DUNBAR CEMENT WORKS QUARRY, EAST LOTHIAN: 45 YEARS ON

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Abstract

The cement works at Dunbar, 20 miles east of Edinburgh, is the only cement clinker manufacturing facility in Scotland. The quarrying of raw materials commenced in 1961 and the cement works was commissioned in 1963. The works is supplied with limestone and shale from an adjoining quarry that works an inlier of Lower Carboniferous strata. A number of planning, environmental and geological issues have had to be resolved in the transition from the northwest to the new northeast quarry, the two areas being separated by a fault zone. Although subject to a planning consent for mineral extraction, the northeast quarry did not have an approved working scheme. Quarry design issues, block modelling, and prediction of pre-homogenisation pile chemistry are reviewed.

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Introduction

The cement works at Dunbar, East Lothian, 20 miles east of Edinburgh, is the only cement clinker manufacturing facility in Scotland. The site is immediately adjacent to North Sea. It has a long history of mineral extraction with the underground mining of limestone from Oxwell Mains Mine supplying a lime works on the site between 1908 and 1959. Previous papers on the Dunbar Quarry are Collin and Waring (1983) and Grimshaw (1992).

The site was selected in the late 1950s / early 1960s by APCM (Associated Portland Cement Manufacturers) as the only economically accessible deposit of raw materials suitable for cement making in Scotland (Figure 1). In 1963 a two-Lepol kiln works was commissioned, with a third kiln added in 1966 increasing the output 700,000 tpa. At this time the factory and quarry employed 550. In 1985, the operation was converted to a single precalciner kiln with a capacity of 850,000 tpa and the number of employees reduced to 250. In 2001, following a £35m investment the plant was up-rated to 1,000,000 tpa and the number of employees further reduced to 140. This investment included the diversion of the A1 trunk road to maximise the recovery of the limestone reserve. In 2006 a further £18m investment in a SOx scrubber was announced. This project is largely complete and due to be commissioned at the end of 2007. The production of sulphur dioxide (SO_2) is related to the high levels of pyritic sulphur present in the limestone and shale.

Geology And Geochemistry

Dunbar Quarry works limestone from part of the Lower Limestone Group of Lower Carboniferous age. The Lower Limestone Group overlies the Calciferous Sandstone Measures which form the base of the Carboniferous, overlying Devonian Old Red Sandstone. The base of the Lower Limestone Group is marked by the lower limestone bed worked in the quarry (Figure 2). The Lower Limestone Group is characterised by repeated marine conditions during which fossiliferous limestones were deposited. The marine conditions are separated by periods of emergence during which time vegetation flourished leading to thin coal seams being formed.

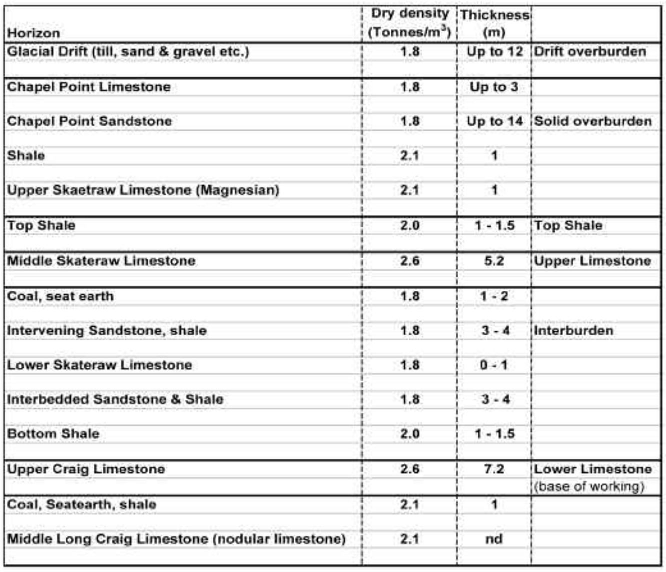
Mining Method

The mining method at Dunbar is a ‘strip mining’ technique that allows rapid restoration and uses one of only two cross pit conveyor bridge transporters in the world (Table 1) (Figure 3). The working cut is advancing in a south-westerly direction. The strip mining operation has been interrupted by a fault zone which has recently resulted in a transfer of the quarry operations from the north-west which has been operational since 1982 to north-east quarry. The division between the quarries is an up-thrown fault block where the limestone beds are absent.

Review Of North-west Quarry Issues

The north-west quarry commenced in 1982 when operations transferred from the original south quarry. A number of quarrying issues have been encountered during this period including lower than expected bulking factors for waste rock, thinning of the upper limestone along the crest of an anticlinal fold and minor faulting with associated dolomitisation of the limestone beds.

Figure 1. *Layout of Dunbar Quarry site.*



Horizon	Dry density (Tonnes/m³)	Thickness (m)	
Glacial Drift (till, sand & gravel etc.)	1.8	Up to 12	Drift overburden
Chapel Point Limestone	1.8	Up to 3	
Chapel Point Sandstone	1.8	Up to 14	Solid overburden
Shale	2.1	1	
Upper Skaetraw Limestone (Magnesian)	2.1	1	
Top Shale	2.0	1 - 1.5	Top Shale
Middle Skateraw Limestone	2.6	5.2	Upper Limestone
Coal, seat earth	1.8	1 - 2	
Intervening Sandstone, shale	1.8	3 - 4	Interburden
Lower Skateraw Limestone	1.8	0 - 1	
Interbedded Sandstone & Shale	1.8	3 - 4	
Bottom Shale	2.0	1 - 1.5	
Upper Craig Limestone	2.6	7.2	Lower Limestone (base of working)
Coal, Seatearth, shale	2.1	1	
Middle Long Craig Limestone (nodular limestone)	2.1	nd	

Figure 2. *Carboniferous stratigraphy of Dunbar Quarry.*

The bulking factor envisaged in 1980 when the North West Quarry was being planned was 30%. Experience has shown this should have been much lower at approximately 20%. This error has resulted in a shortfall of backfill material, making it necessary in 2001 to change the restoration scheme from predominantly agricultural to wetland and coastal scrub woodland on slopes. Figure 4 shows a photomontage of the consented scheme.

The upper limestone along the crest of an anticlinal fold was found to be both heavily weathered, resulting in contamination of the limestone (Figure 5) and reduction in thickness. The contamination reduces the grade of the limestone below kiln feed. The quality of the limestone in the area where the limestone outcropped beneath the glacial drift had not been investigated in detail during the 1970s. Thus, the depth of weathering and associated contamination of the limestone had not been fully anticipated. Structural modelling in 2001 of the base of glacial drift and the top of limestone had however allowed a detailed prediction of the thinning of the

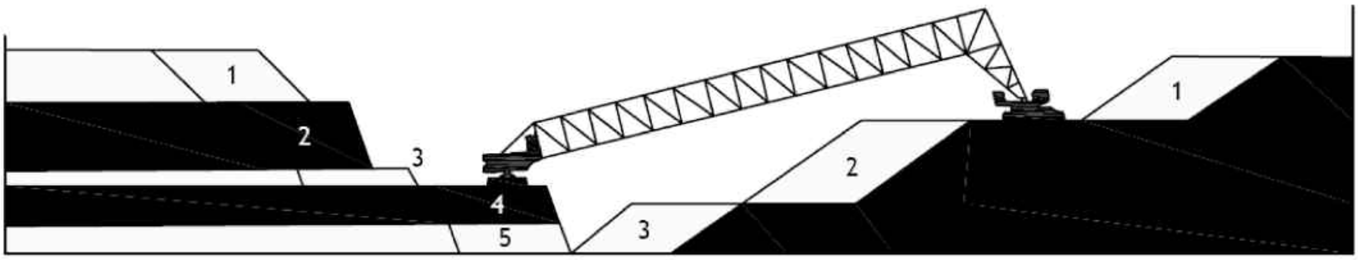
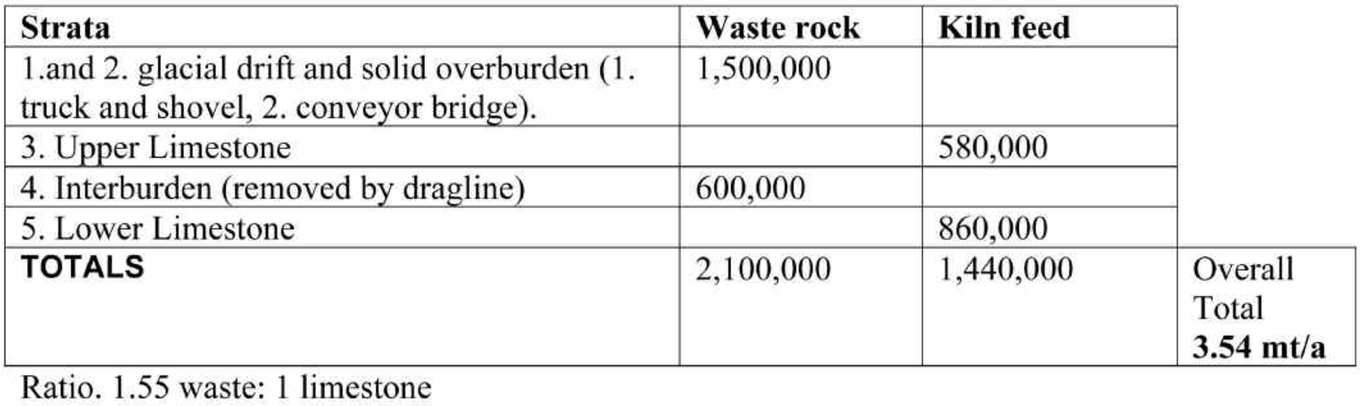


Figure 3. *Configuration of strip mining. Numbers refer to strata given in Table 1.*



Strata	Waste rock	Kiln feed	
1.and 2. glacial drift and solid overburden (1. truck and shovel, 2. conveyor bridge).	1,500,000		
3. Upper Limestone		580,000	
4. Interburden (removed by dragline)	600,000		
5. Lower Limestone		860,000	
TOTALS	2,100,000	1,440,000	Overall Total **3.54 mt/a**

Ratio. 1.55 waste: 1 limestone

Table 1. *Average annual tonnages of waste and limestone feed (numbers in Table 1 and Figure 3 show rock units in geological sequence and once tipped).*

Figure 4. *Photomontage showing the northwest and northeast quarry restoration.*

limestone to be prepared (Figure 6). Limestone from the contaminated areas was recovered with the use of a forked excavator bucket (Figure 7).

The limestone is affected by minor faulting, 0.5m throw. However, the main issue with quality control is the occurrence of dolomitisation immediately adjacent to the fault plane. In some instances the dolomitised stone is clearly visible with a distinct orange colour. In others it has a very similar colour to the unaffected limestone. Dolomitised limestone must be rejected or blended very carefully (Figure 8).

NORTH EAST QUARRY

Planning and environment

The transfer of operations from the north west to north east quarry resulted in both a major planning submission to gain working scheme approval and a capital application to undertake the various projects. Requirements included

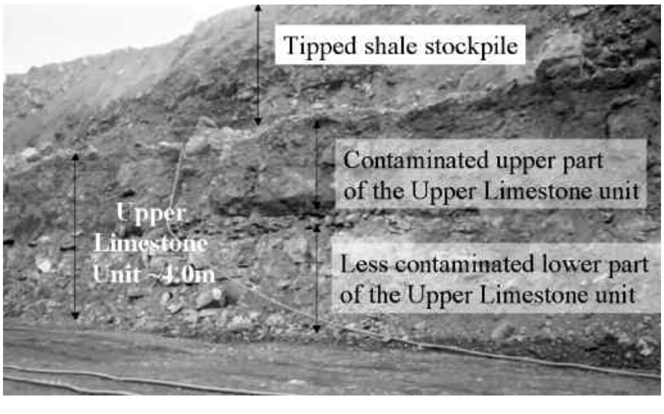


Figure 5. *Photograph of part of northwest quarry showing contamination of the upper limestone.*

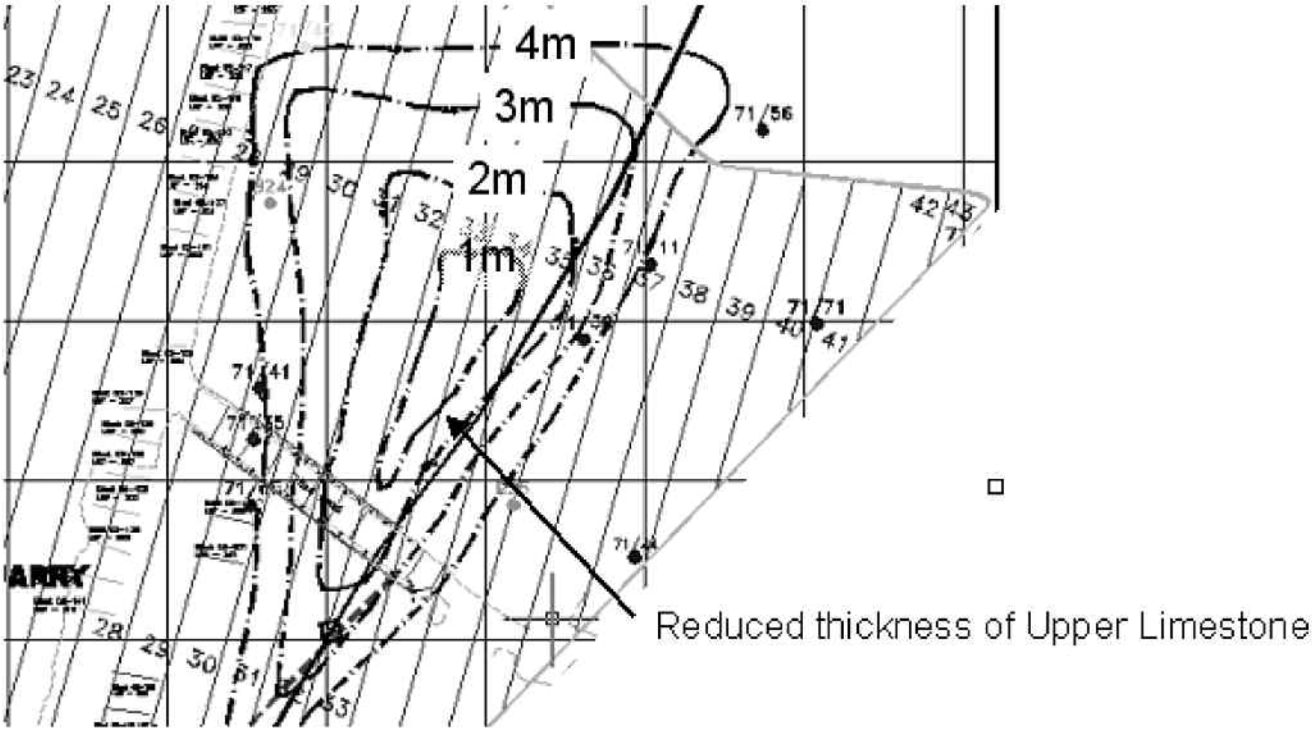


Figure 6. *Extract from the North West Quarry geological information plan showing the reduced thickness of the upper limestone (grid lines at 100m spacing).*

Figure 7. *Photograph showing recovery of limestone from contaminated face.*

diversion of BT phone lines, diversion of underground electricity lines, purchase of adjoining residential property (Cat Craig), relocation of a caravan park, diversion of the works waste water discharge pipe, diversion of the White Sands and Barns Ness public roads, creation of a cycle path, demolition of a the East Barns Farm (a listed building) and completion of extensive archaeological studies (Figure 9). These projects will be on-going for a number of years.

The archeological investigations, undertaken by AOC Archaeology (Gooder, 2003), unearthed evidence of a Mesolithic family of hunter-gatherers who roamed the post glacial Scottish landscape between *circa* 7650 - 8300 BC. The find was very exciting for archaeologists as it gave evidence of the oldest houses yet found in Britain. Structures of this period are extremely rare and there are only a handful of comparable examples in the British Isles. This is the only example so far found in Scotland. The principal finding, a near-circular building (Figures 10 and 11) was marked by deep postholes for large, heavy timbers set at an angle into the ground, suggesting that it was possibly 'dome' like. Previously, Mesolithic structures in Scotland have been limited to windbreaks and other temporary shelters. Large quantities of Mesolithic flints were found on the site and radiocarbon dates confirm that the house was from the early part of the period some 10,300 years ago. The location of the house was identified by a combination of geophysical survey and trial trenching, which led onto detailed excavation and recording of the specific area.

Block modelling

Lafarge utilise block modelling in the mine planning of all sites. This necessitates the creation of four spreadsheet files: -

Collar -	x, y, z - mE, mN, mASL, coordinates for all exploration boreholes,
Survey -	survey of the geometry of the boreholes,
Sample -	chemical samples of core,
Geology -	geological contacts.

Once this database of information has been prepared it is checked then imported, validated and geological surfaces modelled within Surpac. In addition, topographic survey and final pit design is imported. For the northeast quarry a pre-existing design, prepared in using 'LSS' software, was imported. It was not necessary to design the pit within Surpac.

The resulting block model of the 2.5km x 0.85km-sized site contained 250,000 blocks, with a block size of 20 metres x 20m x 2m, with sub-blocking allowed. The total number of boreholes used to model the geology was 123, drilled between 1959 and 2004. A total of 1,948 chemical analysis samples were available.

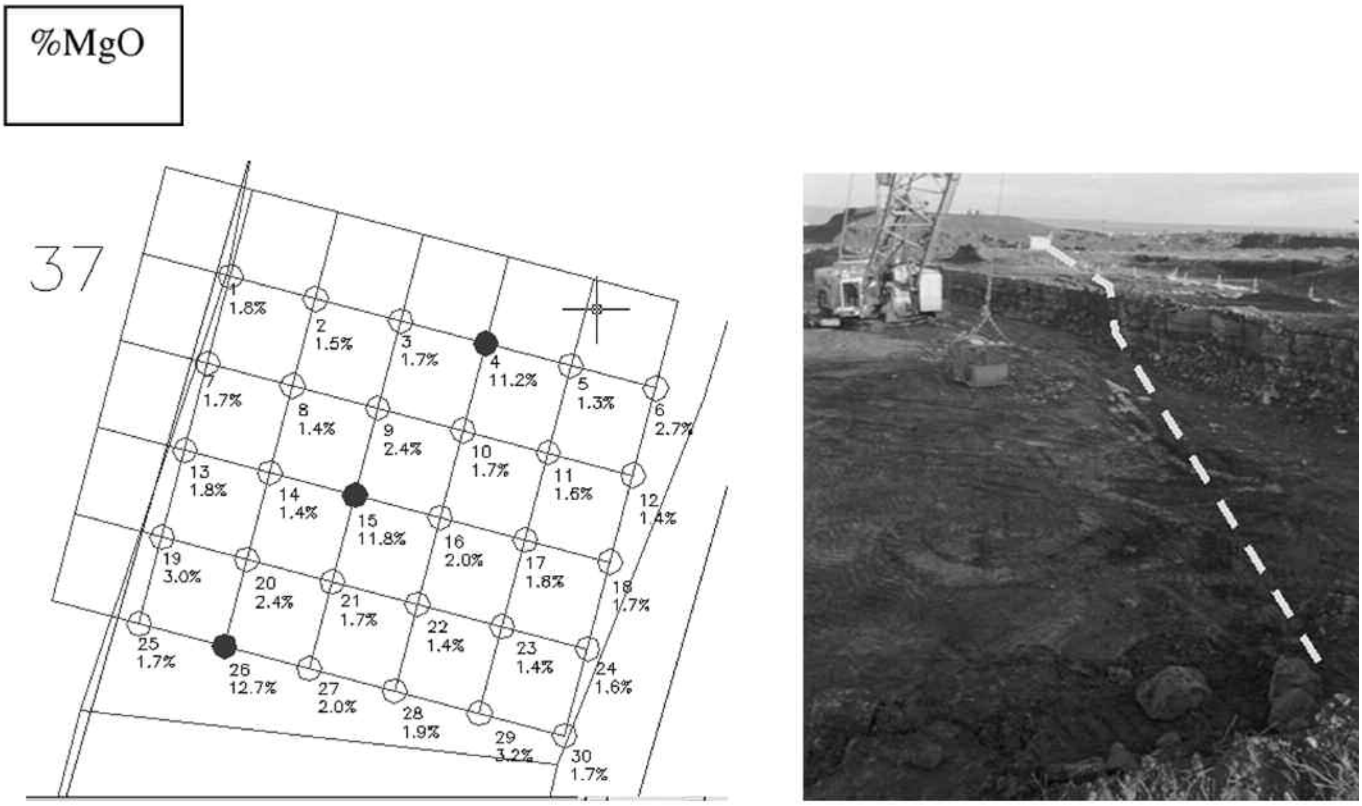


Figure 8. *Upper limestone, blast no 136/137, which has an average MgO of 2.8%, but shows contamination associated with a dolomitised fault up to 12.7% MgO.*

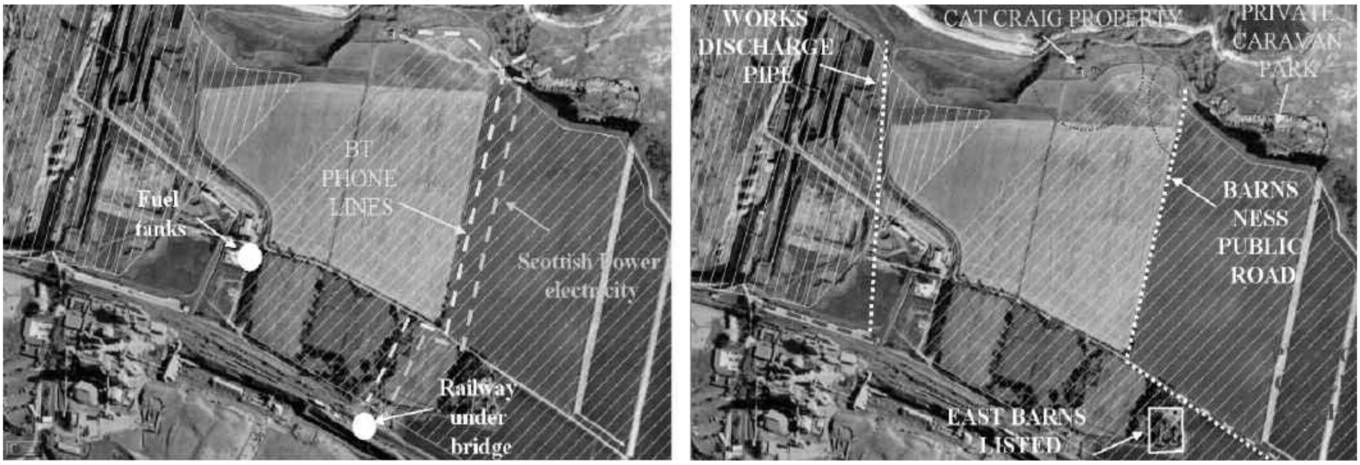


Figure 9. *North east quarry. Details of planning issues.*

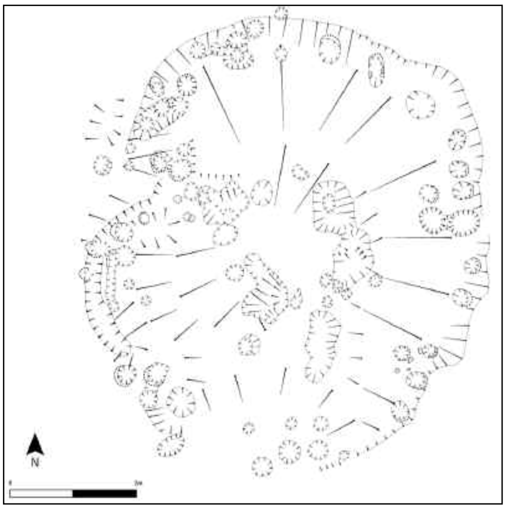


Figure 10. *Layout of Mesolithic house determined by archaeological survey.*

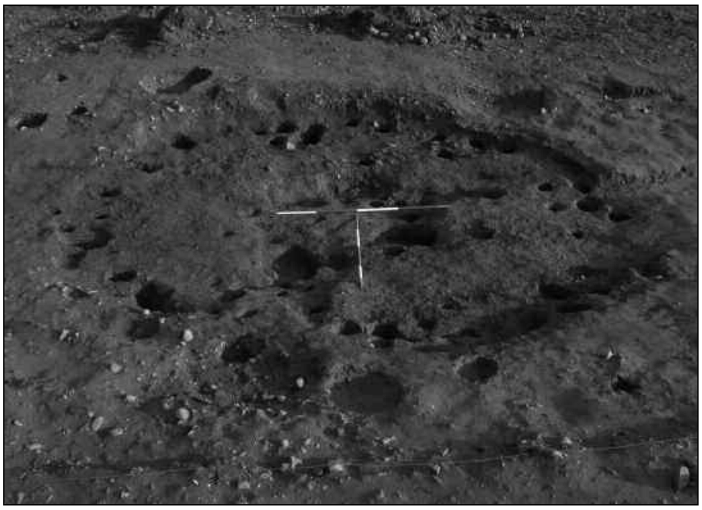


Figure 11. *Photograph of the Mesolithic house.*

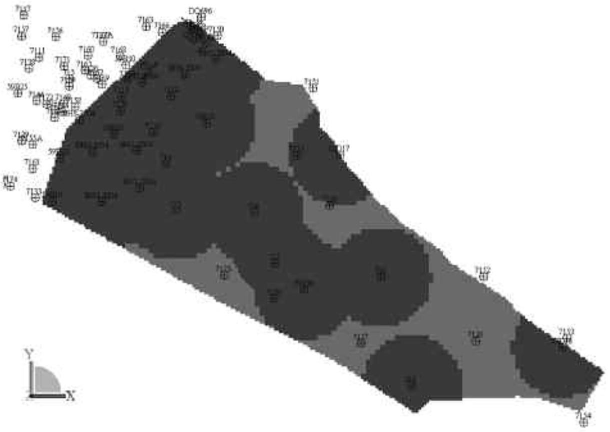


Figure 12. *Block model of 1st and 2nd pass infilling of north east quarry.*

A search ellipse for the first pass, defined from variograms, was an ellipse with a radius of 190 metres (dark area in Figure 12). Beyond this distance a second pass of data infilling using inverse distance was utilised.

In 2004 only 20% Upper limestone and 40% Lower limestone in the north east quarry was considered to be geochemically proven. Limited additional drilling had increased the proven reserve by 2006 to 60% Upper limestone, 45% Lower limestone. The light area in Figure 12 represents the chemically unproven reserve. On the whole, this is considered geologically proven as some of the boreholes drilled in 1971 were not chemically tested, but the limestone is known to be present. The method of block modelling is used to assist with the justification for additional drilling and to allow comparison of the day-to-day production quality with predictions.

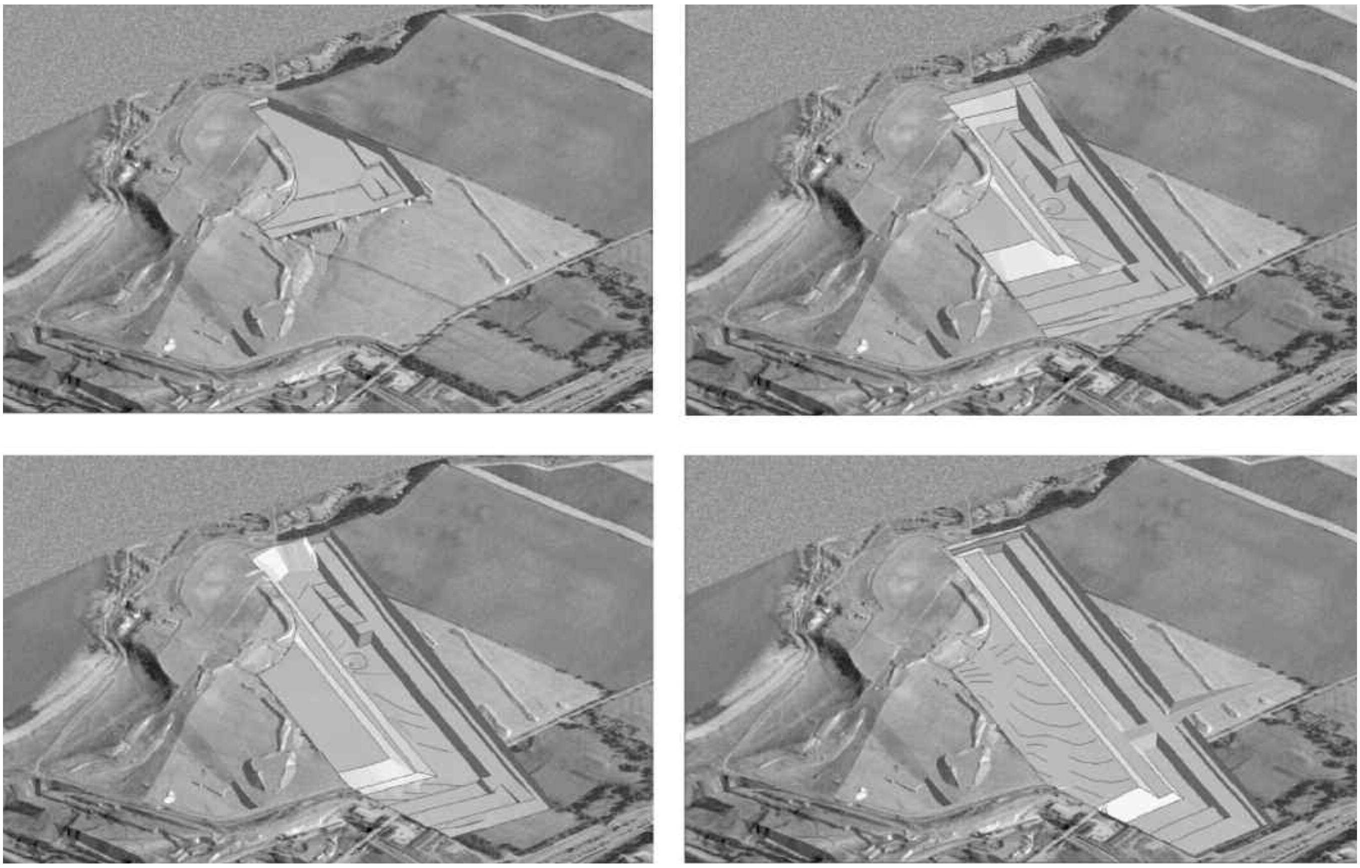


Figure 13. *North east quarry showing phases of box-cut development (prior to acquisition of Cat Craig).*

Figure 14. *The Dunbar 'cheese sampler'.*

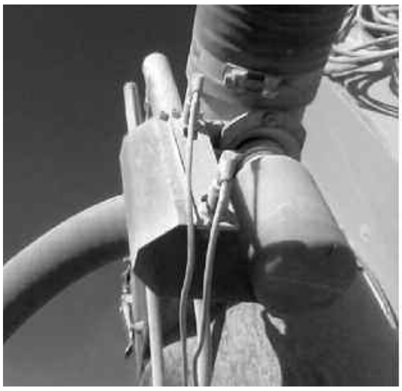
Quarry planning

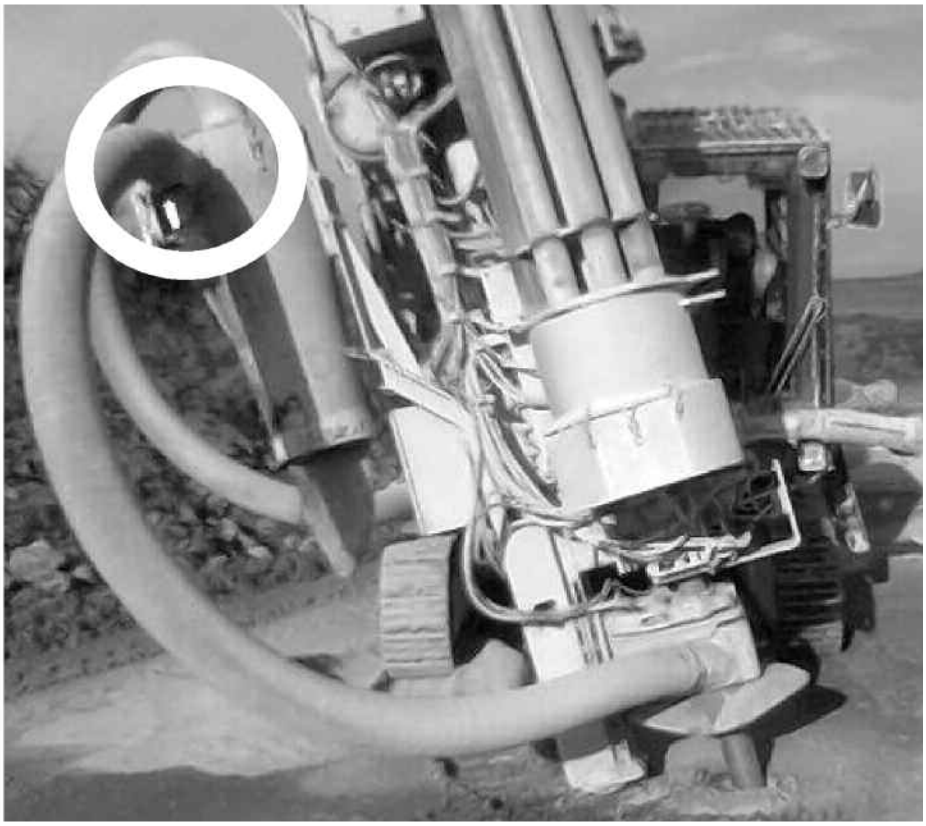
Using the block model, a series of phased development plans for the quarry was created (Figure 13). The geological and geochemical knowledge permitted prediction of quality variations through each phase of development.

RAW MIX CONTROL

In order to control the raw material mix into the cement kiln you start at the quarry. Sampling and analysis of drill chippings is the normal starting point. These have to be correctly sampled to give representative information. The blasts where the samples originated need to be clearly identified and located in order to trace potential problems. Dunbar Quarry progressed in a short period

Piston sampler out of the air stream





Piston sampler in the air stream

AUTEC drill sample device (in operation at Hope Cement Works)

Figure 15. *AUTEC drill chip sampling device.*

Blast No.	Date Fired	Hole No.	SiO_2	MgO	$CaCO_3$	LSF
02-106	08/10/2002	Average	4.9	1.5	85	280
02-110	15/10/2002	Average	4.6	1.5	85	291
02-115	24/10/2002	Average	4.1	1.5	87	334
02-121	04/11/2002	Average	4.1	1.5	88	340
02-126	26/11/2002	Average	4.3	1.3	88	333
02-128	29/11/2002	Average	3.9	1.4	90	370
02-134	17/12/2002	Average	5.2	2.0	84	258
02-137	19/12/2002	Average	4.2	2.8	81	293
02-140	30/12/2001	Average	4.4	1.6	87	319
03-001	06/01/2003	Average	4.2	1.6	88	331
03-006	12/02/2003	Average	4.7	1.7	86	294
AVERAGE		Average	4.4	1.9	86	308

Figure 16. *Extract from blast average table.*

of time from a shovel in the drill chipping pile, to a "cheese" sampler (Figure 14), ultimately ending up with a semi-automatic piston sampler (Figure 15).

The AUTEC drill chip sampler (Figure 15) collects a maximum of 1kg sample in a plastic bottle; it operates by use of a hydraulic piston that enters the air/dust stream. The frequency that that the sampler can enter the air stream is in essence dictated by the face height. If it is set too frequent it will overfill the sample bottle. If too infrequent it will only partially fill the bottle and reduce the reliability. For shallow faces the frequency is very high. At Dunbar two different frequencies are used for the upper and lower limestone beds to maximise the sample size. The geology means that the reliability of the results is very reliant upon the skill of the driller. Switching it off immediately the drill has penetrated the base of the limestone unit, just 70cm of shale in the limestone sample, can reduce the quality to apparently below kiln feed. The technique has proved successful assuming that you provide the right bag size and the laboratory prepare the sample correctly.

Once correct blast hole chipping samples are collected these are analysed by the works laboratory. The results of the analysis of each blast hole are used to calculate an

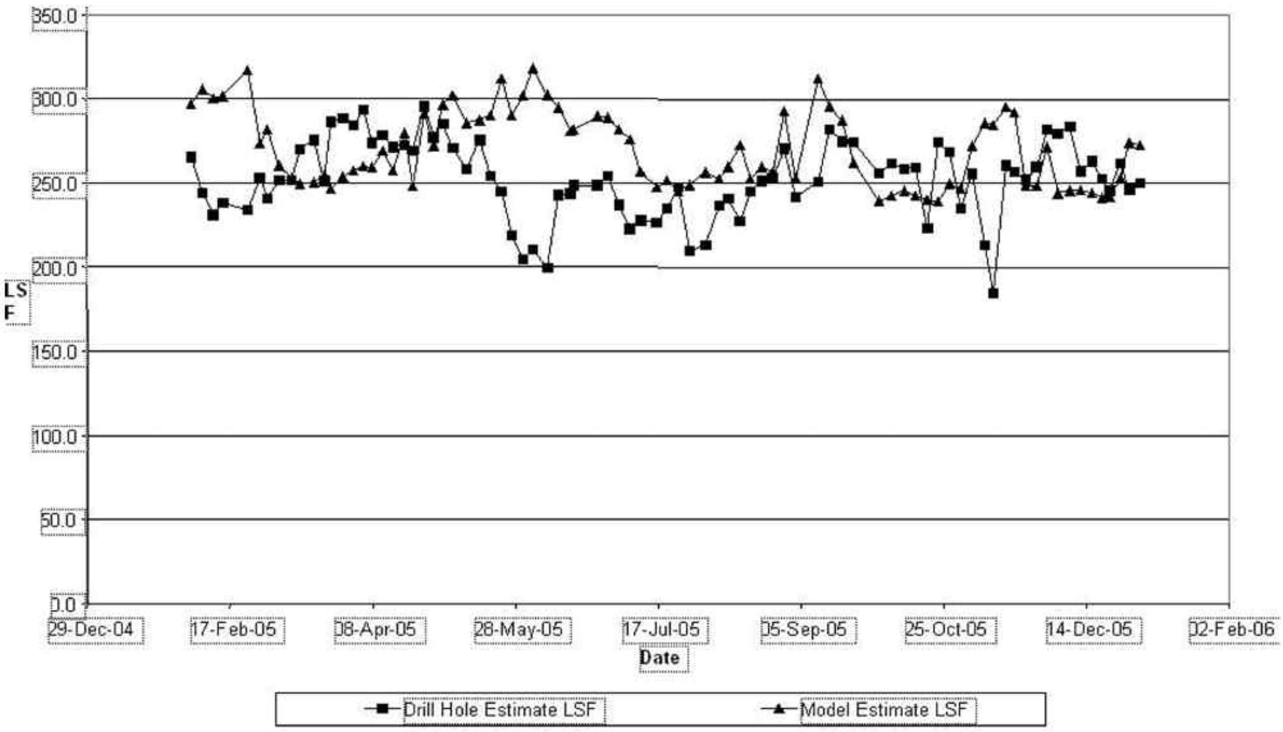


Figure 17. *Comparison between drill hole and block model LSF.*

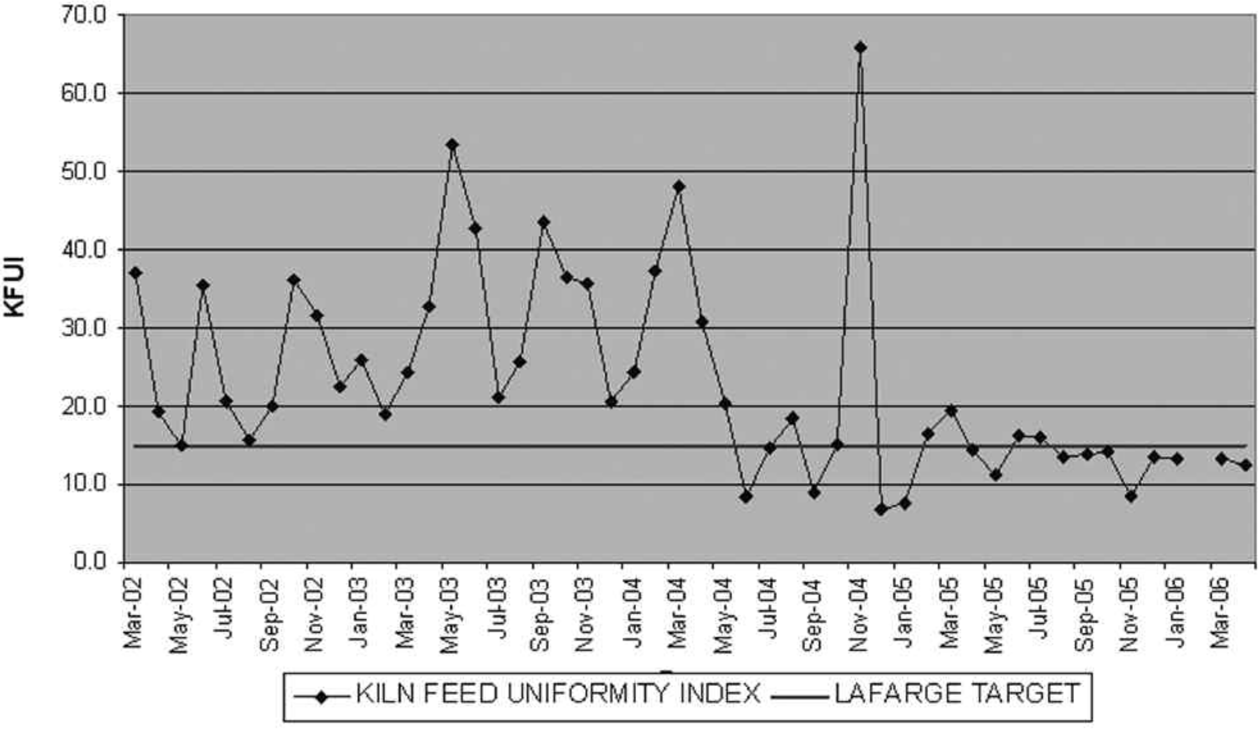


Figure 18. *Progression of the Kiln Feed Uniformity Index (KFUI) at Dunbar. The LaFarge target is at 15 KFUI.*

average chemistry. From this the calcium carbonate and LSF (lime saturation factor) and other cement chemistry target parameters are calculated. As can be seen in Figure 16 blast holes contaminated with small quantities of dolomitic limestone are easily recognised from the increased MgO content.

Using a very simple truck counting exercise recorded by the crusher operator a daily tonnage of upper and lower limestone is calculated. This is related back to specific blasts and a weighted average chemistry calculated for the pre-homogenised limestone pile (representing two days quarry production). A limited number of 'quality' driven quarrying decisions can be made half way through a stockpile build.

The validity of the drill chipping data once the AUTEC sampling device was in use has been verified by reference to the theoretical data from the block model for each blast (Figure 17). This correlation was on the whole a good one. Ultimately it took a lot more than correct sampling to improve the control of the raw material mix. Targeted phased investment involving a combination of improved sand and shale feeders, construction of a surge hopper, statistical blending and end pile modifications all helped at the start of 2005 to reduce the Kiln Feed Uniformity Index (Lafarge's global measure of kiln feed consistency) below the target level (Figure 18). Cross belt analyser technology is the next step to control raw mill feed chemistry further and is now installed and fully functioning.

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