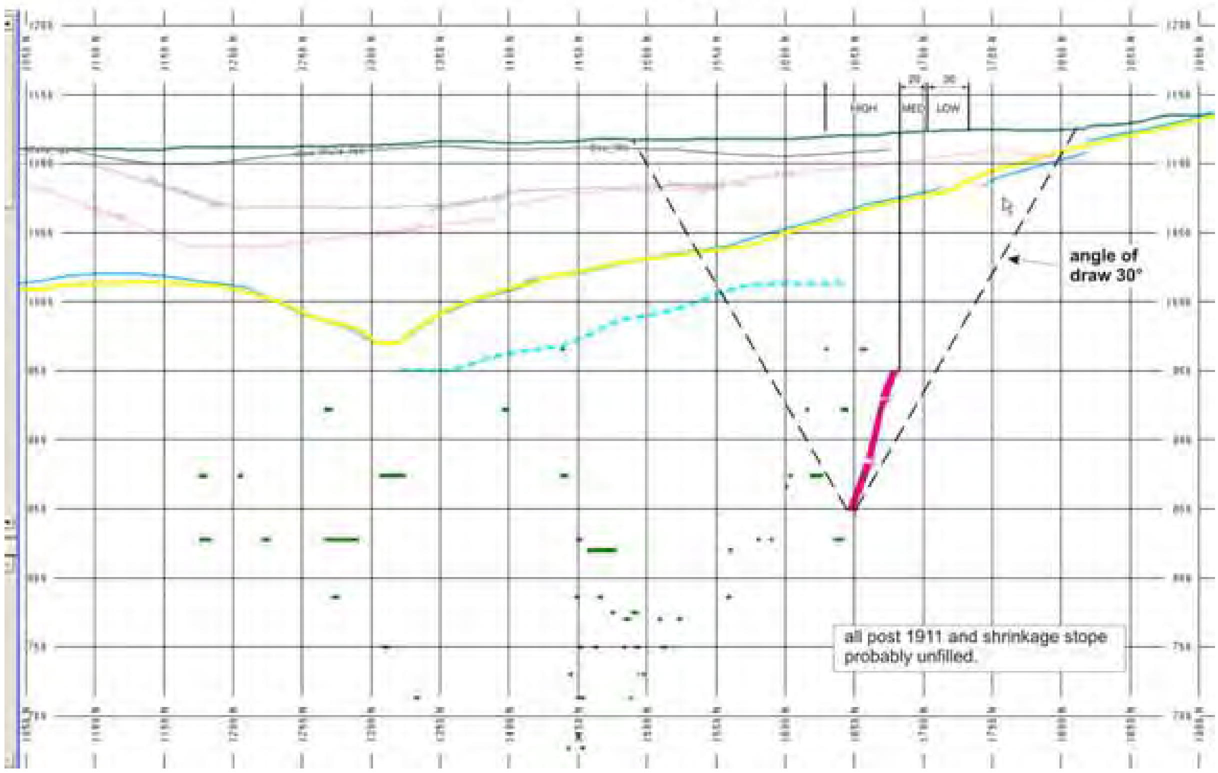
Figure 10 General section through Martha and royal Stopes.


North Branch Lode
2160
North Branch lode stoping all post 1923 to the 1940's and all stopes probably unfilled.

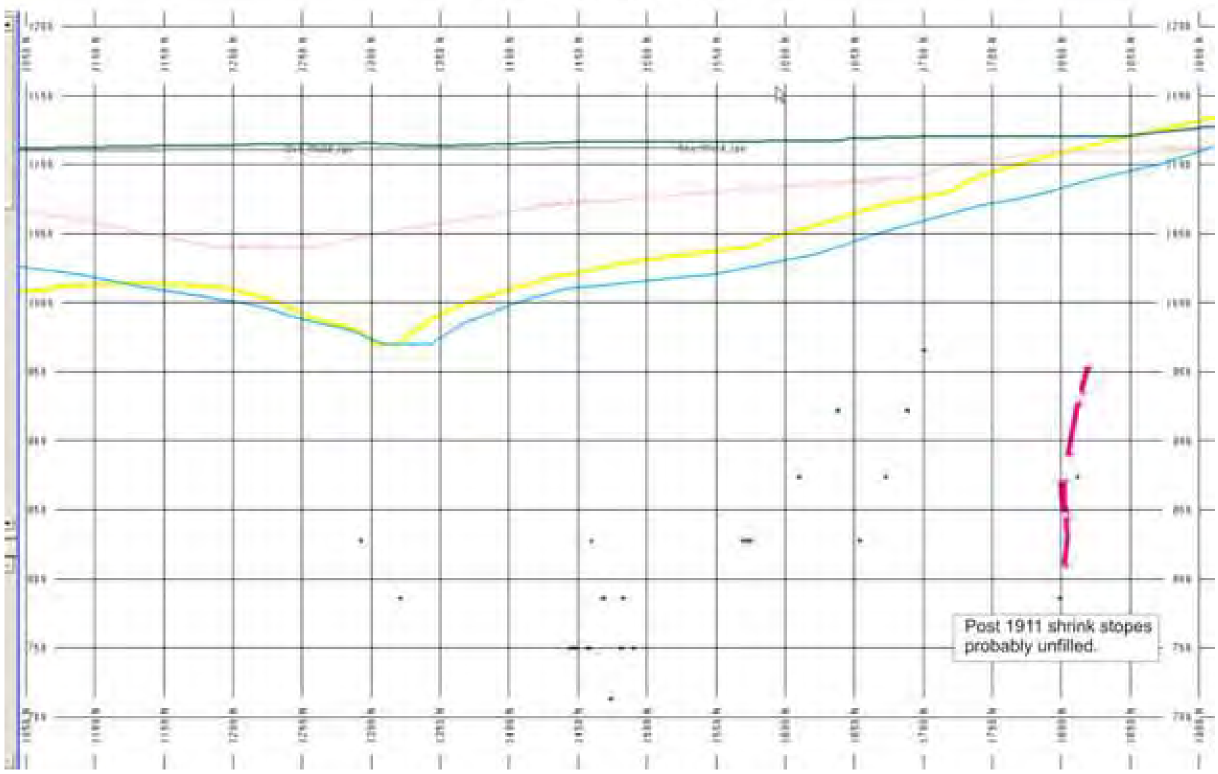

North Branch cross-section @ 2160mE
Stoping all post 1923 - shrinkage - unfilled


Mary stopes
2250
2450
all stoping post 1911 probably shrinkage stopes and not filled

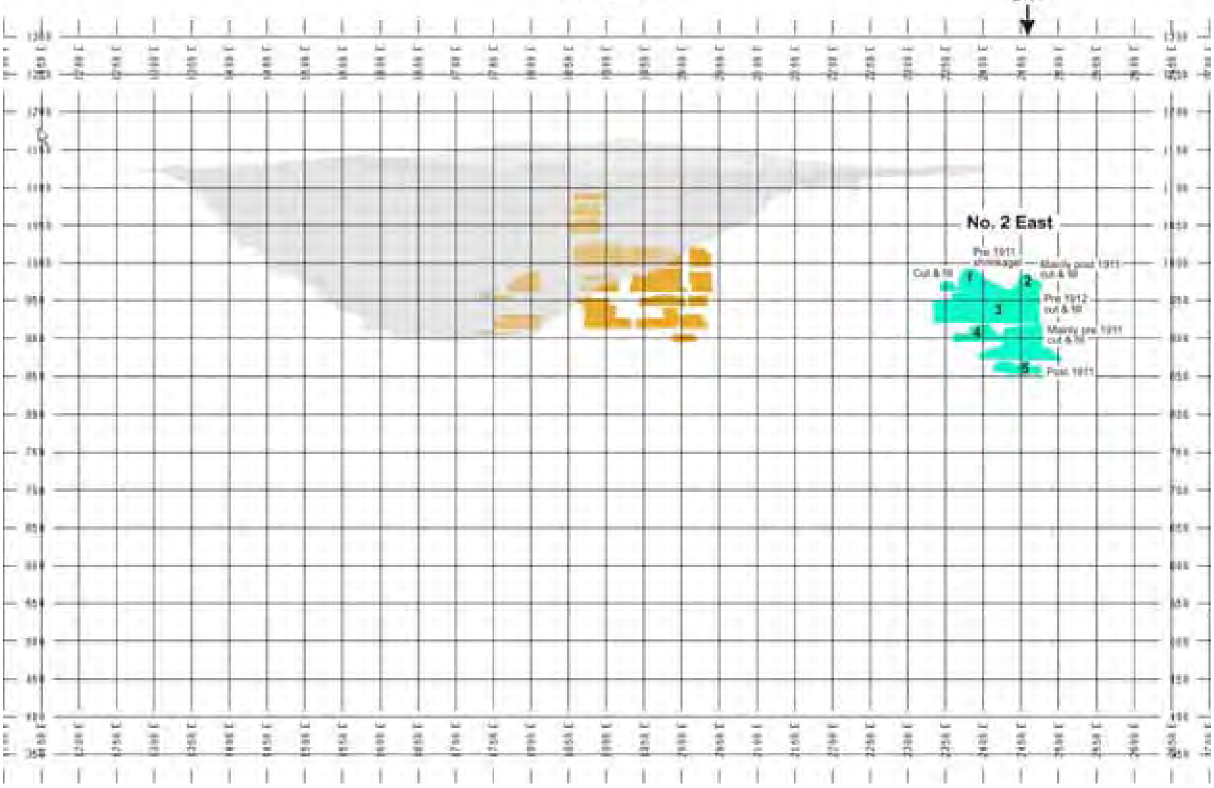
Mary cross-section @ 2250mE



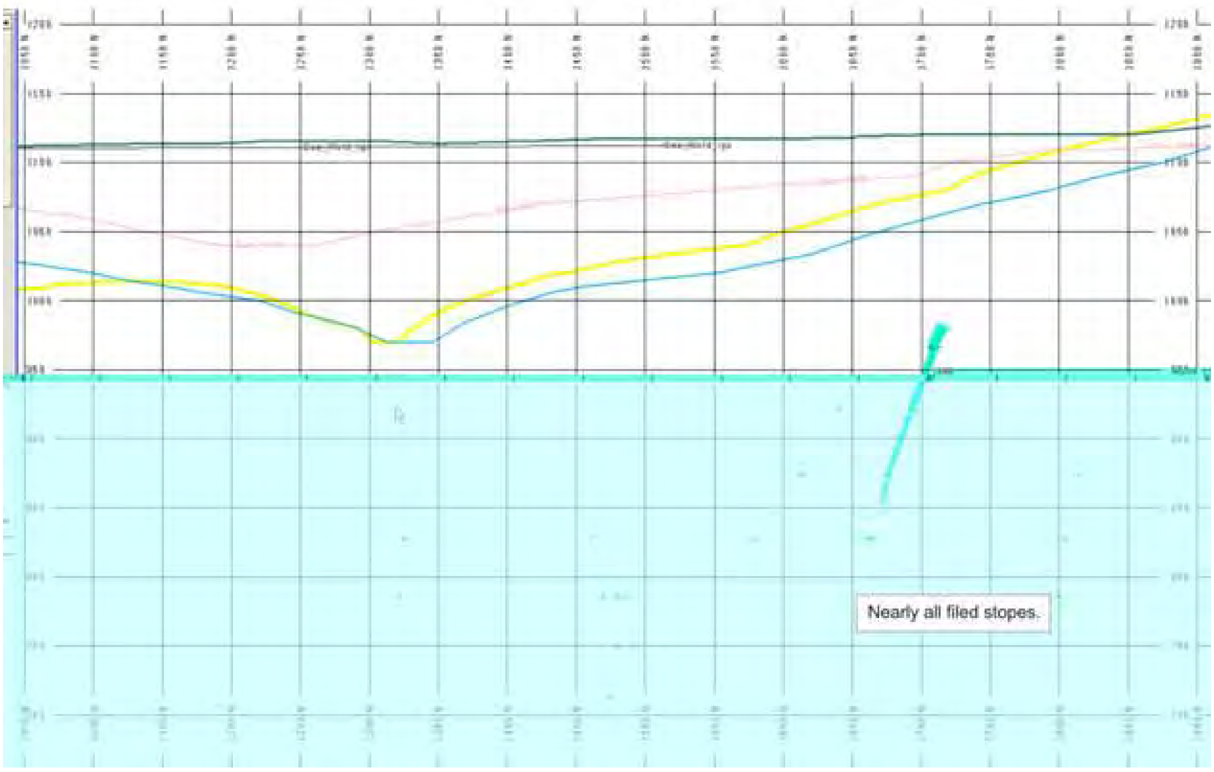
Mary cross section @ 2450mE

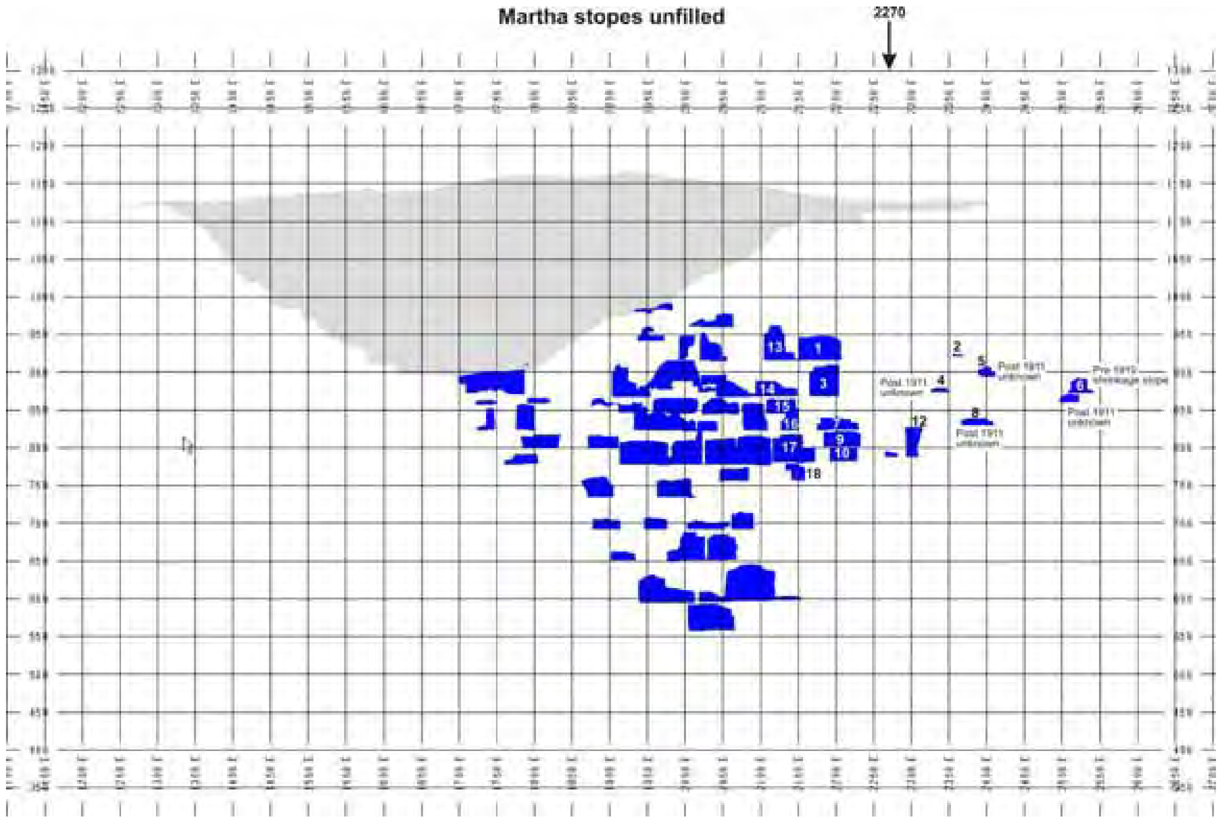


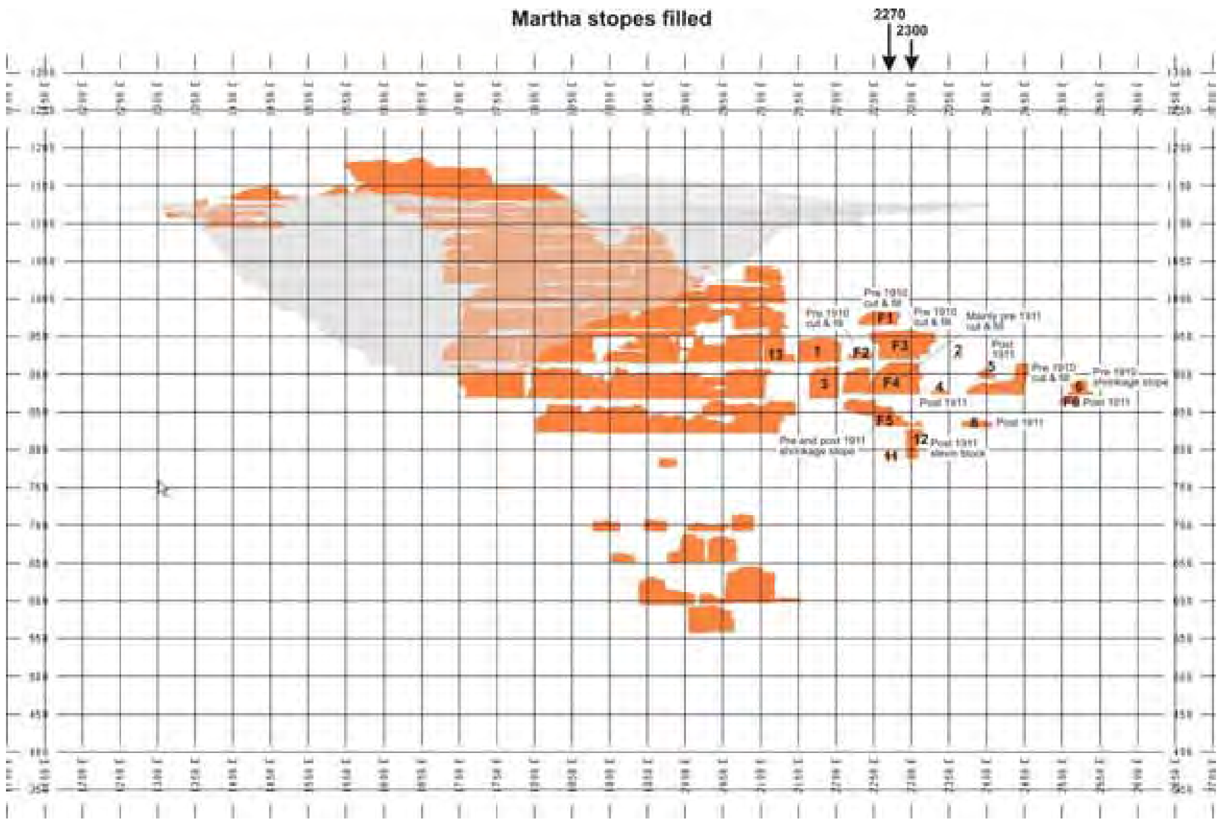
No. 2 stopes



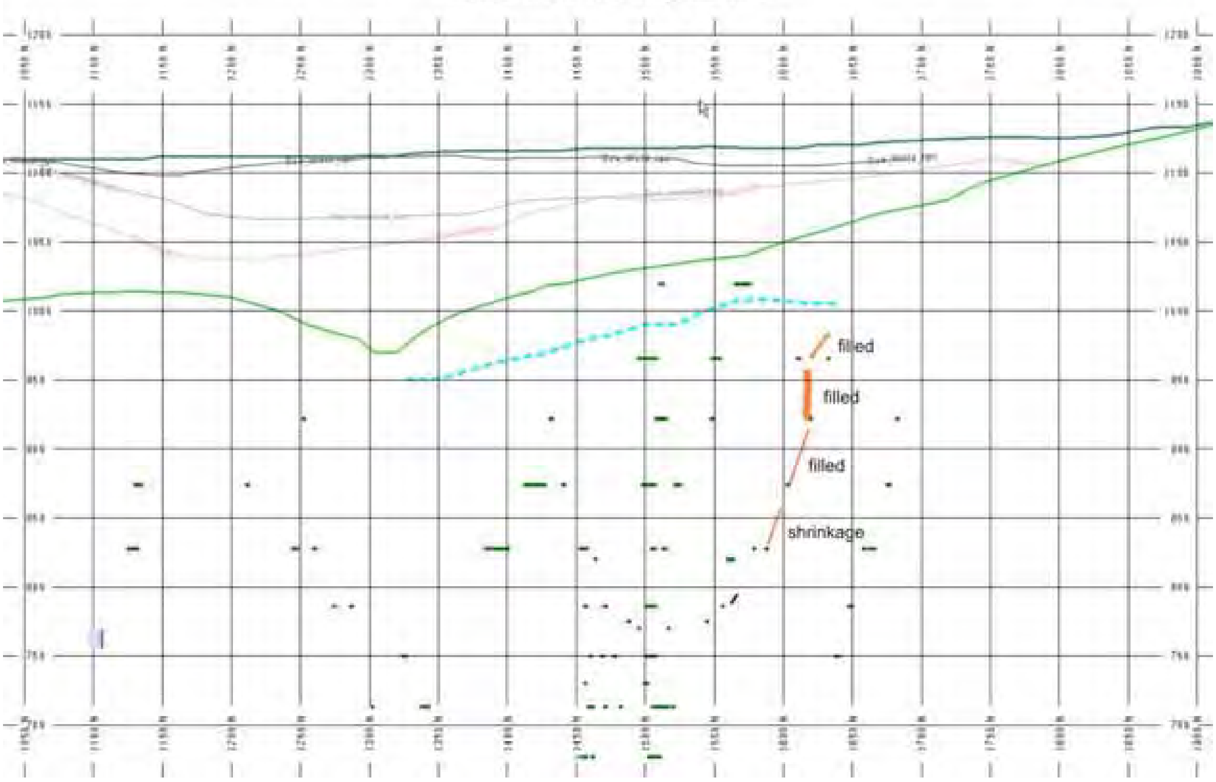
No. 2 cross-section @ 2460mE



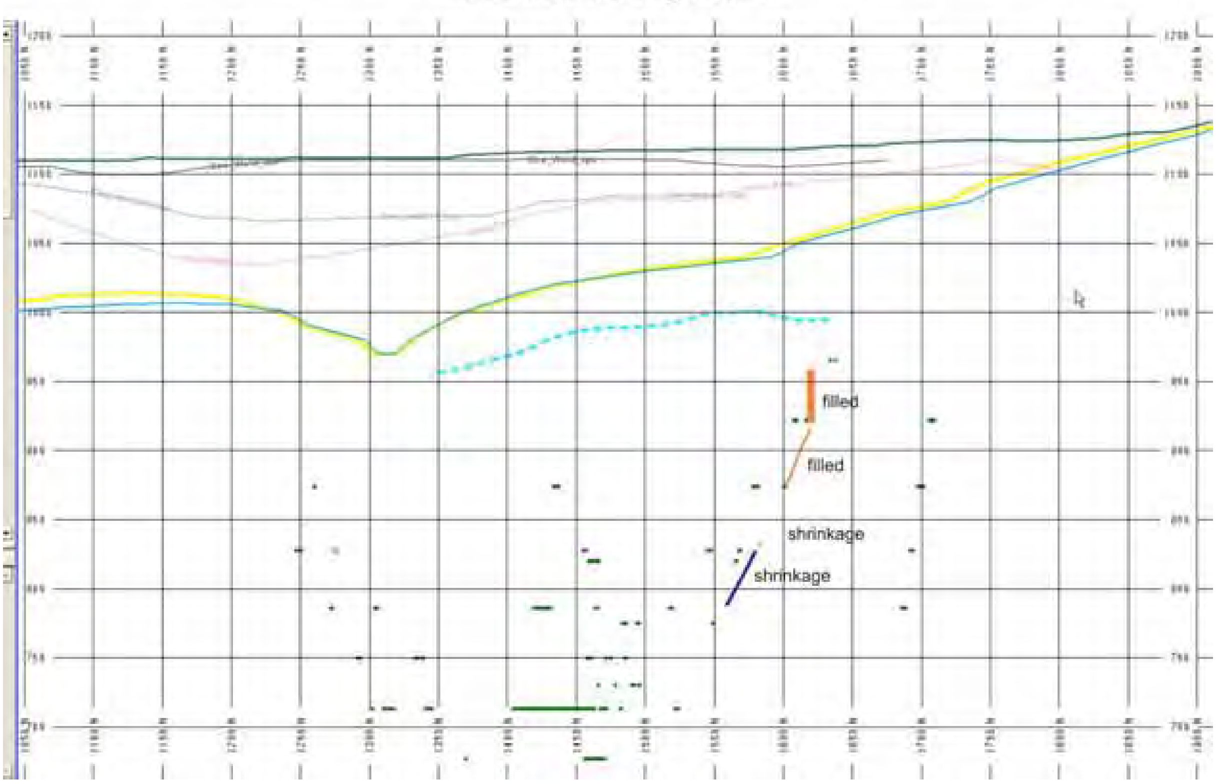

Martha stopes unfilled
2270
Post 1911 unknown
Pre 1910 shrinkage stope


Martha stopes filled
2270
2300
Pre 1910 cut & fill
Mainly pre 1911 cut & fill
Post 1911
Pre 1910 shrinkage stope
Pre and post 1911 shrinkage stope
Post 1911 sleeve block

Martha cross-section @ 2270mE



Martha cross-section @ 2300mE



10.0 APPENDICES

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Remote Sensing Monitoring by Sergei Samsonov, GNS Science

Appendix 1 – T W Maton AusIMM Nelson Paper 2004

Geotechnical Management at the Martha Pit

Trevor Maton[1] BSc(Hons) ARSM MSc MEngSc MMCA MAusIMM

[1] Geotechnical Engineer, Newmont Waihi Gold

Abstract

Subsidence issues associated with historic mine workings have highlighted the need for enhanced geotechnical management of the Martha pit over the remaining life. In conjunction with a detailed analysis of pit slope issues a comprehensive geotechnical management plan has been developed at Martha and is being used as the basis for development of similar plans in other Newmont operations.

This paper covers the geotechnical issues facing the Martha operation and the development and application of the management plan

Background

IGNS, (2002) report that the original Martha mine began as an underground operation in 1879 and by 1952, about 12 million tonnes of ore had been mined to yield 1,217 tonnes of gold-silver bullion. The historic mine extracted four main parallel lodes (the Martha, Welcome, Empire and Royal) together with numerous branch and cross lodes. All lodes dip steeply and are fillings of extensional faults and fractures. Early stoping employed the cut and fill method but this was phased out and largely replaced after 1914 by the shrink stoping method. Stopes were generally not backfilled after 1914 but left open. The workings reached a total depth of 600m from surface on sixteen levels. Man and supply access was by 7 known shafts and IGNS, (2002) report numerous other shafts were developed for ventilation and exploration purposes.

Exploration drilling between 1980 and 1984 identified large open pit reserves within the confines of the historic mining area. Following the granting of consents, the Licensed Pit commenced operation in 1988. The open pit was extended in 1997 to target deeper reserves and this final phase of open pit mining is scheduled to be completed in late 2006. The open pit extracts approximately 1.2 million tonnes of ore annually grading around 3.3 g/t gold and 33 g/t silver. Waste production is tailored to meet the ore supply and will drop significantly in late 2004 from the current stripping ratio of 3:1 to 0.7:1. At completion the pit will have a surface area of 24Ha. with dimensions 840m along strike, 575m in width and 250m deep.

All ore and waste from the open pit is crushed by either jaw crusher or stamler breakers located close to the Eastern wall of the pit and conveyed 3km to the Process Plant and Waste Disposal site respectively.

Bergin, (1993) discusses the geotechnical aspects of the design pit and states that design sectors for the pit slopes were delineated using geological criteria corresponding to domains of material with uniform geological conditions. Four primary divisions of the pit were delineated. These were:

- South of the lode complex
- North of the lode complex
- Post mineral sediments and ignimbrites
- Rock disturbed by mining.

Each of these sectors was further subdivided into oxidised, partly oxidised and fresh rock. The extended pit design in 1997 used similar boundaries for slope design as well as slope performance data from the Licensed Pit. This resulted in the pit slope parameters detailed in Table 1.

Sector	Subdivision	Batter Degrees	Bench (m)	Berm (m)	Overall degrees
North Wall	Oxidised	55-42.5	20	7	
	Partly Oxidised	65			43-46
	Fresh	75			
South Wall	Oxidised	30	20	7	
	Partly Oxidised	60-70			38-40
	Fresh	75			
Post Mineral	Ignimbrites	80	10	6	36
	Tuffs	40			
Disturbed Rock		60	20	7	43

Table 1 Design Pit Slopes at the Martha Open Pit

Many of the mined out lodes at Martha are located within the limits of the present open pit. However a few extend beyond the limits of the pit to beneath previously occupied areas of the town. During 1961, 1999 and 2001, chimney caving occurred from directly above the old workings (Royal Lode) subsiding to surface, which impacted outside of the Mining License area. Following an investigation into these events and the causes by IGNS between 1999 and 2002, the Hauraki District Council declared certain areas above the old workings within the Waihi Township to be hazardous and these areas were isolated and the residents relocated.

The historic Cornish Pumphouse classified as a Category 1 protected building is located close to the South wall of the Martha pit and bounded by the 1999 and 2001 subsidence events.

Geotechnical Issues

The geotechnical conditions at Waihi are significantly impacted by the presence of historic mine workings. In essence caving initiated during the historic mining has resulted in zones of poor quality rock mass within and outside of the pit slope limits. There has been ongoing large scale block movement over the last one hundred years and this large-scale block movement will continue into the caved zones in the future beyond the life of the open pit. Modelling suggests movements with displacements in the order of meters can be expected.

During their operation, the historic workings were well documented in terms of the spatial location and methods of stoping as well as descriptions of caved zones. The extents of the underground workings have been modelled in 3D using Minesight software. Figure 1 shows the extent of the underground workings in relation to the current open pit.

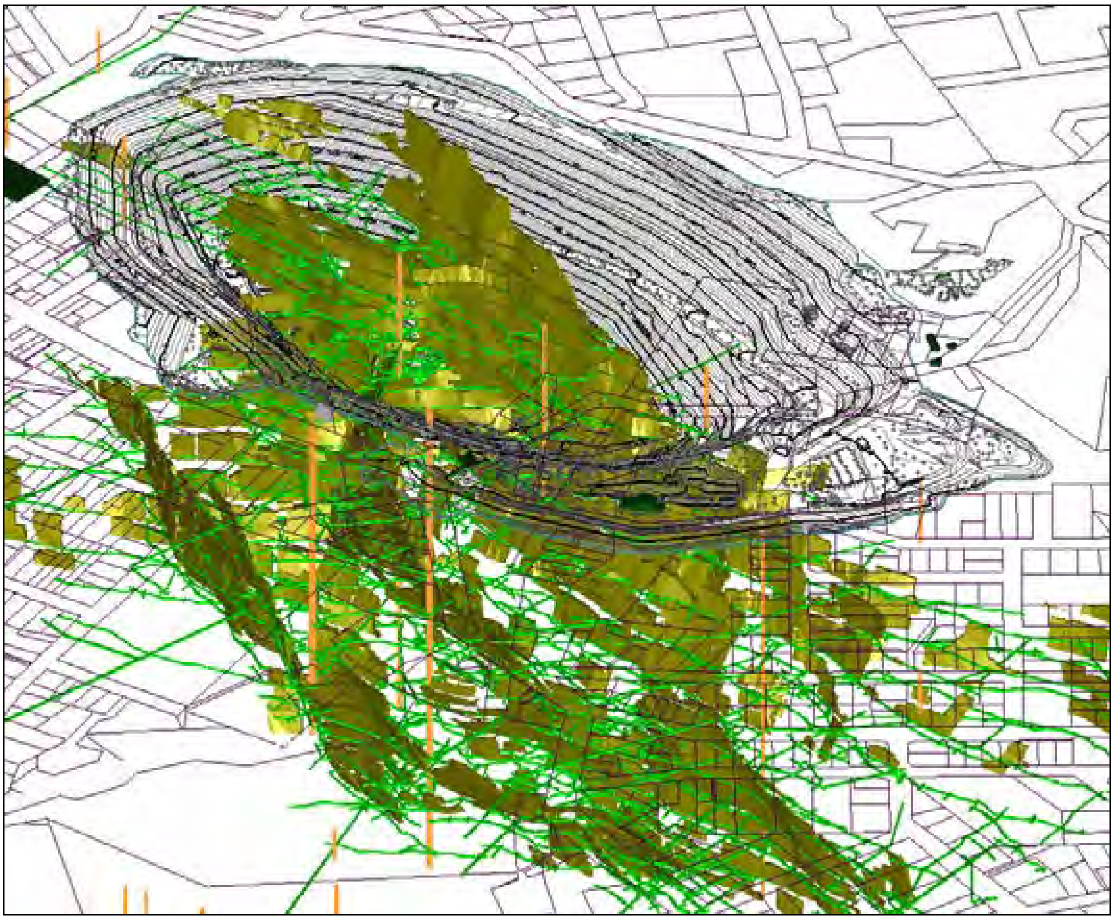


Figure 1 Model of Martha Open Pit and Historic Workings

The modelled pit slopes have factors of safety in terms of static slope stability greater than unity based on considered conservative parameters. This indicates the pit walls as designed can be expected to remain stable given the current rock mass conditions and static conditions. However the ongoing large scale block movement will mean that the pit walls will be undergoing movement during mining far greater than that which would be expected simply from excavation of the pit. This may result in local instability of slopes, if rock mass conditions deteriorate or are poorer in certain zones than modelled. Block movements can be rotational (tilting), downward or lateral. Movements are not expected to be continuous but of a stick-slip nature. For convenience, three states of deformation for the rock types have been delineated. These are:

- Caved zones, complete disaggregation of rock mass comprising rockfill of silt to coarse boulder size;
- Disturbed zones, disturbance due to large scale block sliding on shears, opening of joints and minor local caved zones
- Deformed zones, translational displacement on shears and stopes and minor block subsidence over large areas.

Pit wall mapping, reference to historic records and the 3D model have been used to determine the spatial extent of the caved zones, disturbed zones and deformed zones. These have been termed mining blocks. Pells Sullivan Meynink (2003) identified 10 Mining Blocks bounded by historic stoping on the Martha, Welcome, Empire, Edward, Royal, Letter and Albert veins. Nearly all these Mining Blocks show some ability to translate or rotate. Caved zones have been identified on the hangingwall of the Martha Empire and Edward lodes at 70-80 degrees to vertical and disturbed zones are interpreted to be sliding on pre-existing shears at 60-70 degrees towards the caved zones. Figure 2 shows the interaction of the various caved, disturbed and deformed zones.

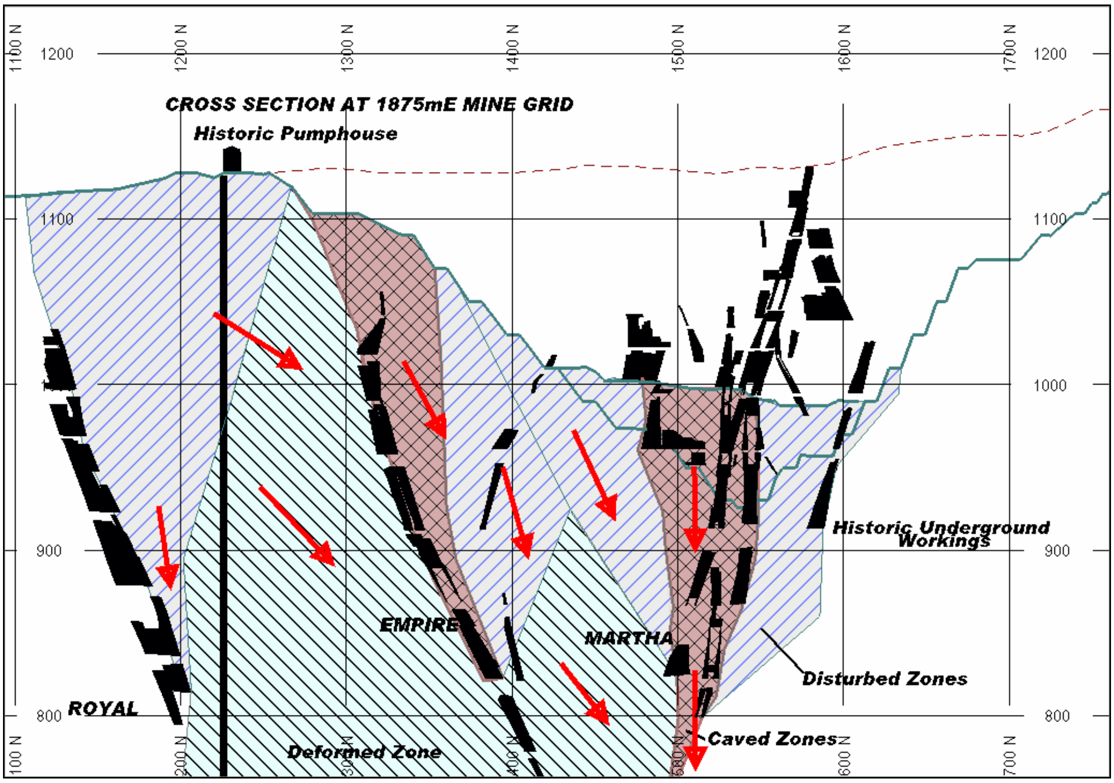


Figure 2 Schematic Caving Model

Understanding the mechanics of pit wall deformation requires an understanding of the underground caving and consequent block movements. Pit wall deformation as a result of the movement into the underground workings is expected to be reasonably constant over time but with some response to open pit excavation. Newmont Waihi Gold expects that rock mass conditions will deteriorate with deepening of the pit as the more extensively caved zones are intersected and has implemented a comprehensive geotechnical management system to address this.

Overview of Newmont Waihi Geotechnical Management System

The purpose of the Geotechnical Management System is to assist in providing a safe working environment for the open pit mining operation by managing the geotechnical risk. The Geotechnical Management System does this through:

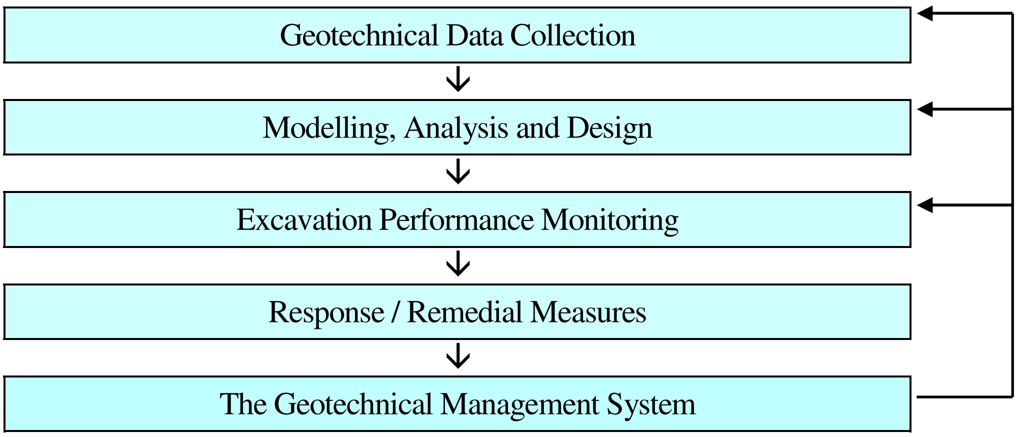
a) Hazard identification involving a range of geotechnical monitoring comprising instrumentation, survey and visual inspection by qualified persons. Trigger levels will be used to define potentially hazardous situations.
b) Exposure assessment involving comparisons with historic trends from monitoring and comparisons with predicted performance modelling from the geotechnical model.

c) Consequence assessment in terms of safety to personnel in the open pit, determined with reference to the risk from the identified hazard(s), the location of personnel and /or structures and status of open pit excavation.
d) Response assessment governed by trigger levels.
e) Mitigation which may involve a range of options such as evacuation, buttressing, changes to berm widths, changes to pit batters, mine extraction sequencing, installation of ground support as well as installation of additional remote sensing devices.

In addition the Geotechnical Management System also:

- Provides a comprehensive record management system related to geotechnical matters.
- Standardises procedures including collecting data, monitoring frequency, excavation practices, working around historic openings, implementing design changes etc.

The Geotechnical Management System is dynamic (meaning that it is updated continually) and comprises the following general activities:



The Geotechnical Management System processes are described in the Geotechnical Management System Manual which is available on the Martha intranet and is grouped into five sections, A to E, for convenience. These sections are:

SECTION A. Overview of the Geotechnical Management System, the roles and responsibilities of key personnel involved in the Geotechnical Management System, location of where information and data can be accessed as well as personnel trained to access the information.

SECTION B. Describes the geotechnical hazard monitoring and response systems particular to open pit geotechnical issues, covering slope failures, subsidence and earthquake, the description of trigger levels. This section is continually updated as trigger levels change; response measures amended or as key personnel change.

SECTION C. Is a reference section which contains the most up to date information from survey, monitoring, remote sensing, instrumentation, pumping records, visual inspection records and pit development status reports.

SECTION D. Is a reference section summarising the geotechnical caving model, the geologic units, and the expected response to mining of the geotechnical blocks.

SECTION E. Contains all relevant standard operating procedures (SOP's) covering probing, monitoring, geotechnical survey, methods of working and. presentation of data. This is updated only as procedures are revised.

Geotechnical Hazard Identification

The Geotechnical Management System is a four level system; green, yellow, red and the Emergency Management Plan in increasing severity of risk assessment.

Under normal conditions (Condition Green) the hazard identification process includes:

- Borehole extensometer data loggers alarmed with triggers set at levels above the current readings and if triggered will transmit a text message to cell phones of supervisory personnel. Data is downloaded and reviewed on a daily basis.
- Inclinometer measurements using time displacement plots and cumulative displacement plots. Results of inclinometer monitoring are communicated by email on a weekly basis as soon as the data has been processed.
- Wall prism monitoring on a weekly basis by total station. Individual or groups of prisms may be monitored at greater or lesser intervals as may be notified from time to time.
- Crusher personnel inspect the crusher slot area on a daily basis to visually assess the cracks in the shotcrete lining. Any changes in existing cracks or new cracking reported to supervisory staff.
- Crusher personnel inspect the tunnel laser on a daily basis. The crusher operator will check the laser offset from target and report any change / deviation from target to the mine survey.
- Geotechnical personnel walk over accessible parts of the pit, surface facilities area and crusher area on a weekly basis noting cracks, subsidence features, blast damage or other signs of instability.

Other forms of monitoring in use from time to time include levelling, crack monitors, wire line extensometers.

Trigger Levels

Based on Martha site experience and a peer review process, trigger levels to trigger the operating conditions have been defined. Trigger levels are described fully in the Geotechnical Management System Manual and relate mainly to magnitudes of displacements or differential displacement for extensometers, inclinometers and prisms above the instrument accuracy level, identification of new cracking, rockfalls, probe hole intersecting cavities and loss of water.

Response On Trigger Levels Being Reached

Figure 3 is a flowchart showing the response mechanism. On one or more of the trigger conditions being exceeded, management are notified by geotechnical personnel. Responses at the Yellow Condition include:

- inspecting the data and the areas affected,
- notifying the Geotechnical Consultant,
- increasing the level of monitoring.
- convene formal meetings and assess risk.

- if excavation is being undertaken in close proximity to the area where the trigger level has been exceeded, then the area shall be considered unstable and Procedures defined for working below unstable walls implemented.

For Condition Red trigger levels, senior management and pit operations supervisory personnel are immediately notified. A decision is made as to whether to invoke the Emergency Management Plan, based on any safety threat which may be present and to evacuate the open pit area in accordance with standard operating procedures.

Extensometer, prism, inclinometer data is analysed by the Geotechnical Consultant and in terms of the open pit prism data, the following procedures are implemented:

- The area of the moving prism(s) is inspected and if the cause of the movement cannot be determined, then mining activity in the area should be reduced or suspended.
- Continued acceleration of the movement should require closure of the pit floor below the moving area until the situation has been fully investigated.
- In the event that an increase in movement greater than four times the survey error is recorded for any reading when there has been no previous accelerations noted on a prism, operations supervisory personnel are to be informed immediately and the area below cleared until the point has been resurveyed.

The Geotechnical Consultant reviews data against geotechnical model predictions and provide recommendation which may include mining sequence, buttressing, additional support to stope backfill, modifying batters / berms or additional instrumentation.

Assessing Geotechnical Hazard

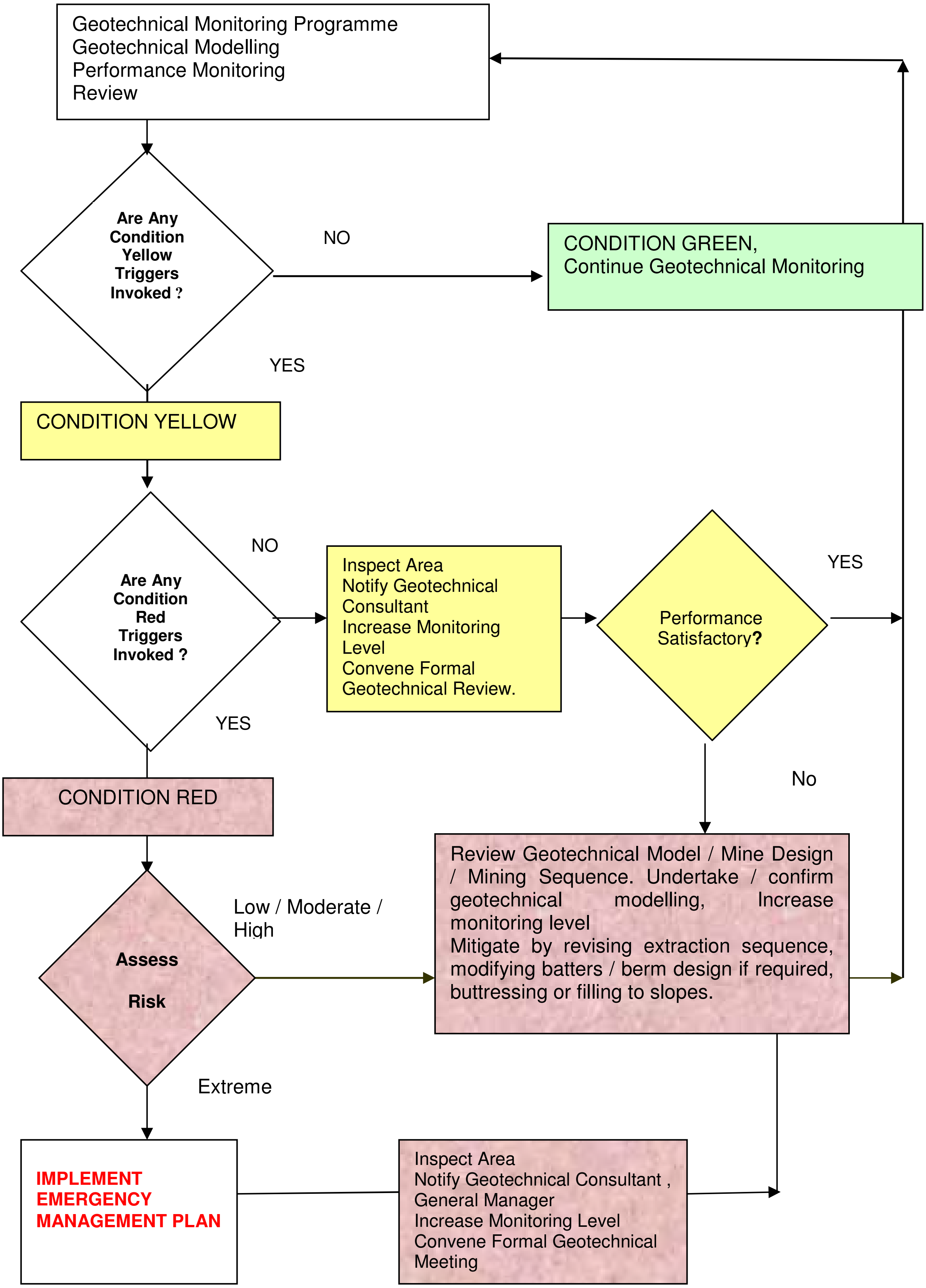
Guidelines are used for assessing the extent of the geotechnical hazard risk posed by the trigger levels previously described. Consideration is given to consequence and the likelihood of the event occurring. Consequence parameters include:

- management factors, ranging from events which can be absorbed through normal activity to events that have the potential to lead to collapse of the business,
- economic cost factors ranging from damage to equipment to large scale wall failure or loss of major haul road.
- safety factors ranging up to potential fatalities.

Further Work

The Geotechnical Management System has been through a rigorous Peer Review process and in place since mid 2003. The system will be formally reviewed, following the first red condition incident. The Geotechnical Management System developed at Martha is being used as the basis for developing systems at other Newmont sites.

Figure 3 Flowchart -Geotechnical Hazard Monitoring & Response



Acknowledgements

The author would like to thank Mr. Tim Sullivan of Pells Sullivan Meynink, Mr. Pete Stacey of Stacey Mining Geotechnical and Mr. John Ashby of Ashby Consultants Ltd for their assistance in developing the Geotechnical Management System. The author would also like to thank Newmont Waihi Gold for permission to publish this paper.

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Appendix 2 – PSM125.L88 report

PSM

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Our Ref: PSM125.L88
Date: 1 March 2006

Mr. Adriaan van Kersen
Newmont Waihi Gold
43 Moresby Avenue
WAIHI NEW ZEALAND

Dear Adriaan,

RE: PUMPHOUSE RELOCATION: GEOTECHNICAL RISK ASSESSMENT OF SITE 4A

1. INTRODUCTION

This letter follows on from requests from Messrs. A. van Kersen and P. Bawden, Newmont Waihi Gold (NWG) to provide advice on re-location of the Pumphouse.

It is generally recognised that the Pumphouse in its current location is at risk from a number of factors. This is reinforced by the recent movements of the structure itself and by the cracking on the slope below it.

It is understood a Working Party has been formed to address longer term pit closure issues including risks associated with further collapse of old underground workings. The Working Party includes local regulatory authorities, IGNS and various technical advisers. The objective of the Working Party is to re-assess the previous risk assessment studies by IGNS of caving and collapse due to underground workings around the Martha mine and to extend those studies to incorporate all areas including the open pit.

NWG have concerns about the overall timing of results from such a study and the potential impacts on the ongoing viability of implementing remedial work on the Pumphouse if there are significant delays. Current estimates indicate results may not be available till mid to late 2006. This timing may cause difficulties for NWG, who have therefore requested early advice on re-locating the Pumphouse.

2. OBJECTIVES AND SCOPE OF WORK

The particular requests from NWG comprised:

1. Risk assessment for siting the Pumphouse at location Site 4A, Figure 1.
2. Assessment of the likely style of and any ground movements that could be expected at Site 4A.
3. If differential settlement does occur, assessment of whether any such movements could be managed without compromising the integrity of the Pumphouse.
4. Advice on whether any ground settlement will be episodic or progressive, the maximum tilt that may occur and the directions of any such tilt(s).

This assessment is based on the following information:

- Monitoring of cracks in Seddon Street by Hauraki District Council (HDC).
- Monitoring data for the southeast quadrant of the pit and surrounding areas by NWG.
- Mapping of cracks in Seddon Street and Hazard Street by NWG.
- A Geotechnical Investigation by Engineering Geology Ltd. of the alternate siting options and of the relocation path.
- Mine geological and geotechnical information provided by NWG.
- General experience of the author, with observation and monitoring at Waihi over the past 10 years.

This assessment has of necessity been limited by available time and is not supported by comprehensive calculation and computer modelling.

However, the assessment is based on more than 10 years of experience with Waihi and very detailed ongoing assessment of geotechnical conditions as the pits have been developed. This experience has also allowed a comprehensive evaluation of caving and subsidence movements and detailed evaluations of the impacts of historic underground mining activities.

3. BACKGROUND TO SITING AND RE-LOCATION

The Pumphouse is approximately 9m x 15m in plan. It is understood a structural engineering study has been carried out on the Pumphouse structure itself and appropriate bracing and support will be used to ensure the integrity of the structure.

Three possible sites were investigated by Engineering Geology Ltd; 4, 11 and 4A. Site 4A is shown on Figure 1. The re-location will entail shifting the Pumphouse to the new site located south west of the open pit and this is understood to be a constraint resulting from two factors, firstly the allowable gradients and secondly moving the Pumphouse away from the underground workings. Geotechnical risk associated with the actual moving of the Pumphouse, including the planned pathway, is not included in the PSM scope of work.

4. CURRENT RISK ZONING

Site 4A lies outside of and approximately 10m from the edge of the Low Risk Subsidence Zone defined by using the IGNS methodology for the previous subsidence collapse risk zoning. The site is also 60m from the edge of the High Risk Zone. This Risk Zoning is for the Royal Lode Workings, the nearest relevant Lode, Figure 2.

The IGNS report concluded in regard to the Low Risk Zone that:

> *".... It is considered unlikely that a sinkhole or collapse crater will form. Rather there could be relatively minor subsidence and ground cracking .... that may cause distortion to a building, such as jamming windows and doors, but is unlikely to be life threatening."*

and

> *"Low probability – the probability of a sinkhole reaching the surface in this zone is less than 0.1%, but there may be relatively minor surface settlement and ground cracking that is not life threatening".*

Site 4A is outside the Low Risk Subsidence Zone.

5. CRACK ZONES

In 1999 a subsidence collapse occurred in the park adjacent to the open pit. At the same time a line of cracking developed in Seddon Street about 120m east of Site 4A. The street and surrounding area were subsequently refurbished but movements on the cracks have continued. Initially in 1999 the cracks showed horizontal separation only, but over time there has also been some vertical downward movement on the northern, pit side of the cracks. Over time other cracks have developed further west in Seddon Street and then more recently in Hazard Street. There are now three distinct cracked zones south west of the open pit, Figure 2.

These zones have all shown different styles of movement and these differences are considered to be a reflection of the subsurface geometry of lodes and stopes, which appear to be the local deformation controls.

The following factors should be noted in regard to these zones:

1. The cracks are not continuous between the three zones.
2. The cracks in each zone have occurred at widely different times, separated by years.

3. The sequence style of cracking and movement in each zone has been different:

   - Zone 1 - Initial "semi-circular" crack shape, which became linear over time.
     - Horizontal separation and vertical dislocation, pit side of the crack down.
     - Approximately linear cracks.
   - Zone 2 - Initial "semi circular" cracks with horizontal separation only.
     - Later development of internal cracks, i.e. closer to the pit and these later cracks show transverse movement, north side of the cracks to the west compared to the south side.
   - Zone 3 - Horizontal separation followed subsequently by some vertical displacement, pit side of the crack up compared to the south side.

4. These zones have similar plan dimensions to the other cracked and deformed areas, Figure 5.

Monitoring of the original cracks in Zone 1 has been undertaken by HDC since April 2004 and this data shows, Figures 3 and 4:

- Total movement to date on cracks over a period of about six years is of the order of 20mm, as recorded visually by HDC.
- The movements are episodic.
- The maximum movement rates are very slow, <0.02mm/day or about 7mm per annum.

6. RELATIONSHIPS BETWEEN CRACK ZONES AND HISTORIC MINING

Detailed review of all the geotechnical aspects of the Martha Mine was undertaken in 2003. That review included an evaluation of the historic underground mining records compiled by NWG. That study concluded in regard to the underground model that:

> *"These components of the model form separate but linked subsidence, movement and collapse mechanisms operating at scales ranging from the local to the global scale. These mechanisms started during underground mining and have probably continued ever since."*

Figure 5 shows a compilation of historic subsidence and more recent cracking superimposed over the old underground workings.

The movements in Zones 1, 2 and 3 are controlled in large part and influenced in the first instance by the very large zone of subsidence and caving centred on the Martha, Edwards, Welcome and Empire Lodes and their intersections. However the secondary influence, which operates more locally, is the individual Lode geometry and associated stopes.

Hence while there is global movement towards the north northeast, this will be manifested more locally as different responses which are affected by local lode and stope geometry and historic mining.

Attachment A presents a series of north south sections showing the lodes, stopes and current ground surface including the open pit. These sections are through each of the three zones:

- Zone 3 - 1400 to 1500m E,
- Zone 2 - 1600 to 1700m E and
- Zone 1 - 1700 to 1850m E.

The sections show the current cracking in relation to the local zones. A series of interpreted sections showing large scale block movements are presented in Figures 6 to 8.

Based on this broad understanding, the interpretation of the deformations in each of the three zones is:

- Zone 1
  - Local "sliding" subsidence on the surface projection of the Royal Lode, which is itself very planar and continuous in the areas of cracking, Figure 6.
  - The cracks are the southern limit of a movement zone extending from the Martha Lode in the north and which comprises in order from north to south the following; a broad subsidence and collapse, local sinkhole formation over the Royal Lode and sliding subsidence along the Royal Lode respectively.
- Zone 2
  - The explanation for Zone 2 is not as straight forward as Zone 1 because it is not as readily explained by local the geometry of the Royal Lode.
  - The cracking is best understood in terms of the movements further north on the pit slope where a prominent reverse scarp formed some years ago. Based on this and the lode geometry the Zone 2 cracks are interpreted to be caused by subsidence of a very large graben controlled by the Edward, Royal and Empire/Welcome Lodes, Figure 7.
  - The reason for the initial "semi circular" crack form is less apparent although experience has shown this is probably a surface manifestation of the initial strains reflected through the 12 to 14m of soil like materials at the surface. This also happened initially in Zone 1.

- The more recent transverse movements across the crack appear to be a manifestation of the fact that the wedge of rock between the cracks and the stopes thins to the west, allowing the block to pivot.

- Zone 3 - This crack, which started as horizontal separation and then manifested a vertical movement, northern side of the crack upwards, is interpreted as large scale "toppling" block rotation towards the north east, Figure 8. However, interpretation of Zone 3 movement is slightly more complex because the sections are oriented north south and the movement vectors are north northeast. Hence for Zone 3 it is difficult to directly relate the cracks shown on the section with the overall mining because the real control on the cracking is the underground mining in the centre of the pit which is further east. In Zone 3 the local stopes on Sections 1400 to 1500mE should be compared with the Martha Workings on Sections 1700 to 1800mE.

Although it appears on first assessment that the cracks form one large continuous area in the southwest of the open pit, the reality is there are three separate zones of cracking and deformation which are all somewhat different. Site 4A is located within Zone 2.

7. ZONE 2

Only Zone 2 is relevant to the Pumphouse re-location to Site 4A. The geological and geotechnical factors relevant to an interpretation of the causes of the cracks and movements to date in Zone 2 and used for prediction of likely future performance are:

1. There are no stopes or underground workings directly underlying the cracks.

2. The Geotechnical Investigations show the subsurface profile at Site 4A comprises:

Borehole 6	0 – 3m	- More Recent Volcanic Ash,
	3m to 14m	- Extremely Weathered Andesite and
	>14m	- Extremely low to high strength rock, Andesite.
Borehole 7	0 to 1.6m	- More Recent Volcanic Ash,
	1.6m to 12.5m	- Extremely Weathered Andesite and
	>12.5m	- Extremely low to high strength rock, Andesite.

3. The upper materials are not readily erodible and this is confirmed by the long term performance of the pit slopes in this area. Hence the risk of longer term erosion and migration of fines into the cracks leading to sinkhole development at the surface is assessed as very Low.

4. Monitoring of the pit walls and the area to the south on the northern side of the cracks shows the whole southwest area is undergoing long term creep movement towards the north northeast. This movement is controlled in large part by subsidence movements of the hanging wall of the old Martha Lode workings.

5. The cracks are aligned approximately normal to the vectors of movement for this area.

Based on these factors the cracking and movements in Zone 2 are interpreted to be caused by large scale creep movements of the block of rock defined by the old underground Workings of the Martha, Royal and Edward Lodes. Experience has shown these movements are unlikely to be entirely linear over time and should vary spatially around the area, simply because the block of rock is so large. It is estimated that the block of rock defined by Zones 1 to 3 is approximately 20M cubic metres. Like most rock mass blocks of this scale it will not be homogeneous. Similarly the old underground workings, which in essence are controlling the creep movements are themselves also not homogeneous.

8. CONCLUSIONS

There is now a wide body of experience with underground related subsidence, collapse and deformation movements at Waihi. The direct experience relates to the period of open cut mining, approximately 17 years, but this has recently been supplemented by the detailed historical review in 2003. This experience shows the principal potential deformation mechanisms at Site 4A are:

a) Sinkhole collapse – similar to the 1999 and 2001 events.

b) Cracking and movement along the edge of an historic cave zone located above old workings.

c) Cracking and differential movement along subsurface geological features reflected at the ground surface.

d) Widespread "global" subsidence, comprising both horizontal and vertical movements and or tilt.

a) Sinkhole Collapse

Site 4A is outside the IGNS subsidence collapse hazard zones. The site is not underlain by a thick layer of recent soil strength material, and is not directly underlain by old underground workings.

The risk of sinkhole collapse at Site 4A is assessed as negligible.

b) Cave zone – related cracking and movement

Site 4A is remote from any known cave zones and is not directly underlain by underground workings.

The risk of these movements at Site 4A is assessed as negligible.

c) Cracking and differential movement along geological features

Site 4A does not directly overlie old underground workings or the line of the ore lodes. No other known geological features (faults, dykes, etc.) pass through the site. In addition, exposures in the adjacent pit wall and as generally confirmed by boreholes 6 and 7, indicating Site 4A is underlain by a large block of better quality and less weathered/altered rock.

Based on this assessment the risk of these deformations impacting on Site 4A is assessed as low.

d) Global subsidence movements

The monitoring by NWG and the cracking shows that Site 4A will be affected by global subsidence; comprising horizontal and vertical movements and probably tilt.

The monitoring of the pit slopes and surrounding areas together with the measurement of the cracks in Seddon St. shows that two potential tilt directions are applicable to Site 4A; north easterly towards the main underground workings and southwest-northwest parallel to the Seddon St. cracks.

Assuming a 100 year design life, which is the norm in civil engineering, the Pumphouse at Site 4A is expected to be subject to:

1. Continued episodic subsidence movements.
2. Continued episodic horizontal movements.
3. Continued differential movements leading to tilt of the structure in at least a north easterly direction but also possibly in two other directions, southeast and northwest.

The final "risk" to the Pumphouse in its new location, Site 4A, is a combination of two factors:

- Firstly the likelihood (chance of occurrence) of the different deformation mechanisms (movements); and
- Secondly the likelihood that implementing cost effective engineering foundation solutions to accommodate such movements will not be feasible.

Based on experience it is assessed that it will be possible to design an adequate foundation system that will be able to withstand deformation within operational tolerances and incorporate remedial measures to provide ongoing rectification of any such deformations. Hence this second component of risk at Site 4A is assessed as very low.

Obviously accurately predicting movements is fraught with difficulty, particularly over the very long term. However, a large period of monitoring (about 15 years) is now available. This monitoring has been used to estimate long term movement rates. Rates of differential settlement have been estimated from differential movement between adjacent surface points located outside the open pit, but within the general area of Zones 1 to 3. Given the uncertainties it is appropriate to be conservative and this will ensure the foundation solutions are able to adequately cope with movements in excess of the predictions. Hence the predicted movements have been increased by 100%. The predictions are:

- Vertical settlement - Global movement of the whole foundation area;
  - 10mm per annum.
- Horizontal movement - Global movement of the whole foundation area;
  - 5mm per annum.
- Differential settlement - Measured southwest to northeast 0.4mm/metre/year.
- Capacity to re-level - On the following axes (mine grid); 120° to 300° and 030° to 210°.

We trust this is in accord with your expectations and would be pleased to discuss any element.

For and on behalf of
PELLS SULLIVAN MEYNINK PTY LTD

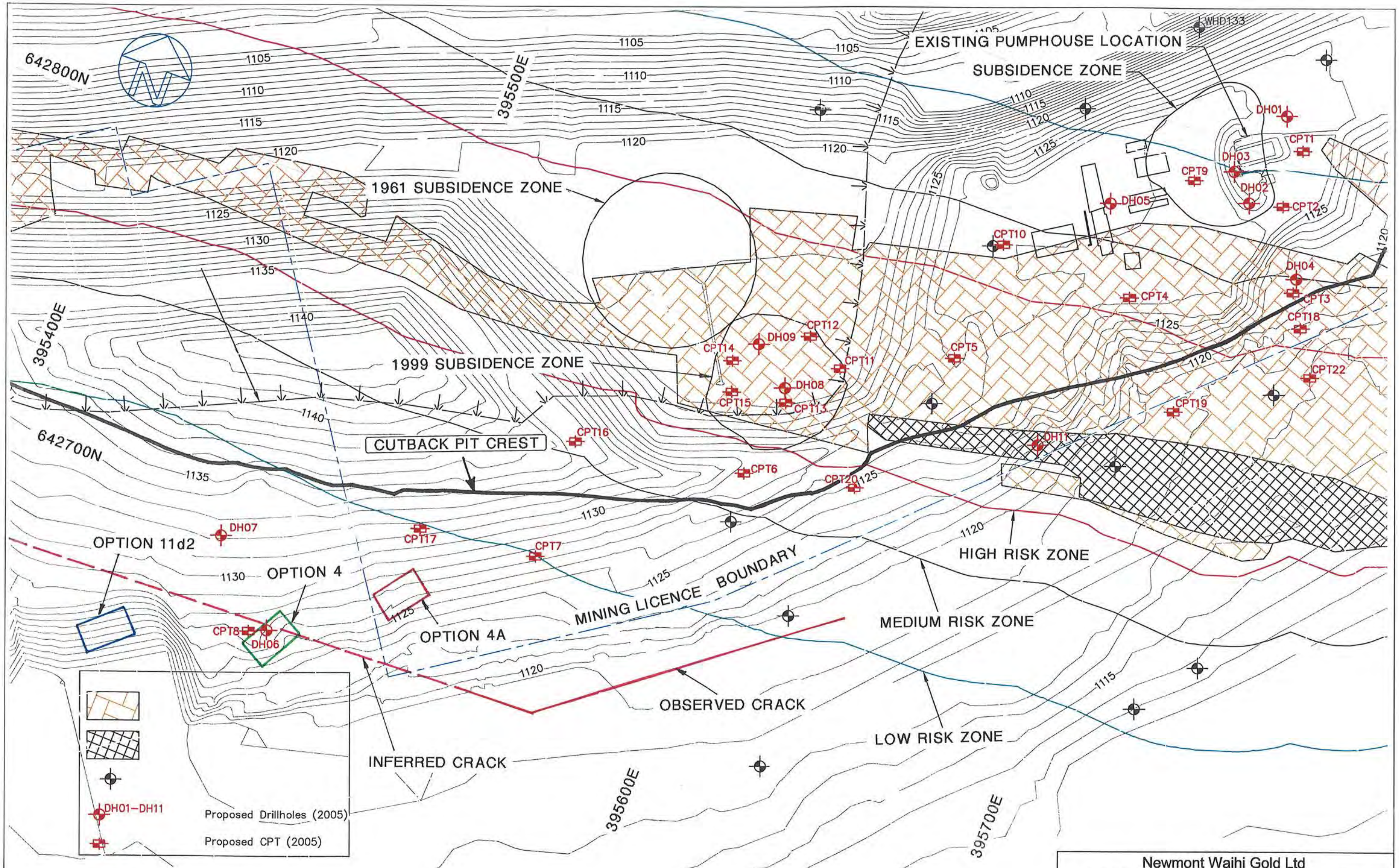
DRAFT

T.D. SULLIVAN

Cc: Peter Bawden

Encl:

Figure 1	Location Plan Site 4A
Figure 2	Cracks & Movement Zones
Figure 3	Seddon Street Cracks – (Zone 1) Horizontal Movements
Figure 4	Seddon Street Cracks – (Zone 1) Vertical Movements
Figure 5	Historic Subsidence Plan & New Zones
Figure 6	Zone 1
Figure 7	Zone 2
Figure 8	Zone 3
Attachment A	Sections showing relationships between underground workings and cracks



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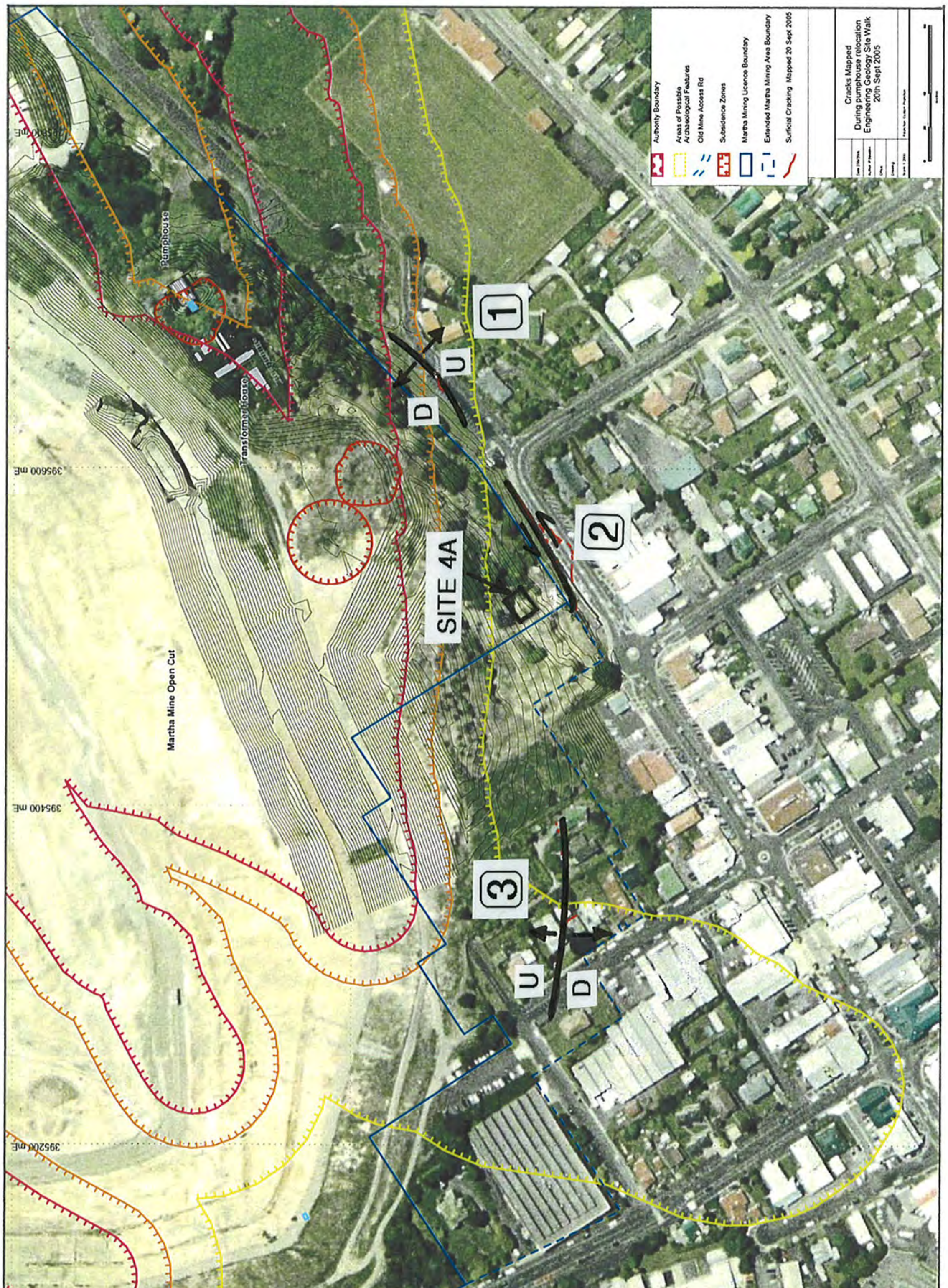
Risk Assessment Pumphouse Re-Location

LOCATION PLAN
SITE 4A

PSM 125.L88

Figure 1



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CRACKS & MOVEMENT ZONES

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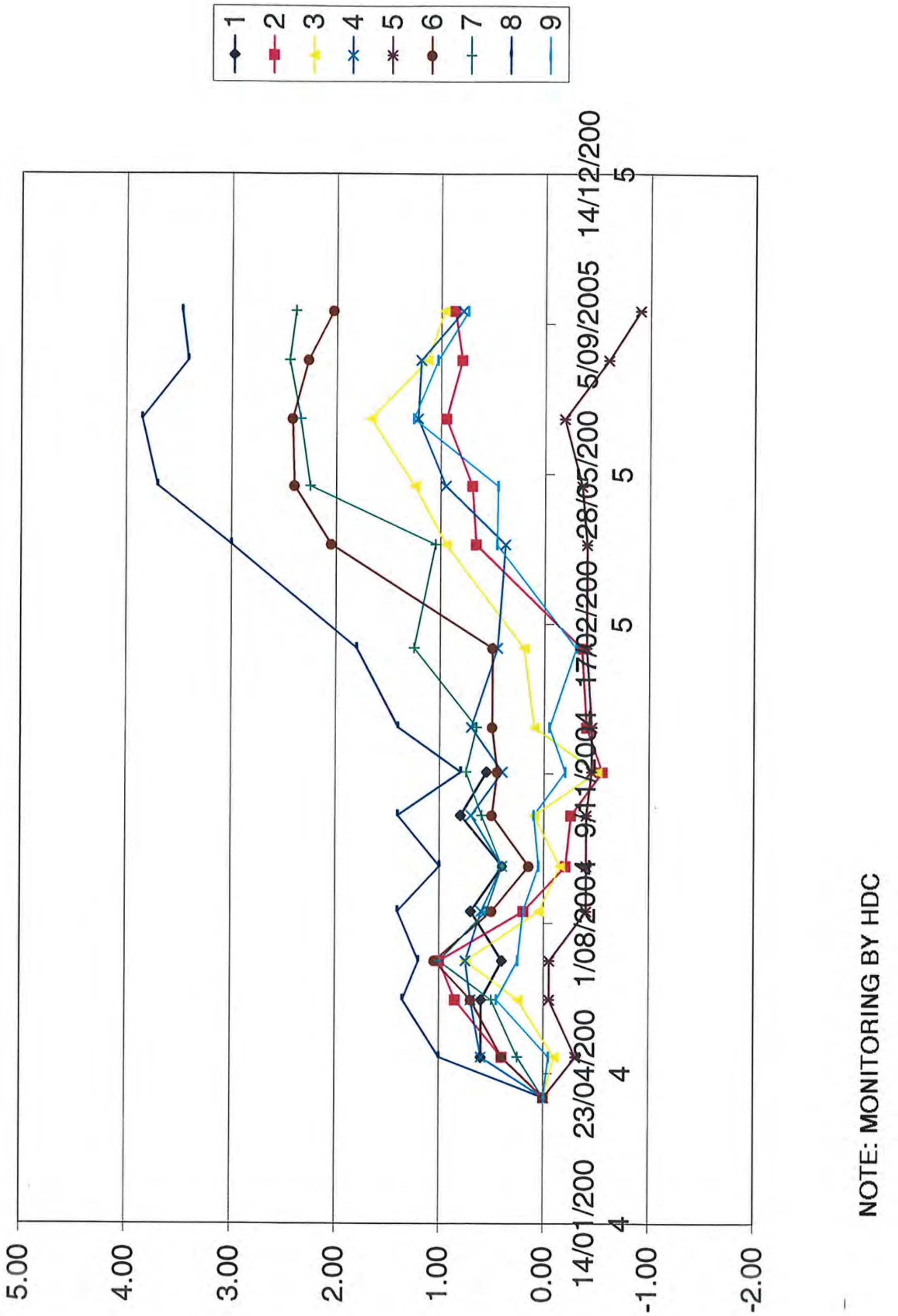
PSM 125.L88	Figure 2



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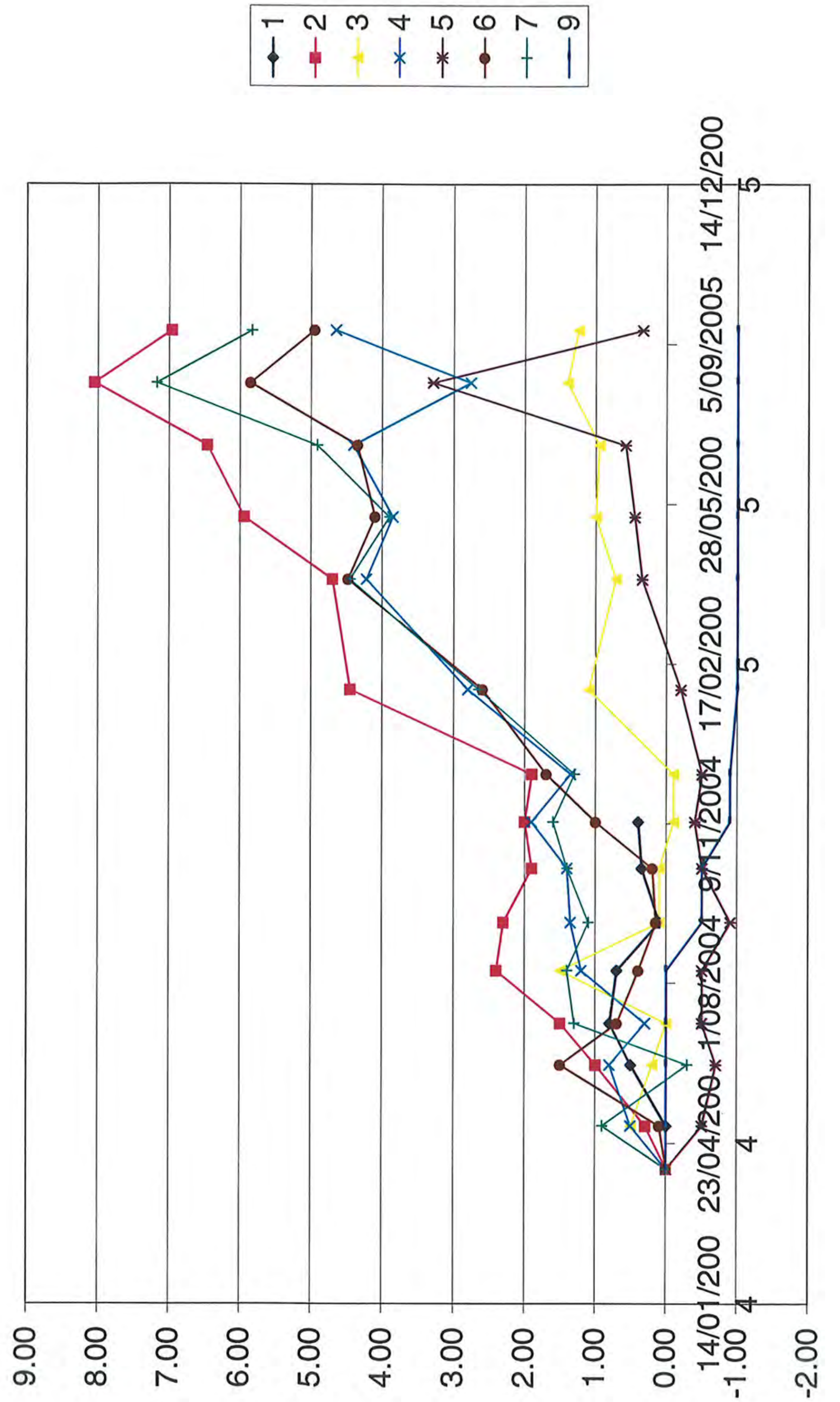
SEDDON STREET CRACKS - (ZONE 1)
HORIZONTAL MOVEMENTS

PSM 125.L88	Figure 3



NOTE: MONITORING BY HDC

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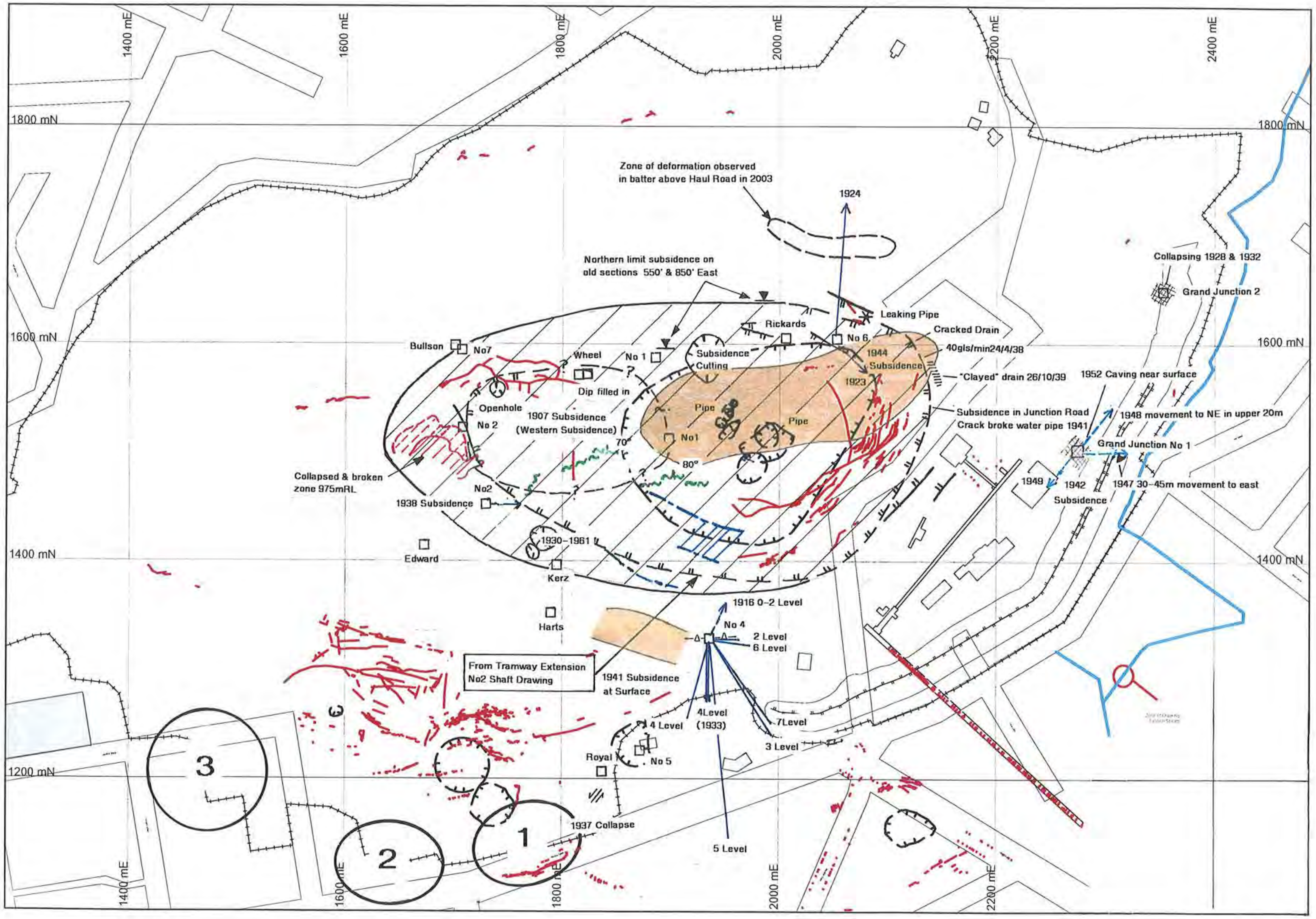
SEDDON STREET CRACKS - (ZONE 1)
VERTICAL MOVEMENTS

PSM 125.L88	Figure 4



LEGEND

- NOTIONAL LOCATION OF WESTERN SUBSIDENCE INFERRED FROM REPORT BY COUPER
- INITIAL SUBSIDENCE CONE
- SUBSIDENCE TRAMWAY EXTENSION PLAN PENCIL ADDITIONS
- SHAFT MOVEMENT VECTORS SHOWING: 1924 - YEAR; 3 LEVEL - LEVEL
- COLLAPSING
- SHAFT
- CHIMNEY CAVE/ SURFACE COLLAPSE
- 1919-1923 BLOCK SUBSIDENCE SHOWN ON OLD SECTIONS
- MAPPING OF CAVE BOUNDARY IN PIT
- ZONE OF FAULTING & DISLOCATIONS IN IGNIMBRITE ZONE
- SUBSIDENCE CRACK No 4 SHAFT 2000

NOTE: DATA FROM TRAMWAY EXTENSION No 2 SHAFT DRAWING & SHAFT DATA

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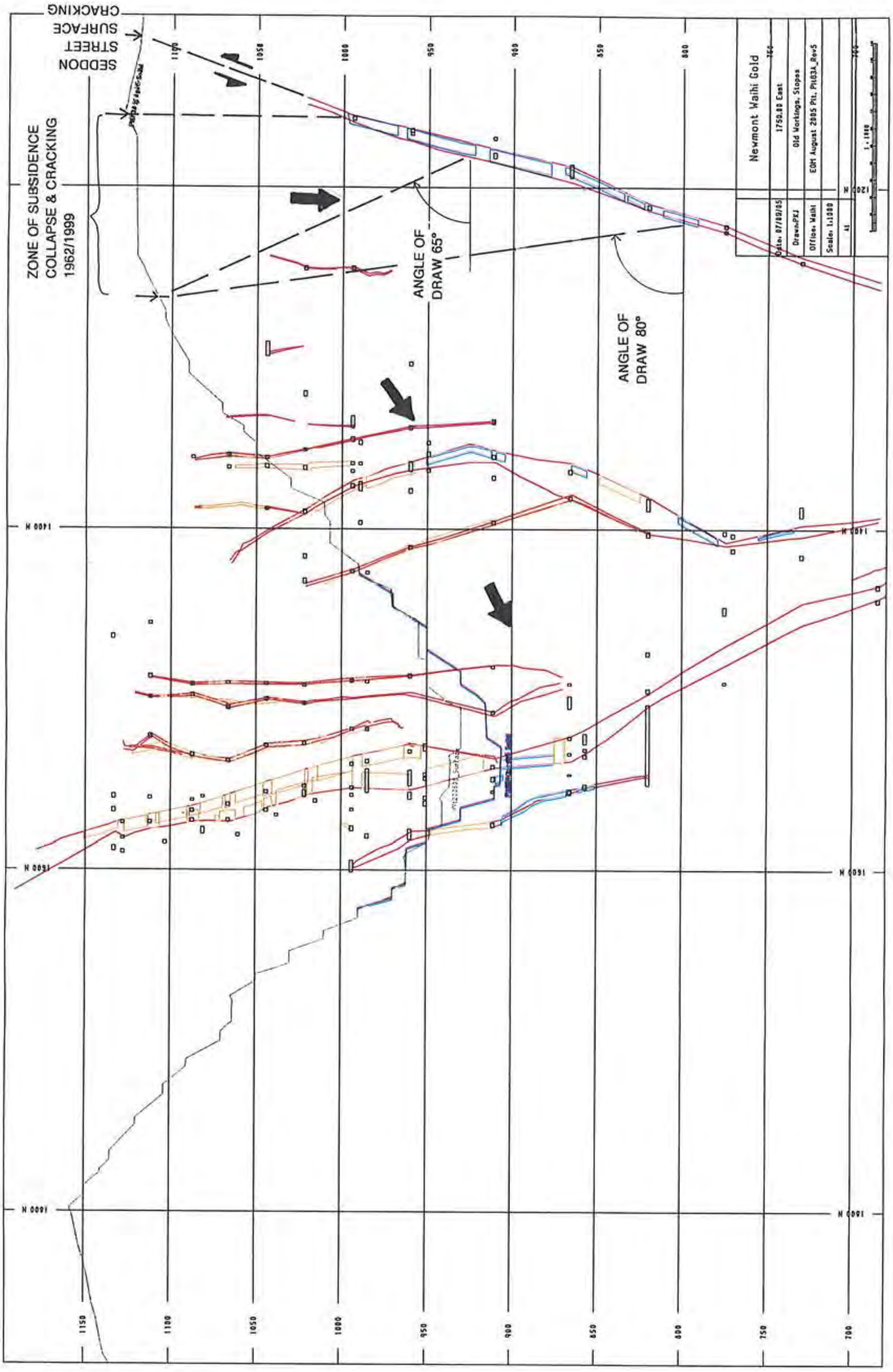
HISTORIC SUBSIDENCE PLAN & NEW ZONES

PSM 125·L88 | Figure 5



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ZONE 1
LARGE SCALE MOVEMENTS

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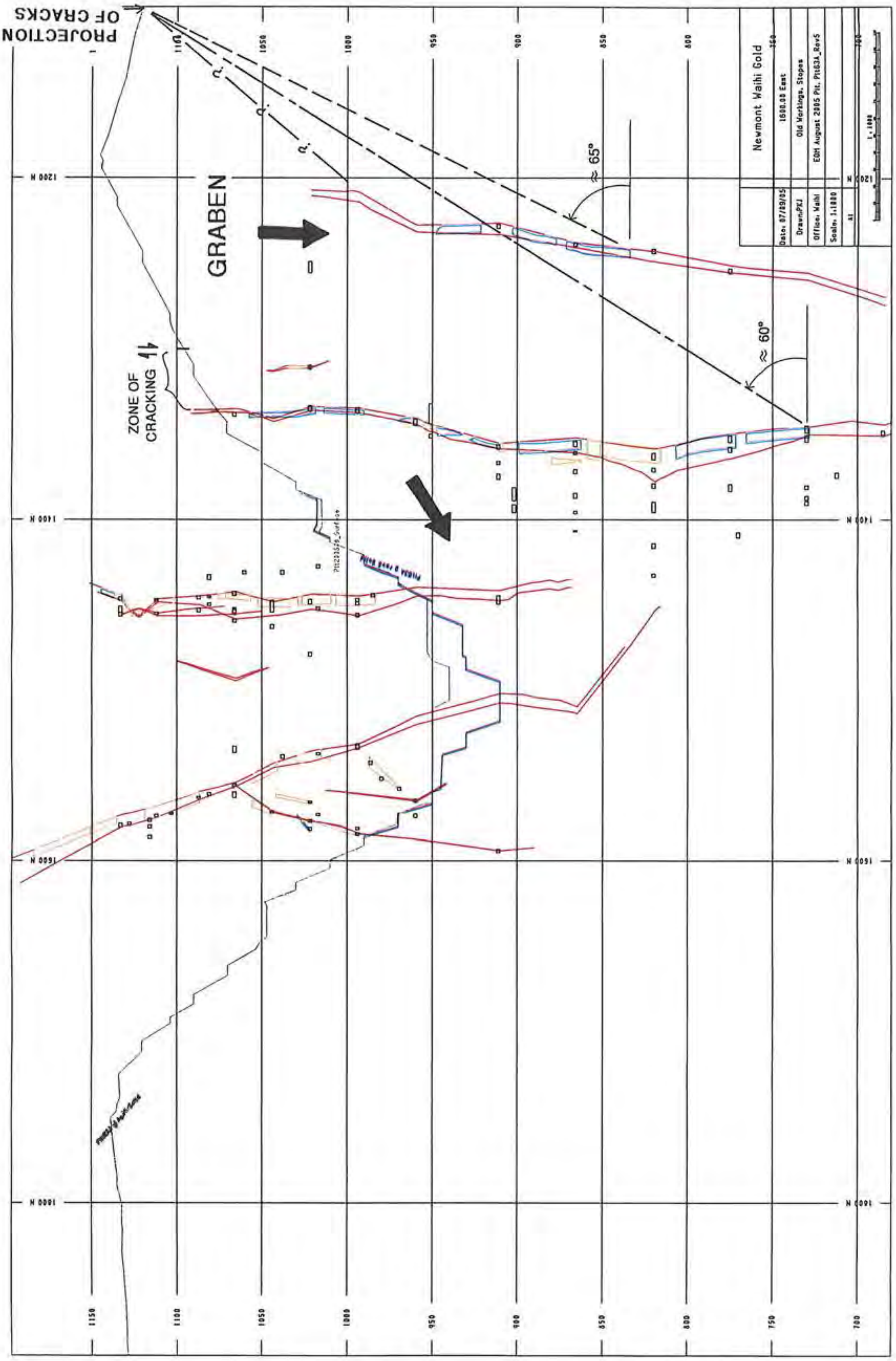
PSM 125.L88	Figure 6



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ZONE 2
LARGE SCALE MOVEMENTS

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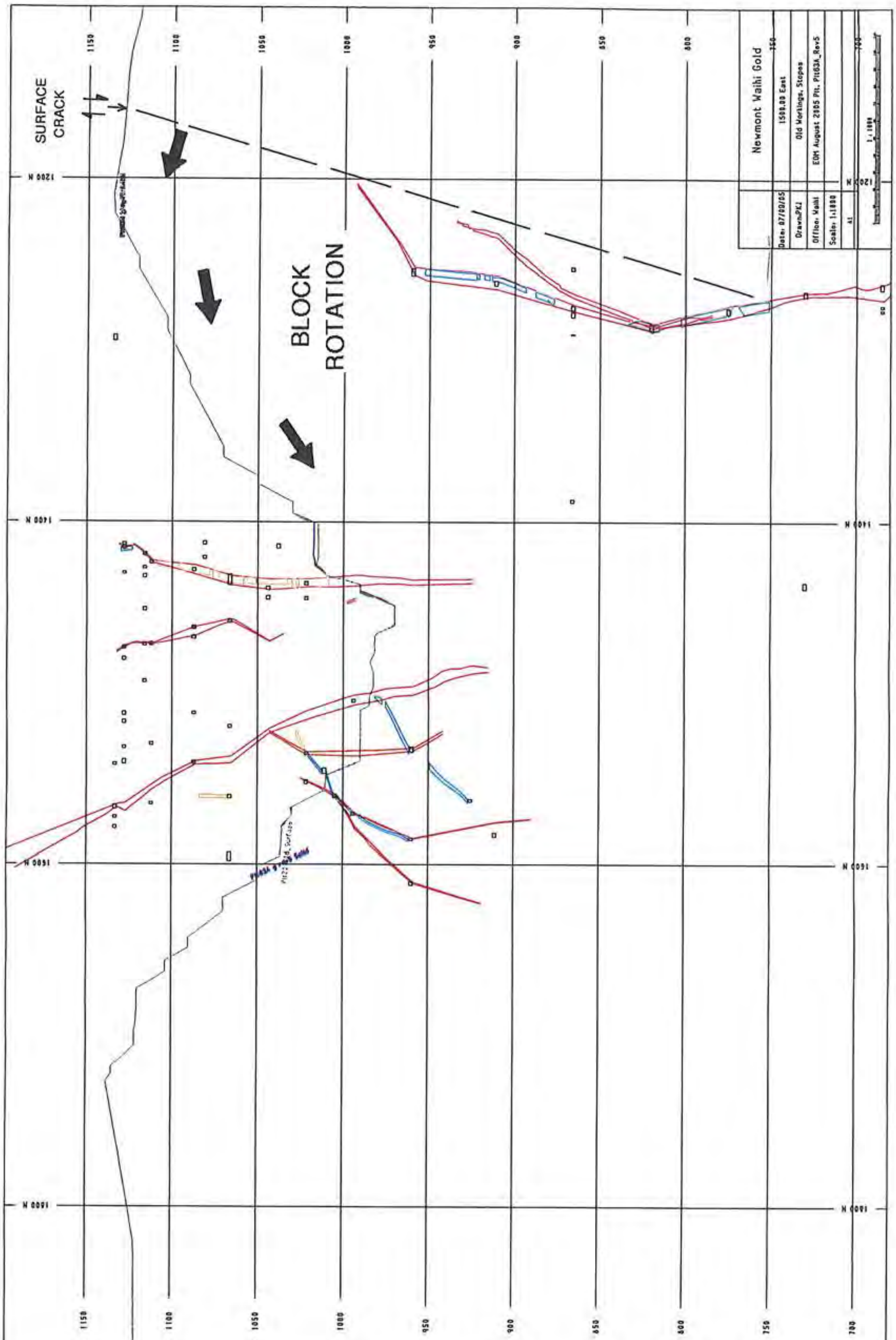
PSM 125.L88	Figure 7



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ZONE 3
LARGE SCALE MOVEMENTS

PSM

Pells Sullivan Meynink Pty Ltd

PSM 125.L88	Figure 8

Appendix 3 – Professor Elms 2002 report on Road Safety in Waihi

Road Safety in Waihi Hazardous Zones

Report to Hauraki District Council

D G Elms 2 October 2002

Introduction

This report assesses the safety to vehicles using routes crossing the hazardous zones in Waihi identified in the GNS report *Waihi Underground Mine Workings Stage II Investigations*.

There are various methods of quantifying risk to life. The GNS Report concentrated only on the risk to people spending a great deal of time in the hazardous zones by way of living there or having their employment there. They used measures of safety related to the risk faced by individuals or, using the ANCOLD criteria, to groups.

With regard to traffic safety, the issue is whether the local authorities should close or otherwise regulate the flow of traffic on roads crossing the identified hazardous zones. Presumably what the authorities want to know is the likelihood of a fatality on the road due to mine subsidence. We'll therefore try to estimate the annual likelihood of a death occurring due to this cause.

Fatality Rate

The annual probability of a collapse occurring somewhere in each lode is given on p54 of the GNS report. We need to calculate from this the annual probability of collapse occurring in a particular place on the lode, presumably where the route crosses it. We'll think of it as the probability of collapse in a 70 m length of the lode, assuming that this is the lode length that might affect a route. We'll express this in terms of probability of collapse per hour as this is the figure we can use for estimating vehicle risk.

Lode	Annual Prob. of a Collapse	Approx Lode Length (m)	Prob. of collapse in 70 m length/yr	Prob. of collapse in 70 m length/hour
Royal	0.0384	1000	2.7 x 10-3	3.1 x 10-7
Edward	0.0068	220	2.2 x 10-3	2.5 x 10-7
Empire	0.0392	400	6.9 x 10-3	7.8 x 10-7

The next step is to look at the risk facing a specific vehicle. We'll assume that if the vehicle is involved in an accident due to subsidence, there is a 20% chance of a fatality. Assume also that the vehicle is travelling at 50 km/hr. We'll only look at the high hazard zone – the risk for the moderate zone reduces to a tenth. At this stage we can be pretty rough as to our assumptions in order to get a very broad estimate as to whether vehicle safety is an issue. If it might be an issue, then we can return to our assumptions and refine them further.

Route		AADT	Length over high hazard zone (m)	Time spent per vehicle (hr) @ 50 k/hr	Prob of collapse per vehicle	Fatality rate, deaths per year
1	Edward	1250	60	.0012	2.96 x 10-10	2.7 x 10-5
2	Royal	1200 (say)	100	.002	6.14 x 10-10	5.4 x 10-5
3	Royal	1270	60	.0012	3.68 x 10-10	3.4 x 10-5
3	Empire	700	130	.0026	20.36 x 10-10	10.4 x 10-5
					Total	21.9 x 10-5

Next, a rough estimate of the normal road safety level.

New Zealand has about 91,200 km of road of all types, and about 420 people are killed a year. This gives a rough figure of 0.0046 deaths/km/yr.

Assuming there are about 20 km of road in Waihi, then you would expect about 20 x 0.0046 = 0.09 or, say, about 1 death in 10 years. Compare this to the above figure of fatality rate in the hazardous zones of 21.9 x 10-5, which translates to about 1 death in 5,000 years. It is of the order of 500 times less risky than the ambient figure. This does not mean that a fatality could not occur due to subsidence: it could. But its likelihood is very low. We need not refine our assumptions further to tease out detail.

To put it another way, I'd personally have no hesitation in driving on any of the three routes myself.

Appendix 4 – Remote Sensing Monitoring by Sergei Samsonov, GNS Science

Remote Sensing Monitoring

by Sergei Samsonov, GNS Science

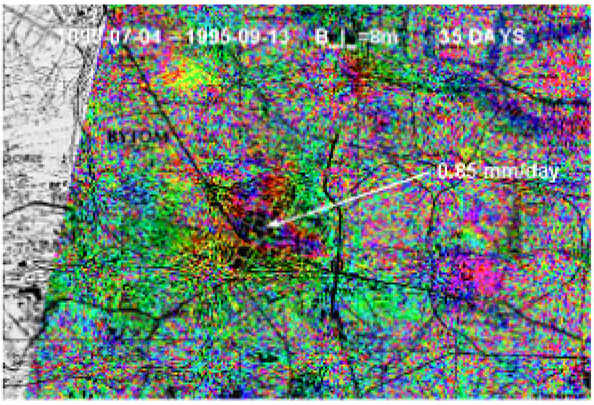
Introduction

Mine subsidence is the lowering of the Earth's surface due to collapse of bedrock into underground mined-out areas and subsequent sinking of surface unconsolidated sediments – sand, gravel, silt and clay. Depending on many factors subsidence can be slow (a few mm per year) or fast (a few cm per day), continuous or sudden. Often subsidence can cause significant changes in topography as well as in hydrography and affect buildings, roads, railways and pipelines.

Typical traditional measurements of surface subsidence are performed infrequently and at sparse locations due to high cost. These measurements usually do not provide sufficient spatial and temporal resolution and, therefore, some of the deformational signal stays unresolved. The proposed space-borne Differential Interferometric Synthetic Aperture Radar (DInSAR) technique on the other hand is relatively inexpensive and can be highly effective in measuring surface deformations with a precision of a few centimetres in images with 20 meter spatial resolution covering 100 km spatial extents over time span from days to years. The complete description of DInSAR technique can be found in Massonnet and Feigl, 1998.

DInSAR uses two or more synthetic aperture radar (SAR) images to generate maps of surface deformation using differences in two-way travel times of the waves returning to the satellite. Once the ground, orbital and topographic contributions are removed the interferogram contains the changes of the surface caused by an increase or decrease in distance from the ground pixel to the satellite. One fringe of phase difference is generated by a ground motion of half the wavelength that is about 3 cm for ERS, RADARSAT and ENVISAT satellites and about 10 cm for ALOS. Phase shifts are resolvable relative to other points in the interferogram only, but absolute deformation can be inferred by assuming one area in the interferogram (for example a point away from expected deformation sources) experienced no deformation, or by using a ground control (GPS or similar) to establish the absolute movement of a point.

In the example below DInSAR was used for mapping of surface deformation caused by extraction of coal at the Upper Silesian Coal Basin (USCB) in Poland. Intensive mining in this region caused very fast surface subsidence as it is seen on Fig 1. Here differential interferograms were calculated from two SAR images each acquired by the ERS satellite on 4 July 1995 and 13 September 2005 (left image) and on 19 January 1998 and 23 February 1998 (right image). The signal in the centre of the left image corresponds to 0.85 mm/day subsidence and the signals on the right image correspond to 3.5 mm/day maximum subsidence. Such differential interferograms with short time span (35 days in this case) are very useful for mapping fast surface subsidence.



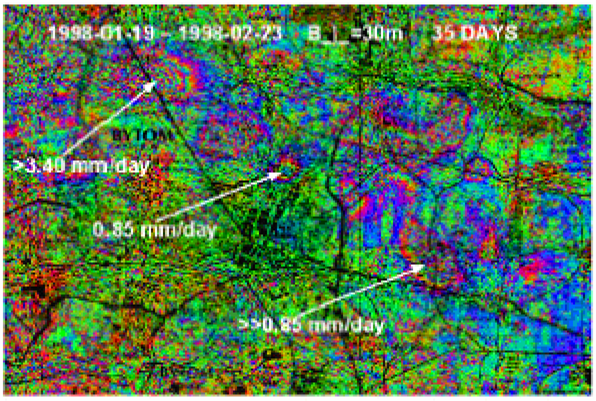


Fig 1. Two differential interferograms calculated from ERS SAR images acquired on 4 July 1995 and 13 September 2005 (left image) and on 19 January 1998 and 23 February 1998 (right image). Areas of surface subsidence are shown with white arrows (Modified from Perski & Jura, 2003).

If subsidence is slow then it is often necessary to use differential interferograms calculated over a larger time span, from a few months to a few years. Such signal is shown on Fig. 2 Three DInSAR images presented here that were calculated for a time span 5 months (left), 8 months (middle) and 11 months (right). After some post-processing, the spatial extent of the deformations was identified with very good accuracy (lower images).

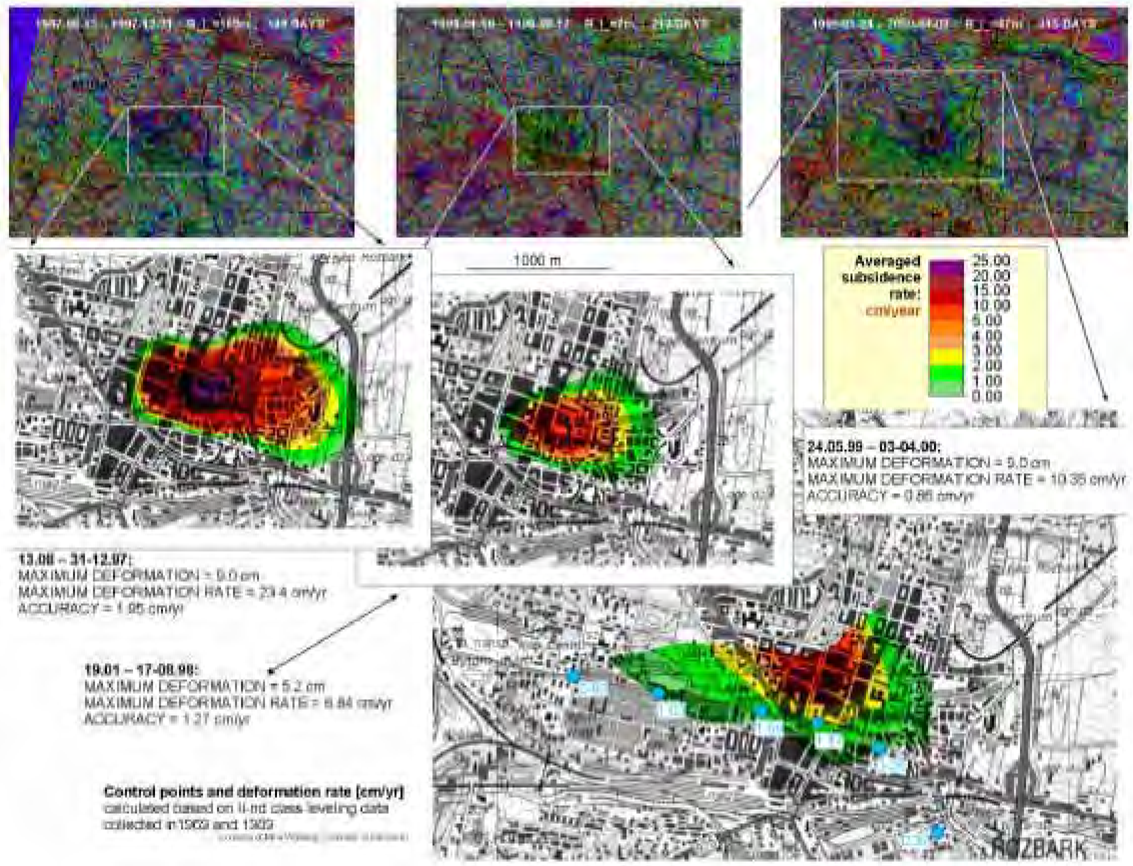


Fig 2. Three long time-span differential interferograms acquired over USCB region. The left interferogram is calculated from two ERS SAR images acquired on 13 August 1997 and 31 December 1997; middle is calculated from two ERS SAR images acquired on 19 January 1998 and 17 August 1998, and right is calculated from two ERS SAR images acquired on 24 May 1999 and 3 April 2000. After some post-processing, the spatial extent of subsidence is identified with high accuracy on lower images (Modified from Perski & Jura, 2003).

Limitations and advanced techniques

The limitation of this technique is caused by signal decorrelation over time due to the fact that surface conditions change. This decorrelation depends on seasonal and weather conditions during SAR acquisitions as well as the type of vegetation cover. However, some advanced processing techniques were developed that often improve the quality of the results. For example, Persistent Scatterers (PS) technique takes the advantage of the fact that some objects on the ground stay correlated (by preserving the shape) over a long time (10 or more years). These objects are buildings, roads, rocks and many more. If many SAR images are available then it is possible to identify stable objects very accurately and to monitor their behaviour over time. Permanent Scatterer (PS) method, presented here on Fig 3, was used to create a high spatial and temporal resolution data set of ground displacements in the San Francisco Bay Area.

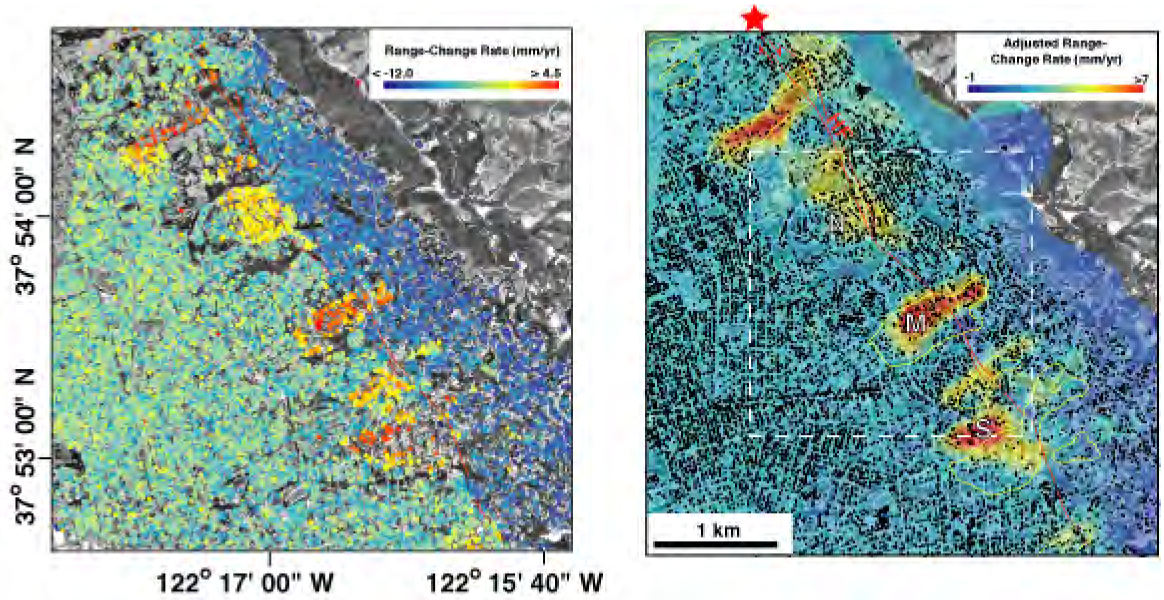


Fig 3.Permanent scatters interferogram of San Francisco region calculated from a large number of SAR images.

Another possibility is to use SAR images from the satellites that operate in L-band diapason. In this case, as it was shown in many previous studies signal stays correlated for a longer period of time and therefore differential interferogram over a larger time-span can be calculated.

Our proposal for Waihi

We propose to use both ENVISAT C-band and ALOS L-band SAR data for monitoring of surface deformations of the Waihi region. It is anticipated that ENVISAT data will provide very good signal resolution over a short period of time and ALOS data will provide spatial extent with very high accuracy over a longer time span.

It is recommended to acquire already available ENVISAT and ALOS data in order to estimate previous deformations as well as to keep acquiring new data when it becomes available. With the help of this data it will be possible to reconstruct four dimensional deformation field of this region with high resolution and accuracy.

The following ENVISAT images are currently available from European Space Agency and can be purchased for about 400 Euros per image:

Date	Orbit	Frame	Track	Orbit_dir
20040822	12959	6435	2380	A
20050529	16967	6435	2380	A
20050807	17969	6435	2380	A
20060618	22478	6435	2380	A
20070218	25985	6435	2380	A

The following ALOS images are available from Japanese Aerospace Exploration agency and can be purchased for about 600-700 NZD per image + GST (depending on exchange rate):

Operation mode	Scene ID	Path	Frame	Orbit	Orbit_dir	Date
FBS	ALPSRP051696420	325	6420	5169	A	2007-01-13
FBS	ALPSRP058406420	325	6420	5840	A	2007-02-28
FBS		325	6420		A	2007-10-16

This data, once available, will be processed at GNS Science with the help of GAMMA Remote Sensing Interferometric SAR Processor and analysed. The conclusion and suggestions regarding future monitoring of Waihi region will be made based on results of processing of the initial data.

References

D. Massonnet and K.Feigl, “Radar interferometry and its application to changes in the Earth surface,” *Reviews of Geophysics*, 36 (4), 441-500, 1998.

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