

Evaluating ventilating air movement in underground limestone mines by monitoring respirable dust generated from production shots

G.J. Chekan, J.F. Colinet, & Roy Grau III

National Institute of Occupational Safety and Health, Pittsburgh Research Center, Pittsburgh, PA, USA

ABSTRACT: Underground limestone mines typically have large entries, ranging from 9.1 to 18.3 m (30 to 60 ft) wide and 4.9 to 12.1 m (16 to 40 ft) high, which may result in low-velocity airflow throughout the mine. Air velocities less than 0.13 m/s (25 fpm) are common, and airflow in the entry can be stratified or readily affected by seasonal patterns of natural ventilation. In addition, limestone mines may have minimal or no mechanical ventilation and often do not have extensive stopping lines, constructed to control air movement throughout the mine. Consequently, it can be difficult to measure air velocities and define airflow patterns by using conventional airflow measuring equipment such as anemometers and smoke tubes. This research describes a different approach for evaluating air movement and flow patterns throughout the mine by measuring respirable dust levels generated from production shots as the dust moves through the mine air circuit. Production shots generate a considerable volume of dust in a very short time and serve as a distinctive point source of dust that can be monitored. Typically, faces are shot on an off-shift with no mining activity, so dust levels from the shots are not influenced by dust generation from loading, hauling, and crushing operations. The respirable dust that becomes airborne after the shot can remain entrained in the air even at very low velocities. This dust moves with the general airflow patterns in the mine. In this study, light-scattering instruments, which log dust concentrations in real-time, were used to monitor the dust movement throughout two limestone mines. Studies were conducted using these instruments to determine if they may provide a viable means to assess overall mine ventilation patterns. Dust samplers were positioned at selected locations throughout each mine to record respirable dust movement after production shots. Dust concentration results indicate that this method can be used to quickly assess mine ventilation patterns. This sampling also identified the length of time that was needed for the ventilation in each mine to clear the dust from the mines after the shots. A summary of the sampling instrumentation, sampling technique, and results of the studies will be discussed.

1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Laboratory is currently involved in various research projects related to worker health and safety in underground metal/nonmetal mines. A primary area of research involves health issues in underground stone mines, a growing segment of the aggregates industry. Methods for reducing worker exposure to noise, silica dust, and diesel particulate matter (DPM) are being addressed through various research programs. One engineering control being addressed is the improvement in mine air quality by developing mine-wide ventilation techniques as a means to reduce worker exposure to silica dust and DPM.

Various research studies have defined some of the primary ventilation considerations for improving airflow in large-opening mines. These studies show that

two key parameters for improving airflow are use of booster fans, such as axial vane or jet fans to improve localized ventilation, and more recently the application of high-volume propeller fans, and the construction of stoppings to direct and control airflow on a larger mine-wide scale (Grau et al, 2002a; Grau et al, 2002b; Head, 2001; Kissel and Volkwein, 2002; Timko and Thimons, 1987). Typically, underground stone operations are drift mines developed after the quarry reserves have been exhausted. Room-and-pillar mining methods are utilized, with pillars of either square or rectangular dimensions ranging from 10.6 to 18.3 m (35 to 60 ft). The entries are considered large mine openings with entry widths ranging from 9.1 to 18.3 m (30 to 60 ft) and entry heights on development ranging from 4.9 to 12.1 m (16 to 40 ft). After benching, entries can be over 18.3 m (60 ft) high. Due to these large openings, ventilation fan pressure is very low, even if significant quantities of air move through

the mine. Ventilation pressures of less than 24.9 Pa (0.1 in w.g.) are common whether airflow is induced by fans, natural, or a combination of both (Grau et al, 2002a). Depending on the extent of the workings, air velocities <0.13 m/s (25 fpm) are common, or in some idle areas of the mine, virtually nonexistent. In addition, airflow in the entries can be stratified, or the direction of airflow can be readily affected by the movement of mine equipment.

Instruments for measuring air velocity in large-opening mines include smoke tubes, low flow anemometers (for airflow >0.26 m/s), or more recently, ultrasonic anemometers. These methods work well for measuring and evaluating localized air movement in main air courses or at working faces, but are limited in use when attempting to assess the overall mine ventilation patterns. Sulfur hexafluoride (SF_6) tracer gas is a commonly used method for assessing mine ventilation systems on a larger scale. Studies show (Thimons et al, 1974; Timko and Thimons, 1982) that it is an effective technique for evaluating the air velocity and airflow patterns for all types of mines. However, this method has two primary limitations. First, depending on the scope of the ventilation study, it can be very time consuming. To conduct a thorough study may require many individuals, positioned at different locations in the mine, collecting hand samples with vacuum tubes at regular intervals over an extended period of time. Second, depending on the number of samples to be analyzed, turn around time for results can be slow and costly.

As a result, NIOSH is investigating a technique to assess airflow patterns in large-opening limestone mines by monitoring the travel path of respirable dust generated by production shots. Production shots are a regular part of the mining cycle and can vary in number and location depending on the mining plan and the grade of stone required to meet production schedules. Typically, faces are shot during an off-shift with no mining activity, so dust levels are not influenced by other sources of dust generated by loading, haulage, and crushing operations or diesel particulate. Production shots, like most rock breakage mechanisms, generate a considerable amount of dust in various size ranges. A majority of the dust is considered oversized and settles out of the air stream. However, the respirable portion, dust particles <10 microns, once airborne can remain entrained in the air even at very low velocities (Baron et al, 1993; Welby et al, 1988; Xu and Bhaskar, 1995). As a result, the respirable dust generated by production shots offers a distinctive point source in that this entrained "dust cloud" can be measured and tracked with real-time dust-measuring instrumentation as it is transported through the general mine air circuit.

The advantages of this production shot monitoring technique are twofold: (1) the technique requires little manpower as the monitors are positioned at various

locations in the mine, before the faces are shot, to record the "dust cloud"; (2) the real-time monitors have a logging feature so that dust concentration data can be downloaded into database software and analyzed in a short time frame.

This paper describes the instrument setup and method for monitoring production shot dust, and details how the results are analyzed to determine the "dust cloud" velocity. Studies were conducted at two limestone mines using this technique to determine if it may be a viable means to assess overall mine airflow patterns. The results proved encouraging as an effective method to quickly evaluate air movement in large-opening mines.

2 SAMPLING INSTRUMENTS AND SURVEY TECHNIQUE

The method employed in these surveys requires a real-time aerosol monitor, which uses light scattering to determine dust concentrations. These concentrations are recorded on an internal logger along with time. Although these light-scattering instruments offer only a relative measure of concentrations, they provide a continuous record of dust levels so that concentrations can be evaluated over any time interval during the sampling period. There are several types of real-time aerosol monitors available, and these investigations used the Thermo-MIE personal DataRam (pDR). In these studies, the instrument was operated in the active mode to monitor respirable dust. In this active mode, dust enters the pDR after it is classified using a 10-mm Dorff- Oliver cyclone combined with a pump operated at flow rate of 1.7 lpm resulting in a D_{50} cut-point of 4.0 microns. This set-up is shown in figure 1.



Figure 1. ThermoMic personal DataRam (pDR) set-up in the active mode with 10-mm Dorff-Oliver cyclone and pump operated at 1.7 lpm.

The pDR operates on one 9-volt battery, providing the unit with power for up to 18hrs, and can store 13,000 data points (concentration values). The data can be downloaded from the unit and analyzed with software provided by the manufacturer or in other types of database software such as Excel.

The objectives of the studies were twofold: (1) to record the travel path and time arrival to determine the average velocity of the “dust cloud” as a means to evaluate the mine’s airflow patterns; and (2) to determine the retention time of the dust or the length of time needed to clear the dust from the mine. The sampling strategy was to set up sampling stations in key locations in the mine’s air course and begin sampling before the faces were shot. Sampling locations were based on suspected airflow patterns in the mine and the potential of dust from the production shots in the working developments to pass that particular location. In most cases, instruments were positioned at least 61m (200 ft) from the shot locations to protect the pDRs from the initial blast pressure and to give the dust time to settle to the normal mine air velocity since blast pressures can provide an initial “velocity assist” to the dust cloud. All instruments were positioned in the same manner, on the rib approximately 1.8m (6 ft) above the floor.

In both studies, the mines shot the faces on the evening shift between 4:00 p.m. and 12:00 a.m. Sampling for the surveys began about 2 hours before the end of the day shift (around 2:00 pm) and continued for approximately 18 hrs until the beginning of the next day shift at 8:00 am. This long sampling period provided sufficient data so as to differentiate between normal background particulate levels generated by mining activity and the dust generated by the shots. In all studies, the pDRs were set to log a concentration every 10 seconds, providing approximately 6,500 concentration values for analysis. In most surveys, 1 to 4 faces were shot at the same time or within minutes of each other. This provided an ample volume of dust whose movement could be monitored.

3 CHARACTERISTICS OF DUST GENERATED BY SHOTS AND METHOD FOR DETERMINING DUST CLOUD VELOCITY

Production shots generate a visible “dust cloud” that contains dust in various size ranges. As the dust cloud travels from the source, the oversize dust begins to settle from the airstream. The respirable dust, <10 microns, remains entrained but begins to break up and dilute becoming visibly less distinguishable as it travels further from the source. Figure 2 shows a characteristic curve when the pDR dust concentrations

from a shot are graphed in relation to time. This example is typical of the “dust cloud” signature of most shots. The definitions for the nine terms in figure 2 are as follows:

1. *Baseline Concentration* – This is the average concentration recorded on the pDR prior to the time of the shots. It represents the background particulate levels under normal operating conditions.
2. *Shot Time* – The time when the shot took place after sampling began, obtained from mine records.
3. *Arrival Time* – This is the length of time from the shot time to when the dust was first detected on the pDR. It is the leading edge of the dust cloud.
4. *Peak Concentration* – This is the highest concentration recorded on the pDR as the dust cloud passes the station.
5. *Peak Time* – This is the length of time from the shot time to the time of the peak concentration.
6. *Average Concentration* – This is the average concentration recorded on the pDR during the duration of the dust cloud. It is the area under the curve and can be compared to the average baseline concentration as a means to evaluate dilution of the dust cloud.
7. *End Time* – This is the length of time from the shot time to the tail end of the dust cloud. The dust cloud is no longer detected as concentrations return back to baseline values.
8. *Duration of Dust Cloud* – This is the length of time it takes the cloud to pass a particular station or the difference between the arrival time and end time.
9. *Return to Baseline* – This represents the time when the pDR concentrations return back to baseline values.

The shape of the curve depicted in figure 2 will change depending upon the distance between the shot location and the pDR sampling location and the mine air velocity. If the pDR is close to the shot location (in most cases <220 m), the curve is characterized by a well-defined, high peak and short duration of the dust cloud. As the distance between the shot and pDR locations increases and the air velocity decreases, the peak concentration decreases. However, the duration of the dust cloud increases as it begins to dilute and lengthen relative to the lower airflow

The method used to estimate the velocity of the dust cloud is based on calculating an average velocity from three different time points on the curve as shown in the example in figure 2. The three points are the “arrival time,” “peak time,” and “end time” of the dust cloud. The time is estimated for each of these events and a velocity calculated for each time based on the distance of the pDR location from the shot location. The velocity is then the average of these three velocities. This method was chosen for several reasons: (1) it defines both the beginning and end point of the dust

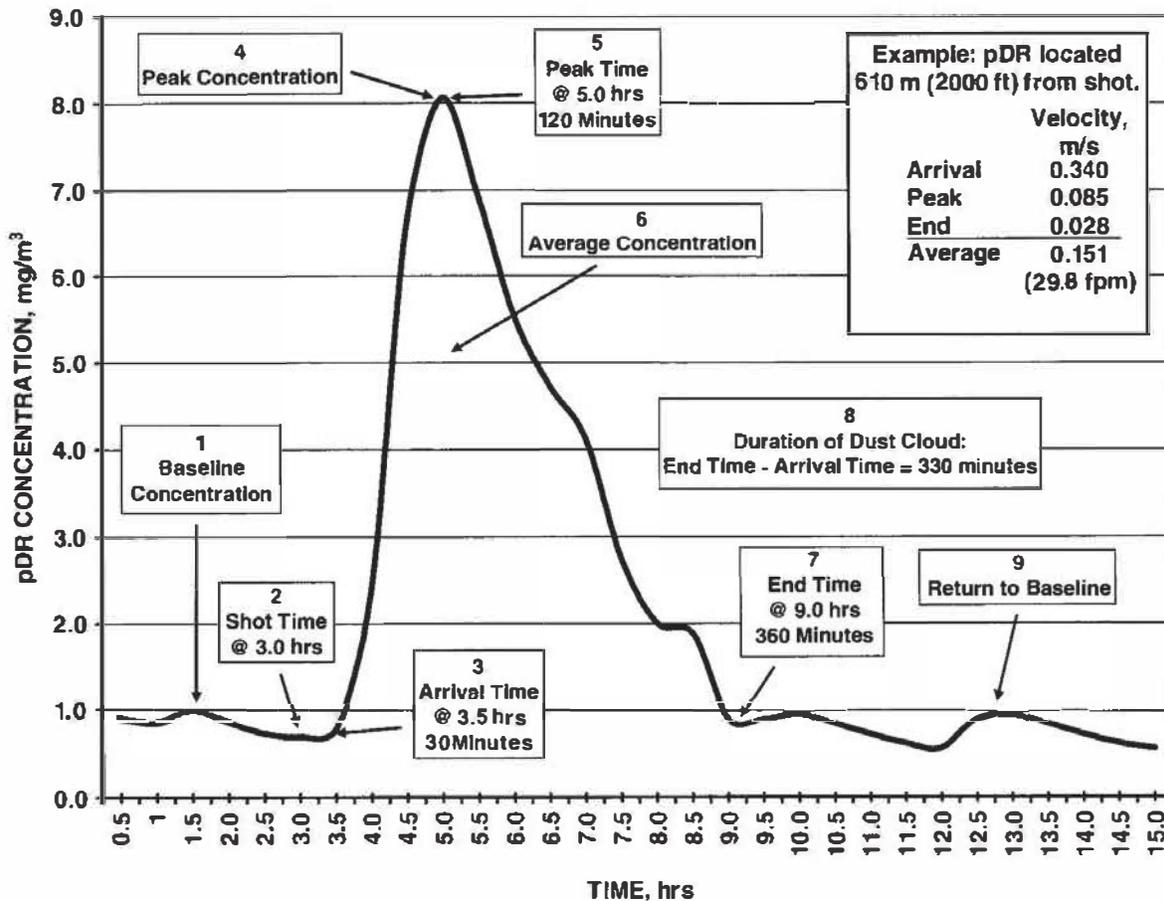


Figure 2. Characteristic curve when the pDR concentrations are graphed in relation to time, with example showing the estimated velocity of the "dust cloud" using the three time points.

cloud as the dust completely clears the station; (2) it takes into consideration the increasing time duration or length of the cloud as it moves further from the source, which gives equal weight to the assessment of the dust cloud velocity as it passes each station; (3) it gives the most conservative estimate of velocity, as compared to using only the arrival time or the peak time.

The optimum results are achieved when one or several shots are in the same location of the mine at the same time. This creates a dust cloud from one general location and gives an easily distinguishable signature on the pDRs. In contrast, when faces are shot at distant locations from each other, or at different times, multiple signatures are logged on the pDR and can be difficult to distinguish from each another. The more pDRs that are in use, the better the general airflow pattern in the mine can be characterized. If mine personnel have a knowledge of the general flow patterns or direction of airflow in the mine, this information proves useful in positioning the pDRs. Otherwise, smoke tube tests at different areas of interest in the mine can be used to determine where airflow is consistent to position the pDRs.

4 CASE STUDIES

The main mine fan used in case I-study A was a Pope 1.8m (6ft) dia., 185.5kW (250hp), 164.9m³/s (350,000cfm), axial vane fan used in the exhaust mode. In addition, two booster fans were used: a Joy 1.53m (5 ft) diameter axial vane fan rated at 74.2kW (100hp) and 70.7m³/s (150,000cfm); a Buffalo 1.37m (4.5 ft) diameter axial vane fan rated at 92.7kW (125hp) and 42.4m³/s (90,000cfm). All of the fans were free-standing, not bulkheaded to separate intake air from return air. In case I-study B, the Pope main mine fan was replaced with two Hartzell Series 10S, 3.66m (12 ft) dia., high-volume, low-pressure propeller fans each rated at 212m³/s (450,000 cfm). These two fans were bulkheaded at a portal and exhausted to the outside air.

An important difference between study A and study B is the increase of ventilating air into the mine and the decrease in total power requirements for the fans. With the addition of the propeller fans, the total airflow increased from 141.3 m³/s (300,000 cfm) to 353.4m³/s (750,000 cfm), while the combined total

power requirement of the fans decreased from 352.5 kW (475 hp) to 315.4 kW (425 hp).

The mine for the case 2 study utilized the same Hartzell Series 10S propeller fans as in case 1. The two fans were bulkheaded and installed in the exhaust mode. In addition, the mine utilized one free-standing

booster fan, a Spendrup Model 1000-50-26H axial vane fan rated at 37.1 kW (50hp) and 21.2m³/s (45,000cfm). The Hartzell Series 10S propeller fans are shown in figure 3.

In both studies, the ventilation air was coursed, and intake entries were separated from return entries using various forms of brattice type stoppings. The brattice type ranged from inexpensive tarp material to heavier mine brattice material. This brattice was sealed as tightly as possible to the ribs, roof, and floor to minimize air leakage. In some instances, air leakage from stopping damage due to either face blast pressures or fatigue by fan pressures was observed.



Figure 3. Hartzell Series 10S propeller fans used in both case studies.

4.1 Case 1

4.1.1 Background

Nine sampling locations in the mine were selected as shown in figure 4. Site locations were based on suspected airflow patterns in the mine and the potential of dust from the production shots in the working developments to pass that particular location and allow for the recording of the dust cloud arrival. Table 1 identifies the reasoning behind placing the pDRs at each sampling location.

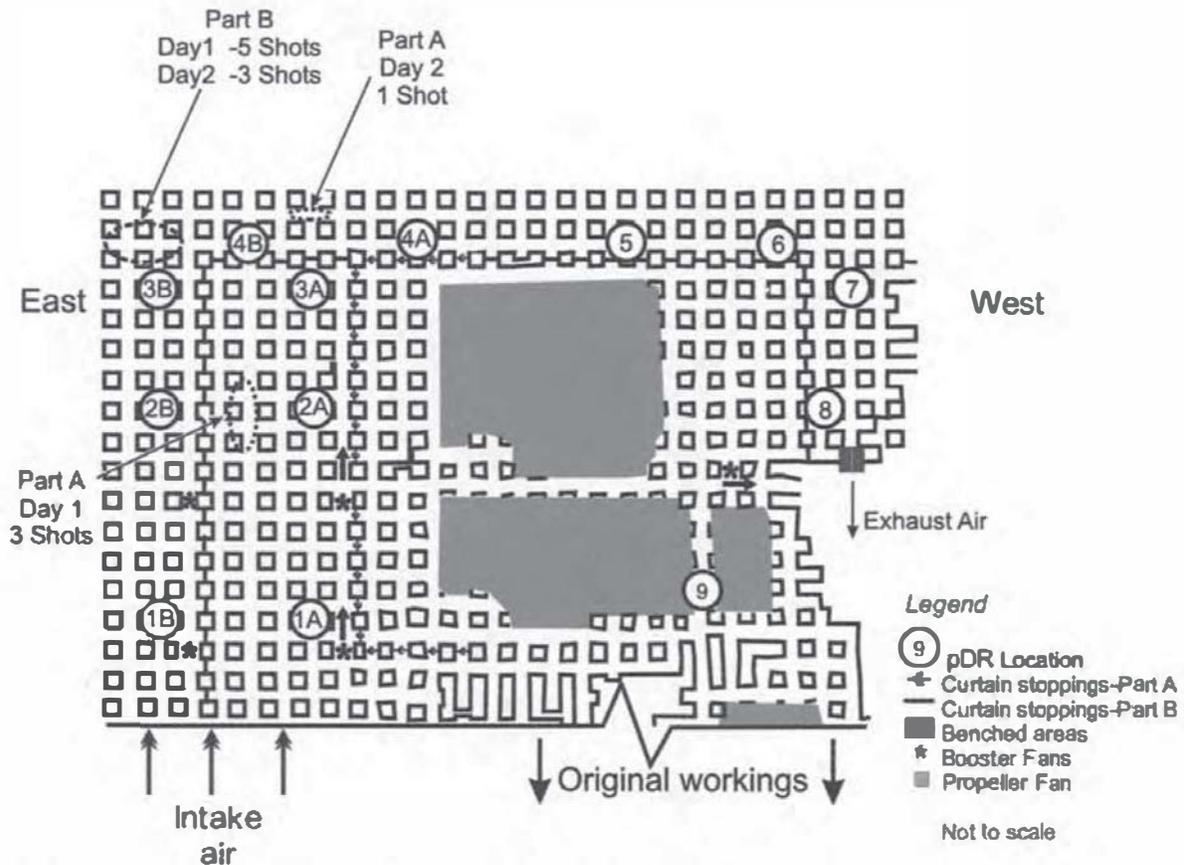


Figure 4. Mine workings for case study 1 showing location of pDR samplers, curtain stoppings, and fans.

Table 1. Case study 1 – pDR location and description for production shot dust surveys.

Station	Purpose
1	Intake air – monitor intake dust levels and dust that might roll back into the fresh air circuit from face shots on east side of mine.
2	General air circuit – 2 stations were located on east side of mine on the inby side of the curtain stoppings to monitor dust migration from face shots on east side of mine.
3	
4	
5	General air circuit – 3 stations were located on the south end of the mine on the inby side of the curtain stoppings. They monitored dust migration from face shots on the eastern side of the mine and were used to assess the effectiveness of the air circuit being planned.
6	
7	General air circuit – 2 stations were located on the western side of the mine on the inby side of the curtain stoppings. They monitored dust migration from face shots on the eastern side of the mine and were used to assess the effectiveness of the air circuit being planned.
8	
9	Return air – monitor dust that might migrate past the location of the main exhaust fan and the propeller fans and thus recirculate into the intake air.

This study was initiated to assess the current ventilation system, particularly on the east side of the mine. In this study, the mine was planning ventilation changes by constructing approximately 30 to 40 brattice type stoppings and installing two low pressure propeller fans, each rated at 212 m³/s (450,000 cfm), to better ventilate the working faces in the mine. It was assumed that the stoppings and fans would increase the volume of air to the faces and establish a directional flow of air from the eastern to the western side of the mine.

The strategy for the dust survey is a commonly used A-B study which consists of sampling before and then after the new ventilation system was completely installed to determine its effectiveness. Two sampling shifts were conducted for the A part of the study and two shifts for the B part. All shots were on the east side of the mine as shown in figure 4. Also shown in figure 4 are: (1) the location of two axial vane booster fans on the east side of the mine, their blowing direction, and the main exhaust fan (Pope 1.8 m dia. used only during the part A study) near the portal on the west side of the mine (these fans are mobile and can be moved depending on ventilation patterns required for mining); (2) the location of the low-pressure propeller fan at the west side of the mine (used in part B of the study) and; (3) curtain stoppings used to direct airflow from the east to the west side of the mine.

4.1.2 Results of part A study

Figure 4 shows the following for part A of the study:

1. The locations of the shots on day 1 and day 2.
2. The stopping line on the east side of the mine.
3. The location of stations 1A, 2A, 3A, and 4A for this part of the study.
4. The location of the last stopping by station 4A.
5. The two booster fans on the east side of the mine.

For part A of the study, the propeller fans were not yet installed. Dust from the shots exited the mine at the portal at the Pope 1.8 m (6 ft) dia. main exhaust fan between stations 8 and 9.

Table 2 summarizes the results of the dust surveys for the two days of sampling. Shown in the table are:

1. The number of shots for each sampling day.
2. The station number.
3. The station distance from the shot.
4. The peak and average concentrations.
5. The arrival, peak, and end times for estimating the velocity of the dust cloud.

As shown in the table, the velocities at stations 3A and 4A were higher in comparison to stations 5 through 9. The line of curtains on the east side of the mine up to station 4A and the two booster fans located on the east side curtain line provided ample airflow to move the shot dust from this area. Once the dust cloud passed the last stopping (figure 4), the dust began dispersing into the benched area as noted by the following: (1) decreasing velocities for stations 5 through 9; (2) decreasing peak and average concentrations; (3) the increasing length of time it took the dust cloud to pass a station (the difference between end time and arrival time); (4) dust arrival at station 9, the return side control station, before its arrival at station 8.

No shot dust was recorded on the intake side at stations 1A and 2A on day 1 and stations 1A, 2A, and 3A on day 2, indicating that airflow was sufficient to prevent the migration of dust into the intake air and indicating that recirculation was not occurring. Also, since dust was recorded at station 9, it indicates the dust was passing the main exhaust fan and it was not effectively moving the shot dust out the nearby portal.

Table 2. Part A of case study 1: estimated velocity of dust cloud before fans and curtains were installed.

Day 1 – 3 shots							
Station	Approximate distance from Shot, m (ft)	Peak conc., mg/m ³	Average conc., mg/m ³	Arrival time, min	Peak time, min	End time, min	Estimated average velocity, m/s (fpm)
3A	45.7 (150)	45.6	11.3	1	2.8	17.5	0.36 (70.5)
4A	121.9 (400)	17.8	5.3	3.8	14.0	81.3	0.23 (45.9)
5	228.6 (750)	2.5	1.3	17.2	31.7	153.2	0.12 (24.1)
6	304.8 (1000)	2.9	1.4	28.8	60.0	196.5	0.095 (18.8)
7	350.5 (1150)	2.2	1.1	38.5	61.8	264.8	0.089 (17.6)
8	411.5 (1350)	1.7	1.0	48.2	96.7	255.7	0.081 (15.8)
9	426.7 (1400)	2.2	1.0	40.8	74.8	244.3	0.11 (21.0)
2A	No dust recorded from shot						
1A	No dust recorded from shot						
Day 2 – 1 shot							
4A	24.7 (150)	11.8	4.1	1.2	7.5	23.8	0.26 (51.6)
5	152.4 (500)	1.2	0.7	15.2	74.5	175.3	0.072 (14.2)
6	228.6 (750)	1.2	0.7	32.3	60.8	175.0	0.068 (13.3)
7	274.3 (900)	1.1	0.6	38.0	49.3	177.5	0.080 (15.7)
8	335.2 (1100)	1.7	0.7	39.5	57.0	187.0	0.090 (17.7)
9	350.5 (1150)	1.6	0.7	31.7	49.2	222.2	0.11 (21.6)
3A	No dust recorded from shot						
2A	No dust recorded from shot						
1A	No dust recorded from shot						

4.1.3 Results of part B study

Figure 4 shows the following for Part B of the study:

1. The locations of the shots on day 1 and day 2.
2. The new stopping line on the east side of the mine that was moved as the mine developed more rooms on the east side of the mine.
3. The location of stations 1B, 2B, 3B, and 4B that were moved for this part of the study. Stations 5 through 9 remained in the same locations.
4. The completion of all stopping around the perimeter of the active faces which completely sealed off the benched area.
5. The relocation of the two booster fans on the east side of the mine.
6. The two Harwell Series 10S propeller fans which were now installed and operational and replaced the Pope fan.

Table 3 summarizes the results of the dust surveys for the two days of sampling. Shown in the table are:

1. The number of shots for each sampling day.
2. The station number.
3. The station distance from the shot.
4. The peak and average concentrations.
5. The arrival, peak, and end times for estimating the velocity as in the example in figure 2.

As shown in the table, the velocities are much higher and more consistent after the installation of the

two propeller fans and the remaining curtains on the south and west side of the mine. The shots on both days were located in the same area of the mine and dust was recorded at stations 4B through 8. The improvement in airflow with the completion of the ventilation system is evident and noted by several points. First, dust from the shots was not recorded at station 9 (return side), indicating that the curtain line was adequately sealing off the benched area and all the dust was now exiting the mine at the propeller fans by station 8, preventing recirculation. Second, the peak and average concentrations are much higher and the duration of the dust cloud (the difference between the arrival and end time) is much shorter in comparison to part A of the study. This demonstrates that the dust cloud was not dispersing but rather staying together and exiting the mine more effectively. Third, no dust was recorded at station 1B through 3B, indicating that airflow on the east side of the mine was sufficient to prevent rollback of the dust from the shots into the intake air.

Also evident is the reduction in the retention time or the length of time it takes the dust cloud to clear the mine. The “end time” at station 8 in tables 2 and 3 provides a means to assess the retention time. Based on the average end time for both sampling days, the retention time for dust shots generated on the east side of the mine in Part A was approximately 3.7 hrs and for Part B was 2 hrs.

Table 3. Part B of case study 1: estimated velocity of dust cloud after fans and curtains were installed.

Day 1 – 5 Shots							
Station	Approximate distance from Shot, m (ft)	Peak conc., mg/m ³	Average conc., mg/m ³	Arrival time, min	Peak time, min	End time, min	Estimated average velocity, m/s (fpm)
4B	91.4 (300)	61.6	17.6	1.7	4.3	69.8	0.43 (84.5)
5	234.8 (800)	17.6	5.7	5.7	12.3	71.7	0.37 (72.4)
6	320.1 (1050)	14.5	4.6	9.3	15.1	111.0	0.32 (63.7)
7	365.8 (1200)	14.9	3.9	10.2	15.8	118.0	0.35 (68.0)
8-Fan	426.7 (1400)	9.7	4.3	12.2	22.3	121.7	0.32(62.6)
9	No dust recorded from shots						
3B	No dust recorded from shots						
2B	No dust recorded from shots						
1B	No dust recorded from shots						
Day 2 – 3 Shots							
4B	91.4 (300)	44.5	6.3	2.2	10.0	61.3	0.29 (57.8)
5	234.8 (800)	15.9	5.5	7.3	16.0	73.8	0.29 (56.6)
6	320.1 (1050)	16.3	4.9	10.7	21.7	88.5	0.26 (52.9)
7	365.8 (1200)	13.1	4.9	11.5	23.0	92.5	0.29 (56.5)
8-Fan	426.7 (1400)	12.3	4.5	13.8	35.8	119.2	0.26 (50.7)
9	No dust recorded from shots						
3B	No dust recorded from shots						
2B	No dust recorded from shots						
1B	No dust recorded from shots						

4.2 Case 2

4.2.1 Background

In this case study, the mine was recently purchased by new owners. Figure 5 shows the mine's development, which was very extensive and originally not well-planned for most of the life of the mine. The new management has begun a more systematic approach to mining, as shown by the projections for future developments. The mine's original ventilation plan relied solely on natural ventilation without the assistance of booster fans. Airflow to the faces especially in the northern and southern areas of the mine was minimal, as air velocity and direction were difficult to characterize with anemometer or smoke tube measurements. Dust from shots tended to migrate through the mine with little directional flow.

These circumstances required some extensive rehabilitation work which included major upgrades in the ventilation system to improve airflow at the faces. As shown in figure 5, this ventilation system included: 1) two Hartzell Series 10S propeller fans that established a directional airflow from the southern portals to the fan; 2) the Spendrup Model 1000-50-26H axial vane booster fan to provide localized ventilation to the working faces; 3) the installation of approximately 50 curtain stoppings (the stopping line is shown in figure 5) on the southern and eastern side of the mine to provide improved airflow to the active faces.

Due to the large extent of the workings and to provide sufficient ventilating air to the new faces, the site selection for the two propeller fans was different from the typical application in that they were located inside the mine rather than at a portal. On the exhaust side of the fan, to the western side of the mine, was a large abandoned benched area. The plan was to dump the exhaust air into this area where the dust would dilute and eventually exit the mine at portals to the west.

In this case, the study was conducted after the new ventilation system had been completed. Figure 5 also shows the 10 sampling stations selected for the study and location of the shots for the two days of sampling. The location of the stations was based on smoke tube measurements placing the pDRs near the faces and spacing them to cover areas of interest where airflow was consistent. Table 4 identifies the purpose of the pDRs at each sampling location.

4.2.2 Results of study: Day 1 and Day 2

Table 5 summarizes the results of the dust surveys for the two days of sampling. Shown in the table are:

1. The number of shots for each day.
2. The station number.
3. The station distance from the shot.
4. The peak and average concentrations.
5. The arrival, peak, and end times for estimating the velocity of the dust cloud.

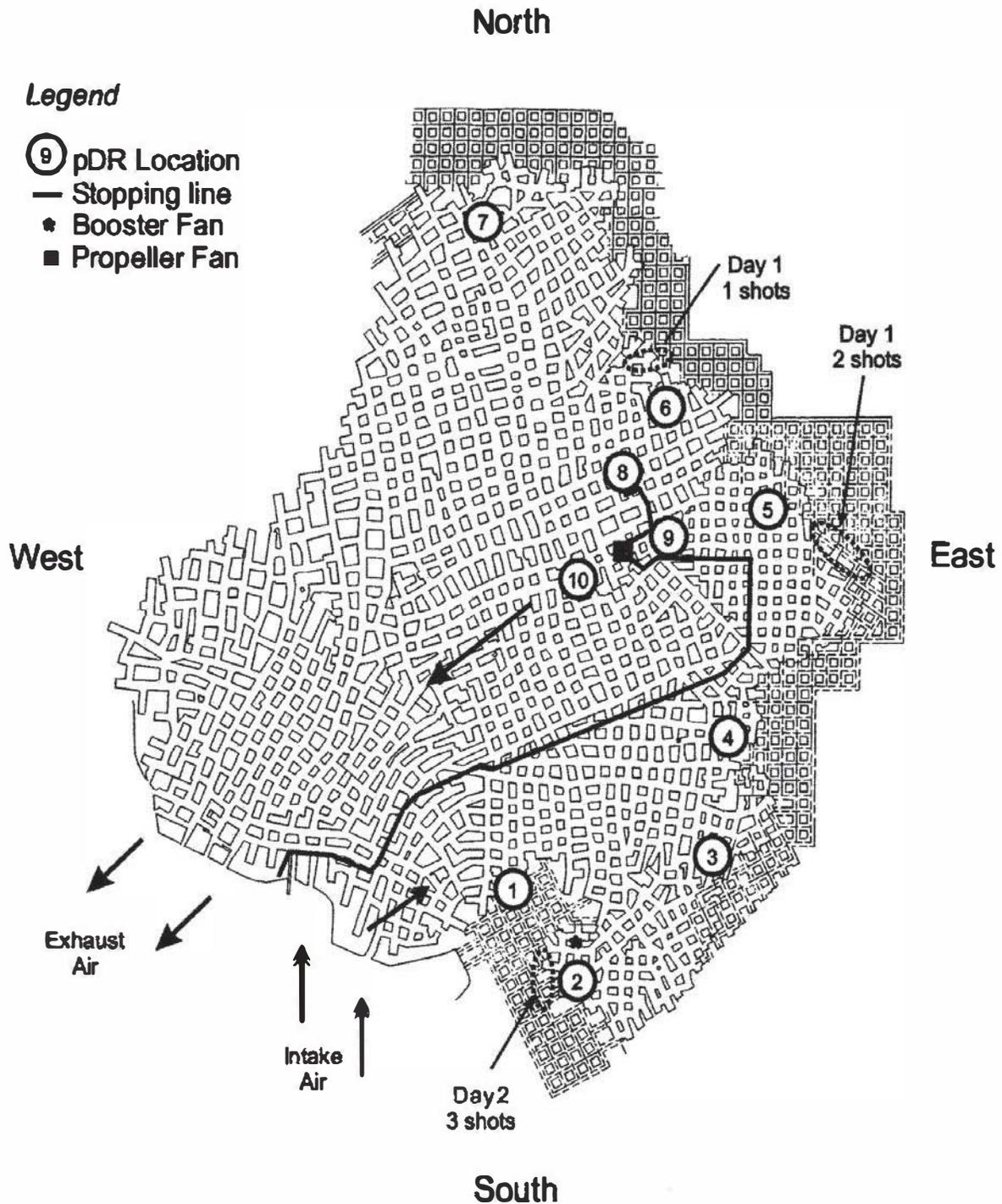


Figure 5. Mine workings for case study 2, showing location of pDR samplers, curtain line, and fans.

There were 3 shots on day 1 of sampling as shown in figure 5. This study was designed to monitor the movement of dust from nearby faces located east of the fan and determine if the ventilation was sufficient to prevent the dust from migrating to other areas of the mine. As shown in figure 5, shot 1 was located near station 6

and shots 2 and 3 were located near station 5. This distance and time spacing of shots (shot 1 was 4 minutes before shots 2 and 3) provided two different signatures on the pDRs. The pDR logs showed that dust from the shot 1 migrated past station 6, to station 8, and then to station 9 at the fan. Dust from shots 2 and 3 migrated

Table 4. Case study 2: pDR locations and descriptions for production shot dust surveys.

Station	Purpose
1	Intake air – monitor fresh air dust levels.
2	
3	
4	General air circuit – 6 stations were used to monitor dust migration from shots in the southern, eastern, and northern faces of the mine.
5	
6	
7	
8	Control station – this station monitored dust that might migrate past the fan.
9	Main fan – monitor dust levels from shots on the intake side of fan before entering return air.
10	Return air – monitor dust levels in the return on the exhaust side of fan.

Table 5. Estimated velocity of dust cloud for case study 2.

Station	Day 1 – 3 Shots						
	Approximate distance from shot, m (ft)	Peak conc., mg/m ³	Average conc., mg/m ³	Arrival time, min	Peak time, min	End time, min	Estimated average velocity, m/s (fpm)
6	61.0 (200)	7.9	1.4	1.2	6.8	152.8	0.34 (67.3)
8	260.0 (850)	3.2	1.2	12.8	25.0	211.7	0.18 (34.7)
5	198.0 (650)	22.2	3.4	4.5	8.0	66.2	0.31 (60.4)
9-Fan	365.8 (1200)	13.2	3.5	10.3	18.0	74.2	0.34 (66.3)
10	579.1 (1900)	4.0	1.8	13.3	27.0	198.5	0.38 (74.1)
1	No dust recorded from shots						
2	No dust recorded from shots						
3	No dust recorded from shots						
4	No dust recorded from shots						
7	No dust recorded from shots						
	Day 2 – 3 shots						
2	122.0 (400)	18.8	5.0	5.2	24.3	284.0	0.16 (31.8)
3	487.7 (1600)	1.9	1.1	30.5	58.8	237.2	0.15 (28.8)
4	731.5 (2400)	1.2	0.8	36.8	61.0	292.0	0.19 (37.6)
5	1188.7 (3900)	1.2	0.6	55.2	75.7	325.7	0.23 (44.7)
9-Fan	1371.6 (4500)	1.1	0.7	60.0	85.5	328.7	0.24 (47.2)
10	1585.0 (5200)	0.7	0.4	72.8	119.3	354.7	0.23 (43.2)
1	No dust recorded from shots						
6	No dust recorded from shots						
7	No dust recorded from shots						
8	No dust recorded from shots						

past station 5 then to station 9 at the fan. The pDR log signatures at station 9 (fan) showed only one peak value indicating that the dust from the different shot locations merged and reached the fan at approximately the same time. This is reflected in table 5.

Since dust was recorded at station 8, some dust was passing the fans. However, the lower velocity of 0.18 m/s (34.7 fpm), lower peak value, and longer duration of the dust cloud in comparison to the other stations all indicate that most of the dust from shot 1 made a more direct path to the fans. Station 10, located approximately 152 m (550 ft), from the fan on

the exhaust side, showed that velocities remained high but dilution was occurring, as evidenced by the lower peak and average concentrations and the longer duration of the dust cloud. No dust was recorded at stations 1, 2, 3, 4, or 7, showing that the established ventilation was sufficient to keep the dust from migrating to the northern and southern areas of the mine. Consistent velocities of the dust cloud were recorded at the 3 stations located in the main circuit averaging 0.33 m/s (65 fpm).

There were 3 shots on day 2 of sampling as shown in figure 5. This study was designed to evaluate the

airflow pattern from distant face locations in the southern section of the mine. These shots were approximately 1432 m (4700 ft) from the main fans as all three faces were shot at the same time and in the same general area. Table 5 shows the pDR results, which are notably different in comparison to day 1, but do show a distinguishable airflow pattern towards the fans even from this distance.

As expected, station 2, located 122 m (400 ft) from the shots, shows the highest peak and average concentrations (18.8 and 5.0 mg/m³, respectively), but the duration of the dust cloud was long (278 minutes) indicating that the nearby booster fan was moving air to these headings but not effectively enough to remove the dust. The leading edge of the dust cloud then moved in sequence to stations 3, 4, and 5, located in the general air circuit, and then to station 9 at the main fans. The peak and average values at station 2 were high in comparison to the remaining stations. Stations 3, 4, 5, and 9 all show a similar pattern of long duration and low average and peak concentrations of the dust cloud. Even at these low values, the signature of the dust cloud was evident at all the stations. These low values may indicate that a majority of the dust took a more direct path to the main fans; but since the arrival times at each successive station are in sequence, the data more likely suggest that the dust cloud was diluting in the southeastern area of the mine and gradually migrated to the main fans.

The calculated velocities at each station were very consistent, increasing slightly as the dust cloud approached the fan. The velocity on the exhaust side of the fan (station 10) was also consistent with these velocities. No dust was recorded at station 1, the intake air, indicating that no dust was migrating back towards the intake portals. Also, no dust was recorded at stations 6, 7, or 8, showing that the dust was not migrating past the fans to the northern areas of the mine.

The study showed that the new ventilation system provided an improved directional airflow in the overall mine air circuit. Day 1 of sampling gave higher velocities than day 2, showing a relation of airflow with proximity to the fans. The average velocity of the dust cloud from the two days of sampling was 0.25 m/s (48.7 fpm). The retention time or the length of time it takes the dust cloud to clear the fans can be estimated by using the "end time" at station 9. This gives dust retention times on day 1 and day 2 of 1.2 hrs and 5.5 hrs, respectively.

5 DISCUSSION

The method described in this paper offers an alternative to evaluating airflow patterns for large-opening mines with low air velocities. The primary feature of this technique is that it yields results that can be used to evaluate the overall mine airflow patterns. This technique

requires little manpower as the pDRs are positioned at various locations in the mine, before the faces are shot, to record the travel path of the "dust cloud." The dust concentration data can then be downloaded into data base software and analyzed in a short time frame. In both of these case studies, the two primary features of the ventilation system was the use of low-pressure propeller fans to increase the volume of air and the construction of brattice stopping lines to direct airflow. The results of the dust survey showed that the planned ventilation systems worked well and provided a directional flow of air which did not exist before the systems were installed. In addition, the retention time of the dust, or the length of time for the dust to travel from the shot location to the main fans, was substantially reduced.

This method provides an alternative approach to the way light-scattering instruments are commonly used. Usually, the time logging capabilities of the instrument are used to determine dust levels in the evaluation of different dust control technologies. In these studies, the instrument is used to assess the movement of air. In contrast to more traditional and widely accepted methods such as anemometers, this method does not directly measure air velocity, but rather the movement of dust as it is transported by the air. Therefore, it must be emphasized that this method may not yield mine air velocities that are comparable to anemometer measurements. Anemometer readings are a point measurement taken at center entry or as a traverse across the entry, and thus may give higher or even lower velocities depending on where the measurements are conducted. As an example, anemometer measurements located at stations near the propeller fans (case 1: station 8, case 2: station 9) gave velocities in excess of 1.3 m/s (250 fpm) – 4 times higher than those estimated by this method. However, this method can provide a realistic indication of how airborne contaminants are being transported throughout the mine.

The application of this method is still experimental and is not meant to replace traditional methods of assessing mine ventilation. Rather, this method can be used as another tool for the ventilation engineer. By monitoring the movement of dust, this method can determine if the ventilating air is moving in the planned direction, to areas in the mine where ventilation is not required, or if recirculation is occurring. This information proved useful to the operators at both mines. It indicated that modifications to the mine-wide ventilation systems were resulting in improved velocities and directional air movement.

REFERENCES

- Baron, P.A., and Willeke, K., 1993. "Aerosol Fundamentals," *Aerosol Measurement – Principles Techniques and*

- Applications*". Weilke K., and Baron P.A., eds, Van Nostrand Reinhold, pp. 8-22.
- Grau, R.H., Robertson, S.B., Mucho, T.P., Garcia, F., and Smith, A.C., 2002a. "NIOSH Ventilation Research Addressing Diesel Emissions and other Air Quality Issues in Nonmetal Mines," SME Preprint 02-187, SME Annual Meeting, Phoenix, Arizona, February 25-27, 2002, 7 pp.
- Grau, R.H., Mucho, T.P., Robertson, S.B., Smith, A.C., and Garcia, F., 2002b "Practical Techniques to Improve the Air Quality in Underground Stone Mines," Proceedings of the North American/Ninth US Ventilation Symposium, Kingston, Ontario, June 8-12, 2002, pp. 123-129.
- Head, H.J., 2001. "Proper Ventilation for Underground Stone Mines," *Aggregates Manager*, January, 2001, pp. 20-22.
- Kissell, F.N. and Volkwein, J.C., 2002. "Improving Ventilation in Underground Stone Mines," *Aggregates Manager*, April, 2002, pp. 20-25.
- Timko, R.J., and Thimons, E.D., 1987. "Damage Resistant Brattice Stoppings in Mines With Large Entries," *Engineering Mining Journal*, Vol. 188, No. 5, pp. 34-36.
- Timko, R.J., and Thimons, E.D., 1982. "Sulfur Hexafluoride as a Mine Ventilation Research Tool - Recent Field Applications," US Bureau of Mines Report of Investigations 8735, 15 pp.
- Thimons, E.D., Bielicki, R.J., and Kissell, F.N., 1974. "Using Sulfur Hexafluoride as a Gaseous Tracer to Study Ventilation Systems in Mines," US Bureau of Mines Report of Investigations 7916, 22 pp.
- Welby, C.G., Cheng, L., Divers, E.F., 1988. "Deposition of Respirable Dust in an Airway," *Respirable Dust in the Mineral Industries: Health Effects, Characterization and Control*, The Pennsylvania State University, University Park, PA. 1988, pp. 298-304.
- Xu, L., and Bhaskar, R., 1995. "A Simple Model for Turbulent Deposition of Mine Dust," Proceedings of the 7th US Mine Ventilation Symposium, Lexington, Ky., June 5-7, 1995, pp. 337-343.

PROCEEDINGS OF THE TENTH US / NORTH AMERICAN MINE VENTILATION SYMPOSIUM,
16–19 MAY 2004, ANCHORAGE, ALASKA, USA

Mine Ventilation

Edited by

R. Ganguli

Associate Professor of Mining Engineering, University of Alaska Fairbanks

S. Bandopadhyay

*Dean, School of Mineral Engineering and Professor of Mining Engineering,
University of Alaska Fairbanks*



A.A. BALKEMA PUBLISHERS LEIDEN / LONDON / NEW YORK / PHILADELPHIA / SINGAPORE

Sponsored by

School of Mineral Engineering, University of Alaska Fairbanks

Society for Mining, Metallurgy and Exploration, Inc.

Silent Seal (Fomo Products)

M&I Power Technology Inc.

Rocvent Inc.

Schauenburg Flexadux Corporation

Spendrup Fan Company

Shaft Drillers International

Transferred to Digital Printing 2005

Copyright © 2004 Taylor & Francis Group plc, London, UK

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publisher.

Although all care is taken to ensure the integrity and quality of this publication and the information herein, no responsibility is assumed by the publishers nor the author for any damage to property or persons as a result of operation or use of this publication and/or the information contained herein.

Published by: A.A. Balkema Publishers, a member of Taylor & Francis Group plc
www.balkema.nl and www.tandf.co.uk

ISBN 90 5809 633 5

Disclaimer

The publisher has made every effort to trace copyright holders and welcomes correspondence from those they have been unable to contact.