Waihi underground mine workings
Stage II Investigations Addendum Report
Edward South provisional hazard zonation

Confidential
Addendum to
CR 2002/46

by Dick Beetham, Laurie Richards, Warwick Smith
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Prepared for

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1.0 INTRODUCTION

GNS has previously carried out an assessment of the sinkhole hazard in Waihi associated with the old underground workings beneath the town area[1]. This report concluded that high, medium and low hazard zones existed over parts of the Royal, Edward South and Empire Lodes. With respect to the Edward South Lode, the report (p6) noted that:

> *The modelled zone of high and medium probabilistic subsidence hazard above the Edward South Lode (Figures 5a, b & 13), in our view warrants further subsurface investigation to determine whether or not a void has commenced migrating to the surface. We note that although the combined empty stopes of the Edward South Lode are modelled to have a probabilistic hazard rating a little greater than the predetermined 10% for a high zone (Table 10), the hazard is significantly lower than indicated for much of the Royal and Empire lodes. In addition the Edward South stopes are deep, have a narrow span, and historical records indicate a good quality rock mass is present around the stopes. It is possible that the stope voids have stabilised and may not be migrating upwards. We recommend that the probabilistic hazard ratings above the Edward South lode be regarded as provisional pending the results of subsurface investigations. Two holes drilled into the uppermost stopes of the lode are recommended to investigate the possibility of void migration. Good evidence that voids are not migrating may allow the hazard rating to be lowered or removed.*

Three holes, ES1 to ES3, have since been drilled above the Edward South Lode between 6 September and 11 November 2002. This report reassesses the sinkhole hazard based on the information from these drillholes. For the sake of completeness, the note also includes observations on the drillhole data taken from earlier email correspondence from GNS and Laurie Richards with Hauraki District Council.

Figure 1 shows the location of drillholes ES1 to ES3. The two shallow inclined holes, ES1 and ES2, were drilled to check for near-surface voids that may have migrated from the stopes towards the ground surface. An example of this type of void can be seen in drillhole RDH06[2] above the Royal Lode in the Seddon Street area where there is a zone of 17m of lost core at least 60m above the top of a filled stope.

The deep hole, ES3, was drilled to see if a void was propagating up from the widest part of the Edward South stopes. Figure 2 shows the drillholes in relation to sections through the stopes. (Figures 1 and 2 are based on drawings from a HDC memo[3]).

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1 Richards LR, Mazengarb C, Beetham R, Brathwaite R, Smith W. *Waihi underground mine workings. Stage II investigations.* Institute of Geological and Nuclear Sciences client report 2002/46. Project no 520W7510. Report to Waihi Underground Mine Workings Technical Working Party, 23 August 2002

2 Opus International Consultants. *Waihi interim subsidence assessment.* Report to Hauraki District Council, 1999

3 Torckler L. *Edward void migration risk assessment drilling.* Memo to Ken Thompson HDC, 11 November 2002

Draft logs prepared by Opus and photos of the drillhole core have been forwarded by HDC to GNS and Laurie Richards. Core recovery parameters are generally excellent, especially considering the fact that the holes are inclined. Apart from core losses in superficial materials, the only areas of lost core indicated in the logs are in ES1 between 63.20 – 63.90 and 65.75 – 66.20 in andesite rock. ES3 was cored from 143m to 320m with the logs showing only a very small zone of less than 100% total core recovery between 307 and 308m where total core recovery is about 95%. The drillhole data indicate undisturbed ground conditions, with no evidence of any void migration.

A detailed assessment of the geological conditions indicated by the drillhole data and core photos has previously been carried out by GNS[4] and is summarised in the following paragraphs.

The drill core photos show that the andesite rock mass in the vicinity of the Edward South stopes in ES3 generally has a *good* rock mass classification (using the CSIR Geomechanics Classification), with a range from quite extensive areas of *very good* to small areas of *poor* rock mass. The zones of poor rock are plotted on Figure 3. The rock mass from the start of coring at a downhole depth of 143m to the first significant (0.5m wide) shatter zone at 236.5m is generally good to excellent. There is another 0.5m wide shear zone at 246.5m, but the first wider zone of poor rock mass begins at 256.5m. The rock mass vertically above the upper Edward South stope, as seen in the ES3 drillcore logs between 200m and 256m (Figure 3), has full core recovery and generally a good to excellent rock mass rating parameters (Total and Solid Core Recoveries 100% apart from very minor lengths, and average Rock Quality Designation[5] of 62%). In our experience and judgement a void is most unlikely to propagate upwards through such a good rock mass with so few defects. Thus in our assessment the ES1 and ES3 drillholes (Figure 4) show clear evidence that:

(a) a void is not propagating upwards from the southern end of the Edward South stopes, and
(b) the good to excellent rock mass quality present vertically above the stopes at this point (Figure 3 and the core photos) is most likely to prevent a void from propagating upwards.

Thus in our judgement, where it is clear from the drilling that there is no void, and where the rock mass quality appears to be good enough to prevent a void from forming, the low hazard rating can be removed. In addition the stopes at the southern end of the Edward South lode are too small (total source volume of ED258, ED264 and the small southern tip of ED259 is less than 2,500m^3 and the average stope span is less than 3m [Figure 4]) for a void to migrate upwards through ~300m of rock to the surface. On the basis of this evidence we have removed the low hazard zone from the southern end of the Edward South stopes to the point

[4] Beetham D. *Edward South drilling.* Email to Ken Thompson HDC, 22 November 2002

[5] Rock Quality Designation is a modified core recovery percentage where the pieces of sound core over 100mm long are summed and divided by the length of the core run – essentially a percentage of the *good* rock recovered from an interval of borehole

where stope ED259 (Figure 4) increases suddenly in height and volume. The extent of the revised low hazard zone is shown on Figures 5, 6, 7, 8 and 9.

The ore lodes in the Martha Mine are often associated with faults or shears. The ES3 core photos show the quartz lode beginning at about 274m with associated shatter and shear zones on both the hanging and footwall sides. The ES3 drillhole intersects the lode some 47m above the top of the stope (Figure 3). Most of the poor rock mass seen in the ES3 drillcore is located on the footwall side of the lode extension. By comparison, the crown and hangingwall rock mass conditions are much more favourable than those in the footwall. It is the hanging wall rock in this case that provides stability and will inhibit or prevent upwards void migration.

2.0 HAZARD ASSESSMENT FOR EDWARD SOUTH STOPES

The supplementary drilling program has confirmed the previous impression that the rock mass above the Edward South Lode stopes is better than the general quality of rock above the upper areas of other lodes. As noted in the GNS report[1], the Edward South Lode is also at a greater depth and has smaller stope thicknesses (2.3 to 4.7m in top stopes) than is typically the case at Waihi. This area is also outside the area of previous subsidence.

In the earlier GNS report[1], a method was developed for assessing the probability of voids migrating through to the surface. This involved a collapse model which assumed that the shape of the migrating void approximated to a frustum of a tapered rectangular solid section (see Figure 36 of GNS report[1]). The collapse geometry is controlled by weak sheared surfaces at the contacts between the ore and the country rock on the hangingwall and footwall and by an angle of break on the lateral edges of the void. The height to which the void can migrate depends on the length of the stope, the angle of break and the bulking properties of the rock. Stopes with moderate to high probabilities of void migration to the surface (0.1 to > 10%) were found to be located mainly in the areas of previous subsidence.

Figure 4 shows the layout of the stopes in the Edward South Lode. Stope ED258 and 259 effectively act as one stope since there is no significant vertical pillar between these. The top stopes ED258/259 and ED260 have low probability of caving to surface.

Historical information located by GNS (p36 of GNS report[1]) has indicated that *Arches under 9 level at the top of stopes ED264, 265 and 266 were shot out in 1935 and 1937.* The hazard assessment therefore had to consider the possibility that all the stopes shown on Figure 4 had effectively amalgamated and the total volume of all these stopes would be available to receive caved material. Hangingwall or stope back failure along the length of the top three stopes combined (ED258, ED259 and ED260) resulted in a high probability of caving through to the surface when analysed using our @Risk model.

Drilling of the three holes, ES1 to ES3, has indicated that no continuous void has developed above the line of the three stopes ED258, ED259 and ED260. ES3 has sampled a relatively small section at the southern end of this total length and there may be undetected sections of caving ground to the north of ES3 above part of stopes ED259 and ED260. However, lengths of stope shorter than ED260 or ED258/259 become geometrically stable before they can reach the ground surface and any smaller sections of caved stopes are therefore not significant with respect to their possible effects at ground surface. Also the new investigation holes ES1 and ES2 show that a void from these stopes has not migrated up to within 100 m of the ground surface.

3.0 CONCLUSIONS

The recommendations in the GNS report[1] for proof drilling above the Edward South Lode have been carried out. The three drillholes have had high core recovery parameters and do not indicate evidence of caving ground. They indicate a good quality rock mass at depth (drillhole ES3), and give qualified assurance that voids are not migrating upwards.

In order for a void to propagate to the surface from the top stopes of the Edward South Lode, failure needs to occur along a substantial length of the stope. Data from the drillholes indicate that this is not the case. In the earlier GNS report[1], the pessimistic assumption was made that the top three stopes had combined because the intermediate pillars had been mined. The rock mass above the Edward South Lode top stopes appears to have remained stable since 1937 when the last arches were shot.

Historical information indicates that the arches above ED264, ED265 and ED266 were shot out in 1935 and 1937. This would still leave a substantial body of solid rock between ED263 and ED 266. The previous assumption that all the stopes in the area (ED258, ED259, ED260, ED264, ED263, ED265, ED266, ED195 and ED267 – see Table 10 of the GNS report[1]) had combined may be an unnecessarily pessimistic modelling assumption given the lack of evidence for void migration from the recent drilling program. Modelling void migration using a smaller number of stopes combined together gives a lower probability of void migration reaching the surface.

Based on the new drillhole and other evidence presented above, the earlier provisional classification of the area above the Edward South Lode as **High** hazard can now be reduced to **Low.** As well the southern extent of the hazard zone can be decreased since the deep and shallow drillholes ES3 and ES1 clearly show (Figure 4) that a void has not developed in that area. In our judgement the hazard rating for the entire Edward South lode cannot be completely removed by considering the three drillholes, as a small uncertainty remains. The Low hazard classification of the remainder of the lode is recognition that the three drillholes do not fully investigate the entire length of the Edward South lode, so that there remains a greatly reduced possibility that an upward migrating void may be present undetected in the region below or between ES1 and ES2.

3.1 Revised risk assessment

In the main GNS report[1] (Section 6, P36) the hazard zones are defined as:

- Low probability **L** Sinkhole probability less than 0.1% - but there may be minor surface settlement and ground cracking deformation (where there are adjacent high and medium hazard zones).
- Moderate probability **M** Sinkhole probability 0.1 to 10%
- High probability **H** Sinkhole probability >10%

As stated above, it is our judgement that the investigation drillholes ES1 to ES3 have not entirely disproved the presence of a migrating void, but they have allowed us to reduce the hazard zone above the Edward South stopes to low, and to reduce its length (Figures 6 and 7). Within the assigned low hazard rating the probability of a sinkhole reaching the surface is less than 0.1%. Using the methodology described in the GNS report[1] the annual probability of a collapse forming at the surface in the low hazard zone is **0.00004 (4×10^{-5}) or 0.004%**.

Individual Risk. As described in the GNS report[1] risk assessment methodology on p55, 58, 59 & 60, there is a 20% probability that a future sinkhole collapse might cause one fatality and the occupants are there 24 hours per day, then;

	A		**B**	**C**	
Lode	Annual probability of crater forming on lode now–	Length of lode low hazard(m) from Figs. 5a & 10	Aspect ratio with 40m diameter crater	Annual probability of crater forming at any point on lode	Annual probability of a fatality of a person on the lode
				(A x B)	(0.2 x C)
Edward	<0.00004	~200	40/200 = 0.2	<0.000008 = < 8×10^{-6}	<0.0000016 = 1.6×10^{-6}

Therefore the annual probability of an individual death on the Edward South lode is estimated to be <1.6×10^{-6}, which plots within the acceptable risk area of Figure 10.

Fatal Accident Rate (FAR) is the probability of death per hour x 10^{8}. FAR for Edward South lode with a Low hazard rating is **0.018**. This is two orders of magnitude less than the FAR due to an accident at home = 2, the FAR due to an industrial accident = 6, and the FAR due to a car accident = ~50. Although the FAR due to a subsidence is an involuntary risk, it is a great deal less than the ambient rate that we all accept in day to day voluntary activities.

Societal Risk. The factory/warehouse building located within the Edward South lode low hazard zone is currently empty, but was occupied by up to 88 people until recently. The annual probability of a collapse at any point on the Edward South lode is estimated to be 8 x 10^{-6} (column C of table in paragraph 21). Assuming a severe case where there are 90 people working in the area of a 40 m diameter collapse, and that if a collapse occurs there will be a 20% fatality rate. The 90 people are there 8 hours per day, 5 days per week. Then there is an annual probability of less than 8 x 10^{-6} 8/24 x 5 x 52/365 that there would be 18 fatalities, or <1.9 x 10^{-6}. This gives a point on the ANCOLD derived societal risk diagram (Figure 10) which is within the acceptable risk area.

Conclusion. Individual and societal risk estimates indicate that the risk to people living and working in the low hazard zone remaining above the Edward South lode is well within acceptable risk limits (Figure 10).