Restoration Blasting near Limestone Caves at Mt Etna Limestone Mine

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Introduction

The Pacific Lime Mt Etna mine is approximately 30 km north of Rockhampton Queensland. The limestone produced at the mine is the raw material for lime and cement manufacture. These products are used for building and construction, water purification, gold and base metals recovery, in road stabilisation, sugar milling and refining, and in a range of industrial processes.

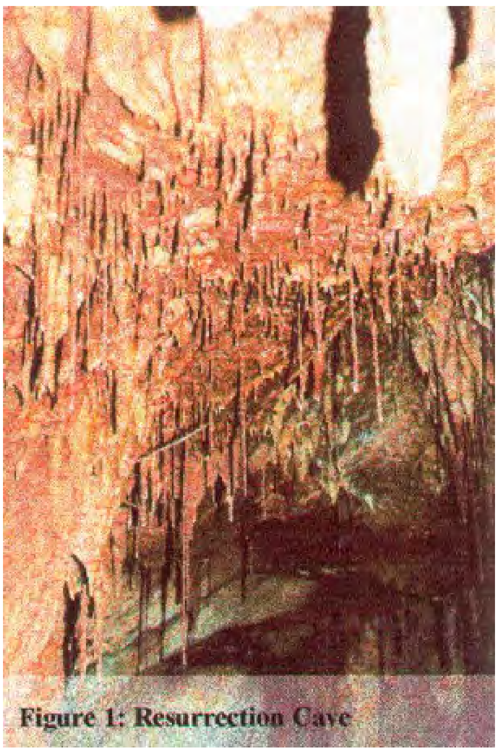
Figure 1: Resurrection Cave

Limestone deposits throughout the world are associated with the formation of caves, as natural weathering processes cause limestone to be dissolved by weak carbonic acid, formed by carbon dioxide mixing with water. Limestone is deposited in formations inside the cave when water flowing into the cave loses its carbon dioxide into the air, causing the dissolved solid to precipitate out of solution. This process takes many hundreds of years to produce large formations, with the rate of deposition usually around 1 cubic centimetre every 15 to 25 years.

The area around the Mt Etna mine has many caves containing a range of formations, and these caves are a well-known tourist attraction.

Blasting associated with the mining operations at Mt. Etna during the late 1960's inadvertently created an opening into a previously unknown cave at the site. This opening is the only entrance to the cave, which became know as Quarryman's or Resurrection Cave.

Resurrection Cave contains some of the most impressive formations in the area, including stalactites, shawls, straws, and helictites. Straws and helictites are among the most fragile of limestone cave formations, and take many hundreds of years to grow.

Background

During the late 1980's there was a prolonged dispute about further mining at Mt Etna. At the end of this period, it was decided that the future restoration of disturbed areas on Mt Etna should be determined by consultation between the company, community representatives and suitable experts and the Mt Etna Mine Rehabilitation Advisory Committee (MEMRAC) was formed.

The committee set out a range of trials and activities that culminated in the presentation of a Premier's Award for Environmental Excellence in 1996.

Apart from a range of different plant types and planting methods, the trials included a proposal to carry out blasting to remove some of the engineered appearance of the old mine workings. An initial blast was carried out in late 1994. The blast was successful in removing the engineered face and creating a planting medium but did not fully meet the expectations of the rehabilitation plan. This was because the blast was laid out like a normal production blast and produced a rather even slope and material size which contrasted with the natural topography of Mt Etna. The three years of extreme drought that followed also did not assist the successful establishment of vegetation cover on the area.

Following this experience it was decided to adopt a different approach to fulfil the objectives of the Mt Etna Rehabilitation Strategy. Blasting was still proposed for old mining faces to ensure that the north west slopes of Mt. Etna were suitable for re-establishment of flora and fauna. This time, however, the blast design used the existing slope of the mountain as a guide, to produce landform that is typical of the area.

There were 4 main priorities to the restoration blasting,

1. An effective slope with character as close as possible to the natural slope on the mountain.

2. Ensure that the structure and formations in the caves close to the blasting area were not damaged.

3. Ensure that the final slope was safe for replanting of flora.

4. Ensure airblast and flyrock from the blast was controlled.

Figure 2: Resurrection Cave Formations

The closest cave to the restoration blast was Resurrection Cave, which is well known as having the most spectacular limestone formations in the area. Ensuring that the cave and its formations were not damaged was a priority of the blast design process.

Two reclamation blasts were fired. The first was a test blast that was used to confirm that the design blasting parameters for the main blast would control airblast, vibration, and achieve a satisfactory final profile.

A comprehensive face survey and blast modelling were used to design the blasts and all charging parameters.

Community consultation during the lead up to the blast design process allowed local groups to have input to the blast design so that the blast could achieve all the objectives of the local stakeholders.

Community Consultation

A high level of community consultation and involvement had been a feature of the decision to proceed with this second restoration blast. This consultation, started by Pacific Lime, involved the MEMRAC team and other interest groups in agreeing on restoration objectives. The groups were:

- Local caving society
- National Parks and Wildlife Department
- Department of the Environment
- Mines Department

Orica Explosives' Blasting Specialist was briefed on the various requirements of the local interest groups, and was asked to provide a proposal for restoration blasting to achieve the objectives agreed during the community consultation process. The proposal was presented to the interested parties who accepted the proposal, and agreed to proceed with the restoration blast.

Restoration Blasting Objectives


Figure 3: Slope before Blasting

Environmental

Overall undisturbed slope on this side of Mt Etna is about 42 degrees. The overall slope of the existing mine benches is less than this, being between 40 and 30 degrees. However, the high slope angle of the bench faces discourages flora establishment and use of the area by fauna.

The objective of slope restoration was to return this part of the mine to a landform capable of ultimately sustaining the continued establishment of the native flora and fauna lifecycle. Restoration of the North West-facing slope of the old mine needed blasting of the existing benches to achieve a more natural landform.

Variation of the rehabilitated slope angle along the blasted area was a priority to ensure the final slope looked as natural as possible. Consistency of blast result was not desired, with large boulders needed to give fauna a habitat typical of the area.

Final slope variations were introduced by varying the energy in the blast.

Vibration Control

There are three caves near the restoration blast:

- Bat Cleft Cave - about 100m from the nearest end of the blasting area.
- Winding Staircase Cave - about 60 m from the blasting area.
- Resurrection Cave (also called Quarryman's Cave) - about 50 m from the blasting area.

Resurrection Cave is the only cave with significant limestone formations. Both Bat Cleft Cave and Winding Staircase Cave are solute cavities, and have no formations. The greatest possibility of damage was to Resurrection Cave where fragile formations were most likely to be damaged by vibrations from blasting.

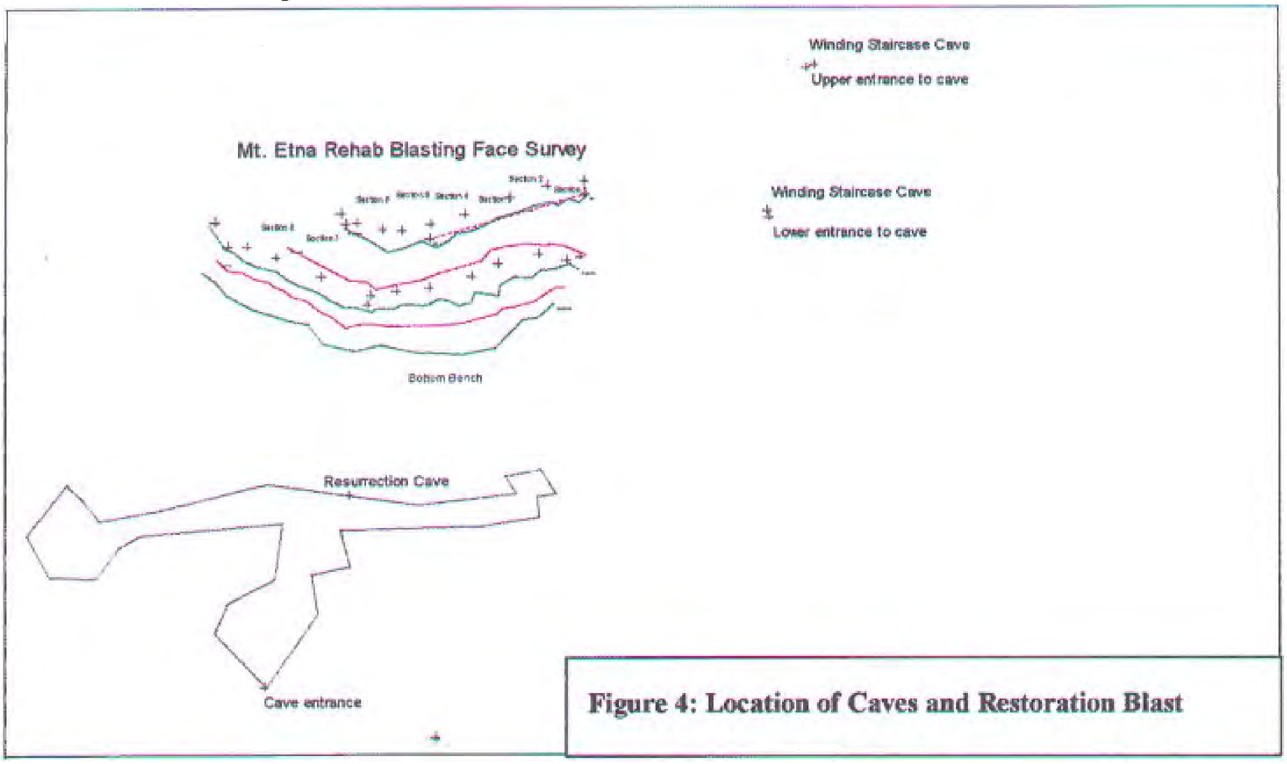

Figure 4: Location of Caves and Restoration Blast

Data collected during 1990 was used to develop a formula for predicting vibration from the restoration blasts. This general formula was established by the United States Bureau of Mines over many years and is recommended for use by the Australian Standards Association in AS2187 Part 2.

Using the data collected, the formula has the form:

$$V = 612 * \left(\frac{\sqrt{Q}}{R} \right)^{1.57}$$

where:

V = Peak Particle Velocity in mm/s
Q = 28 kg
R = 50 m

This predicted a maximum vibration at Resurrection Cave of 18 mm/s.

The vibration levels need to damage intact hard rock range from around 500 mm/s for softer types such as limestone, to around 2000 mm/s for very hard rocks such as dolerite.

In the late 1960's production blasting opened Resurrection Cave. Blasting at this time was aggressive and many blast holes were fired instantaneously. This frequently resulted in nearly 1 tonne of explosive being fired at any single instant.

The vibration levels likely to have been generated were calculated using the formula above, and predicted a ground vibration of 420 mm/s.

At these vibration levels, blasting was likely to have caused damage to the formations in the past. The photos taken by Peter Briggs show some stalactites in the cave that have been damaged, but it is not known whether this was caused by blasting. The fact that most of the formations, particularly fragile ones, are undamaged indicates that they have withstood considerable vibrations during blasting in the past. The predicted vibration from the restoration blast was 4% of the levels that the cave had already been subjected to during the previous blasting operations.

A photographic survey of Resurrection Cave was conducted to provide a record of the condition of the formations before the blast A re-survey after the blast showed that no formations were damaged by the restoration blast.

Slope Safety

Ensuring final slope safety was a priority, to allow for safe access for tree planting and watering during early establishment of the plants. Access to the muckpile was prohibited for 48 hours immediately after the blast to allow unstable voids in the rock pile to settle.

Unstable boulders produced from the blast were moved using an excavator to prevent them from rolling down the slope. This ensured the slope was safe for people accessing the slope from time to time.

Restoration Blasts

Two restoration blasts were planned. The first blast was used to test the blast design and blast outcomes on a small scale before committing to the larger main blast.

The test blast was located at the western end of No. 4 bench. The main blast was to include the remainder of No. 4 bench and a section of No. 5 bench

However, drilling difficulties on No. 5 bench indicated that the blast result on this bench would be difficult to predict, so this part of the blast was abandoned. Drilling on this bench intersected many voids and cracks in the limestone, causing loss of air pressure for flushing drill cuttings from the hole. Drilling air was also venting through cracks out of the face of the blast.

Charging these blast holes with explosives was going to be difficult, and likely to cause flyrock and airblast. Based on the hazard potential of blasting this bench, the quarry manager, Don Kime, decided that satisfactory restoration could be achieved by using an excavator and rock breaker.

Blasting Process

Face Survey

The first step of the blast design process was to determine the shape of the current faces. The face was surveyed using laser equipment to provide accurate information about the shape of the face to be used for the slope design. Sections through the blast area were used to develop a proposed blasting strategy for the slope.

Final Slope Design

The overall slope of the mountain was used to guide the design by placing on the plan lines at 40 degrees inclination Blast hole depths were calculated to produce a blast that breaks up the tall faces into shorter sections with blast rubble at the base to allow vegetation establishment.

The Orica Explosives blast simulation program Sabrex, backed up the author's extensive knowledge and experience in blasting to design a blast that proved very successful. The simulated sections from Sabrex are shown in Figure 5.

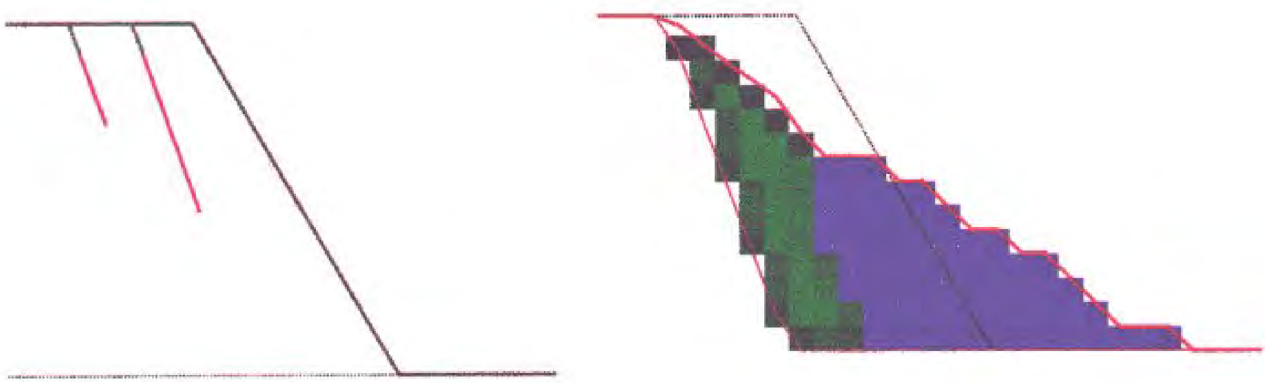

Figure 5: Blast Simulation of Typical Section

Test Blast

Drilling Conditions

Drilling of the test blast was made difficult by the numerous cracks and voids encountered. This frequently caused loss of return air and indicated that charging of the blast needed extreme caution to avoid overcharging causing flyrock and airblast.

Figure 6: Test Blast Location

Charging

Charging of the test blast was extremely difficult. Voids and cracks caused ANFO to be lost from the blast holes and consistent column rise was rarely achieved.

Layflat tube filled with stemming material was used to block the ends of blast holes and also to provide a bridge across voids part way up the holes.

Modifications to the planned blast charging design were made frequently to overcome these problems. Approximately 200 kg of explosive was used to charge the test blast.

Result

The test blast result was considered extremely successful by all whom witnessed the blast. No flyrock was produced, and noise and vibration was low.

The crest of the bench moved forwards slightly, then dropped to the bench below, producing a level section with fine material for tree planting, and a mix of fine and coarse fragmentation, plus large boulders.

Airblast at the nearest residence was 112 dB and no vibration was recorded.

Figure 7: Test Blast Result

At Winding Staircase Cave, airblast was 119 dB and vibration recorded as 35 mm/s, while at Resurrection Cave entrance 3.53 mm/s was recorded. However, both of these vibration monitors were not mounted effectively because of difficulties in positioning the mounts at both these locations.
More time was needed to overcome these difficulties than was originally allowed.

Main Blast

Drilling Conditions

Drilling conditions for the main blast were much better than the test blast. Few voids were encountered in the rock indicating that the rock was of higher quality and was likely to fragment easier than the test blast.

To ensure that fragmentation was not excessive, some modifications were made to the charging design to lower the powder factor, and encourage the creation of larger rocks.

Charging

Charging conditions for the main blast was good. Only 3 blast holes contained voids that needed special treatment.

Result

The blast was fired 5 minutes early due to the approach of a thunderstorm.

The top part of the bench lifted and dropped in a similar fashion to the test blast, but rock sizes produced were a more consistent than the test blast because fewer cracks and voids were encountered in the rock.

A few large boulders were produced near the start of the blast, and a good mixture of fine material was mixed with moderate sized rock.

Everyone interested in the blast outcome also considered this blast successful. A small section of the blast was fragmented but failed to move forwards due to the low powder factor in this area. This section was pushed forward by an excavator that to move the material into final position.

Airblast and vibration were as follows:

Bates Residence		Resurrection Cave		Winding Staircase Cave	
Vibration	Airblast	Vibration	Airblast	Vibration	Airblast
0	110.1 dBL	10.9 mm/s	N/R	6.1 mm/s	120.1 dBL

Impact of Main Blast on Caves

A photographic inspection of Resurrection Cave showed that no damage to formations had occurred in the cave.

Final Mechanical Treatment of the Slope

An excavator was be used to move a small amount of the material to ensure slope safety, and to achieve the desired final profile.

Main Blast Photos

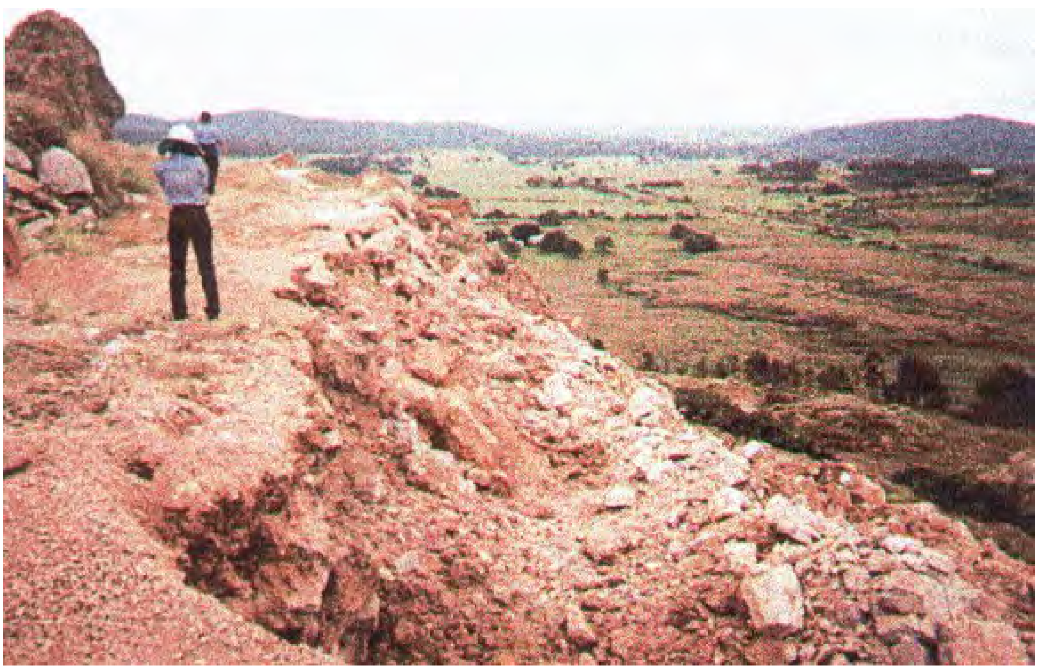

Figure 8: Main Rehabilitation Blast Photos

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Conclusion

The reclamation blasts were fired and achieved all objectives. The blast moved only the top part of the face needed to achieve the final profile, which now matches the existing overall slope of the mountain.

Minimal vibration was recorded at Winding Staircase and Resurrection Caves and airblast was low. No damage was caused to the limestone formations in Resurrection Cave. Community groups expectations were met and all were pleased with the result.

One of the most important factors which lead to community support for the restoration blast was the mine's approach to the problem. Community groups had been involved in all aspects of the rehabilitation process leading up to the blast and their views of the blast outcomes were incorporated into the blast design.

The experience of the previous blast designed without proper consideration of rehabilitation objectives made the groups very wary of another blast. The assurances provided by the presenting the restoration blasting proposal to community for their approval satisfied their concerns about the outcome of the restoration blast.