

VICTORIAN GEOLOGICAL MAPPING AND 21ST CENTURY DATA COLLECTION TECHNIQUES USED FOR QUARRY PLANNING - FFESTINIOG QUARRY

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ABSTRACT

Commercial scale slate quarrying and mining in the Blaenau Ffestiniog area of North Wales began in the early 1800s. The current Ffestiniog Quarry now works the remnant pillars that remain following the closure in the late 1960s of what was once the largest underground slate mine in the world. Following the 'Great Fall' of 1882/3 in which a large area of mine workings collapsed, there were proposals to quarry (or untop) the disturbed ground to recover the remnant pillars. The Victorian geologists mapped in detail the complex geological setting in each of the chamber and pillar pairs to establish whether this would be economically viable. This paper describes how the same exercise has been undertaken in the 21st century using modern data collection and volumetric calculation techniques in the context of the requirements of the Quarries Regulations 1999. Modern evaluation confirms the accuracy of the Victorian mapping, which has been used to quantify the amount of recoverable slate block remaining in the pillars (and chamber floors and roofs) in the ground.

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HISTORICAL BACKGROUND

Slate rock has been quarried in the upper Vale of Ffestiniog on a commercial scale since the late 1700s. The industrial revolution in Great Britain and Ireland required vast quantities of roofing slate to cover the roofs of factories and workers houses. Location and poor transport facilities initially hindered export capacities, however the opening of the Ffestiniog railway in 1836, combined with the continued high demand for roofing slate, resulted over the next century in massive output and the hey day for slate production in the Ffestiniog area.

Ffestiniog Quarry now comprises a series of surface excavations and deep mine workings previously collectively known as the Oakeley Mines. The Oakeley Mines originally comprised three adjacent areas worked by different companies under separate leases. Indeed two adjacent mines working the upper slate units were underlain by the third mine working a lower slate bed. By 1840 all the easily won slate from the surface quarries was exhausted and thereafter underground mining for slate ensued, pioneering the chamber and pillar technique. This comprised the development of a series of parallel chambers c. 13m wide separated by solid pillars 8-10m wide. The chambers and pillars are aligned on average c. 6-8° west of north and follow the "pillaring line" along which the slate naturally splits. The mines were worked in a series of levels or floors, and connecting roadways led to inclines, from where the slate block was transported to the surface.

With the mining leases running out, without any certainty of renewal, and mining and pumping costs ever increasing as the slate beds were chased deeper underground, progressive pillar robbing led to the inevitable. The "Great Fall" of 1882/83 resulted in the dramatic movement of c. 6.5Mt of material. The fall of ground destroyed large areas of the upper mines. The disaster led to one of the longest arbitration cases in legal history which eventually resulted in the lease owners, the Oakeley family, winning the case and amalgamating all workings into the largest slate mine in the world.

As part of the arbitration process, in 1886 the mine owners commissioned a detailed survey and geological mapping of the entire mine complex. This was beautifully drawn up in a series of geological cross sections through each chamber and pillar pair. Shown on these sections, and on an accompanying plan, is the proposed Victorian excavation limit for a surface mining excavation to remove the fallen rock in order to "untop" the best quality slate within the remaining pillars (see Figure 1). The "untopping" works began in 1890s and were still ongoing in 1901 using steam powered excavators. However progress, due to slow excavation by hand and later by steam shovel, was difficult and the surface excavation never reached the Victorian proposed excavation limits. The excavation void in 1907 is shown in Figure 2 and the highwall in 1940 following the initial phase of "untopping" is shown in Figure 3.

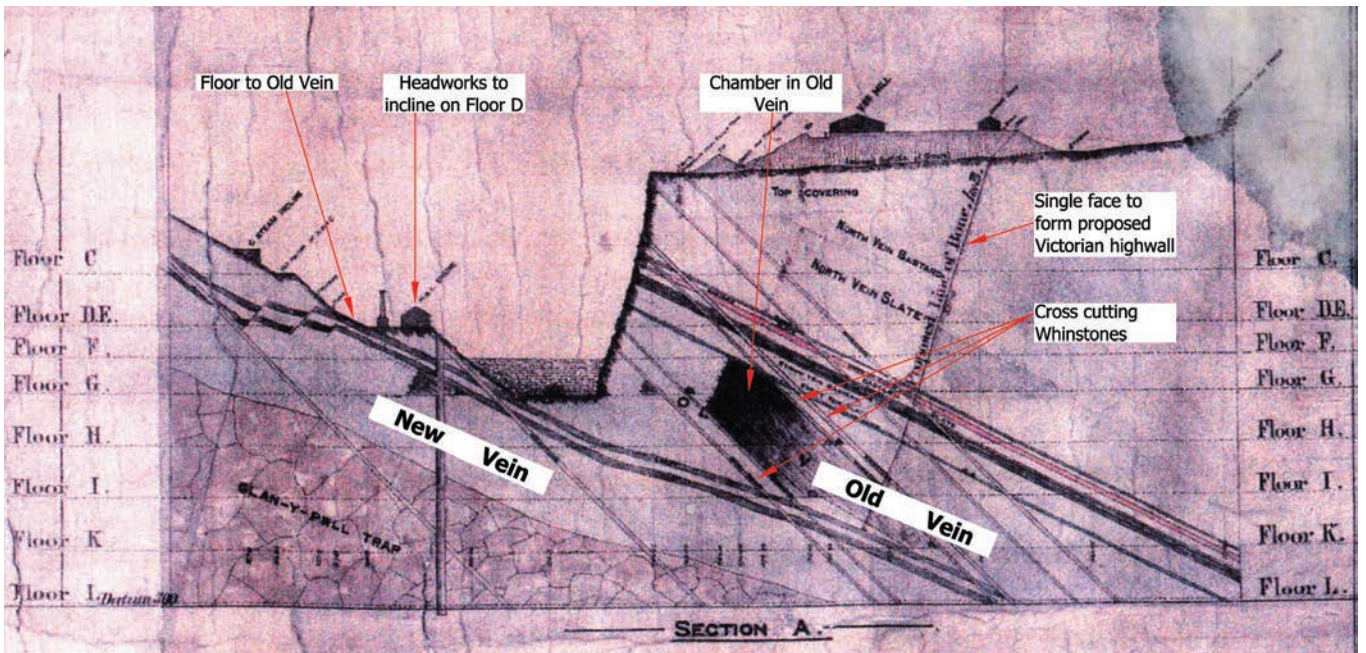


Figure 1. Victorian geological cross section through a pillar. Note Whinstones cross cutting slate beds.

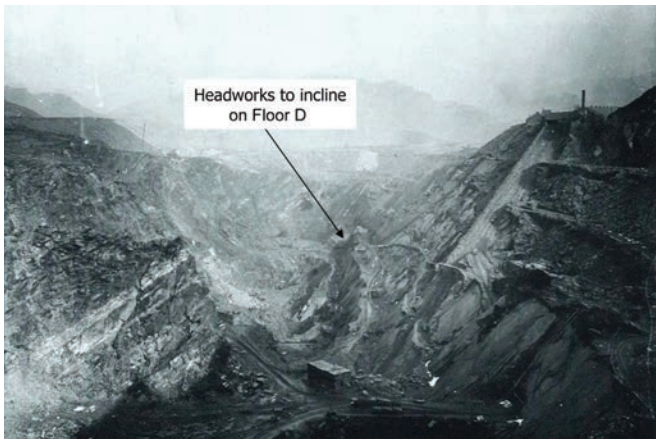


Figure 2. Oakeley workings in 1907. The cleft left by opencast workings and by partially removing upper sections of the Great Fall from Isberwood (1988), AB Publishing.

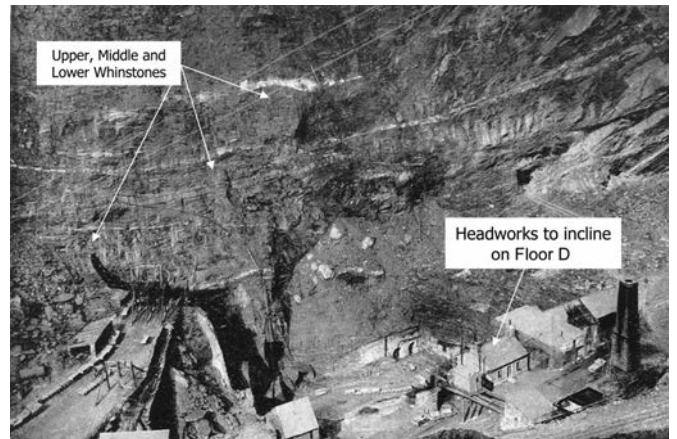


Figure 3. Oakeley workings in 1940 showing the inclines accessing the slate beds and the cross cutting Whinstones from North (1946), The National Museum of Wales.

The demand for slate steadily decreased from the 1890's and the mine eventually closed in 1969. There have been sporadic surface workings since then and more recently, concerted efforts to work ("untop") the remaining pillars in a similar manner to that proposed by the Victorians following the Great Fall. This comprised pushing back the NW highwall into the adjacent mountain side by a further 30m to expose the steeply dipping slate block below. Figure 4 shows the highwall of the re-named Ffestiniog Quarry in 2008 with the *in situ* rock mass adjacent to the fallen ground of the "Great Fall".

GEOLOGICAL SETTING

The slates exposed on the site form part of the Nant Francon Formation of Ordovician Age. They are underlain by volcanics which form the footwall and are interbedded with volcanic units and chert bands. These have been later cross cut by a series of quartz veins locally known as whinstones. The whole sequence dips to the NW at 25°; cleavage also dips to the NW a little steeper than bedding at 38-40°. The cross cutting

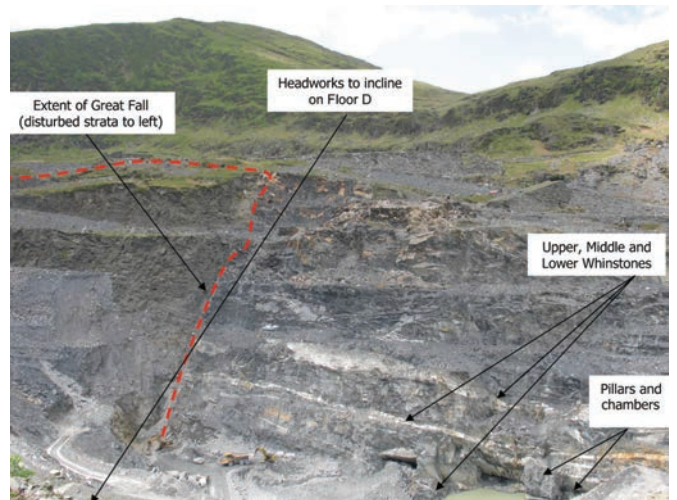


Figure 4. NW highwall of the Ffestiniog quarry workings in 2008.

whinstones dip at 50° with an azimuth 20 north of bedding/cleavage. There are 4No. persistent joint sets all of which are utilised in the extraction of slate block. The orientation of the chambers and pillars follows the

“pillaring line” along which the slate preferentially breaks but which is not coincident with any of the discontinuities within the rock mass.

Many of the slate beds (known as veins) were worked for roofing slate, the best quality slates were recovered from the Old Vein and later the New Vein beds, shown in Figure 1.

RESOURCE ASSESSMENT

Recently, an assessment of the available resources was undertaken to aid in planning the future quarry development, using a combination of the historic Victorian mapping and sections verified by 21st century mapping and quarry design tools. The assessment was undertaken to consider the lateral extent, *i.e.* the number of pillars, which could be commercially viable.

Access to the mine workings was not possible due to the level of the ground water and safety concerns. The extent of the remaining *in situ* pillars was therefore determined by digitising the mine plan based on the original Victorian surveys and an underground survey of 1931. Positioning of these historic plans relative to the modern GPS surveys on an OS grid was possible from tying known positions of a vertical water balance shaft, drainage adit and incline houses which are still accessible on site.

Critical to the resource assessment was the location of the slate beds and the cross cutting whinstones (shown on Figure 1) which dictate the quality of the best slate block which lies between them. As the strike of the slate beds and the whinstones is slightly oblique to one another, and the dip of the whinstones is greater than the

bedding then the block modelling of the reserves was not straight forward.

The position and orientation of the top of the Old Vein and whinstones along the highwall was established using a digital photogrammetric technique (ShapeMetrix) which accurately models the excavated faces in 3D by triangulation. From the triangulation, the position and orientation (where surface topography on the face allowed) of all the relevant geological features and surfaces could be determined. A rendered image of the highwall and inferred geological features is shown in Figure 5.

Each of the relevant features was also modelled by digitising each of the Victorian cross sections. When the current face position and traces of relevant surfaces from the ShapeMetrix analysis were superimposed with the surfaces modelled from the cross sections, the fit was remarkably close, *i.e.* within 1m both vertically and horizontally. Consequently it was considered that the models derived from the cross sections would be sufficiently accurate for use in the block modelling for the resource assessment.

The resource assessment considered the quantities of slate block within all remaining pillar and chamber (roof and floor areas) pairs. The quantities of quality slate block between each of the whinstone partings was calculated to a final depth limit (dictated by pumping limitations). An appropriate recovery factor was assigned to each parting so that an optimisation assessment could be undertaken which considered the volume of overburden to be removed to the volume of recoverable, saleable slate block from each pillar and chamber pair (see Figure 6).

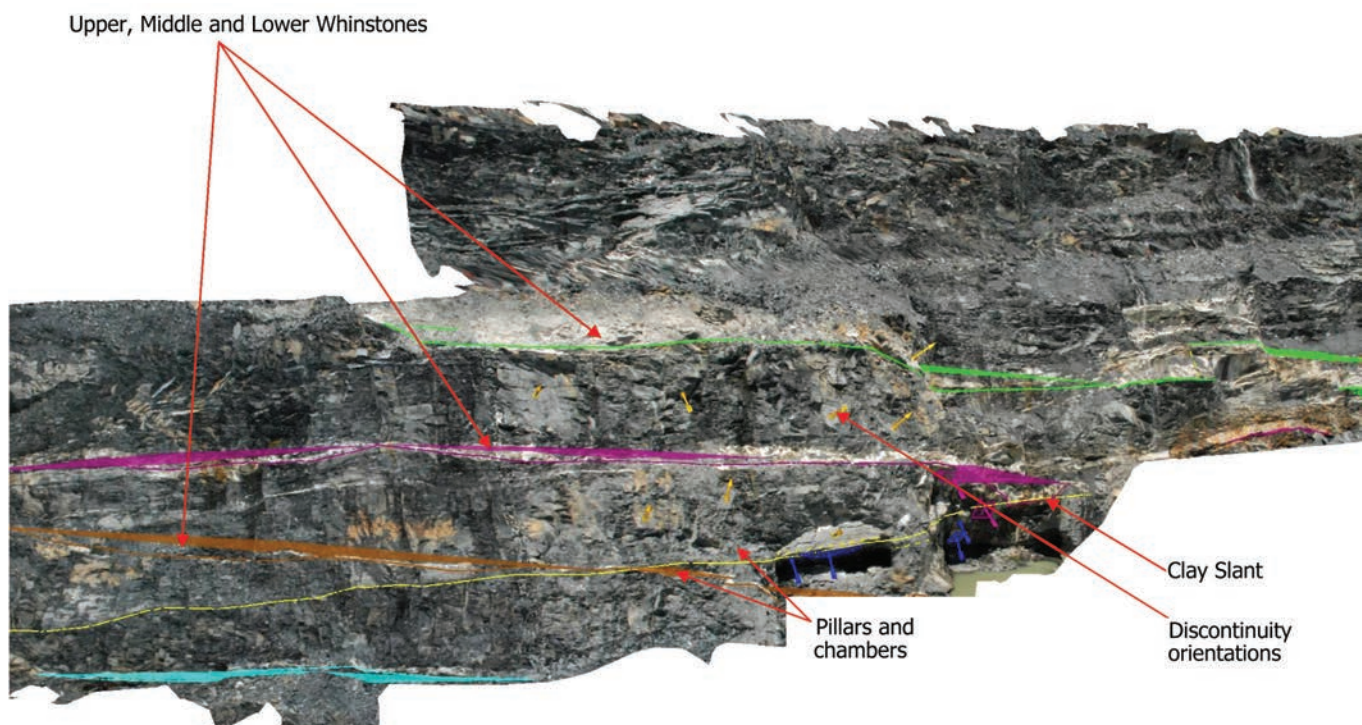


Figure 5. ShapeMetrix 3D rendered image used to determine the positions of the top of the Old Vein (Clay Slant), cross cutting Whinstones, pillar and chamber positions, bedding orientation (roof of chamber) and joint orientations.

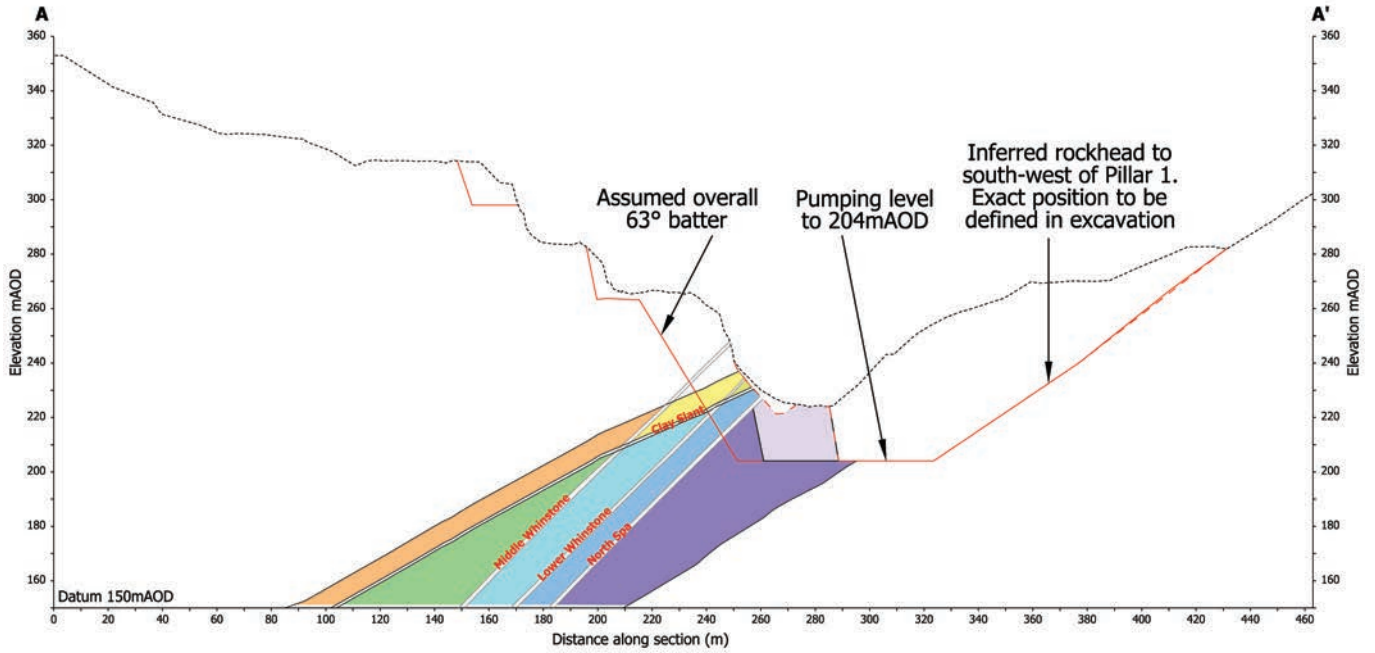


Figure 6. Section showing each of the units/partings (coloured) used to quantify volumes of remaining slate block, within the final excavation profile. Note, due to the oblique strike of Whinstones relative to bedding the volumes of each parting varied for each pillar and chamber.

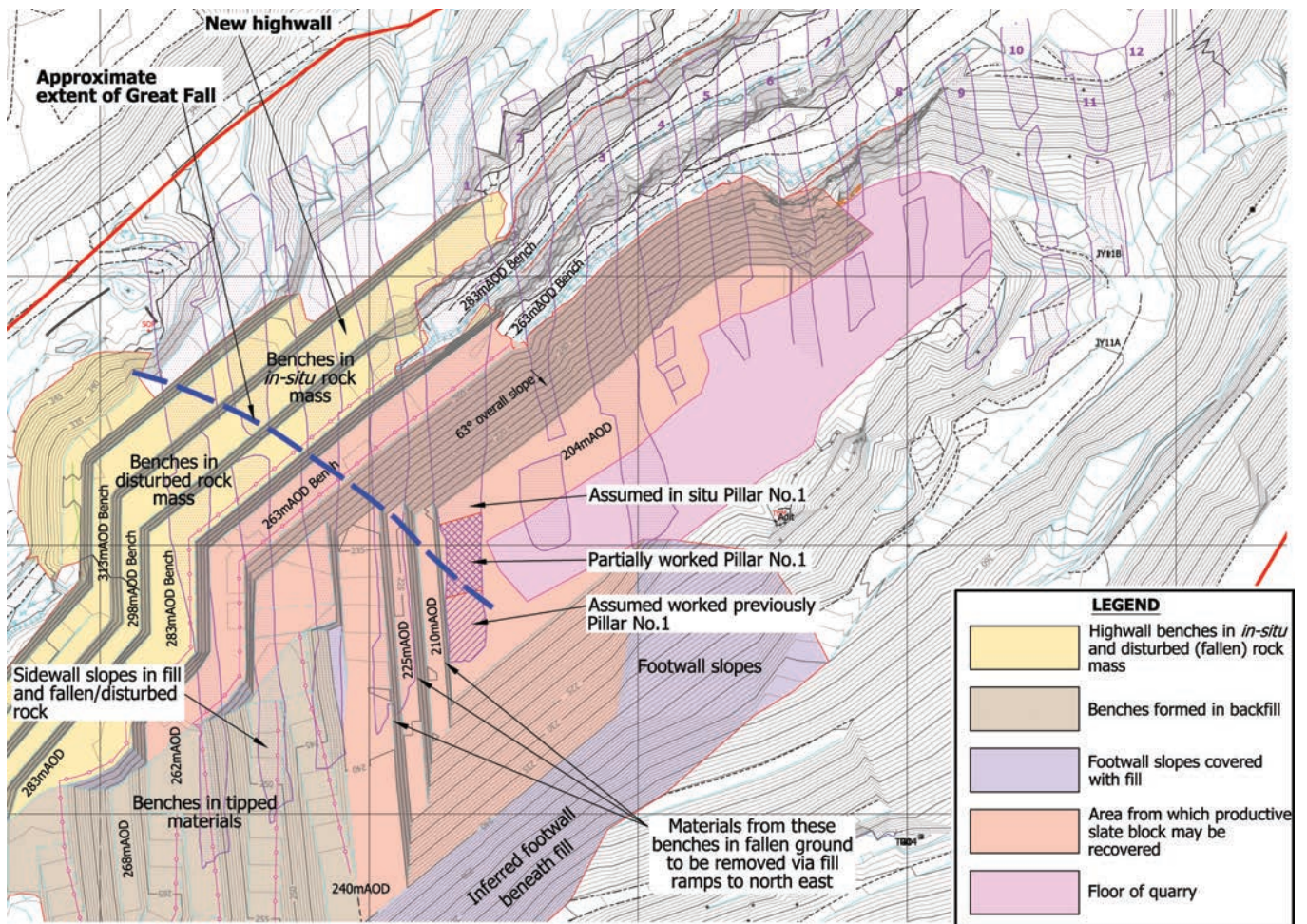


Figure 7. Excavation design based on geotechnical analysis and materials recovery optimisation analysis.

EXCAVATION DESIGN AND FACE MAINTENANCE

The optimised final open pit design is shown on Figure 7. Each of the quarry faces comprises very different geotechnical domains requiring different materials analysis and slope design. These included:

- Highwall; is split laterally into areas of a disturbed rock mass (i.e. within the area of the Great Fall), and a non-disturbed rock mass in which the upper zone is moderately weathered, and a lower zone in which there are numerous, stacked old workings. The undisturbed and disturbed zones required different final batter designs (see Figure 4),
- Footwall; the bedding surface comprises the base of the Old Vein. The extensive workings in the underlying New Vein workings are separated from the Old Vein by a 6m thick chert band.
- Sidewalls; the western side wall is split into two sections, an upper layer of recently tipped slate waste and a lower section comprising disturbed strata above the Old Vein chambers with materials fallen into and down the former Chamber No.1 West.

The excavated face design in undisturbed rock accommodates anticipated break-back based on kinematic analysis of discontinuities measured both from direct measurement and from the photogrammetric triangulations. Rockfall analysis down actual excavated slope profiles, also derived from the ShapeMetrix triangulations, was used to size the minimum bench widths required in order to maximise recovery (see Figure 8).

After developing the quarry design and undertaking geotechnical stability analyses, the bottom most face to the top of the Old Vein was formed, initially by bulk

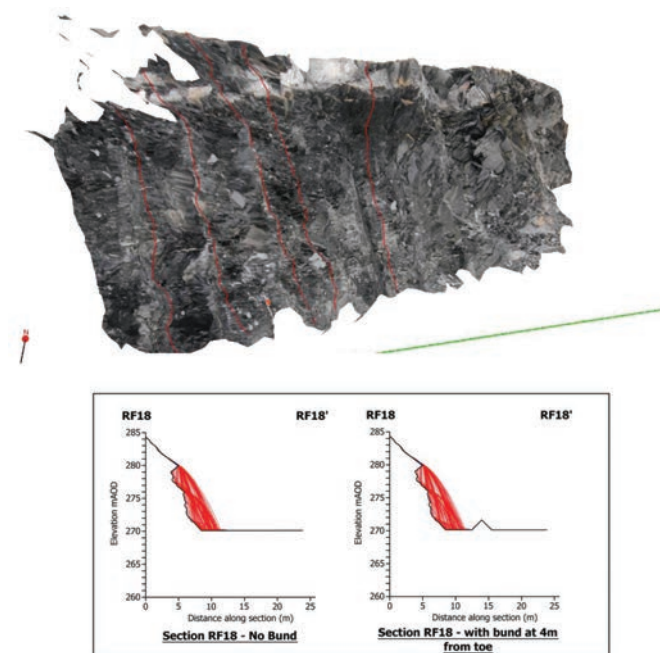


Figure 8. ShapeMetrix 3D images used to accurately profile the face to determine face profiles where rockfall may occur. Rockfall analysis undertaken every 5m along the bench.

blasting to a height of 18m to 22m. This was carefully scaled by roped access and machine as the blast pile was reduced. The face was then netted, and locally bolted, to control future localised rockfall. Extraction then continued by working the pillars progressively in 4m high lifts using narrow diameter drilling and black powder (which leaves a clean face). As the face height increased it could no longer be scaled by machine if it were to markedly degrade, consequently the face netting was progressively extended 6m behind the deepening face. Figure 9 shows the development to the completion of the proposed design, and working of the last pillar (Pillar No. 1) to final depth.



Figure 9. 2009-2010 development to recover Pillar No.s 1 to 5.

END NOTE

At the time the paper was presented to the 2010 EIG conference the quarry had recently been forced to close. Collapses of a series of deep chambers 200m to the west of the working area progressed towards the active quarry area over a period of 2 months. Cracking in the upper benches above the worked out pillars occurred in January 2010 and it was considered too unsafe to access the floor area below. Sadly this has ended 160 years of slate mining in the Oakeley Mines area.

REFERENCES

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- North, F.J., 1946. The Slates of Wales. The National Museum of Wales.