IMPACT OF AGGREGATES EXTRACTION AND TRANSPORTATION ON THE HISTORIC ENVIRONMENT

English Heritage Archaeology Commissions Project

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FINAL PROJECT REPORT

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1 EXECUTIVE SUMMARY

This project examined the impacts of dust, noise and vibration from aggregates quarry working and transportation on two historic villages, Cromford in Derbyshire and Horton in Ribblesdale, Yorkshire, which both contain listed buildings and structures that are in close proximity to large aggregates workings. The quarries studied were both hard rock quarries, where rock was extracted and crushed on site.

1. Monitoring and consultation

Summer (August, 2005) and winter (January, 2006) field monitoring campaigns were undertaken to measure dust, noise and vibration near the quarries and transport routes leading from them. Measurements were made inside and outside listed and historic buildings in the villages, these being mostly domestic dwellings for which special arrangements had to be made with the local residents. Local authorities, quarry operators and the local community were extensively consulted as part of the research.

2. Dust

The results show that quarry dust was found inside all the houses that were investigated, up to distances of almost 1km from the quarry perimeters. Freshly worked quarry dust was identified under the microscope because of its sharp edges. This is potentially abrasive to delicate surfaces and finishes. The dust was readily weathered in the outdoor environment and could be washed from building surfaces by rain. The main nuisance/damage potential for the dust was on outdoor surfaces not washed by rain and indoor surfaces and on delicate outdoor surfaces such as the paintwork on cars. This could have implications for the maintenance of historic street materials such as delicate leadwork and old glass.

3. Noise and Vibration

Quarry wagon noise was found to detract significantly from the setting of the historic villages particularly at Cromford, which experiences the most intensive quarry traffic. Ground borne vibration whether from quarry blasting or wagon transportation was found to be well below the threshold at which damage to even the most delicate structures is thought to begin. Quarry blasts that occurred during monitoring did not result in any measurable vibration in the villages.

4. Policy implications

Given the strict regulation of the industry and the demonstrably low impact on the historic environment and communities, the results of this research may be used to support the argument for working quarries that are an essential source of good building stone for the repair of historic buildings. They are what sustain the great building traditions, providing local materials that often have been used for centuries.

2 ACKNOWLEDGEMENTS

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3 INTRODUCTION

The UK aggregates industry extracted 220 million tones (Mt) of natural aggregates in 2000. Whilst sand and gravel production declined between 1965 (100 Mt produced) and 2000 (85 Mt produced), crushed rock production has shown a considerable increase over this period, from 60 Mt in 1965 to 130 Mt in 2000 (Source: British Geological Survey).

Aggregates industry production peaked at 303 Mt in 1989. Increased demand from the 1960s to 1980s was fuelled by road construction and higher maintenance standards required a higher proportion of aggregates. However from the 1990s on there has been a decline in the production of primary aggregates due to greater use of recycled aggregates, foreign imports and more recently the effect of the Aggregates Levy. UK Production has now stabilized at around 200-210 Mt. The industry itself expects production to continue at this level for the next decade or so (Quarry Products Association). UK government allocations (ODPM, 2004) indicate that crushed rock aggregates extraction in England will continue at current levels in the short-term but may rise further into the future.

There has been a trend towards the exploitation of larger quarries in remote areas and the closure of smaller local quarries as these have become uneconomic. As a result aggregates are now transported over much greater distances than previously. In 1997 road transport accounted for 94.5% of these journeys, with the remainder consisting of rail (5%) and water (0.5%). Of necessity, extraction will take place in some of England’s most historic and valued landscapes, where these resources are located, and which can be transported economically to nearby urban conurbations. The expansion of aggregates extraction and transportation over the last 40 years has led to an increase in its potential impact on historic sites and buildings in England’s villages and towns. Mineral extraction processes can cause considerable damage to the historic environment, local buildings and along transport routes. It has therefore been timely to investigate these issues.

This project developed a methodology to investigate the impact and provide guidance on ways in which impacts can be better managed.

3.1 Potential for interaction of the aggregates industry and the historic built environment

The geology of the British Isles means that many of the sources of crushed rock aggregate occur in upland areas of England, such as the Peak District and Yorkshire Dales. These are areas of great natural beauty with vulnerable historic landscapes, archaeological sites and buildings. Because of the high cost of transporting heavy aggregate materials over long distances it is expected that demand for aggregates from these areas, supplying the nearby West Yorkshire, Lancashire and Midlands conurbations will continue for the foreseeable future. In the East Midlands out of a total of 2166 Crushed Rock Permissions, 284 (13%) fell within the Peak District National Park, whilst in the Yorkshire and Humber region, 149 Crushed Rock Permissions out of a total of 471

(32%) were in a National Park. The vast majority of these were in the Yorkshire Dales National Park with a few permissions in the North Yorkshire Moors National Park.

3.2 Scope of the present project

The scope of this project was to investigate physical impacts of aggregates extraction and transportation on the historic environment and to develop a methodology by which these impacts could be studied. The main physical impacts of aggregate transportation and extraction were perceived to be vibration, noise and dust and these were investigated. Issues such as the visual intrusion of quarries in the historic landscape and what happens to quarries that are no longer in use fell outside the scope of the project. However the perceptions of local residents of the aggregates industry were investigated.

Vibration has the potential to cause several types of damage to historic buildings and monuments:

- It is supposed that over long time periods, load reversals (i.e. the flexing of materials induced by the vibration as it passes through a material or the air) can result in damage to delicate historic finishes such as renders and plasters. When amplified through the height of a structure or as a result of responsive floors, there is some evidence that ground borne vibrations can result in objects moving along surfaces.
- Blasting of hard rock is the most common source of vibration in aggregates extraction, a source which does not exist in sand and gravel extraction.
- Some ground borne vibration can also be generated through processing plant and vehicle movement, for example wagons climbing steep hills in villages.

Noise, whilst not actually harmful to the physical historic environment, reduces the quality of life of communities and the amenity value of the experience and enjoyment of visitors to historic areas.

Rock dust can be emitted from passing aggregate wagons and then distributed further afield by re-suspension by other vehicles, pedestrians and the action of the wind. Most rock dust will consist of fairly large particles, which cannot travel very far before falling out of the atmosphere due to gravity. However smaller particles will also be generated and these could be transported much further because they are not so readily deposited from the atmosphere. Three main damage effects to the historic environment are likely to be caused by rock dust:

- *Soiling* is the visible dirtying of building exteriors, interiors, furnishings and fittings due to the accumulation of dust. Many quarry dusts will be light in colour and therefore show up more clearly on dark materials. Soiling may be harmless in itself, but it could necessitate frequent cleaning in order to meet aesthetic expectations. Cumulative damage could result from the physical abrasion involved in cleaning
- Dust can also bring about *chemical attack* on some materials. An accumulation of surface dust may increase or deplete the moisture content of

the surface; rock dusts (e.g. from limestone and sandstone) are likely to be alkaline in nature and possibly chemically reactive on a wide range of surfaces.

3.3 Project aims and methodology

The overall aims of this project, which has both strategic and national importance, were to propose a methodology for investigating the impact of aggregates extraction and transport on the English historic environment. Including monuments, buildings and associated contents in order to inform future work, to contextualise the impact of aggregate extraction in terms of the historic environment and to involve and inform the communities affected or interested in this activity. It was intended to study the effects of both quarrying and road transport of aggregates and focus in particular on the impact of dust, noise and vibration.

The project methodology combined:

- desk-based studies of the aggregates industry
- consultation with local authorities, heritage organizations, local residents and quarry operators, and
- measurement campaigns at case study sites, where the potential for aggregates industry impacts on the historic environment had clearly been identified.

The specific objectives were to:

1. Study the potential effects of the aggregates industry on the historic built environment through desk-based investigations to answer specifically:
    - 1.1 What are the effects of noise, vibration, dust and other pollution?
    - 1.2 What are the effects of different operations in the industry, e.g. extraction (blasting, drilling, cutting); crushing and transportation (specifically by road) from source to point of use?

2. Identify places in the case-study areas where the historic built environment may be at risk from potential or actual aggregates extraction or transportation to answer specifically:
    - 2.1 What is the extent of the potential risk across the case-study areas?
    - 2.2 What is the number of sites that may be affected, now and in the future?
    - 2.3 What sites in areas where extraction is currently taking place are suitable for experimental investigation?

3. Investigate the actual effects of the aggregates industry on the historic built environment by experiment and monitoring two case study locations to answer specifically:
    - 3.1 What is the effect of noise on residents and visitors?
    - 3.2 What is the effect of vibration on historic buildings?
    - 3.3 How significant is aggregate transport compared to other road traffic?
    - 3.4 What is the effect of aggregate dust on sites, buildings and contents?

3.5 Is there evidence of damage from these effects?
3.6 How far from quarries and transport routes do these effects extend?
3.7 How do residents and visitors perceive the effects on historic buildings?

4. Develop guidelines on the effect of the aggregates industry on the historic built environment. These will answer the following questions:

4.1 What is the potential for damage from aggregates working and transport on the historic built environment?
4.2 Is there a 'safe' distance from quarries or their transport routes beyond which any damage is considered acceptable?
4.3 What additional costs in terms of repair and maintenance of historic buildings are incurred as a result of proximity to aggregates workings?
4.4 How can these risks be managed?

3.4 Selection of case study locations

It was decided to undertake the fieldwork at two locations where the potential for aggregates industry impacts on the historic environment had clearly been identified, in order to have the possibility of comparing and contrasting two different sites. Summer and winter sampling campaigns were suggested by English Heritage so that any seasonal differences could be investigated.

The project case study locations were identified through consultation of reference materials, maps and discussion with various stakeholder organisations:

- The initial stages of site selection were undertaken through a desk based study, which entailed reading through literature from the British Geological Survey (BGS) including the Directory of Mines and Quarries (Cameron et al, 2002) and the BGS Britpits Website, both of which provide comprehensive information on aggregate workings in Britain
- Ordnance Survey (OS) maps and Geographical Information Systems (GIS)
- English Heritage Aggregates Levy Sustainability Fund (ALSF) Advisers were consulted
- Local authority representatives (e.g. mineral planning officers and conservation and design officers), who were able to indicate areas of potential interest
- Local residents and business owners

Using this methodology, a short list of potentially suitable locations was drawn up. In July 2005 scoping visits to three possible areas were undertaken. Two areas were in upland limestone areas in the north and midlands of England where crushed rock is quarried- Derbyshire and the Yorkshire Dales. The third area visited was the Purbecks in Dorset, a low lying coastal area of southern England where dimension stone and some sand and gravel is extracted. The quarrying activity in Dorset was of interest but operated on a much smaller scale than that in the more northerly sites and did not exhibit the clear interactions with the historic environment which were observed at other sites. After visiting the areas it was decided that two sites in Derbyshire and Yorkshire stood out for the interactions which would most likely meet the project's objectives.

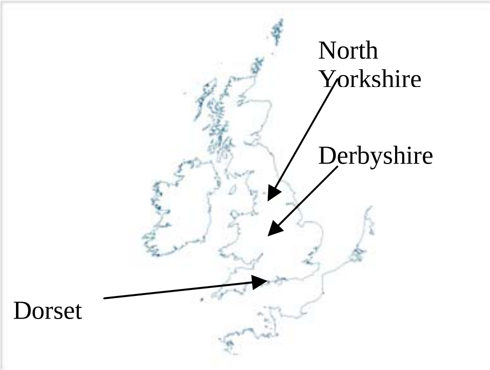


Figure 1: Geographical location, within the UK, of the three areas of the scoping visits to determine specific sites to investigate during the project.

Before the scoping visits the local English Heritage (EH) Historic Buildings Inspectors and Aggregates Levy Sustainability Fund Advisers were contacted. This interaction was intended to gain knowledge from EH of specific issues within their areas, however the level of information gained during this activity varied from site to site as some offices were able to provide more information than others.

During each of the scoping visits, meetings were arranged with local authority representatives who introduced the project team to the surrounding area and highlighted locations where the aggregates industry has potential to interact with the historic environment. Persons consulted included a Senior Conservation Archaeologist at Yorkshire Dales National Park Authority, an Urban Design and Conservation Officer from Derbyshire County Council, and a mineral planner from Dorset County Council and a Conservation Officer from the Purbecks District Council.

From these meetings and the visits the two case study sites selected were Horton in Ribblesdale in North Yorkshire, which has Horton Quarry located at its perimeter and Cromford, Derbyshire, which has Dene Quarry located nearby, both quarries produce crushed limestone aggregate.

3.4.1 Criteria for Selecting Monitoring Sites

Monitoring sites for this project were properties which fitted one or more of the following criteria:

1. Location within a historic environment close to quarrying activity, preferably listed but not essential if other criteria are closely matched
2. Close proximity to a quarry site with observed possible impacts
3. Close proximity to transport activity derived from a quarry site with observed possible impacts
4. Permission would be granted to undertake monitoring on private land

The case study sites were chosen so that the impact on the historic environment of both aggregates extraction and transport, often along small country roads and through towns and villages, could be studied and which would allow a methodology that can be replicated elsewhere, to be developed.

3.4.2 Geographical Information Systems (GIS)

A project GIS was developed during the initial stages of the project to assist the site selection process, primarily by identifying listed structures and their proximity to quarrying activity. The British Geological Survey (BGS) provided a GIS consultation service to the project, providing the necessary support to develop this tool for the project. After consultation with BGS it was decided that ARC/GIS version 9 software would provide the most suitable technology for this task. Electronic OS Base maps were downloaded from the ESRI (UK) Geographical Information Systems website for the chosen areas of Horton in Ribblesdale and Cromford in 1:10,000 and 1:25,000 scale formats, as both provided varying topographic information.

BGS provided electronic data on site boundaries of mineral permissions surrounding the areas identified and English Heritage provided electronic data sets for surrounding listed buildings and ancient monuments both of which were input into the GIS. With the help of these data and local knowledge, properties of interest identified during the scoping visits were contacted by post to negotiate access to their properties. From the responses received, properties closely fitting the project criteria in terms of proximity to quarrying activity and transportation and historical value were selected.

In the latter stages of the project locations of the properties surveyed during the project and transport routes taken by quarry traffic were also added to the project GIS.

3.5 Potential quarry impacts on the historic environment

In the introduction it was stated that the main impacts from aggregates extraction and transportation were identified as dust, vibration and noise. This section describes in more detail the specific impacts that might be expected from these environmental factors.

3.5.1 Dust

There is no universal size definition for dust, although in terms of surface mineral working it is considered to be any solid matter which is borne by the air and can range from the smallest individual smoke particle up to 2mm. Particles less than 1micron (μm) in diameter tend to behave more like gases than solids and are referred to as ‘fumes’. Due to their size these particles have a long airborne residence time. Particles which are above 75μm are known as silt or sand and have a very short airborne residence time.

As a result of quarrying activity, a range of dust particles are produced and can be transported outside the quarry location according to their mass and size. The distance dust particles can be transported also varies according to meteorological conditions and surrounding topography. It is important to note that dust is always present in the atmosphere and quarrying is just one source, other anthropogenic sources include combustion (e.g. fires, power stations and motor vehicles) and building and demolition work.

Dust particles can be produced at the following stages of mineral working:

- Soil movement – soil stripping and storage
- Overburden (soil and other material which overlies the economic mineral) excavation
- Mineral type and moisture content
- Blasting events
- Mechanical handling of minerals such as during crushing and grading
- Vehicle movements on roads on and off site


Figures 2 and 3: Mobile processing plant at Arcow Quarry, North Yorkshire (figure 2, left) and a quarry wagon crosses a historic bridge, Horton in Ribblesdale, (figure 3, right).

3.5.2 Noise

Noise, whilst not actually harmful to the physical historic environment, reduces the quality of life of communities and the amenity value of the experience and enjoyment of visitors to historic areas. Noise generated at open sites such as crushed rock aggregate quarries can, depending on distance, surrounding topography and prevailing wind direction, be transmitted beyond site boundaries. Sources of noise at crushed rock quarries include:

- Mobile plant (e.g. Excavators, front loading shovels, dozers and haulage vehicles)
- Static plant (e.g. permanent processing plant)
- Semi-mobile plant (e.g. mobile processing [figure 2] and screening plant)
- Road wagons transporting material to market/depots (figure 3)

3.5.3 Vibration

Vibration has the potential to damage historic buildings and monuments through physical separation and cracking of renders and plasters; failures and cracks in the building fabric; gradual or slow movement of objects inside buildings, for instance those located in display cabinets or on shelves. Vibration can be transmitted from aggregate activity through air, within the frequency range 20Hz–20KHz. This manifests itself as noise. However, this research was principally is interested in ground borne vibration through the ground and which can affect historic buildings and structures. It is supposed that over long time periods, load reversals can result in damage to delicate historic finishes such as renders and plasters. When amplified through the height of a structure or as a result of responsive floors, there is some evidence that ground borne vibrations can result in objects moving along surfaces. Blasting of hard rock is the most common source of vibration in aggregates extraction, a source which is eliminated in sand and gravel extraction. Some ground borne vibration can also be generated through processing plant and vehicle movement, for example wagons climbing steep hills in villages (figure 4).


Figures 4 and 5: quarry wagon ascending hill within the historic village of Cromford figure 4, (left); dislodged material after a blast at Horton Quarry (figure 5, right).

4 CASE STUDY SITES

This section describes the two case study locations of the project, their historic environment, local quarrying activities and operating conditions.

4.1 Cromford, Derbyshire

Cromford in Derbyshire is on the southern edge of the Peak District National Park. It is located off the main A6 trunk road, and the village high street (B5036) is itself a busy through route. Cromford has significant cultural and historical importance in terms of its industrial heritage. In 1771 Richard Arkwright came to the village to establish a water powered cotton mill on the river Derwent. The mill was the first of its kind and was to revolutionise the textiles industry. Cromford Mill was so successful that Arkwright (along with his financiers) built further mills, such as Masson Mill which lies approximately 1 mile away in Matlock Bath and Haarlem Mill in Wirksworth.

Arkwright also built houses for his workforce and these form a large proportion of the listed buildings in Cromford today. Arkwright was particularly keen to attract large families to the mills, for this reason cottages, a school, a chapel and a hotel were built to accommodate the expanding work force. North Street was constructed in 1776, consisting of three storey terraced cottages on either side, the first planned street in Derbyshire. At the end of the street is the school which was built on Arkwright's insistence that all children who went to work in the mill would be able to read and write. North Street and the school are both used to this day.

Due to the area's links with Richard Arkwright's pioneering water powered cotton mills the Derwent Valley Mills have been designated as a World Heritage Site. Many of the houses in Cromford have been listed, mainly as grade 2*. Notable areas of listed buildings are Cromford Hill with its busy road, and North Street. Most of the housing stock either side of these two roads is listed and therefore a significant location to focus this research project. Figure 6 is a GIS map output showing the location of listed buildings as turquoise circles.

During the scoping visit to Derbyshire and whilst meeting the Derbyshire District Council Urban Planning and Conservation Officer, other sites around Derbyshire were visited, including locations within the Peak District National Park such as the spa town of Buxton and Tunstead Quarry. Whilst visiting Cromford it was possible to obtain an immediate understanding of quarrying activity in the area as there was a high level of quarry related traffic traveling through the town in both directions to and from Dene Quarry which is situated to the southwest of the town. A rough estimate of 80% of the traffic from the quarry (based on reports received from the quarry) travels through the town. Figure 6 shows the outline of Dene Quarry and its proximity to the village. Considering these two attributes it was decided that Cromford closely matched the project criteria for selection.

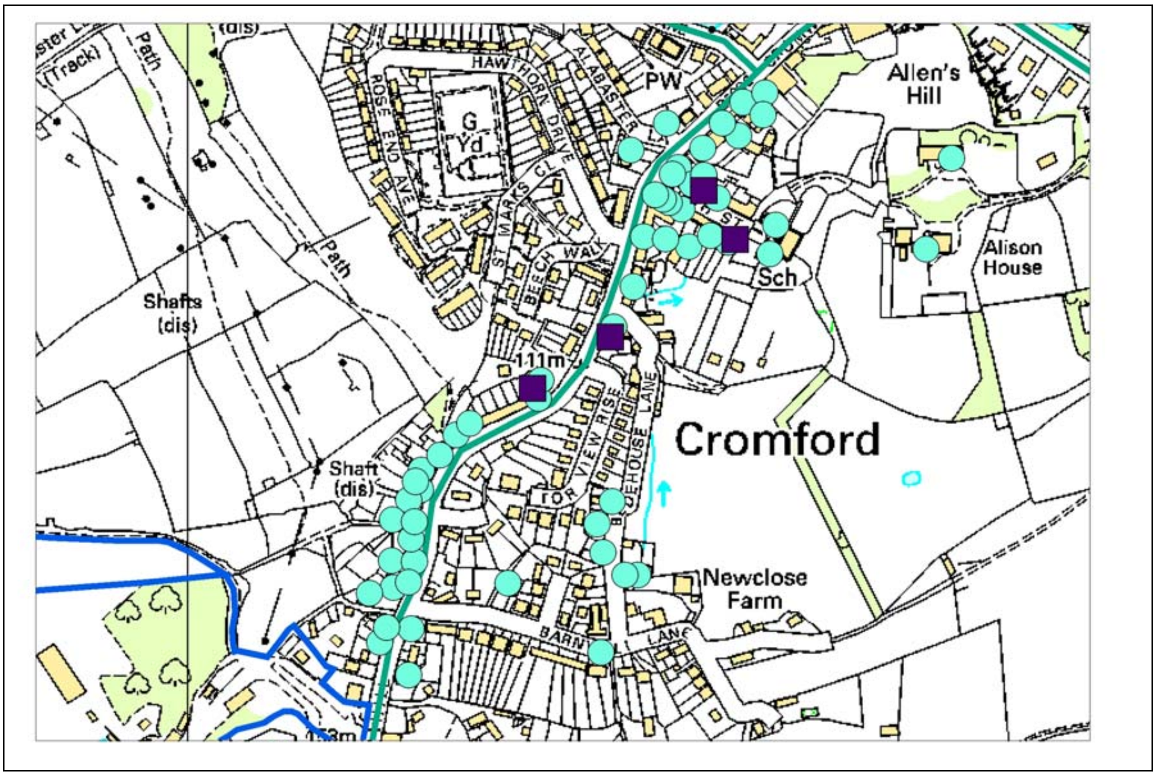


Figure 6: GIS output maps of Cromford, Derbyshire. Circles= listed buildings, Squares=project monitoring sites. The solid green lines drawn along roads indicate quarry transport routes. The quarry boundaries, bottom left corner are marked with a solid blue line.

4.1.1 The Quarry at Cromford

When entering Cromford from the A6, the Greyhound Hotel can be seen on the right (built by Arkwright in the 18th Century). The road running up through the residential part of the town is the B5036 (Cromford Hill). The entrance to the quarry is approximately one mile up this road on the right hand side but it is not visible from the road. The only view of Dene Quarry can be seen when standing on a rocky outcrop to the southeast of the quarry known as ‘Black Rock’, figure 7.

Dene Quarry began operating in 1942 and is currently managed by Tarmac plc. It has almost reached the limit of its planning permission, presently covering 103 of the 109 acres permitted and extending down 80m at its lowest point, its maximum permitted depth. The permitted output of the quarry is 1 million tones per annum, current production is 980 000 tones per annum. It is estimated that the quarry has a remaining working life of 10-15 years.

Figures 7-10: top left, figure 7, Dene Quarry; figure 8, top right, North Street; figure 9, bottom left, Arkwright's school at the end of North Street; and figure 10, bottom right, Cromford Hill.

4.1.2 Operating conditions for Dene Quarry, Cromford

The Mineral Planning Authority (MPA) responsible for Dene Quarry is Derbyshire County Council, which has produced a local plan for minerals extraction. This plan sets out how minerals extraction will be managed during a specified time scale. It is against this document that planning extensions and applications are considered. In essence, if a minerals planning application falls outside the guidelines of the document it is unlikely permission will be granted unless it is of national interest.

Dene Quarry was granted an extension to its operating permission in 2005. Below is a summary of the conditions which were attached to the permission:

- Access to the quarry will be from Cromford Hill, with roads being maintained free of debris derived from the quarry.
- Operating hours of quarrying activity are to be adhered to. Between 0530 and 1900 hours noise levels arising from the development shall not exceed 55dB (continuous sound level for 1 hour). Between 1900 and 0530 hours the noise levels arising from the development shall not exceed 42 dB as received at the noise sensitive properties. Noise levels will be monitored in accordance with the MPA guidance.
- Silencers and reverse warning devises are to be installed on vehicles.
- Operations on site will be managed to minimise the production of dust. Dust emissions will be monitored in accordance with guidance from the MPA.
- Blasting activity is to be carried out at prescribed times. Limits on resulting vibrations are also detailed.
- Limitations of the working of soil stripping and storage, with a view to the generation of dust.

4.1.3 Selection of monitoring locations

It was intended to carry out project monitoring inside and outside historic buildings that could be affected by quarrying activities. At Cromford this implied that monitoring would need to take place in private dwellings as these, with the possible exception of the local school, were the historic buildings most likely to be affected by the quarry. From the advance visit to Cromford and through an analysis of where the listed buildings are located addresses on North Street and Cromford Hill were identified as most suitable for the project. A letter was sent to householders at forty six addresses on Cromford Hill and North Street explaining the aims of the project and inviting them to participate by making their property available to monitor. The project offered to pay a sum of £50 to each property to compensate for any inconvenience experienced by participating in the summer and winter measurement campaigns.

Six positive responses were received and from these, two properties located on each side of Cromford Hill and a further two properties located on North Street were selected for investigation. All of the selected properties are grade 2* listed.

The monitoring locations are marked as squares in figure 6 and are shown in figures 11–13, below.

Figure 11: 54 Cromford Hill. Located on the west side half way down Cromford Hill. This is the nearest property to Dene Quarry (350m from the quarry perimeter), with the rear of the property facing the quarry.

Figure 12: 101 Cromford Hill, is located on the eastern side of Cromford Hill approximately 50m down the hill from number 54.

Figure 13: 14 North Street, located at the far end of the cul-de-sac. It is the house with the green door and flower pots outside in the right of the picture above. 3 North Street, (not pictured) was located on the opposite side of the street. Only the exterior of this building was monitored during the project.

4.2 Horton in Ribblesdale, Yorkshire Dales

Horton in Ribblesdale is a picturesque small village in the North Yorkshire Dales. It has many distinctive natural features, which have developed as a result of the melting of glacier ice eroding the limestone and sandstone rocks some 300 million years ago. This created crags, hills, caves and expanses of fissured rock pavements, valleys and waterfalls. The limestone upland environment today has created a highly suitable habitat for a variety of flora and fauna.

The town is located in the shadows of the western side of the mountain Penyghent, which together with Ingleborough and Whernside combine to form the Three Peaks of the Yorkshire Dales. Horton in Ribblesdale is the traditional starting (and finishing) point for climbing the Three Peaks. The Pennine Way long distance footpath which starts at Edale in the Derbyshire National Park and finishes at Kirk Yetholm, also passes through the village. Thus the village attracts many walkers and tourists.

The area has a long history of human occupation, with Neolithic and Late Upper Paleolithic Age tools found in nearby caves. Lead mining also began in the area in Roman times and continued into the 19th century. In 1876 the construction of the Settle – Carlisle Railway, was completed after 6 years. The railway was built to support a growing market between the Midlands and Scotland but did not fare well against competition from other routes to Scotland. During the 1970s and 80s a drop in traffic and passengers, lack of investment and increasing maintenance costs resulted in British Rail deciding it was not cost effective to keep the line open. However, local authorities and enthusiasts joined together to make a case for preserving the line for its potential as a tourist attraction.

The line also carries considerable freight traffic and in the past served several of the quarries in Ribblesdale. However rail transport is currently not used by either of the two quarries closest to the village, Horton Quarry and Arcow Quarry, due to adverse economics and market places. The recently renovated Ribblehead Viaduct, located less than 10 miles north of Horton in Ribblesdale has 24 stone arches carrying the line north and is a renowned part of the historic environment of Ribblesdale. Of importance also are the dry stone walls and solid limestone buildings which give the character of the Yorkshire Dales and are central to its historic environment.

4.2.1 The Quarry at Horton

When approaching Horton in Ribblesdale from the south on the B6479 the dominance of quarrying in the area is first visible to the west where the first of three quarries, Dry Rigg, is extracting gritstone from an escapement running in a northerly direction. Of the three quarries this is the smallest. The second quarry, moving north up the Dale is Arcow, which is operated by Tarmac. It is located on a geological boundary between an area of gritstone and limestone and so it is able to produce both. Dry Rigg and Arcow quarries are located between one and two miles away from Horton, and are factors in the wider environment of Ribblesdale, but do not directly influence Horton. Haulage vehicles from all the quarries mostly travel south to the main aggregates markets in the West Yorkshire and Manchester conurbations, thus wagon traffic to Dry Rigg and Arcow does not pass through Horton.

The main quarry affecting Horton village is Horton Quarry, operated by Hanson Aggregates. It began operating in the 1880s and is currently permitted to extract 600,000 tones of crushed limestone per annum. The quarry currently covers 212 acres but is permitted to cover 242 acres. There is no restriction on depth, which is currently 120m. In common with most quarries in England Horton Quarry has permission to continue working until 2042 and has several decades of economic working life remaining. The haulage route for wagons from Horton Quarry runs through the village with a small number of vehicles turning north. Most wagons travel south to their depots and markets.

4.2.2 Operating conditions for Horton Quarry

The Yorkshire Dales National Park Authority (YDNPA) has control over aggregates extraction in the National Park through its mineral planning department. This department has the authority to grant or deny an application depending on whether it conforms with the minerals and waste local plan or whether it is deemed necessary to the national interest.

When planning permission has been granted, it is common practice for conditions to be attached to the permission which can restrict quarry related activities, e.g. times of work and reducing impacts of dust.

Horton Quarry has been permitted to work within conditions which are deemed reasonable to safeguard against impacts from noise, dust and vibration. The main operating conditions are:

- All vehicles shall enter and leave the quarry via Cragg Hill Road
- No heavy goods vehicle shall enter of leave the site between specified times
- Cragg Hill Road will be surfaced with bituminous macadam and maintained free of pot holes for the duration of the development. It will be swept as frequently as required to prevent dirt and dust from the quarry entering the public highway and shall be sprayed frequently to limit the generation of dust.
- Vehicles will be clean and sheeted when leaving the site
- Quarrying or processing activities shall take place between specified times
- Ground vibration as a result of blasting shall not exceed a peak particle velocity of 6mm/s in 95% of all blasts measured over a 6 month period, and no individual blasts shall exceed a peak particle velocity of 8mm/s as measured at vibration sensitive residential buildings
- Blasting shall take place between specified times
- Noise emissions from on site operations shall not exceed specified noise levels
- Reverse warning devices shall not be audible at nearby residential properties
- Machinery within the site shall be operated and maintained, to minimise noise emissions
- Except with the prior written approval of the National Park Authority and with the exception of equipment located within the primary crusher building no pneumatic rock breaking equipment shall be used on site.

4.2.3 Selection of monitoring locations

Initial research had identified Horton in Ribblesdale as a potential area for interest as there is a high concentration of aggregate quarries located nearby. The village is also within the Yorkshire Dales National Park. Part of the remit of National Parks in Britain is to conserve and enhance the natural beauty, wildlife and cultural heritage of the area, and so it was felt the historic environment in this area would be of interest to the project. On selecting Horton in Ribblesdale as one of the project case study sites it was important to gain further detailed information to assess which properties would be useful to survey.

During the scoping visit to Horton a number of listed and unlisted properties were identified as fitting the criteria for selection. A similar approach to Cromford was used for Horton. By consulting the GIS dataset (provided by English Heritage) and the village post office in Horton, 23 addresses were obtained and a letter sent to each householder. Seven positive responses were received from which the following three properties (in figures 14–16) were selected.

Figure 14: Beecroft Hall, an unoccupied farmhouse that is the closest property in Horton to the quarry, just 175m from the quarry perimeter. Although the property is listed, it has fallen into disrepair due to the covenant placed on it that prohibits inhabitation. On initial inspection of the property and the surrounding land deposits of dust were observed.

Figure 15: 2 West View. This unlisted property is located at the junction between Crag Hill Road and the B6479, which is the only exit road from the quarry and so all haulage vehicles pass by the property and stop just outside the house before turning onto the main road out of the village. The property is 600m from the quarry perimeter.

Figure 16: 2 Bransghyll Terrace. Located directly on the B6479, this unlisted property was of interest for its position on the main haulage route out of the village. It is approximately 900m northwest of the quarry and together with the other 2 properties forms a useful geographical spread of monitoring sites.

Figures 17: A loaded, sheeted aggregates wagon crosses the historic bridge at Horton having left Horton Quarry and set out on its journey south, probably to the West Yorkshire or Manchester conurbations.

Horton in Ribblesdale does not contain as many listed buildings as Cromford. The style of houses is typical of Dales villages, but listing has been restricted to larger farmhouses such as Beecroft Hall and the historic stone bridges over the river Ribble, which still carry all road traffic through the village, including quarry wagons (figure 17). It was decided to concentrate further investigations in Horton on a couple of properties which were located in close proximity to the haulage activity coming from the quarry. These are represented in figure 18 as squares and are located on Cragg Hill Road and Bransghyll Terrace. Beecroft Hall was also monitored because it provided a useful contrast, being close to the quarry boundary, but away from any roads.

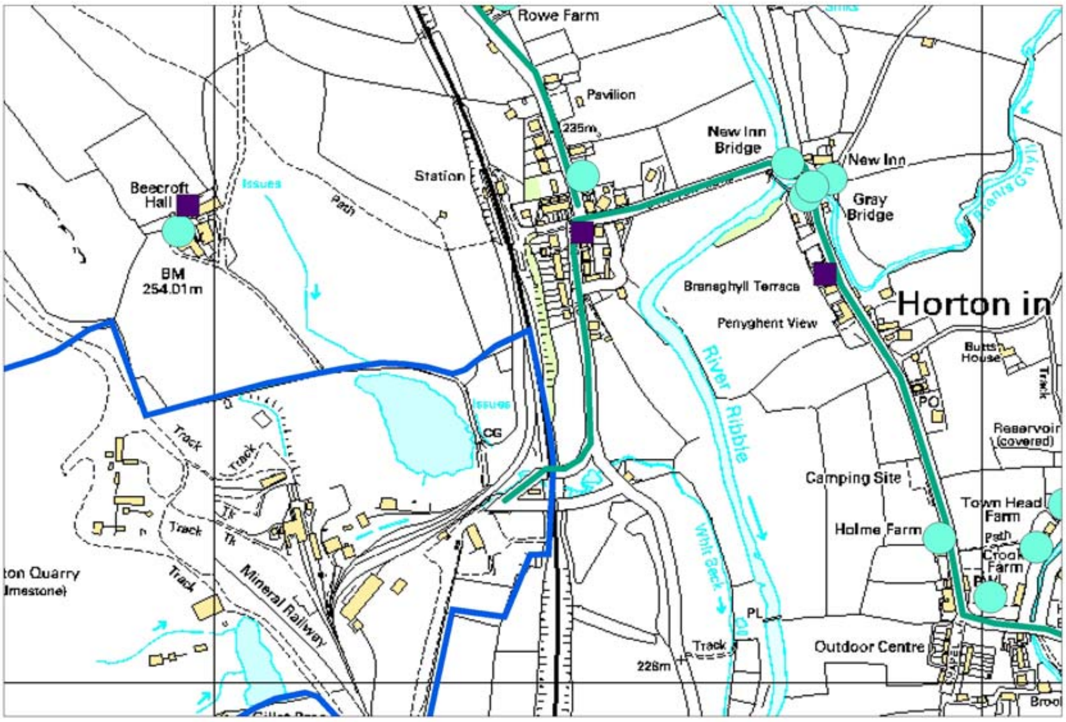


Figure 18: GIS output maps of case study sites, Horton in Ribblesdale, North Yorkshire. Circles=Historic listed buildings, Squares=project monitoring sites. The solid green lines drawn along roads indicate quarry transport routes. The quarry boundaries, bottom left corner are marked with a solid blue line.

Beecroft Hall is held under a covenant, which prohibits inhabitation. The covenant was made at a time when blasting techniques were primitive and could have resulted in material being thrown beyond the quarry boundary, causing injury and damage to property and injuries. This phenomenon known as 'flyrock', has largely been eliminated due to developments in extraction techniques and planning regulations. Nevertheless, the covenant remains and the property has been uninhabited for approximately fifty years although the surrounding land is still used for farming.

5 FIELDWORK MEASUREMENT METHODS

The main research methodology of the project was the site measurement campaign. At each of the case study sites summer and winter measurement campaigns were undertaken, so that seasonal variations due for instance, to the weather could be investigated. These involved an intensive set of dust noise and vibration measurements outside and inside the case study buildings. Real time measurements were undertaken over a period of 3-4 days at each site. Interviews were conducted with local residents and site visits arranged with the quarry operators. Sampling equipment was also set up for long-term measurements of dust concentrations, for retrieval and analysis 4-8 weeks after the original deployment.

Brief descriptions are given below of the measurement methods used for dust, noise and vibration. Figure 19 summarised the sampling and analysis methods and their data outputs. More detailed technical information on the sampling and analysis methods is presented in section 9 of this report.

5.1 Dust

Dust was identified as one of the main potential threats to the historic environment originating from the aggregates industry. The approach to the study of dust involved its characterisation in the case study areas and from the quarries in order to understand its physical and chemical properties and hence its potential as a damage agent. The second aspect of the dust studies was the measurement of dust levels at various locations at the case study sites in order to understand how dust concentrations varied with time and distance from the quarry and other dust sources such as transport routes, and to measure the amount of quarry dust deposited on the outside and inside of historic buildings. Meteorological effects on dust deposition and transportation were not specifically investigated, though observations of the weather during the short-term active sampling were made and seasonal variation of dust concentrations was studied.

Dust was measured using two passive sampling methods: Frisbee Gauge and sticky samplers and one active sampling method.

Passive sampling by Frisbee Gauge. Atmospheric dust deposits in a 30cm diameter metal dish (like an upturned Frisbee) either due to gravity or rainfall and is washed into a collection vessel by rainfall. After 4-8 weeks' exposure the Gauge is retrieved and the dust quantified by weighing. It can also be analysed by various chemical techniques (described in the Technical Appendix) to identify the elements and minerals present.

Passive sampling by sticky sampler. Atmospheric dust deposits by gravity on a horizontally mounted 1.2cm diameter metal disk coated with an adhesive layer. After 4-8 weeks' exposure the sampler is returned to the laboratory analysis. Scanning Electron Microscopy (SEM) can then be used to identify the particle and mineral types present and to count the number of deposited mineral particles. These techniques are described fully in the Technical Appendix.

Real time dust data were also collected using an optical particle counter that gave minute by minute readings of the airborne dust concentration.

In addition, samples of quarry product dust were provided for analysis by Dene and Horton quarries and a dust sample was collected from the access road to Horton Quarry.

5.2 Noise

A hand held sound intensity meter was used to establish instantaneous noise intensity maxima arising from passing vehicles. In the winter field campaign a sound logger was additionally used to record the noise intensity at 1 second intervals. This was combined with the use of a video camera to pick up the readings from the hand-held unit and also to record the type of passing traffic. Through the microphone in the video recorder it was possible to hear the noise as well as record its intensity.

5.3 Vibration

A seismograph was used to measure the ground-borne vibrations as close as possible to the foundations of the buildings being examined. The sensor measured the vibration as peak particle velocity, which is the standard unit for characterizing vibration callused by traffic and industrial processes. It was set to trigger at 0.1mm/s, a very low peak particle velocity and would record the magnitude and date/time of any vibration event above this threshold.

Table 1: Summary of the measurement methods employed at each case study site during the summer (August–September 2005) and winter (January–February 2006) campaigns at the two project case study sites

Cromford, Derbyshire

Sampling location	**Site characteristics**	**Approx. distance from quarry**	**Frisbee Gauge**	**Sticky samplers**	**Particle counter**	**Noise**	**Vibration**
54 Cromford Hill	On busy road and main quarry wagon route (2m from main road)	350m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside	Inside and Outside	Inside and Outside
101 Cromford Hill	On busy road and main quarry wagon route (3m from main road)	600m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside	Inside and Outside	Inside and Outside
14 North Street	Cul-de-sac off main quarry route (~50m from main road)	750m	No	Inside and Outside at 0.2, 1 & 2m	Inside and Outside	Inside and Outside	Inside and Outside
3 North Street	Cul-de-sac off main quarry route (~50m from main road)	750m	No	Outside at 0.2, 1 & 2m	No	No	No

Horton in Ribblesdale, Yorkshire

Sampling location	**Site characteristics**	**Approx. distance from quarry**	**Frisbee Gauge**	**Sticky samplers**	**Particle counter**	**Noise**	**Vibration**
Beecroft Hall	In fields away from any road	175m	Yes	Outside at 0.2, 1 & 2m	Outside	No	No
2 West View	On quarry access road, no other through traffic (3m from road)	625m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside	Inside and Outside	Inside and Outside
2 Bransghyll Terrace	On main road through village and one of the quarry routes (3m from road)	875m	No	Inside and Outside at 0.2, 1 & 2m	Inside and Outside	Inside and Outside	Inside and Outside

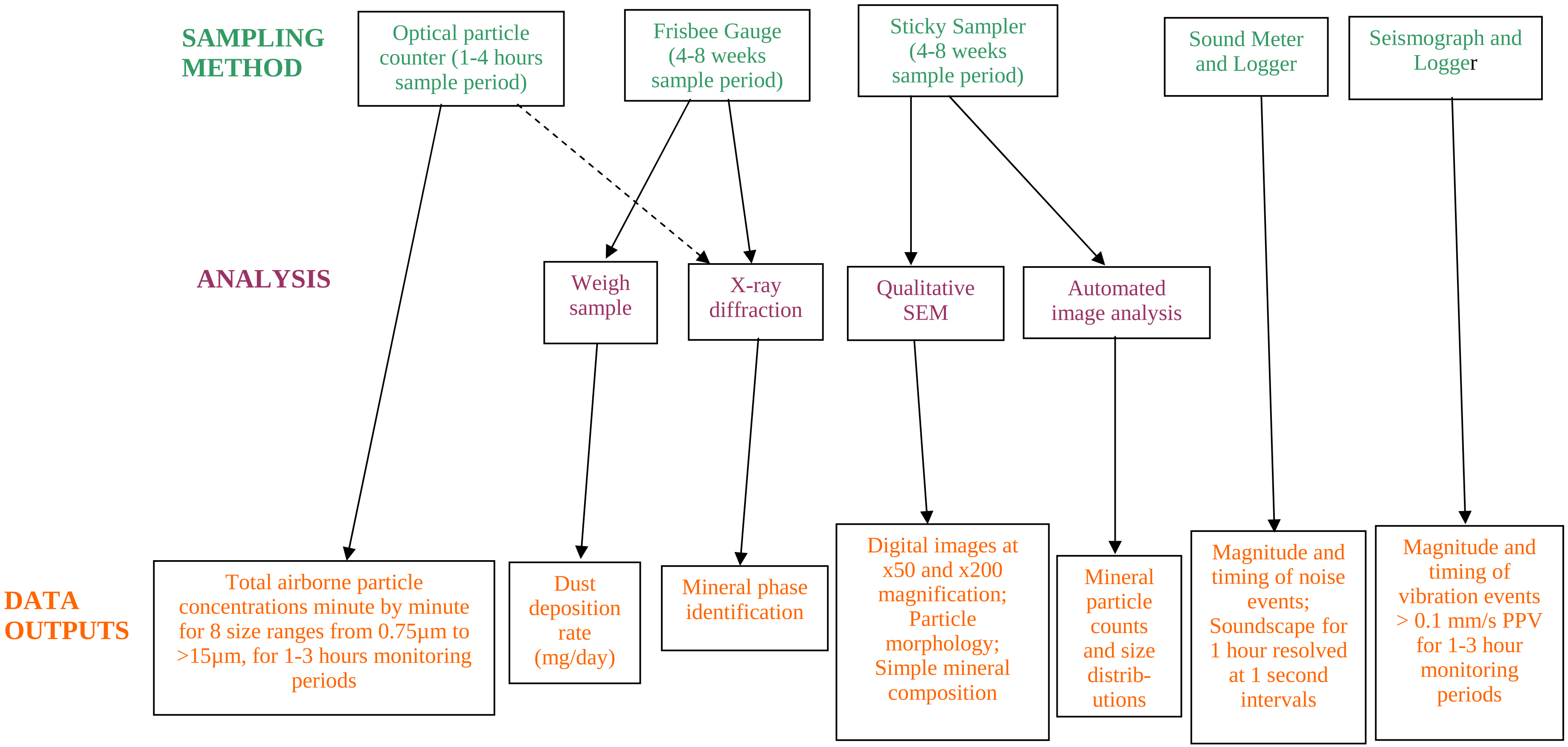


Figure 19: Summary chart of the sampling and analysis methods employed in the project and the types of data output they generated. Note that the instrumental methods of measurement (optical particle counter, sound meter and seismograph) generated their data outputs directly, whereas extensive analytical work was required on the collected dusts samples in order to generate the data. This analysis work is described in the Technical Appendix. The dotted arrow indicates that x-ray diffraction was attempted on the optical particle counter samples but was unsuccessful because insufficient sample could be collected.

6 KEY PROJECT FINDINGS

6.1 Dust

This section addresses the original aims and objectives as set out in the Project Design and answers, where possible, the specific research questions set out in section 2.3.

What is the effect of aggregate dust on sites, buildings and contents?

Analyses of the sticky stubs has found that calcite, the main mineral component of the limestone that is quarried at Horton and Dene quarries, is the main or one of the main minerals collected on samplers at all the sites tested, both indoors or outdoors. The possible sources of calcite in Horton and Cromford are quarry dust and soil dust, which is derived from the underlying limestone. Whilst soil dust cannot be ruled out as a source, studies of calcite particle morphologies showed that many particles were sharp-edged as if freshly cleaved by mechanical processing. The same morphology was evident in the analysed samples of quarry product, suggesting that quarry dust is a significant source of the calcite particles found. Other calcite particles deposited on the samplers showed evidence of pitting as if from rainwater dissolution.

The particle morphology suggests that ‘fresh’ dust could be abrasive due to its original mechanical processing and therefore potentially damaging to delicate surfaces. Damage could occur to indoor contents, for instance, when surfaces on furniture or painted wood are dusted.

Limestone dust is uniformly light-coloured and could cause more visible soiling than general household dust. This could lead to objects in an area affected by quarry dust being cleaned more frequently with greater risk of abrasion. However it also appeared from the electron microscope studies that calcite particles are readily weathered by rainwater, removing sharp edges and reducing their abrasiveness.

Dust could also cause soiling on the exteriors of buildings and on other surfaces such as roads. These effects were reported anecdotally during the sampling campaigns in Cromford in particular and indeed white dust blooms were visible on Horton Quarry access road and on Cromford Hill. However, the lack of calcite in the Frisbee gauges samples, can be explained by the solubility of calcite in rain water, and is therefore readily washed away from road and building surfaces by rainwater in the case study areas, which are both areas of high annual rainfall. The dust is essentially the same material as the local building stone, and would dissolve to give an alkaline solution that would not be expected to contribute to building weathering.

No damage to buildings or contents due to quarry dust was observed during the sampling campaigns. However the case study historic buildings were all private homes and they did not provide the opportunity to look for the types of damage to collections described above. As already stated the effect on building exteriors would be expected to be minimal.

How far from quarries and transport routes does the dust extend?

The sampling sites were located between 175 and 875m from the quarry perimeters, and all samples contained significant amounts of calcite.

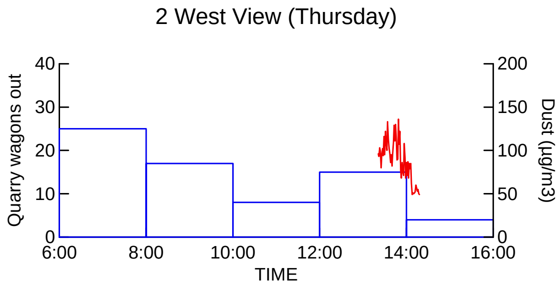
From the sticky stub particle counts there was no obvious falling off of mineral particle deposition moving further away from the quarry. Deposition seemed to depend on a combination of proximity to the quarry and to road traffic, which was not necessarily quarry related, as can be seen from table 2, below.

Table 2: Particle deposition at 1m height at four sampling sites as averages of summer and winter measurements. Traffic data for Cromford was provided by Derbyshire County Council and quarry wagon data by Dene and Horton Quarries.

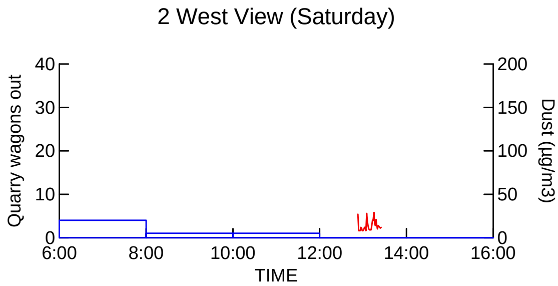
Site	Average deposition of large (10-100µm) particles (/mm^2/4 weeks)	Distance from quarry (m)	Road conditions	Estimated working day traffic (one way)
101 Cromford Hill	980	600	Busy through-road	200 quarry wagons, 5000 other vehicles
Beecroft Hall	505	175	none	none
14 North Street	383	750	Cul-de-sac off Cromford Hill	No through traffic
2 West View	238	625	Quiet residential road, but on quarry access road	70 quarry wagons, negligible through traffic

These data suggest that (i) direct transportation of dust from quarry operation and wind-blown dust from workings and stockpiles and (ii) road vehicles could be both significant mechanisms in the transportation of mineral dusts. The highest deposition measurement was actually made on Cromford Hill, a busy road where quarry vehicles are only a small proportion of the overall traffic (4%). Dust deposition here may be more related to the resuspension of road dust by all passing vehicles than dust coming off quarry wagons, which are sheeted and also subject to wheel washing before leaving the quarry. However, given the significant levels of calcite detected, it is likely that a proportion of this road dust originates from the quarry. The second highest deposition rate was at Beecroft Hall, which is in open countryside, but very close to the perimeter of Horton Quarry.

The active monitoring data also provide evidence for the contribution of road traffic to local dust concentrations. Figure 20 plots the winter dust levels outside 2 West View, Horton in Ribblesdale, with the number of loaded wagons leaving the quarry, comparing a typical working Thursday and the following Saturday when very few vehicles were despatched.



Mean dust concentration = 99 µg/m^3
Number of quarry wagons = 69



Mean dust concentration = 14 µg/m^3
Number of quarry wagons = 8

Figure 20: Comparison of quarry wagon traffic (histogram bars shown in blue, left axis) and dust levels (red line, right axis) for a working day and non-working day in the winter campaign.

A comparison of Thursday and Saturday dust concentration outside 2 West View in the summer shows a similar pattern, although quarry wagon data are not available for this period (figure 21). The weather was warm and dry on the days the optical particle counter was used at Horton during the summer and cold and dry in the winter.

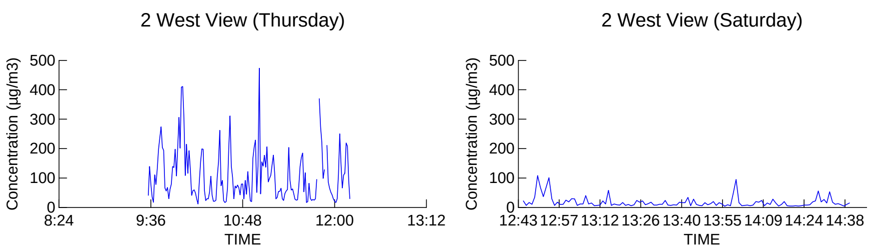


Figure 21: Mean dust concentrations: Thursday 114 µg/m^3, Saturday, 18 µg/m^3.

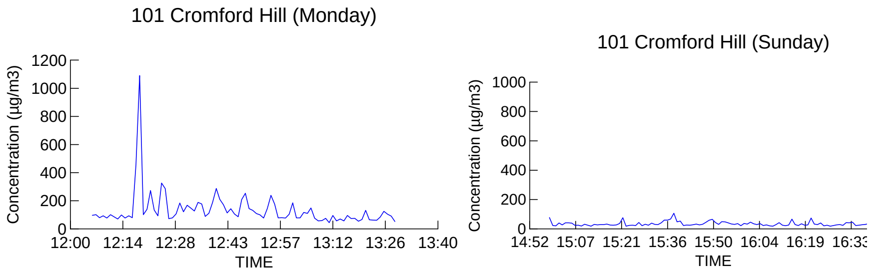


Figure 22: Mean dust concentrations: Monday 134 µg/m^3, Sunday, 35 µg/m^3.

The same effect can be observed in Cromford, as can be seen from measurements outside 101 Cromford Hill, from the winter sampling (figure 22). However, the higher Monday dust levels cannot be attributed to quarry traffic alone, which is estimate to be only 4% of the total traffic descending Cromford Hill during a working day (0600-1900hrs). The weather was dry with occasional showers on the days the optical particle counter was used at Cromford during the summer and cold and dry in the winter.

How do dust at levels in Cromford and Horton in Ribblesdale compare with other environments?

There is clear evidence for the contribution general traffic and quarry wagon traffic make to airborne dust at the sampling sites, and calcite mineral dust is ubiquitous in the deposited samples collected, but how dusty is the environment near these two quarries compared with other locations?

Table 3 compares calculated particle deposition rates based on Frisbee gauge measurements from Cromford and Horton with typical values for other sites. The loss of calcite from the Frisbee samples (section 9) measurements at Cromford suggest that average dust deposition is below that found in urban areas. However some measurements are comparable with urban environments and the maximum measured is in the ‘light industrial category’. At Horton the only measurements available are from the current project, and these are similar to the Cromford measurements, indicating that the site is less dusty than typical urban sites.

Table 3: Calculated particle deposition rates (mg/m^2/day) compared with previous measurements.

Measurement	*Minimum*	*Maximum*	*Mean*
Horton, Summer data	26.3	32.9	30.0
Horton, Winter data	11.3	21.8	18.2
Cromford, Summer data	24.3	38.2	31.3
Cromford, Winter data	13.6	17.7	15.7
Previous measurements, Dene quarry perimeter (Hards, 2000)	**11**	**120**	**41**
Typical values, urban (De Koning, 1986)	**65**	**100**	
Typical values, light industrial (De Koning, 1986)	**100**	**200**	
Typical values, heavy industrial (De Koning, 1986)	**150**	**350**	
Around cement plant (Ali-Khodja *et al.*, 2005)	**520**	**1340**	

Table 4 summarises minimum, median and maximum dust concentrations measured by the Grimm optical particle counter at the sampling sites, in comparison with data from central London (data from non-quarry rural sites were not available). The optical particle counter records all particle types, not just minerals, in the size range 0.75 to >15µm.

Table 4: Summary statistics of Grimm monitoring data

Measurement	*Minimum*	*Maximum*	*Median*
Horton, Summer data (outdoors)	4	570	28
Horton, Winter data (outdoors)	8	752	54
Cromford, Summer data (outdoors)	39	987	149
Cromford, Winter data (outdoors)	13	1090	41
Urban site for comparison (central London (not roadside)			**60**

Cromford in summer is the dustiest site, exceeding by more than a factor of two the median dust level measured at a central London site. Whilst the highest dust concentrations were measured on the busy roadside sites at 54 and 101 Cromford Hill, it should be noted that the cul-de-sac 14 North Street also had quite a high median value (139 µg/m^3). Cromford in winter and Horton all year round were less dusty than the London site. It is difficult to explain why Horton was dustier in winter than summer, as the other data collected suggest summer is the dustier season.

How do residents perceive the effects of the dust from quarries on the local environment?

Two residents from Cromford Hill participated in a meeting in May 2006 at which the preliminary project findings were presented. In addition, residents of both Cromford and Horton were interviewed about their perceptions of the effects of quarrying on the villages, during the January 2006 sampling campaign.

Cromford residents said they noticed quarry dust depositing on their cars and other vehicles. One resident described this as ‘sharp’ to the touch and that it had to be brushed off carefully otherwise it could scratch the paintwork. Other residents mentioned that dusty streaks could be seen on vehicles and windows after rainfall. Residents also noticed quarry dust inside their properties, on indoor windowsills on North Street as well as Cromford Hill.

Overall their perception was that Cromford had a dusty environment. It is interesting to compare this observation with the scientific measurements. The Grimm optical particle measurements showed that in the summer Cromford was dustier than the London urban environment, whilst the Frisbee measurements indicated that it was on average less dusty that typical urban environments, though some measurements were of the order of urban dustiness. It may be that the nature of quarry dust, for instance its light colour and abrasiveness, makes it more noticeable than urban dusts which may be more heterogeneous in composition and darker in colour.

Only one resident in Horton mentioned dust as an issue, indicating that they thought dust from passing wagons made their windows dirty.

Dust inside buildings

In this report, it is suggested that the main risk of damage to heritage materials from quarry dust is to vulnerable materials in collections indoors. At the case study sites the indoor mineral dust particle count was measured at several of the houses. Total airborne particles were also measured using the Grimm optical particle counter. Graphs of these data are given in section 9. The data are summarised in table 5, below, with some comparative measurements from indoor environments.

Table 5: Summary statistics of the Indoor particle measurements in µg/m^3.

Measurement	*Minimum*	*Maximum*	*Median*
Horton, Summer data (indoors)	26	996	180
Horton, Winter data (indoors)	47	4190	291
Cromford, Summer data (indoors)	6	824	93
Cromford, Winter data (indoors)	31	1019	122
Busy museum entrance hall			**290**
Same entrance hall, by night			**15**
Recommendation of US National Bureau of Standards for museum environments			**75**

The particle concentrations indoors are generally higher than those found outdoors, with particularly high peak values, of the order of several 1000 µg/m^3. Similar data have been observed elsewhere, such as in the example of the busy museum entrance hall, where the movement of people who re-suspend dust from the floors with their footsteps and shed clothing fibres and skin particles, contributes to the high airborne dust concentration found. In domestic dwellings there are fewer people but in a smaller space they may create a similar effect. Also the presence of soft furnishings and pets will contribute further organic particulate matter that will be detected by the Grimm, but are not included in the deposited mineral particle counts.

Figure 23 compares the indoor and outdoor mineral particle counts of small (1-10µm) and larger (10-100µm) particles at 1m height, for three of the properties. At 101 Cromford Hill during the summer the indoor particle count exceeds the external count. This may be due to the contribution of indoor plaster dust from ongoing building work. However calcite particles were detected in all of the indoor samples, and whilst the indoor concentration of mineral dust is generally less than outdoors, significant amounts of mineral dust were found indoors.

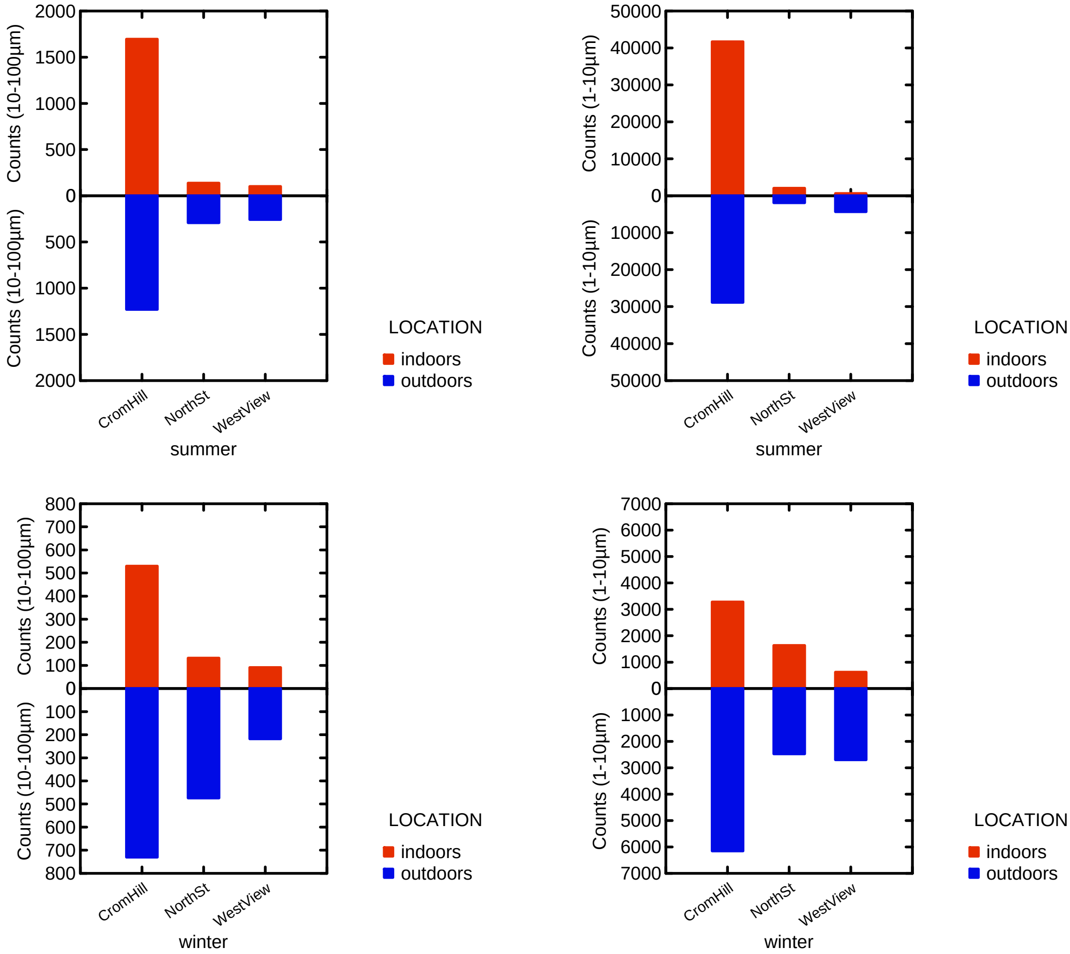


Figure 23: Comparison of outdoor and indoor particle counts from the sticky samplers, 1m height. Outdoor data are the bars below the x-axis, indoor data are above.

Dust deposition measurements were also made at 3 different heights above ground level, both indoors and outdoors. These data are shown in figure 24. There is no evidence for more particles to be deposited at one height compared with another, within the height of the ground floor of a building. However from the SEM pictures it was apparent that some of the lower level samples did contain more coarse sand and gravel particles than the higher samples, which could be caused by splashing of rainwater outdoors.

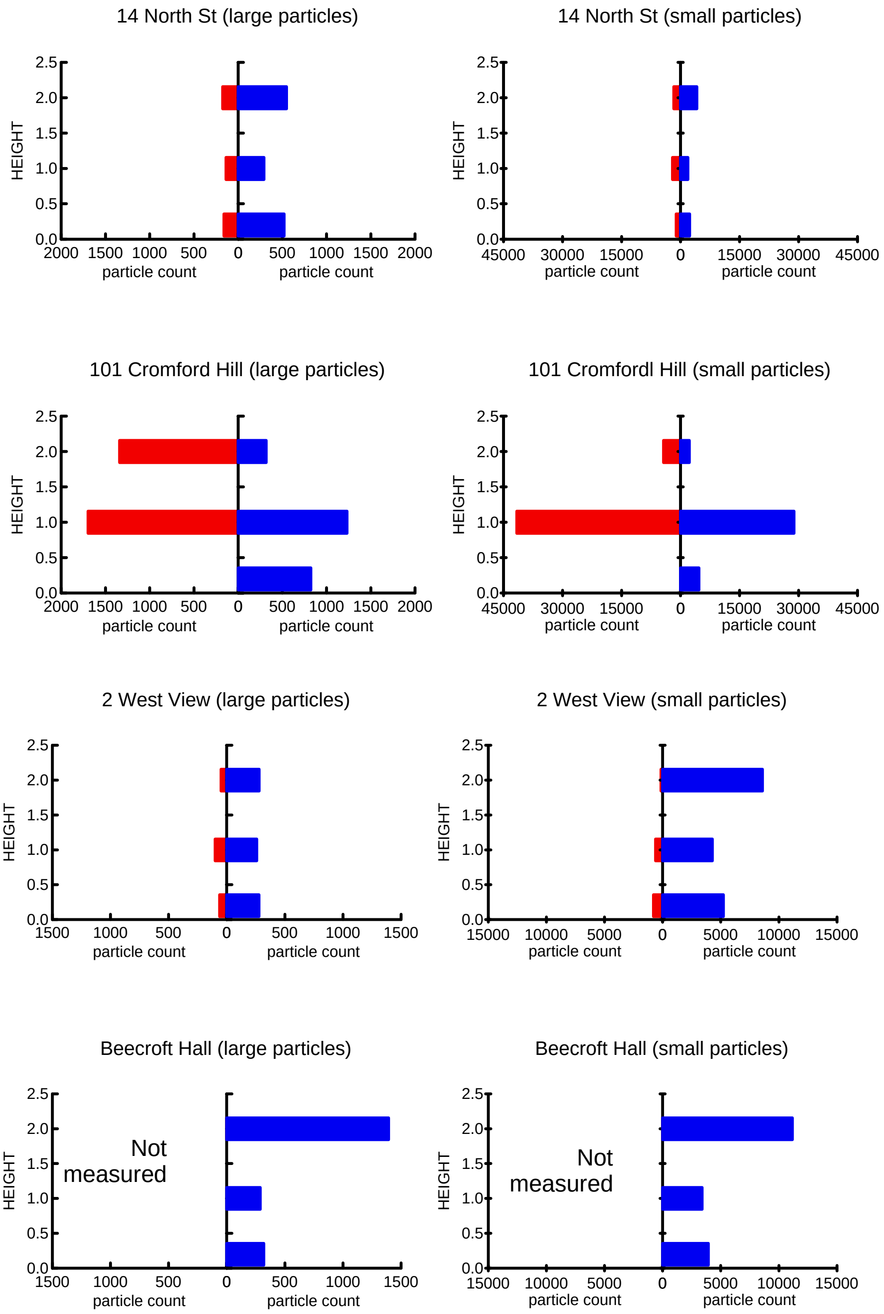


Figure 24: Comparison of deposition measurements at different heights above ground level. Red (left side of axis) = indoor samples, Blue (right side of axis) = outdoor samples.

6.2 Noise

What is the effect of noise on residents and visitors?

Data from two case study sites: 2 West View (Yorkshire) and 54 Cromford Hill (Derbyshire) were found to yield the most comprehensive results to answer this research question. Figures 25 and 28 show the data for an hour at each of the sites. As well as the sound intensity aggregated over one second (solid line), the estimated time of passing of wagons associated with aggregates extraction are shown as circles. The location of the circles with respect to the vertical axis shows the estimate of peak sound level indoors associated with the event.

Two sets of horizontal dotted lines are shown. These represent World Health Organisation (WHO) guidelines for maximum exposure indoors (lower line) and outdoors (upper line). These thresholds do not apply to instantaneous measurements: the WHO specification of a dose of 55 L_{Aeq} T dB means that 55dB constitutes a nuisance for outdoor living areas when experienced for longer than a 16 hour daytime period. Thus, short term events with instantaneous maxima of greater than 55dB are acceptable provided that the ambient conditions are somewhat below 55dB. A triangle is used to represent times at which the geophone unit triggered. They are placed arbitrarily with respect to the vertical axis. A horizontal dashed line represents, in each case, the dosage calculated over the hour long period.

In each case the “soundscape” is dominated by short transient peaks representing traffic. Given the short duration of these events with respect to the hour long sample period, the dotted line is thought to give a good estimate of sound dosage over a working day in each case. Figure 26 shows that, aggregated over an hour the sound levels measured at 2 West View do fall below the WHO recommendation. This finding is repeated at the other site in Yorkshire (2 Bransghyll) as shown in figure 27. The two sites on Cromford Hill in Derbyshire, however (figures 29 and 30) show that over the hour long monitoring period, the sound dosage is considerably higher than the WHO guideline. When averaged over the 16 hour “daytime” period suggested by the WHO which would capture periods outside of the working day, it is likely that the level would drop below 55dB.

The WHO guideline, and indeed any guideline which specified noise dosage over an extended period, implies that sound levels do not vary significantly throughout the time period in question. In the case of vehicle noise, the nuisance aspect is likely to be more closely related to the extent to which sound fluctuates with time. It is also related closely to the attitude of the subject towards the source of the noise. Local residents in Yorkshire, for example, accept that quarrying is an important means of income and a local employer and are thus sympathetic to the associated sounds. An external visitor to an important historic site would conceivably take a different view.

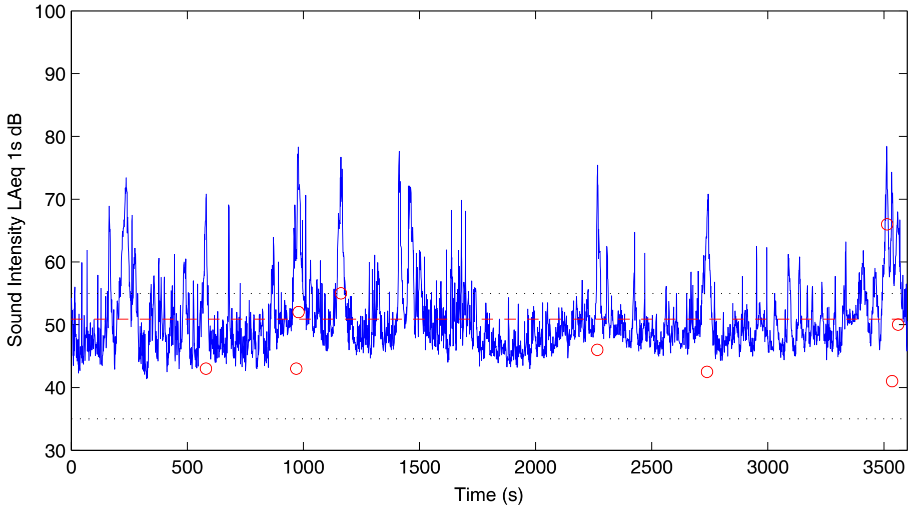


Figure 25: Sound intensity measurements, 2 West View 11.05am–12.05pm Thursday 12th January 2006

Nine wagons associated with aggregates extraction passed 2 West View while sound and vibration was being monitored. These events (three of which are shown more clearly in figure 26 below) typically had a peak intensity of around 70-75dB. Other traffic – buses, motorcycles and 4x4 vehicles for instance were also seen to have peak intensity values of a similar magnitude.

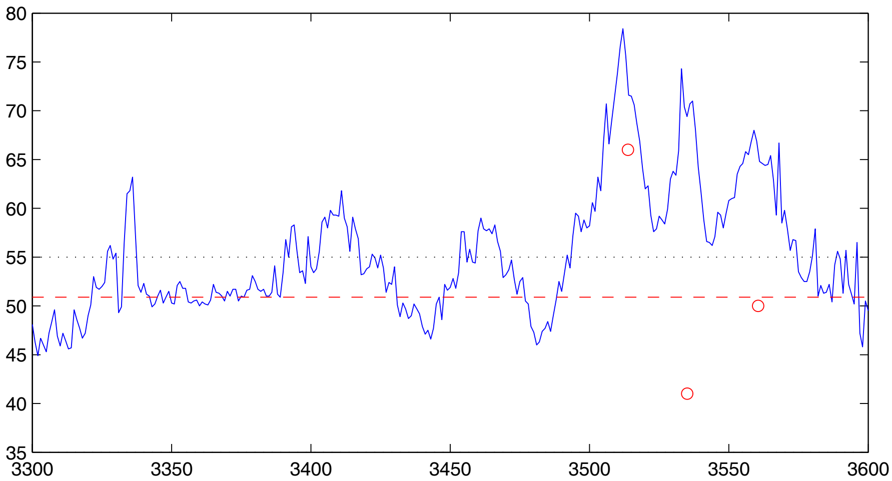


Figure 26: Sound intensity measurement Detail – 2 West View

A comparison of peak sound intensity externally with the same value measured indoors yields some interesting results which are summarised in table 6. This shows that the attenuation varies quite considerably between events from a minimum of 12.4dB (a reduction in intensity of a little over half) to a maximum of 35 which is around a 10fold decrease in intensity. The glazing in the front window behind which the readings were taken was of a double-glazed type incorporating a vacuum. Based on the evidence from the sound track of the recording of the period, the reason for the large variation is likely to relate to the frequency content of the sound in each case. Each wagon has a rather distinctive sound, the frequency content of which depends on speed, revs/minute of the engine and, critically, impacting of components of the wagon particularly when empty. It seems likely that the double glazing is better at attenuating some frequencies than others, but this matter would require further investigation outside the scope of this study.

Table 6: Attenuation of noise from aggregate lorry events 2 West View

Event	Ext	Int	Att.
	LAeq 1s dB		
A	70.8	43	27.80
B	78.3	43	35.30
C	78.3	52	26.30
D	76.7	55	21.70
F	75.4	46	29.40
G	70.8	43	27.80
H	78.4	66	12.40
I	74.2	41	33.20
J	68	50	18.00

As figure 27 shows, the results from 2 West View bear a close resemblance to those at 2 Bransghyll which is around half a mile away.

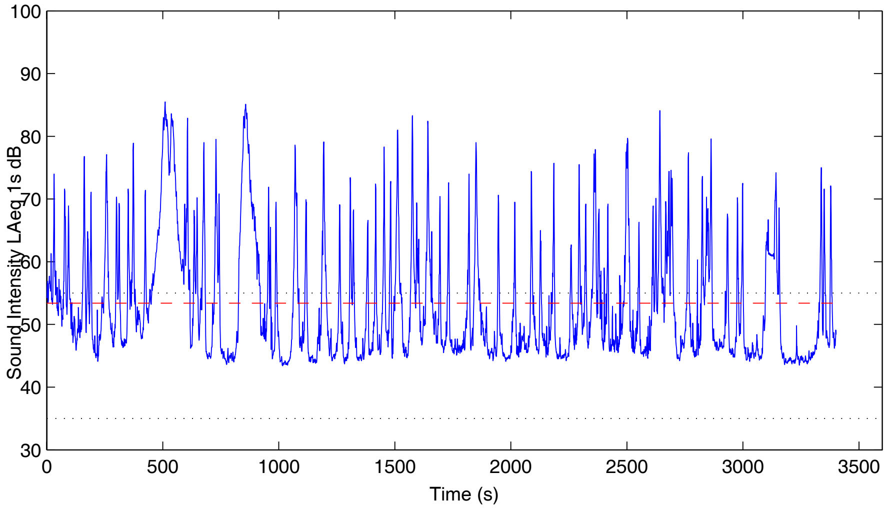


Figure 27: Sound intensity measurements, 2 Bransghyll 11.25am–12.20pm Friday 13th January 2006

The picture is rather different at the two sites in Derbyshire as indicated by figures 28 and 30. As the more detailed view of a five minute period in figure 29 shows, individual traffic events are less significant compared with the background noise. The instantaneous sound intensity from aggregate-related wagons is approximately double compared with values measured in Yorkshire with a typical value of around 85dB. The higher sound intensity of these wagons and in general is related to the rather enclosed nature of housing either side of Cromford Hill and also to the steepness of the hill placing greater demands on the engines of vehicles traveling on it.

A total of 33 aggregate-related wagons were counted from the video sequence during the 1 hour monitoring period. As the circles in figure 28 indicate, the attenuation of the sound from outside to indoors varies significantly. It is likely that effectiveness of the windows at 54 Cromford Hill consisting of single glazing with an additional panel of secondary glazing – is also frequency dependent. The average instantaneous internal intensity is 62dB representing an attenuation, on average, of 23dB. This is a little lower than the average attenuation of 26dB measured in Yorkshire.

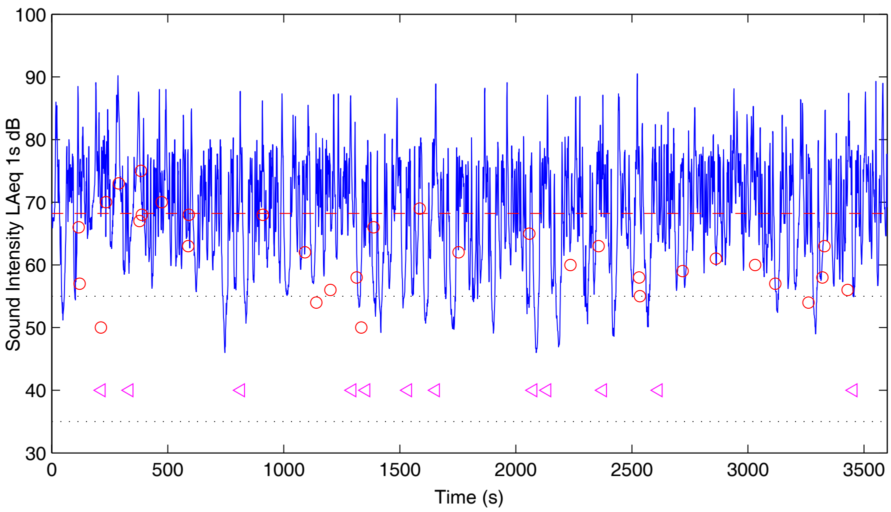


Figure 28: Sound intensity measurements and vibration trigger times, 54 Cromford Hill 1.35am–12.35pm Tuesday 17th January 2006.

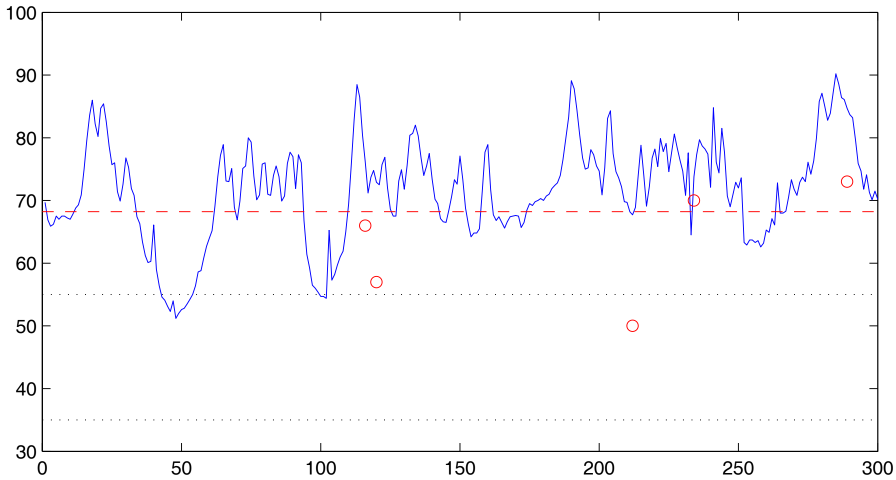


Figure 29: Sound Intensity Measurement Detail – 54 Cromford Hill.

The sound profile at 101 Cromford Hill is shown in figure 30 to have a similar profile to that of 54 Cromford Hill.

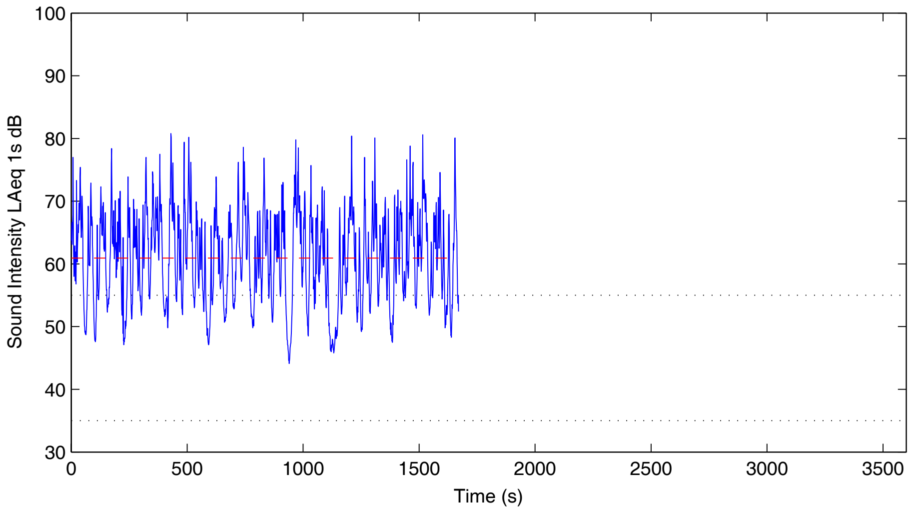


Figure 30: Sound intensity measurements, 101 Cromford Hill 9.55am–10.25 Monday 16th January 2006

To try to get a feel for the extent to which aggregates-related traffic contributes to the noisiness, a technique is suggested where the area under all peaks above a specified "annoyance" threshold is calculated. The proportion of this related to aggregates activity can then be calculated.

For 54 Cromford Hill, for example, figure 31 shows all sound intensity activity above 80dB. Figure 32 shows a peak resulting from a typical aggregate wagon. By calculating the area under the graph for the 33 events and dividing by the total, a proportion of 74% is reached, i.e. during the measuring period 74% of the sound activity > 80dB was from aggregates traffic. This figure helps to give a picture of the extent to which aggregates activity contributes to annoying noise. The tool requires some more development but helps to set the noise effect of aggregate extraction in its context.

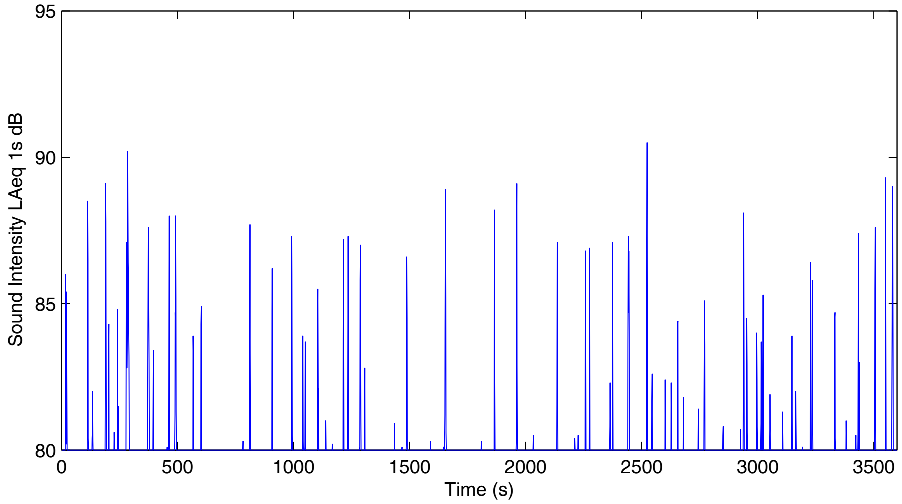


Figure 31: Instantaneous peaks above 80dB, 54 Cromford Hill.

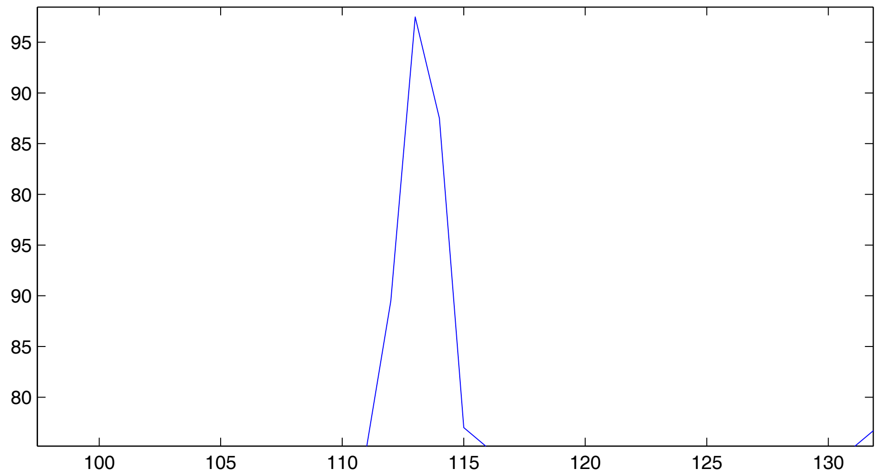


Figure 32: Typical peak arising from aggregate wagon, 54 Cromford Hill.

6.3 Vibration

What is the effect of vibration on historic buildings?

The seismograph unit was found to trigger quite frequently due to the passing of wagons related to the aggregates extraction industry. For example, when the geophone unit was placed outside 54 Cromford Hill, 12 events were found to have caused the unit to trigger during an hour period. The maximum value was 0.475mm/s.

Typically, peak velocities (known as peak particle velocities or PPVs) of 0.3-0.475mm/s were found near the foundation of buildings and bridges in Horton (see table 7) as a result of passing aggregates wagons. Unladen wagons were equally likely to cause measurable events. It was difficult to predict the likelihood of any particular aggregate wagon triggering the detector.

It is of note that a quarry blast at Horton quarry during the Horton village monitoring failed to trigger the seismograph.

Table 7: Peak PPV triggers at each monitoring location, summer and winter.

Date	Time	PPV (mms^{-1})	Location	Source
Summer				
17/8/05	11.23am	0.375	Bridge over River Ribble, Horton	Wagon
17/8/05	14.40	0.300	2 West View, Horton	Wagon
19/8/05	14.31	0.325	Barn adjoining main road, Horton	Wagon
23/8/05	9.29	0.375	54 Cromford Hill, Cromford	Wagon
No trigger			101 Cromford Hill, Cromford	All traffic
No trigger			North Street	All traffic
Winter				
12/1/06	11.03	0.475	2 West View, Horton	Wagon
13/1/06	11.32	0.400	2 Bransghyll, Horton	Wagon
16/1/06	13.50	0.475	54 Cromford Hill, Cromford	Wagon
No trigger			101 Cromford Hill, Cromford	All traffic

Little is known about the cumulative effect of prolonged exposure to low amplitude vibrations. However even the most conservative codes of practice regard the threshold of 0.5mm/s as not posing a threat to structure, even those with delicate finishes.

These findings are some-what counter-intuitive. There is a feeling amongst local residents that vibration from aggregates wagons is palpable and probably the cause of structural damage such as settlement. Evidence from this study does not corroborate this view. The reason for the apparent large vibration dose is probably two fold:

- The ground-borne vibration is accompanied by air-borne audible and inaudible excitation. The combined effect can be rather dramatic.
- Humans are more sensitive to vibration, than the buildings they occupy.

7 CONCLUSIONS

Dust

- Mineral dust likely to have originated from Horton and Dene quarries was detected at all the locations studied, indoors and outdoors, in the summer and winter sampling campaigns. The locations were between 175 and 800m distance from the quarry perimeters.

- Fresh quarry dust may be abrasive to historic materials due to the sharp edges of mechanically cleaved calcite particles.

- Quarry dust is weathered by the action of rainwater, producing more rounded, pitted particles. Its solubility in rainwater means that it is readily washed away from building and road surfaces at the case study sites, which were in areas of high annual rainfall.

- No evidence of long-term soiling of buildings by quarry dust was observed at the case study sites. Dissolved calcite is unlikely to be detrimental to building surfaces, though recrystallisation could lead to whitish deposits.

- Quarry dust can be transported by direct airborne movement from quarry workings or from vehicle loads and bodies. This latter mode of transport has been reduced in recent decades by the compulsory practice of sheeting wagons and also because of wheel washing of vehicles before they leave the site.

- General road traffic may contribute to the re-suspension quarry dust deposited on roads. Roads and road traffic are significant sources of mineral dust in their own right.

- Mineral dusts likely to have come from the quarries were found inside all the houses. If such dusts are abrasive they may have the potential to damage delicate surfaces.

Noise

- Noise could be a significant nuisance factor for local residents and for the context of the historic environment. This was particularly evident at Cromford where, during one hour of measurement, 74% of loud traffic noise (>80dB) was caused by aggregates wagons. This is in the context of a working day where aggregates wagons comprise less than 5% of total traffic on Cromford Hill.

Vibration

- At all sites ground borne vibration from either quarry blasting or traffic was below the level thought to damage even the most sensitive structures.

- Perceptions of damage from ground vibration may be exaggerated by the simultaneous airborne vibration and sound caused by traffic or blasting. Humans are probably more sensitive to vibration than structures.

8 GUIDELINE RECOMMEDATIONS

The most significant impacts on the environments of the two case study sites are related to transportation rather than on-site quarry operations such as blasting. The impacts are more intense at Cromford which experiences approximately three times more quarry wagon movements every workday than Horton. The impacts of dust, noise and vibration are discussed below.

The dust measurements show that levels of airborne and deposited dust at both the case study sites are comparable with *or below* those found in non-industrial urban environments. The highest airborne dust levels were in Cromford during summer 2005, whilst at Horton dust levels are generally well below urban levels. Dust was mentioned as a significant nuisance by residents of listed buildings on Cromford Hill and also on the North Street cul-de-sac, located some distance away from the main traffic route. Dust was not mentioned as a nuisance by Horton residents.

Whilst the overall dust levels at Cromford are no higher than typical urban levels, quarry dust is a significant feature in the environment. The unusual properties of the quarry dust compared to other urban dusts may make it more noticeable: its light colour and the abrasiveness of fresh dust in particular. However the main mineral component of quarry dust, calcite is easily dissolved in rainwater and washed off building surfaces. Hence there is little accumulation of quarry dust on the external surfaces of buildings or roads, particularly in the high rainfall upland locations that were studied. Thus quarry dust does not constitute a long-term external soiling problem for most buildings in the case study areas. However it could accumulate on building surfaces that are not washed by rain, and does constitute a short-term nuisance between periods of rainfall. If rainfall decreases in the case study areas due to climate change, for instance, and in other drier areas, it may become a more significant problem.

The main threat from quarry dust is probably as a soiling nuisance indoors, on delicate material such as textiles or books, where cleaning to remove dust can cause damage. Fresh, abrasive quarry dust can also scratch vulnerable surfaces such as paintwork or polished furniture. All of the indoor measurements show that quarry dusts is found inside properties, as one of the most abundant mineral components of the deposited dust. It was not possible to investigate the actual effects of the dust on for example historic collections which are of interest to English Heritage as all of the interiors studied in the project were domestic dwellings.

Both quarry operators at Cromford and Horton work to high standards in controlling dust through measures such as wheel washing and sheeting of wagons, so the dust concentrations experienced at both villages may reflect the best that can currently be achieved given the size of the industries and current operating practices.

Noise from quarry transportation is highly significant in the soundscapes of both villages, affecting their historic environment setting. Once again Cromford, is more affected than Horton. Although 95% of the working day traffic on Cromford Hill is not quarry related, the 5% of quarry wagon traffic was found, in one sample period, to cause 75% of the loud noise (>80dB) events. Also it is likely that the background noise level on Cromford Hill exceeds the World Health Organisation guideline of 55LA dB. Residents of the case study houses in Cromford have cited quarry traffic noise as a significant nuisance, particularly in the early morning when the first wagons leave the quarry at 6am. In contrast Horton was found to be significantly quieter with average noise levels well below the 55LAdB value. Here one resident considered motorbikes to be a more significant nuisance than the wagons.

In summary, at Cromford in particular there quarry wagon noise has a significant impact on the historic setting. In the future, wagons design improvements may reduce their noise output. However these improvements could be offset by the use of larger vehicles. The largest wagons that serviced the quarries during this study were 6-axle articulated lorries with a tare weight of approximately 12 tonnes and loads of up to 30 tonnes of aggregate. Also, as wagons get older or are not well maintained they become more prone to rattle.

The vibration studies show that ground borne vibration induced by blasting or wagon movements has always been substantially below the thresholds at which any building damage is considered to occur. This was the case for houses only 1-2m away from roads and also for structures such as historic bridges on wagon routes. Whilst the possibility of long-term cumulative damage cannot be ruled out, the effect of current wagon types on structures appears to be nil.

Is there a 'safe' distance from quarries or their transport routes beyond which any damage is considered acceptable?

Noise and vibration both fall off rapidly away from their sources. Few quarry blasting events took place during the project monitoring periods and none of these produced a measurable response on the seismograph which was located at the case study buildings.

In contrast, quarry dust was detected at all the monitoring, sites up to 875m from the quarry perimeters. There is some evidence that dust levels drop off with distance, but it is also evident that mineral dusts are highest on busy roads such as Cromford Hill where there are probably also other significant dust sources.

What additional costs in terms of repair and maintenance of historic buildings are incurred as a result of proximity to aggregates workings?

The study results suggest that the physical impacts on historic buildings are relatively minor. In vulnerable locations it may be necessary to exclude quarry dust from building interiors by keeping windows closed and improving the seals of doors and windows, though care must be taken not to cause other problems such as high internal humidities, which may result from restricting ventilation. Additional cleaning of interiors and exteriors may be necessary. Measures to reduce the noise impact indoors may be considered, such as multiple glazing, but such interventions may result in an unacceptable change to the character of historic buildings. It may be advisable to devise a monitoring programme for indoor dust deposition and perhaps cumulative vibration effect and to study in more detail the benefits and risks of multiple glazing.

How can these risks be managed?

Heritage managers should consider monitoring buildings near quarries or transport routes to gauge their vulnerability to dust, noise and vibration impacts. It is very useful to have read the local quarry operating conditions, which are held by the relevant local authority. These detail various environmental control provisions to regulate the impact of the quarry on the local area; they may also specify the maximum vehicle size and permitted access routes. The local authority may also be able to share data it has collected from the quarries to demonstrate compliance with operating conditions, for instance on dust and vibration.

The two sites studied in this project are operated responsibly by two of the larger UK quarry companies and in many ways they can be considered as examples of current best practice. Both companies recognize that they have a business interest in ensuring that any negative impacts on their surroundings and local communities are minimized so that their operations may continue and expand in the future.

The impacts of on-site quarry operations seem to be more readily controlled than the impacts of wagon transportation, which is difficult to avoid on small country roads through villages.

The greater use of rail transport would help to diffuse the pressure. At Horton Quarry there used to be a rail link to the nearby Settle-Carlisle railway. The operator is currently considering whether rail transportation can be reintroduced. The economic viability of rail depends on the scale of the operation. The current level of quarrying at Horton does not justify economically a rail link. However an expansion of the scale of quarrying at Horton could make rail transport viable, and indeed a necessity in any expansion of its operation.

9 FURTHER WORK

Below is a list of research questions that have arisen from this one-year pilot scale project that could be investigated as part of any future research:

Dust

- How far beyond 1 km does quarry dust travel?
- How do weather conditions affect the transport of dust, e.g. prevailing wind direction and rainfall patterns
- Can we develop a more specific mapping technique for quarry dust?
- How does quarry dust morphology and chemistry affect the surfaces of historic materials? In particular, the potentially abrasive properties of quarry dust could be investigated.

Noise

- What is public perception of nuisance of noise?
- How might low level vibrations affect delicate structures over long periods?
- How best to characterise the nuisance levels of noise? WHO recommendations are not necessarily the most suitable.
- Investigate possibility of “flux adjustment” of noise to achieve best attenuation through glazing e.g. to eliminate high frequency clanking of wagons.

Complex issues

- Investigate the resolution of tensions between multiple glazing and reduction of noise penetration, the impact of resultant air tightness from multiple glazing and the increase in the risk of high levels of humidity and mould growth. This has consequences also for the application of the new Part L of the Building Regulations to the existing building stock.
- What are the cost/benefits of quarrying to the local community and environment?

10 TECHNICAL APPENDIX

10.1 Dust sampling methods

Frisbee Gauges

Frisbee gauges consist of a metal collecting dish, shaped like an upside down Frisbee that is connected by a tube to a collection bottle, of 5-10L capacity in the base of the device. They are designed to collect dust that settles out of the air by gravity, or is washed into the collector by rainfall. Thus the sampling method will measure dust deposition rates under local meteorological conditions. The method was developed by the Stockholm Environment Institute (York), Warren Spring Laboratory (Stevenage) and Selby District Council. It has also been described in a British Standard (Vallack, 1995). The method employed in the present project was developed from the British Standard by the British Geological Survey (BGS) and is considered to be 30% more efficient than the original method method. Five Frisbee gauges were used in the project sampling campaigns and all were deployed in winter and summer sampling at both case study sites. The Frisbee gauges were provided by the project subcontractor, British Geological Survey.

On retrieval from the field the device was dismantled and the collection bottle taken to the laboratory for filtration to collect the suspended particulate matter, which was then dried and quantified by weighing. The collected particles were analysed by scanning electron microscopy to study the sample morphology and elemental composition, and x-ray diffraction in order to characterise the minerals present. Deployment on site, retrieval and filtration were undertaken by University College London and the subsequent chemical analysis was carried out by BGS at their main site at Keyworth, Nottingham.

Figure 33: Frisbee Gauge deployed at Beecroft Hall, Horton in Ribblesdale, winter 2006.

'Sticky' samplers

The second method of passive sampling used small 'sticky' samplers consisting of 11mm diameter aluminium electron microscope stubs, coated with a double-sided carbon adhesive tape. These were deployed on the internal and external wall surfaces of the case study buildings. This method of dust sampling has previously been employed by British Geological Survey to study mineral dusts and is similar to other methods used to study dust in historic buildings (e.g. Yoon and Brimblecombe 2001). Duplicate stubs were deployed at each sampling location, fixed in place using a bracket and blutak (figure 34). Stubs were exposed in vertical profiles, at heights of 0.2m, 1m and 2m above ground level. After approximately 6 weeks exposure the stubs were retrieved, placed in a sealed box and returned to British Geological Survey for analysis The collected dust was characterised by scanning electron microscopy (SEM), in cooperation with UCL. In addition to these methods of sampling dusts deposited from the atmosphere, quarry product samples were provided by Hanson Aggregates (Horton Quarry) and Tarmac plc (Dene Quarry), and a sample of road dust was taken from the quarry access road at Horton Quarry. These samples were all submitted to BGS for SEM analysis.

Figure 34: Sticky samplers deployed at Beecroft Hall, Horton in Ribblesdale, winter 2006.

Active sampling method

Suspended atmospheric dust particles were counted inside and outside each case study building using an optical particle counter (Grimm Portable Dust Monitor Series 1.100, figure 35). This instrument uses a pump to draw in air and a laser technique to count the particles in the air. Particles are classified into eight size ranges, from 0.75-15µm and > 15µm. A concentration measurement for each size range is logged every minute, enabling a picture of the variation in indoor and outdoor dust concentrations over a time period to be built up. The particle counter was deployed for 2-3 hour periods at each of the case study sampling sites in order to gain a snapshot of the short-term variation in dust concentration at each site, indoor as well as outdoor.

The Grimm monitor also collects the sampled dust on an internal filter. In the summer sampling campaign filters were changed after sampling at each case study building SEM analysis at BGS to see if it was possible to characterize the airborne dust. The amount of dust collected in the short sampling periods employed was insufficient to yield results from this analysis.

Figure 35: Grimm optical particle counter deployed at 2 West View Terrace, Horton in Ribblesdale.

10.2 Dust analysis methods

Gravimetric analysis
Samples collected from the Frisbee gauges were dried and weighed.

The methodological descriptions for Qualitative SEM analysis, X-Ray Mapping, Automated Image Analysis by SEM and X-Ray Diffraction from the British Geological Survey commissioned report, CR/06/045, which was prepared on behalf of the project, can be found below.

Qualitative SEM analysis
Scanning Electron Microscopy (SEM) is a method which allows specimens to be imaged at magnifications far greater than can be achieved with conventional optical microscopy. It can be used to characterise the morphologies of particles and measure their chemical compositions to determine their mineralogical constituents. Typically, particles as small as 0.1µm (10^{-7} m, or one ten thousandth of a millimeter) in diameter can be imaged by SEM. SEM was used in this study to make qualitative observations of the dust samples and record images showing the typical particle distribution, giving an indication of the sizes and morphologies present. In addition, chemical analysis of individual grains was carried out to identify the mineral phases present in the samples. Imaging was carried out using Back-Scattered Electron Imaging mode, whereby contrast in the image is dependent on a combination of topography and atomic density of the phase imaged. This means the images contain information on both shape and mineral phase (since different mineral phases have different atomic densities). The examinations were carried out using a Leo 435VP SEM operated at 20 KeV, with a solid-state 4-element (diode) back-scattered electron detector. Qualitative chemical analysis of individual grains was carried out using an Oxford Instruments ISIS 300 Energy-Dispersive X-ray (EDXA) spectrometer with a Si-Li X-ray detector.

X-ray mapping
The Leo SEM/ISIS 300 system was also used to produce element maps of selected areas of certain samples, using X-ray analysis. These maps are produced by scanning the

electron beam over the sample and recording the intensity of characteristic X-rays from the selected elements at each point within the sample area chosen. The resulting images map out the relative concentration of that element over the sample area, although it should be pointed out that the data are not calibrated and so give relative rather than absolute, elemental concentrations. Maps of five separate elements (Si, Ca, Al, Fe and S) were produced, together with a back-scattered electron image of each area.

Automated image analysis by SEM

Automated Image Analysis (referred to here as AIA) is a technique mostly used for characterising populations of fine particles in a rigorous quantitative manner. AIA tends to make use of the imaging capabilities of SEM, sometimes together with microchemical analysis. Properties that can be measured generally include particle size distribution, particle shape distribution and sometimes properties based on chemical analysis such as mineral phase category present, leading to a modal mineralogical analysis. AIA works by controlling an SEM according to a programmed routine. The SEM automatically acquires a set of images of the sample, covering the area required. The images are then digitally processed to identify and measure the particles. The aim of this analytical work was to characterise the population of inorganic particles collected on a selection of the passive deposition sticky samplers, in order to compare them. The particles were to be characterised in terms of their size, and the distribution of particles across a range of sizes. This is known as the particle size distribution and can be shown as a histogram or a curve showing the cumulative frequency of particles versus size. The size parameter usually measured is the Equivalent Spherical Diameter or ESD. This means the diameter that the particle would be if it were perfectly spherical with the same imaged area. If possible, other particle characteristics were to be measured (e.g. Feret ratio, a measure of sphericity). 21 samples from the Summer sampling period were selected by UCL for Automated Image Analysis, comprising a set from each of four buildings, two in Cromford and two in Horton. A further 7 samples were selected from the Winter period, comprising all the Indoor and Outdoor samples at 1.0m height. Automated Image Analysis was also carried out on two quarry product samples from Horton and Cromford and the road dust sweeping from Horton.

X-Ray Diffractometry

X-Ray Diffractometry (XRD) is a method of identifying the principal minerals present in a bulk sample. It works by focusing a beam of X-rays at a powdered sample and recording the reflections given off by crystalline particles present. Every crystalline mineral phase has a characteristic pattern of reflections with peaks at particular angles of reflection. Thus minerals can be identified from the recorded pattern, and the relative amount of each mineral can be estimated or determined from the intensities of the peaks (in counts per second). The frisbee-gauge filter membranes were analysed by XRD to investigate what mineral phases were present amongst the particles on them. Each membrane was attached to a silicon wafer and mounted in an aluminium sample holder prior to analysis. The samples were analysed using a Philips PW1700 series diffractometer equipped with a cobalt-target tube and operating at 45 kV and 40 mA. The whole-rock samples were scanned from 5 to 85 $°2\theta$ at 0.70 $°2\theta$/minute. Diffraction data were analysed using PANalytical X'Pert software coupled to an International Centre for Diffraction Data (ICDD) database running on a PC system.

10.3 Sound measurement methods

During the initial summer data collection campaign (August 2005), a hand held sound intensity meter was used to establish instantaneous sound intensity maxima arising from wagons associated with aggregate extraction. Readings were taken in conjunction with a hand-held GPS unit allowing data to be incorporated into GIS software. Typical peak values of 80dB were measured for passing wagons. It was difficult, however, to reach a consensus view for any particular spot since the maximum value at any point varied considerably from wagon to wagon. It was further noted that by taking only instantaneous measurements from activities relating to aggregates extraction, noise from other sources was in effect filtered out.

During the winter campaign, a different strategy for monitoring sound was developed to overcome the perceived shortcomings of the technique used during the summer campaign. Two different units were used to measure the sound intensity caused by aggregate extraction. The first hand-held unit giving an instantaneous reading summarising sound intensity over the last second in time. A second unit with the facility to log the aggregated sound intensity over a given period was used. The collection period was set at the lowest possible value of 1s to characterise most effectively the "soundscape" at each location. Figure 36 shows the recording data logger outside 2 West View. A video camera was used to pick up the readings from the hand-held unit and also to record the type of passing traffic. Through the microphone in the video recorder it was possible to recreate the sounds whose intensity were being measured. Four historic locations, two in Derbyshire and two in Yorkshire, were the subject of this technique. Figure 37 shows stills from the video sequences taken at 2 West View and 54 Cromford Hill. In each case it is possible to see the hand-held sound intensity logger in the foreground and a wagon associated with aggregates extraction passing on the road outside.

Figure 36: Sound intensity logger and geophone unit outside 2 West View

Figure 37: Stills from video sequences recorded at 2 West View (left) and 54 Cromford Hill (right)

Both sound intensity meters give a reading in decibels (dB) scale which is related to the logarithm of the ratio of the change in pressure which manifests itself as sound to the pressure representing sound at the threshold of perceptibility. A change in sound intensity of 10dB represents a doubling / halving of the underlying pressure parameter. In all cases the sound measured is weighted so that, as far as human perception of the nuisance is concerned, the reading is independent of the frequency – or pitch – of the sound. This weighting is carried out automatically within the sound intensity meters.

A further parameter is sometimes used to give an impression of the time over which particular sound events occur. This leads to the concept of noise dose where a particular timebase is given and the average intensity over that period gives an impression of the dose. For example, the World Health Organisation specifies a dose of 55 L_{Aeq} T dB as constituting a nuisance for outdoor living areas where T is 16 hours. Thus, short term events with instantaneous maxima of greater than 55dB might be allowable provided that the ambient conditions were somewhat below 55dB.

10.4 Vibration measurement method

A seismograph was used to establish the ground borne vibrations as close as possible to the foundations of the buildings being examined. The transducer itself is a geophone which gives a readout of vibration on buildings in terms of velocity (mm/s). It is widely accepted that the damaging effects of ground vibration on structures are most usefully described in terms of a peak particle velocity (PPV). Predictions of possible damage can be given in terms of displacement or acceleration. These parameters have the considerable disadvantage of being frequency dependent. For example, a displacement of 1mm is considerably less damaging at 1Hz (one cycle per second) compared with the damaging effect of, say, a 10Hz vibration with the same displacement.

The unit was set to trigger at 0.1mm/s. In other words, the unit would start collecting information about vibration experienced by the geophone as soon as the level reached 0.1mm/s. This was the lowest trigger level available and was close to the resolution of the instrument. The geophone was set to record events during each of the four hour-long monitoring periods.

Figure 22 shows the red geophone transducer unit connected to the yellow data collection and storage unit adjacent to 2 West View, Horton in Ribblesdale.

10.5 Results of dust analysis

A summary of the dust sampling methods employed at each case study site during the summer (August–September 2005) and winter (January–February 2006) campaigns at the two project case study sites are in table 8, below.

Table 8: Summary of the dust sampling methods employed at each case study site during the summer (August–September 2005) and winter (January–February 2006) campaigns at the two project case study sites.

Sampling location	Site characteristics	Approx. distance from quarry	Fris-bee Gauge	Sticky samplers	Particle counter
54 Cromford Hill	On busy road and main quarry wagon route	350m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside
101 Crom-ford Hill	On busy road and main quarry wagon route	600m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside
14 North Street	Cul-de-sac off main quarry route	750m	No	Inside and Outside at 0.2, 1 & 2m	Inside and Outside
3 North Street	Cul-de-sac off main quarry route	750m	No	Outside at 0.2, 1 & 2m	No

Horton in Ribblesdale, Yorkshire

Sampling location	Site characteristics	Approx. distance from quarry	Frisbee Gauge	Sticky samplers	Particle counter
Beecroft Hall	In fields away from any road	175m	Yes	Outside at 0.2, 1 & 2m	Outside
2 West View	On quarry access road, no other through traffic	625m	Yes	Inside and Outside at 0.2, 1 & 2m	Inside and Outside
2 Bransghyll Terrace	On main road through village and one of the quarry routes	875m	No	Inside and Outside at 0.2, 1 & 2m	Inside and Outside

10.5.1 Sticky samplers

(Description and tables from British Geological Survey commissioned report CR/06/045)

The sticky carbon tabs used for passive deposition of indoor and outdoor dusts were briefly examined by Scanning Electron Microscopy (SEM). The purpose of this was to characterise and image the different particle types, describing their shapes, surface textures and chemistry. All the summer samples were examined (36 in total, from 7 sites) but of the winter samples, only those from four of the sites were examined, giving a total of 21 samples. The purpose of this was to list the main particle types present in each sample and to take representative, comparable images showing the distribution of particles in each sample. A more detailed SEM examination was then conducted of all the Outdoor samples taken in the summer at 1.0 m height, totalling seven samples (one from each site).

Representative digital photographs of each sample were taken at two magnifications: x50 and x200. These images are available on request. The images give a visual means of comparing the density of particles present and average particle sizes in each sample. Images were also taken of individual particles much higher magnification, in order to illustrate their size, shape and textures in more detail (Plates 58 to 60). The SEM was operated in Back-Scattered Electron mode which means that that material with greater mean atomic density (i.e. composed of heavier elements) appears brighter in the images. Therefore, the carbon substrate appears black and the inorganic particles such as silicates appear very bright. Organic particles such as hairs and plant fibres appear very dark grey.

Organic particles were not examined or described other than to note the presence of hairs and fibres. Generally, inorganic material occurs in far greater densities in the outdoor samples than the indoor ones. The outdoor samples also tend to have a greater abundance of coarser (sand grade) material. The low outdoor samples (0.2 m) tend to have significant medium to coarse sand grade material, which tends to be absent at greater heights. There is sometimes a slight reduction in grain size and particle density with height, although at two sites (Beecroft Hall outdoor, 14 North St indoor) the uppermost (2 m) samples have far higher densities of particles than samples at 0.2m and 1m heights. A general overview of these observations is given below, explaining them in more detail.

Natural mineral particles:

A suite of natural mineral particle types were seen in all samples. The most common ones were always calcite and quartz, with lesser amounts of feldspar, mica, chlorite, kaolinite, dolomite, barite, clays, Fe oxides and aggregated soil particles. Calcite is the chief constituent of most limestones and also occurs in the soils developed above limestones. It was generally present in slightly greater abundance than quartz and makes up a particularly large proportion of the smallest grains in some samples. Some calcite particles appear quite angular with fresh surfaces, implying recent fracture such as during quarrying. Calcite grains were also frequently seen in aggregated soil-like particles, suggesting that some at least derives from local soils. Many of the calcite particles are clearly deeply pitted by cracks running along the ‘cleavage’ structure of the mineral and in fact, at high magnification, it becomes apparent that all the calcite particles are etched along their cleavage planes (e.g. Plates 58 a and b). The most likely explanation for this is dissolution by acidic rainwater. Limestone may also contain barite, dolomite and fluorite, all of which were seen in these samples, mainly at the Cromford sites. In particular, dolomite and barite were commonly seen at 54 and 101 Cromford Hill. These may be indicative of quarrying activity although again, they may have come from the soils and barite also has common industrial applications.

The common soil and sedimentary minerals are also present in minor to major quantities in all samples: quartz, silicate minerals (feldspar, micas, clays, chlorite, kaolinite), Fe oxides and Ti oxides. These are all common constituents of siliciclastic rocks (e.g. gritstones, sandstones and siltstones) and soils. They may therefore have derived from local soils or from the silicate-based materials disturbed during quarry operations, including soil overburden, glacial deposits and rocks such as sandstones, siltstones and gritstones. They may also be derived from construction materials such as building sand and gravel. It is therefore difficult to identify the sources of these particles with any certainty. Examples are shown in Plates 59 a and b and 60 a.

Common salts (mostly NaCl with some KCl, gypsum and rarely $CaCl_2$) were commonly seen in the winter, at three of the four sites whose winter samples were examined: 2 West View, 101 Cromford Hill and 14 North St. Salt is known to be a common component of house dust, originating either from the sea, atmospheric chemical processes or from road gritting (Bérubé *et al.*, 2004). The fact that these were prevalent during the winter suggests that road gritting might be the chief source.

Anthropogenics:
A suite of materials commonly associated with industrial processes were often seen as rare components of the samples, often occurring together and almost exclusively occurring outdoors. The most common of these are fly ash particles which are spherical alumino-silicates produced as a waste product of combustors used for power generation (Xhoffer *et al.*, 1992). Fly ash is a common constituent of outdoor particulate as it is emitted high into the atmosphere and can travel long distances in suspension. Also observed were Fe ± Ca ± Mg ± Al silicates, often with obvious vitreous textures and therefore likely to be slag, also a waste product of industrial smelting. This is a common urban dust component and may sometimes be used as a source of aggregate in road-building etc. Fe sulphide particles were also occasionally seen. This is a natural mineral phase but is also one of the primary constituents of metal ores. These particle types were often all seen in the same samples or sites, suggesting local industrial sources: at 2 West View Horton, at 101 Cromford Hill in winter, and at 14 North St in winter.

A group of particle types were seen which are likely to originate from cement, concrete and plaster used in construction. The cement and concrete particles mostly consist of Ca silicates, Ca-Al silicates, with occasional Ca-Al sulpho-silicates and Ca-Al-Fe oxides and were present indoors and outdoors, in both summer and winter (e.g. Plate 60b). Plaster was identified by the presence of both gypsum and mixtures of Ca phosphate and sulphate, sometimes with minor K. These associations tended to occur indoors at particular sites (2 West View, 101 Cromford Hill and 54 Cromford Hill).

A group of sodium-based salts and silicates were observed in very small amounts, always in indoor samples and chiefly at two sites: 2 West View (mainly in winter) and 14 North St (Summer and Winter). They include Na-Al silicates (possibly zeolites, rarely with Ca), Na phosphate, Na sulphate and Na carbonate, all of which are major components of laundry detergents (Dall'Acqua *et al.*, 1999).

The stubs which had been mounted outside were observed on return to have undergone corrosion of metal surfaces, chiefly the aluminium mount. Examination by SEM showed fragments of Al oxide and mixed Al/Fe oxides on the carbon tab surfaces of these stubs, particularly those sampled in winter. These particles are therefore regarded as contamination, and it should be borne in mind that they will have been included in the automated image analysis.

A small number of unusual anthropogenic particles were seen, all in indoor samples, whose origins are unknown. They include Al-Zr oxide, zirconium metal and a Ti-Cl-O bearing particle. Zirconium has numerous manufacturing applications including use in bulb filaments and incorporation into corrosion-resistant materials. Al-Zr oxide is a ceramic with applications in dentistry. The Ti-Cl-O particle may be a mixture of Ti oxide and a chlorinated organic compound and may derive from some kind of cleaning agent.

Summary of site characteristics, Horton

2 West View: calcite, silicates, Fe oxides. Industrial products outdoors, road salts in Winter, laundry products indoors.
Beecroft Hall: calcite, silicates, Fe oxides. Little else.
2 Bransghyl: calcite, silicates, Fe oxides, minor industrial products (outdoors) and cement (indoors).

Summary of site characteristics, Cromford

54 Cromford Hill: calcite, barite, silicates including soil and clays, Fe oxides. Plaster indoors.
101 Cromford Hill: Calcite, dolomite, barite, silicates, Fe oxides. Industrial products and road salts in Winter.
3 North St: calcite, silicates, Fe oxides.
14 North St: calcite, dolomite, barite, silicates, Fe oxides. Laundry products indoors. Industrial products (outdoors) and road salts in Winter.

10.5.2 Automated image analysis

Tables 9 and 10 below show summary statistics obtained for the Summer and Winter samples, respectively. The data were normalised to show the numbers of particles (in each size category and in total) per mm^2 of sample surface area, per 4 weeks of collection time. Both the total particle numbers actually counted and the normalised particle numbers per mm^2 per 4 weeks are shown.

Table 9: Summary statistics from automated image analysis of sticky tab collectors: Summer samples. NB Low magnification = x114; high magnification = x1140. O = outdoors; I = indoors. Stdev = standard deviation in the mean.

				ESD (µm):				Feret ratio:				Particle numbers:	
Sample	Magnif.	In/out	Height (m)	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max	Total count	per mm^2 per 4 wks
2 West View, Horton													
g6	Low	O	0.2	10.7	8.2	2.5	66.1	0.67	0.13	0.19	0.92	1667	278
	High	O	0.2	1.9	2.5	0.3	28.4	0.67	0.14	0.30	0.94	392	5227
g8	Low	O	1	10.2	7.0	2.5	66.0	0.67	0.13	0.24	0.92	1544	258
	High	O	1	2.0	2.5	0.3	21.6	0.66	0.14	0.24	0.90	257	4283
g10	Low	O	2	11.1	8.0	2.5	83.6	0.66	0.14	0.13	0.92	1673	279

	High	O	2	1.8	2.7	0.2	36.1	0.68	0.14	0.23	0.96	774	8600
g2	Low	I	0.2	8.5	3.6	2.5	28.9	0.65	0.15	0.19	0.89	234	60
	High	I	0.2	2.0	1.8	0.3	10.2	0.66	0.13	0.28	0.90	94	783
g17	Low	I	1	4.8	2.3	2.5	23.9	0.69	0.10	0.35	0.92	454	100
	High	I	1	1.5	1.6	0.3	8.1	0.67	0.14	0.24	0.89	82	608
g5	Low	I	2	4.6	1.8	2.5	15.7	0.69	0.12	0.26	0.92	296	49
	High	I	2	2.8	1.8	0.6	5.8	0.66	0.11	0.47	0.82	20	133
Beecroft Hall, Horton													
g26	Low	O	0.2	5.3	3.2	2.5	33.0	0.69	0.11	0.20	0.93	1912	319
	High	O	0.2	1.2	1.5	0.3	21.9	0.68	0.13	0.20	0.92	591	3940
g28	Low	O	1	6.0	5.2	2.5	67.4	0.69	0.11	0.28	0.92	1733	289
	High	O	1	1.4	2.1	0.2	32.6	0.68	0.13	0.23	0.93	510	3400
g30	Low	O	2	5.1	3.1	2.2	59.5	0.69	0.11	0.19	0.94	8339	1393
	High	O	2	2.1	2.9	0.2	45.8	0.67	0.14	0.12	0.95	1676	11170
14 North Street, Cromford													
b36	Low	O	0.2	6.9	7.7	2.5	126.4	0.69	0.12	0.18	0.92	2341	520
	High	O	0.2	1.6	1.9	0.3	15.1	0.68	0.14	0.29	0.92	243	2314
b39	Low	O	1	6.6	5.8	2.5	60.9	0.68	0.12	0.18	0.93	1722	291
	High	O	1	1.6	2.1	0.3	23.5	0.68	0.13	0.24	0.92	224	1875
b41	Low	O	2	6.5	5.0	2.5	68.2	0.69	0.11	0.30	0.92	1639	546
	High	O	2	1.4	2.0	0.3	26.1	0.70	0.15	0.19	0.97	559	4141
b33	Low	I	0.2	5.1	2.9	2.2	27.0	0.68	0.12	0.25	0.92	724	161
	High	I	0.2	2.2	2.1	0.3	11.8	0.68	0.15	0.16	0.93	165	1100
b34	Low	I	1	5.9	2.9	2.5	23.3	0.68	0.12	0.26	0.94	410	137
	High	I	1	1.7	2.4	0.3	14.6	0.70	0.14	0.24	0.92	247	2058
b29	Low	I	2	6.2	3.5	2.5	43.6	0.68	0.13	0.22	0.92	1054	176
	High	I	2	1.5	2.3	0.2	19.6	0.68	0.15	0.22	0.92	258	1720
101 Cromford Hill, Cromford													
b1	Low	O	0.2	8.0	7.1	2.5	65.7	0.67	0.14	0.19	0.92	912	822
	High	O	0.2	1.8	3.1	0.3	30.7	0.71	0.14	0.26	0.96	419	4656
b3	Low	O	1	5.9	3.5	2.2	85.2	0.67	0.14	0.10	0.95	7376	1230
	High	O	1	1.2	1.7	0.2	36.5	0.70	0.13	0.27	0.92	2162	28830
b6	Low	O	2	6.0	3.0	2.2	33.9	0.67	0.13	0.19	0.96	1900	317
	High	O	2	1.7	2.0	0.3	15.9	0.69	0.13	0.18	0.91	267	2225
b8	Low	I	0.2	x	x	x	x	x	x	x	x	x	x
b9	Low	I	1	9.0	11.0	2.5	153.8	0.66	0.14	0.20	0.92	2541	1695
	High	I	1	1.6	2.6	0.2	21.6	0.68	0.13	0.29	0.92	624	41670
b11	Low	I	2	8.5	5.9	2.5	51.7	0.66	0.13	0.19	0.94	2008	1340
	High	I	2	3.0	6.2	0.3	54.6	0.68	0.17	0.16	0.89	258	4333

Table 10: Summary statistics from automated image analysis of sticky tab collectors: Winter samples. NB Low magnification = x114; high magnification = x1140. O = outdoors; I = indoors. Stdev = standard deviation in the mean.

				ESD (µm):				Feret ratio:				Particle number:	
Sample	Magnif.	In/out	Height (m)	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max	Total	per mm^2 per 4 wks
2 West View, Horton													
9	Low	O	1	5.7	4.5	2.5	93.7	0.70	0.11	0.27	0.92	1303	218
	High	O	1	1.4	1.6	0.3	16.3	0.69	0.13	0.22	0.92	405	2700
3	Low	I	1	5.9	4.8	2.5	62.2	0.67	0.13	0.10	0.92	546	91
	High	I	1	1.5	1.8	0.3	9.3	0.69	0.11	0.40	0.89	65	619
Beecroft Hall, Horton													
15	Low	O	1	6.4	5.8	2.5	103.1	0.69	0.12	0.14	0.92	3247	721
	High	O	1	1.6	2.4	0.3	21.0	0.69	0.12	0.27	0.92	704	6705
14 North Street, Cromford													
63	Low	O	1	6.6	5.2	2.2	57.2	0.69	0.11	0.28	0.92	2839	474
	High	O	1	2.1	3.1	0.3	27.8	0.68	0.13	0.13	0.95	260	2476
57	Low	I	1	5.6	4.0	2.5	43.9	0.68	0.11	0.22	0.92	792	132
	High	I	1	1.6	2.2	0.3	17.0	0.67	0.13	0.23	0.92	220	1630
101 Cromford Hill, Cromford													
39	Low	O	1	6.9	6.2	2.2	88.8	0.69	0.11	0.20	0.92	3290	730
	High	O	1	1.7	2.3	0.2	25.0	0.68	0.13	0.14	0.95	738	6150
33	Low	I	1	5.4	2.9	2.2	56.7	0.68	0.12	0.24	0.92	3174	530
	High	I	1	1.9	2.2	0.2	12.0	0.67	0.14	0.20	0.92	443	3281

There is remarkably little variation in Feret ratio characteristics in the populations, as can be seen from the summary statistics in Tables 2 and 3.

10.5.3 Frisbee gauges

The suspended particulate matter collected in the Frisbee gauges was quantified by weighing and analysed for mineral composition by XRD. The weight of sample and its collection time was used to calculate a particle deposition rate, shown in table 11, below, that could be compared with previous measurements.

Table 11: Calculated particle deposition rates (mg/m^2/day) compared with previous measurements.

Measurement	*Minimum*	*Maximum*	*Mean*
Horton, Summer data	26.3	32.9	30.0
Horton, Winter data	11.3	21.8	18.2
Cromford, Summer data	24.3	38.2	31.3
Cromford, Winter data	13.6	17.7	15.7
Previous measurements, Dene quarry perimeter (Hards, 2000)	**11**	**120**	**41**
Typical values, urban (De Koning, 1986)	**65**	**100**	
Typical values, light industrial (De Koning, 1986)	**100**	**200**	
Typical values, heavy industrial (De Koning, 1986)	**150**	**350**	
Around cement plant (Ali-Khodja *et al.*, 2005)	**520**	**1340**	

Hards (2000) used Frisbee gauges to measure monthly total deposition masses from three sites on the perimeter of Dene Quarry in Cromford, over 12 months, totalling 35 measurements over a year. These data showed that the on average Cromford was less dusty than a typical urban environment.

The Frisbee measurements from the present project were comparable with Hard's measurements, but it should be noted that XRD analysis found a complete absence of calcite, one of the main mineral components found in all the samples collected on the sticky stubs, from the Cromford and Horton Frisbee samples. This is probably due to the calcite dissolving in rainwater in the collection vessel. The rainwater may be slightly acidic and also the addition of anti-algal tablets could have increased its acidity, facilitating dissolution of the calcite. Therefore the deposition rates calculated from the Frisbee gauge results are probably an underestimate of the actual rates at the two sites. That said, it is worthwhile to note that the mean deposition rates for non-calcite particles were similar at Cromford and Horton, and that the summer deposition rate was about twice that of the winter rate.

10.5.4 Optical particle counting

These data are presented as time plots for total particulate matter concentration measured as µg/m^3.

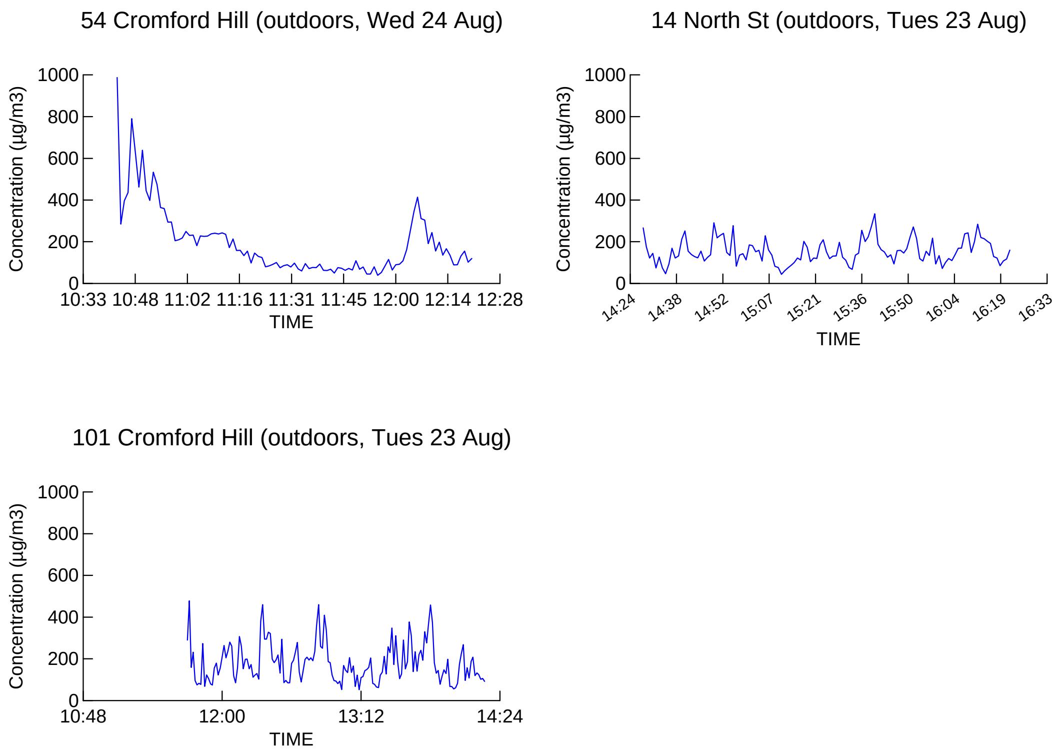


Figure 38: Outdoor samples, Cromford, Derbyshire, summer 2005.

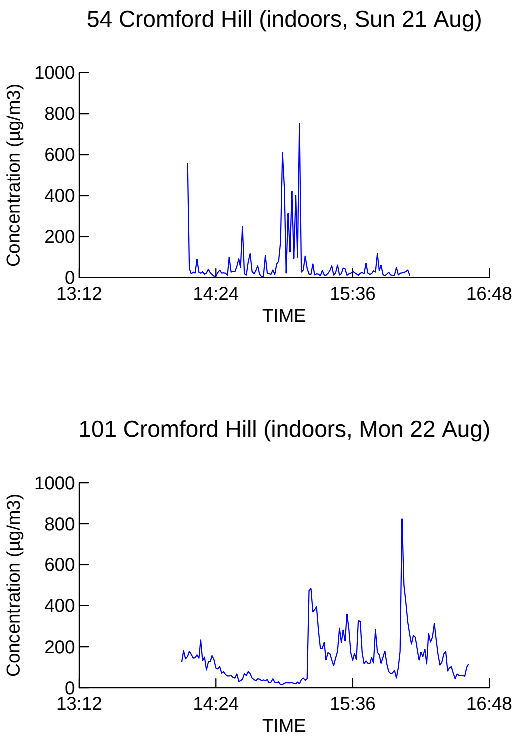


Figure 39: Indoor samples, Cromford, Derbyshire, summer 2005.

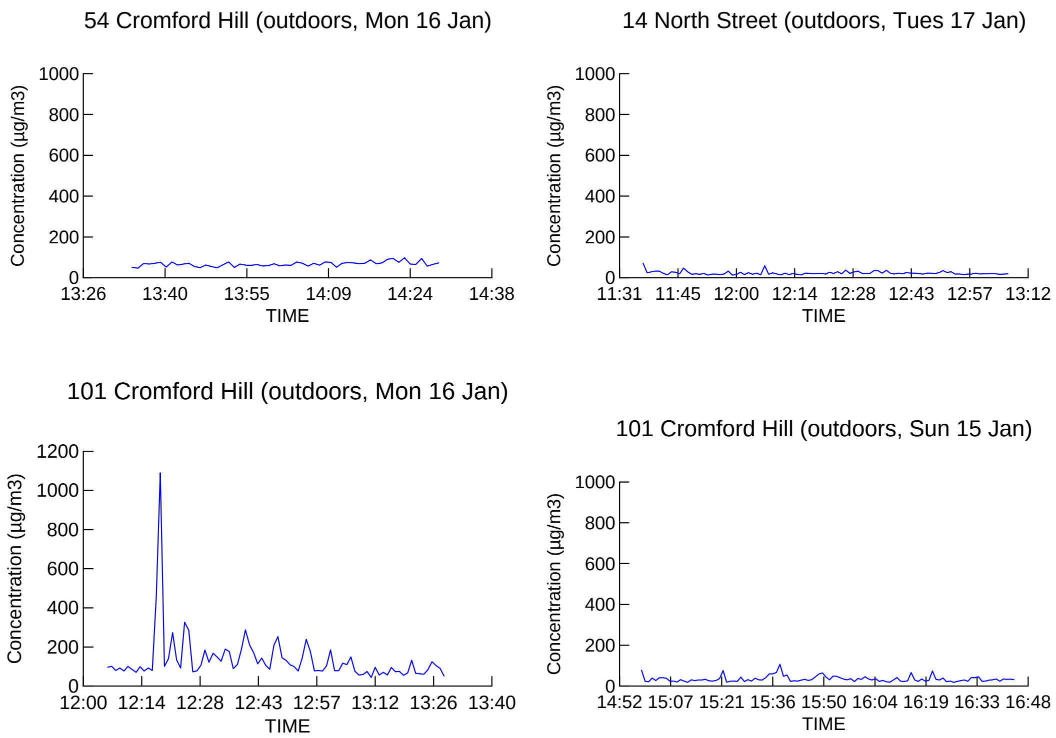


Figure 40: Outdoor samples, Cromford, Derbyshire, winter 2006.

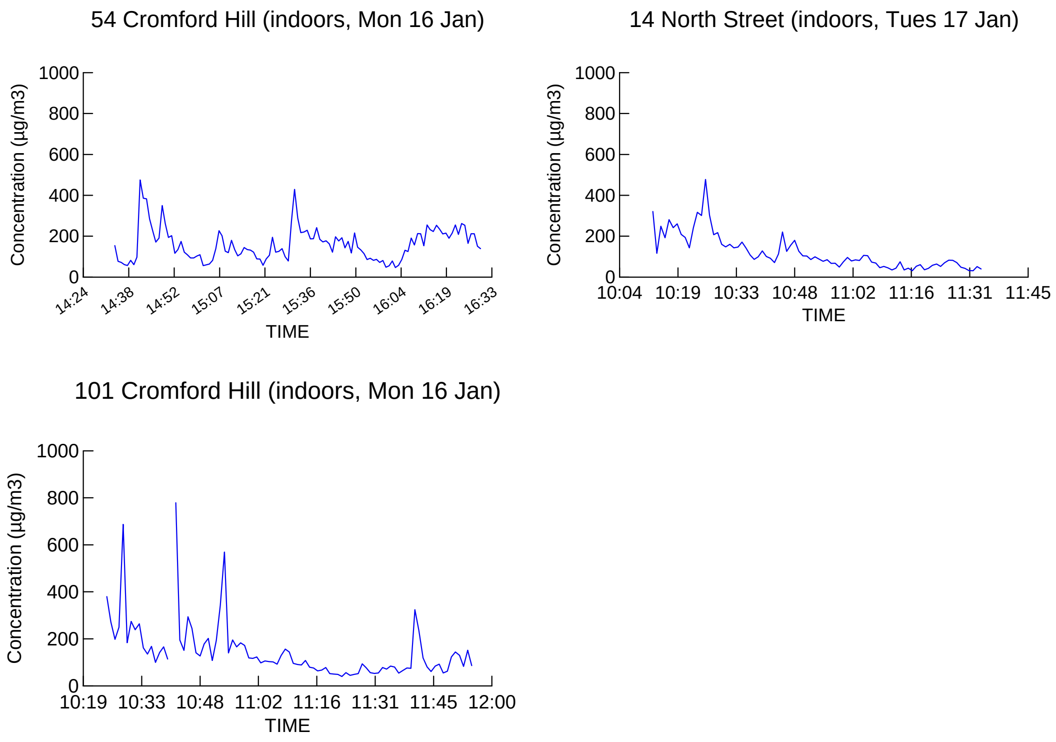


Figure 41: Indoor samples, Cromford, Derbyshire, winter 2006.

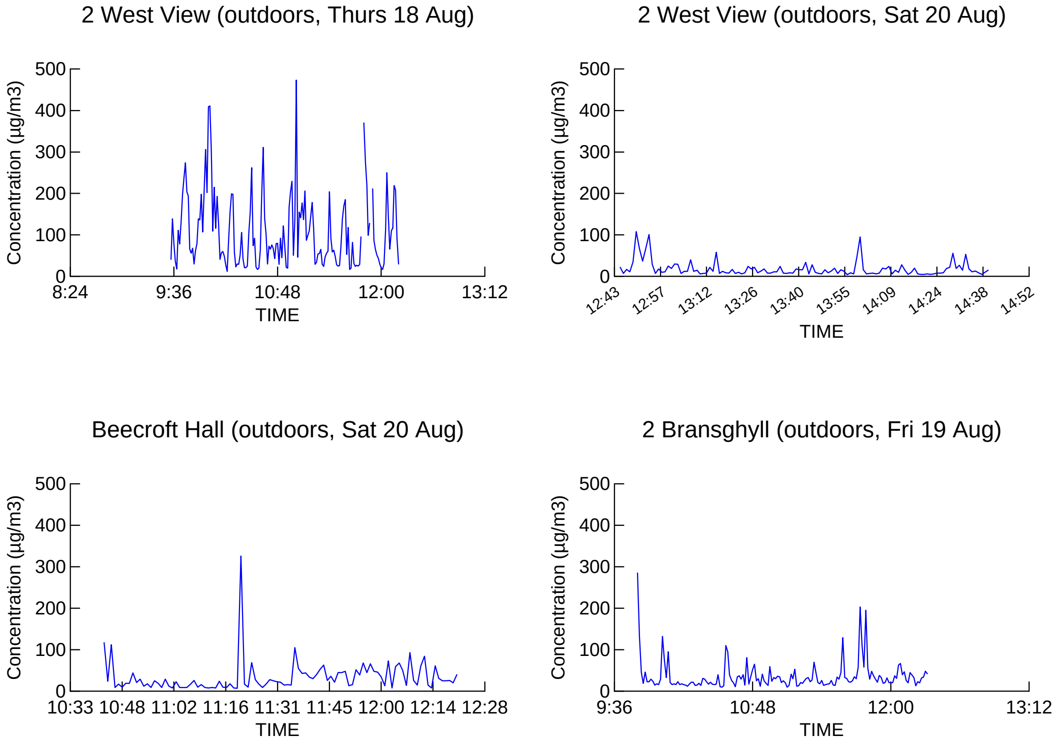


Figure 42: Outdoor samples, Horton in Ribblesdale, summer 2005.

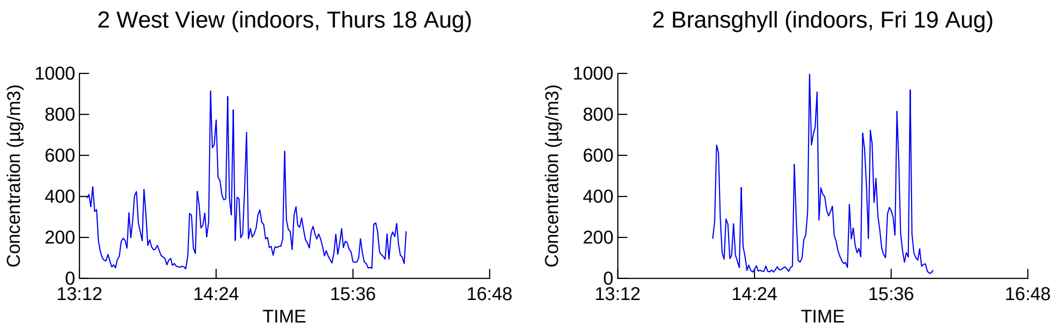


Figure 43: Indoor samples, Horton in Ribblesdale, summer 2005.

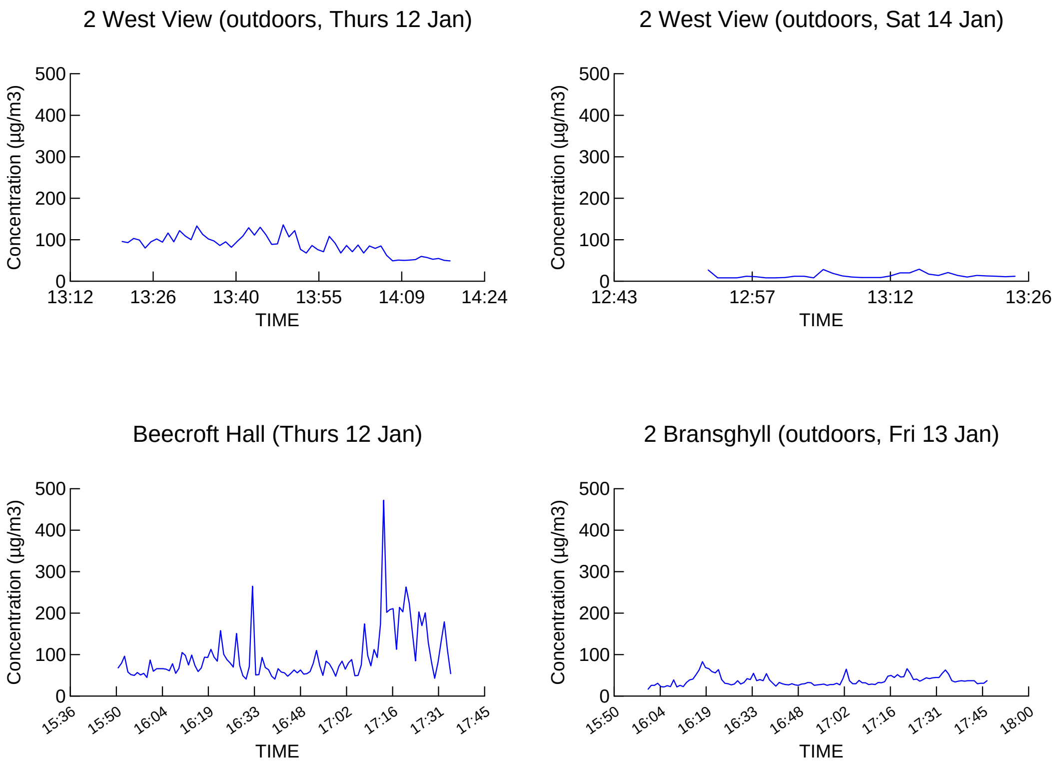


Figure 44: Outdoor samples, Horton in Ribblesdale, winter 2006.

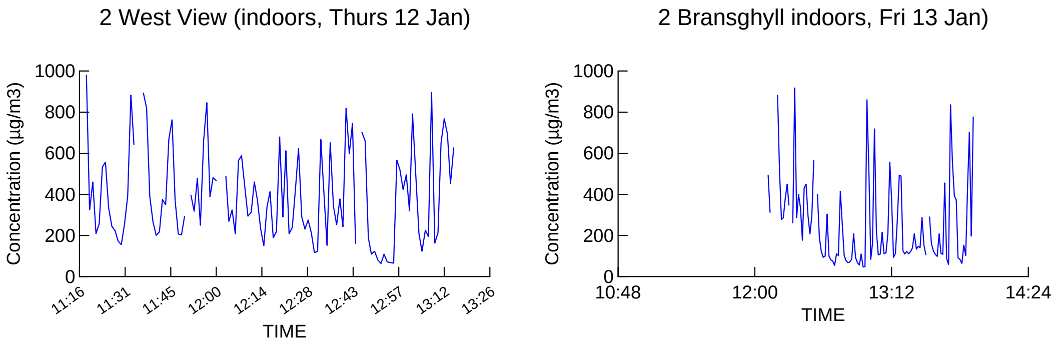


Figure 45: Indoor samples, Horton in Ribblesdale, winter 2006.

11 REFERENCES

Ali-Khodja, H, Boumegoura, N and Habbas, B. 2005. Spatio-temporal deposition fluxes of dust and trace elements around a cement plant in the vicinity of Hamma Bouziane, Algeria. *Fresenius Environmental Bulletin*, **14**(3), 237-247.

Bérubé, K A, Sexton, K J, Jones, T P, Moreno, T, Anderson, S, Richards, R J. 2004. The spatial and temporal variations in PM10 mass from six UK homes. *Science of the Total Environment*, **324**(1-3), 41-53.

BS 7385-1 Evaluation and measurements for vibration in buildings Part 1: Guide for measurement of vibration and evaluation of their effects on buildings, 1990.

Breuning-Madsen, H and Awadzi, T W. 2005. Harmattan dust deposition and particle size in Ghana. *Catena*, **63**(1), 23-38.

Dall'Acqua, S, Fawer, M, Fritschi, R, Allenspach, C. 1999. Life cycle inventories for the production of detergent ingredients. EMPA report no. **244**, *Eidgenössische Material-Prüfungs- and Forschungsantalt*, St Gallen, Switzerland.

De Koning, H W. 1986. Low cost methods for air pollution analysis. *In:* R M Harrison & R. Perry (*eds.*), *Handbook of Air Pollution analysis.* Chapman and Hall.

Goforth, M R and Christoforou, C S. 2006. Particle size distribution and atmospheric metals measurements in a rural area in the South Eastern USA. *Science Of The Total Environment*, **356**(1-3), 217-227.

Hards, V L. 2000. Developing techniques in mineralogy and petrology. Collection and analysis of airborne dusts, a pilot study: Dene Quarry, Cromford, Derbyshire October 1998 – October 1999. *British Geological Survey Technical report* no. **IR/00/57**.

Merefield J R, Stone, I, Roberts, J, Dean, A and Jones, J. 1995. Monitoring airborne dust from quarrying and surface mining operations. *Transactions of the Institution of Minig and Metallurgy*, (*A: Mining industry*), **104**, A76-A78.

Office of the Deputy Prime Minister (ODPM). 2004. Guidelines for the Provision of Aggregates to 2016.

Romo-Kroger, C M. 2006. A qualitative study of atmospheric aerosols and particles deposited on flat membrane surfaces by microscopy and other techniques. *Powder Technology*, **161**(3), 235-241.

Thornburg, J, Rodes, C, Lamvik, M, Willis, R and Rosati, J. 2006. Image analysis method (IAM) for measurement of particle size distribution and mass availability on carpet fibers. *Aerosol Science And Technology*, **40**(4), 274-281.

Vallack, H W. 1995. Protocol for using the dry dust Frisbee Dust Deposit Gauge. *Stockholm Environment Institute at York.*

Xhoffer, C, Wouters, L, Artaxo, P, van Put, A and van Grieken, R. 1992. Characterization of individual environmental particles by beam techniques. *In:* J Buffle and H P van Leeuwen (*eds.*), *Environmental Particles*, *Environmental Analytical and Physical Chemistry* Series vol **1**, Chelsea, USA: Lewis.

World Health Organisation, 'Occupational and community noise', Factsheet No. 258, 2001. URL: http://www.who.int/mediacentre/factsheets/fs258/en/.

Yoon Y.H. and Brimblecombe P. 2001. 'The distribution of soiling by coarse particulate matter in the museum environment' Indoor Air 11, pp. 232-240.