# An Instrument and Method for Measurement of Dust Fall in Caves

*Neville A. Michie*
*Department of Physical Geography*
*Macquarie University*
*Sydney, Australia*

## Abstract

Dust fall in show caves causes a slow degradation of the aesthetic values that attract visitors to the caves. Some material falls directly to the pathway to be trodden underfoot and re-entrained in the air, while finer material, when released to the air is widely advected through the caves where it settles on all surfaces. Strategies to control dust have examined pathway design, reducing dust material brought into the cave and maintenance activities to remove deposited material.

An essential part of an investigation of methods to reduce dustfall is a means to measure the dustfall with sufficient sensitivity and precision to be able to evaluate quite short term changes in the rate of dust fall. An instrument is described which has been used in a variety of experiments measuring dustfall in Australia and UK. The method of using the instrument and considerations useful for designing observation programs are discussed. The instrument is sensitive enough to measure a dust film of 3 micrograms per square centimetre, about half the threshold of perception of critical observers. The sensitivity of the measurements allows short experimental programs to compare alternate strategies of dust management. A total of 10,000 visitors could be sufficient for a trial comparing alternate management methods.

## Introduction

Current world's best practice in show cave management involves the construction of pathways that are specially designed to immobilize the particulate material dropped by visitors, so that it can be collected and removed from the cave. If material is not immobilized it may be re-entrained by the subsequent visitors walking on it and may spread onto the area adjacent to the pathway where cleaning may be very difficult.[1]

Recent research[2] [3] has shown some new aspects of the dust distribution processes. The dust released by cave visitors can be considered as having two components. The first component is of particles large enough to fall straight to the floor, where management strategies involving the pathway can be applied. The second component is of particles small enough to be swept into the plume of warm air rising from the visitors,[3] [4] see Figure 1. Table 1 shows the settling properties of airborne particles and it can be seen how the particles are able to stay suspended in the air for times that range from seconds to days.[5]

That this airborne dust is a major problem was shown by the spectacular visual improvement at Jenolan Caves, Australia, when steam and water cleaning were used to restore caves which had for years been used for cave tours.[6] [7]

Measurements in eastern Australia, Western Australia, and England have shown a remarkably constant rate of deposition of airborne particulate material from show cave visitors.[8] The rate of release is in the order of one microgram of dust per person per second, and although this seems quite a small quantity, with one million visitors a year visiting a cave for one hour, over a period of ten years this amounts to 36 kilograms of dust. This quantity excludes the much greater mass of coarse particles that fall directly on to the pathways, this is dust that remains suspended in the air for hours and deposits on every surface within hundreds of feet of the pathways.

Although a relatively small amount of work has been done on dust analysis in caves,[9] [10] [11] [12] there is a considerable literature of work done in similar situations in museums, industrial sites, and homes. It is reasonable to assume that the dust fall in caves is composed of fine mineral dust, smoke, organic material shed by the humans, natural organic material of plant origin including pollens and spores, and textile degradation particles.

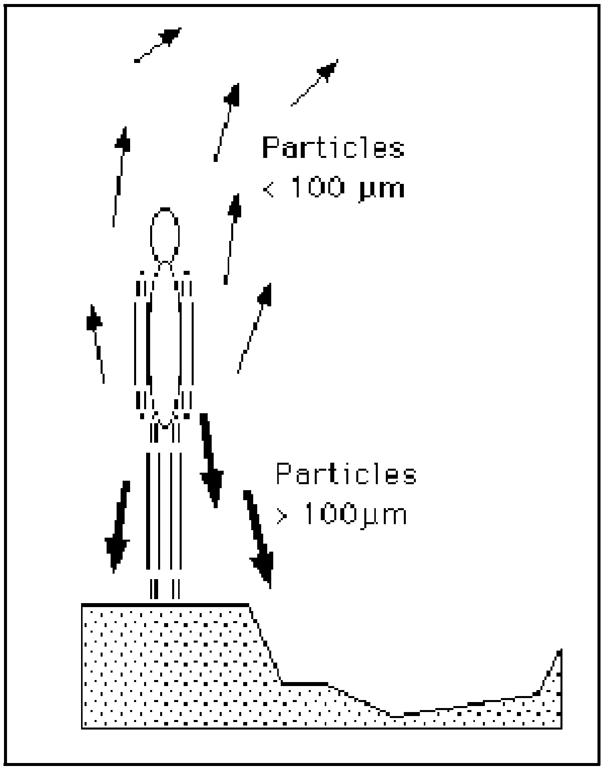

*Figure 1 - Differentiation of dust by particle size as it is released from the subject.*

Measurements by the author ([3] and unpublished measurements) have shown that the particle size distribution in caves during cave tours is remarkably similar to that indoors and out of doors in both urban and rural situations. The particle size range of interest is between 0.1 and 100m (Figure 2).[8] As air movement in caves is often quite slow, the usual fate of the suspended particles is to be deposited throughout the cave.

Figure 2 shows the measurements of dust sampled from the air in Jenolan Caves with an APS Aerodynamic Particle Sizer. The size categories are based on the surface area of the particles. Other parameters such as number or mass for the size categories would give different histograms with different maxima.[3] Surface area is used as a measure of particle size distribution because it is the property that is linearly related to the visual effect of the particles when they deposit on a solid surface.

The rate of visual degradation by dust fall of the cave is imperceptibly slow so a cave manager may be unaware that damage is occurring. Ten years is the time scale for serious degradation of a cave to occur, but over ten years human memory and perception tend to be unreliable. This is one reason why it is necessary to find a method to measure the visual degradation of the cave before serious damage is done.

The management methods already applied to many caves—the building of railings and paths, have already greatly contributed to the protection of the caves from dust when compared with unmanaged caves. The impact of just one visitor to a show cave produces an impact that is usually several orders of magnitude less damaging to the cave than the visit of one caver to a wild cave. This, in most tour caves, may be only due to the elimination of getting mud on clothes. Once on clothing mud dries and is rapidly launched into the air as dust.

This reduction of impact is at the expense of considerable cave development, which, although it is a form of cave damage, should be

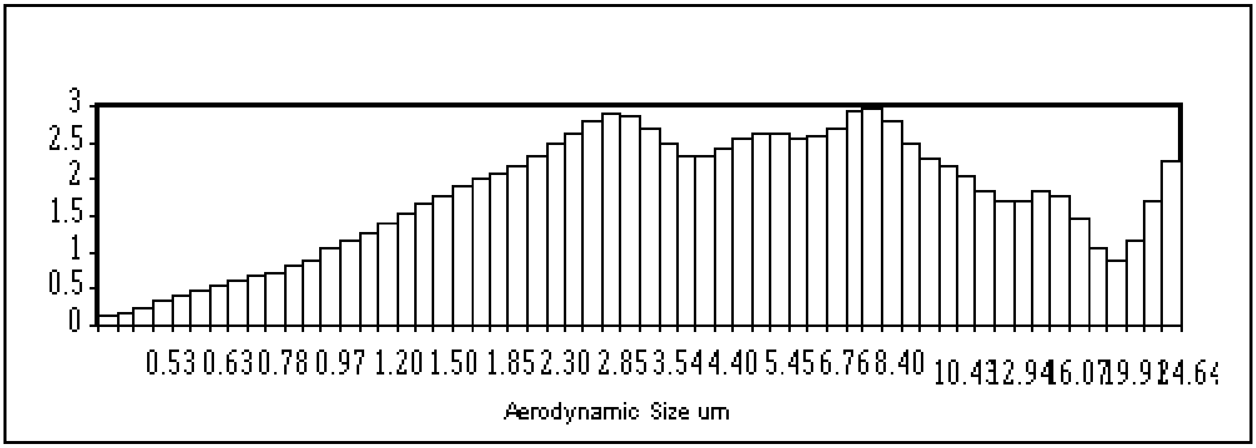

*Figure 2 - Distribution of aerodynamic size of dust particles sampled in a show cave, this graph shows relative particle surface area per category per cc of air sampled*

| Particle Diameter (µm) | Settling Velocity (m/s) | Brownian Displacement in 10s (mm.rms) | Time to settle one meter |
|---|---|---|---|
| 0.01 | 6.95 x $10^{-8}$ | 1 | 166.5 days |
| 0.1 | 8.65 x $10^{-7}$ | 0.12 | 13.38 days |
| 1 | 3.48 x $10^{-5}$ | 2.3 x $10^{-3}$ | 7.98 hours |
| 10 | 3.06 x $10^{-3}$ | 7.0 x $10^{-3}$ | 326.8 sec |
| 100 | 2.61 x $10^{-1}$ | 2.2 x $10^{-3}$ | 3.83 sec |

*Table 1 Physical behaviour of aerosol particles. Data from Baron and Willeke (1993)*

a one-off activity that will greatly reduce all future impacts.

The method described here presents a consistent measure of the optical absorption of the dust film as a direct indicator of the visual degradation by the dust film of the cave. The method has been developed to allow comparisons of dustfall between different sites and times and to give an absolute measurement of the problem suitable for the evaluation of dust management techniques and to aid the incremental development of better cave management practices.

## Dust Management Strategies

There would seem to be two main strategies to deal with the deposition of airborne dust. The first is to prevent the dust getting into the caves the second is to remove it from the caves.

### 1. Reduction of dust entering caves.

The dust is transported into caves via two main routes; direct transport into the cave in the air exchanged from the surface[12] and dust carried in by visitors.[8]

The air that enters the cave may be part of a natural circulation that is part of the cave's original microclimate or be due to man-made changes that could or should be reversed. Either way management of the areas outside the cave may achieve a reduction in the dust concentration in air entering the cave. Dust in parking areas, bare earth and gravel paths, and poorly vegetated land areas can all contribute to the ambient dust levels outside the cave and all can be improved by alternative management methods. The dust levels outside caves that are of concern are much less than is easily visible. Any management of the airflow into a cave may need to be balanced with respect of the needs for fresh air for the visitors and the need to maintain an appropriate microclimate.

The dust that is carried in by the visitors can be controlled by a number of methods, either to reduce the dust on the clothing or to reduce the quantity released in the cave. Some of the dust released in the cave will fall directly to the floor, it is important that this dust is not trampled and raised into the air to have a second chance to be spread through the cave.

Possible dust control strategies might include:

- Mats to clean the shoes before visitors enter the caves
- Air curtains to dust down visitors at the entrance
- Air jets to brush dust off visitors as they pass through the entrance.
- Mats or carpet on the flooring to absorb and immobilise dust until it can be cleaned up and removed from the cave.
- Frequent cleaning of pathways to remove dust.
- Reduction of the tduration of the tour, distance walked or amount of exercise in the cave, as each of these parameters are associated with more dust release.
- Issuing covering clothing to reduce dust release.

Some of these strategies may be more applicable in a particular situation than others. In most caves the cost and efficiency of the strategy will be important and there is much scope for new ideas to be tried.

### 2. Removal of dust from the caves.

There seems to be little prospect of removing dust from the air in caves as the aerodynamic size of the particles makes their movement relative to the air quite slow. Filtering, electrostatic precipitation, and such methods only work if all the air in the cave is cycled through engineering hardware. Such installations are used in museums and industrial clean rooms, but in caves would be expensive and difficult to make aesthetically and ecologically acceptable. So if the dust has gained entry to the cave the only option is to remove the dust from the cave surfaces.

The removal of dust from the caves has been done at Jenolan[6] [7] originally by the use of steam but now by water sprays. To enable routine cleaning it proved necessary to harden the cave by the installation of redesigned concrete paths, drains, and sumps to collect the contaminated washing water. The use of washing becomes very difficult when earth and mud formations are present. When washing is unsuitable because of mud or fine porous speleothems the only remediation now used is to pick up the fibrous material leaving the majority of the particulate material covering the surface.

## Method

### The Physical Measurement Process

To determine whether new management methods have made an improvement to dust control, trials should be conducted to evaluate the methods. To run trials a reliable sensitive method of dust measurement is required. This method has been investigated for some years.[3]

Glass Petri dishes, with an identification number engraved on them, as a surrogate surface, are placed in an array of sites considered to be representative of the cave being managed. The exposure of the dishes is relatively unimportant, even when sheltered by a covering surface 28mm above the dish the dust deposition was only reduced by 50%.[3]

The dust particles collect on the glass dish by two main processes, molecular diffusion and collision for the smaller particles and gravitation for the larger particles, both processes applying to some extent to all particles.

The smaller particles will deposit on all surfaces, the larger particles preferentially deposit on horizontal surfaces.

At suitable intervals of time the dust film on each dish is measured with the optical densitometer. The optical processes in the measurement depend on the interaction of the dust with the light beam. Solid matter reacts to light in a number of ways and except for very specific conditions will always absorb, reflect, refract, or diffract incident light.

This interaction is greatest when the index of refraction of the particles is most dissimilar from the surrounding medium. For this reason the dishes are dried by gentle warming on the hand for about a minute before measurement to remove any water that may be between the particles. At high humidity there is often a water film that reduces the light interaction by matching the indices of refraction between the particles and other particles and the glass.

The optical densitometer is designed to make a robust measurement of the proportional area of obscuration on the surface of the dish. By collimating the light source and detector, any light that is absorbed, diffracted, refracted, or reflected by the dust film from the light beam is lost to the detector. The collimation of the beam greatly reduces the sensitivity of the measurement to particle colour, giving a measure of the covering power of the film.

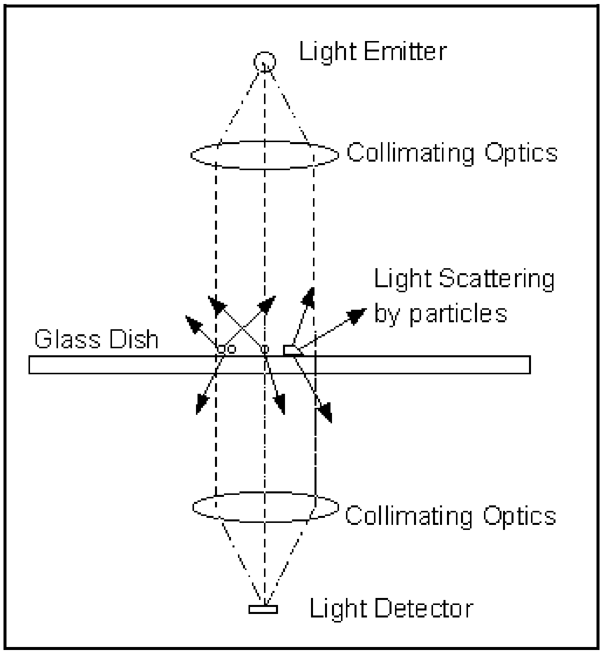

*Figure 3. Optical system of the dust film measuring instrument.*

To make the instrument insensitive to ambient light, a coded modulation of the light beam is analysed by the detector so that incident light is not detected. The instrument is self calibrating, only linearity of the measurement system is required to get full accuracy.

This is very important in a cave where lenses tend to fog or get smeared. A paper tissue may be frequently wiped over the optical surfaces without loss of precision.

The sequence of operation of the instrument is to:

(a) With a paper tissue polish the new dish until it is thought to be clean.

(b) Place it on the instrument and adjust the scaling control to get a meter reading of 1,000 units.

(c) Remove the dish, and if it was a perfect dish a number of about 1,084 should be shown, as the light lost by reflection from the two surfaces, top and bottom, of the glass remove about 8.4% of the light from the beam.

If the reading is much higher than 1,084 then the polishing process may be inadequate and should be repeated. When the dish is satisfactorily clean, record the value of the instrument after the dish is removed as a zero value for that dish.

When a dish has been exposed to dust fall for a suitable time and the dust film on the dish is to be determined, set the instrument to the value near 1,084 that the dish had when clean, dry the dish by warming, clean the underside of the dish with a paper tissue, then place the dish on the instrument.

The reading will then be some value less than 1,000, depending on the density of the dust film.

A value of 990 will show that 1% of the light has been blocked by the dust film.

The response of the instrument becomes non-linear with respect to the quantity of dust on the dish as the film gets thicker.

A formula converts the measurement to linear units, the formula is simple to use in a spreadsheet program or a PC executable program is available to convert the data.

$$Q = 1000 * \mathrm{LOG}_e(1000/R)$$

where Q is the quantity of dust in units of opacity
R is the reading from the instrument of the dish with dust.

## Discussion

The unit of measurement , the Q unit, is the quantity of dust needed to cover 0.1% of the surface. (i.e. reduce the transmission of light by one part in a thousand). This is a practical unit of measurement but the mass of dust needed to reach this level depends on the nature of the dust, mainly the diameter of the dust particles.

Carey[13] and Hancock, Esmen & Furber[14] examined the level of dust coverage that produced perceptions of dustiness under indoor conditions. 0.2% to 0.45% coverage (Effective Area of Coverage or EAC) was perceptible, while 0.4% to 0.7% was perceived as "dusty" or "dirty." These levels of dust were for black dust on a white background, the visual effect may be less when there is not a large color contrast between the dust and the substrate. The effects of dust in caves have more than a visual effect, the biological and mineralogical pollution of the surface effects subsequent growth of speleothems as well as the microbiological and biological communities.

Measurements in caves by the author have shown values that indicate an Effective Area of Coverage as high as 30% in deposits that had accumulated over a year. The relationship between mass of dust deposited in the cave and the density of the film measured in the dish in a tour cave was 30 milligrams of dust per square meter of cave surface gave a measurement of an Effective Area of Coverage of 1%. This was a density on the dish of only 3g/cm2. The instrument will resolve 0.3g/cm2.

The use of the Petri dishes to sample the dustfall allows other methods of analysis to be used in conjunction with the optical measurement.

Sampling the dry deposition of particles has been reviewed by Nicholson,[15] but although previous workers have used Petri dishes for sampling dustfall, the use of the dishes does not seem to have been previously used in an integrated sampling and measurement system for dust fall.

The problem of dust that has fallen being dislodged from the dish does not seem to exist as the high humidity of the cave ensures that strong forces of adhesion come into play when the dust contacts the dish.

The sampling schedule and processing of results using this method means that useful management feedback can be obtained from only 10 to 20 hours of work a year, a quite practical amount of time to devote to management practice evaluation.

So far only one instrument has been built, but it is available to continue the task of developing a robust, effective technology of impact minimization in tour caves. The next stage in this work is for a cave manager to take part in a demonstration project to be mounted in a tour cave to continue the process of method development and to demonstrate the achievable levels of reduction of impact. More participating cave managers and more instruments should quickly follow if significant success is achieved.

## Conclusion

The management of dust in show caves may be effected by varying management practices so that there is less dust deposited in the caves. To determine the incremental improvement of each improvement of management, a robust objective measurement of the rate of dust deposition is needed. Fortunately sampling problems do not seem to be of major concern so that a modest measurement program using optical measurement of dust deposited on a suitable substrate will be able to identify the most effective and economic methods of dust reduction. Dust-free parking areas and paths, vegetated moist soils instead of bare earth, dust and mud absorbent path coverings near the cave entrance, even air curtains and air jets to dust the visitors as they walk through may be feasible.

Control of conditions outside the caves may be a major method of dust reduction, for both dust advected directly into the caves and for dust carried into the cave in textile materials worn by visitors.

The optical method described here is robust and very sensitive and should match the requirements of many cave managers.

## Literature Cited

[1] Jablonsky, P.; Kraemer, S. and Yett, W.. (1993) "Lint in Caves" IN: *Proceedings of the National Cave Management Symposium*, Carlsbad, New Mexico, October 27 - 30 1993 pp 73 - 81

[2] Michie, N.A.. (1996) "Investigation of Visitor Impacts at Jenolan Caves." IN: *Proceedings of the International Symposium Show Caves and Environmental Monitoring* 24th to 26th April 1995 Frabosa Soprana (Cuneo) Italy pp 235 - 239

[3] Michie, N. A. (1997) *An investigation of the climate, carbon dioxide and dust in Jenolan Caves, N.S.W.* PhD thesis Macquarie University department of Physical Geography pp 298

[4] Michie, N. A. (1999) "Measurement of dust in show caves." IN: *Proceedings of the 13th Australian Cave and Karst Management Association Conference*, Naracoorte 1999. In Press.

[5] Baron, P. A. and Willeke, K. *(1993)* "Gas and Particle Motion." IN: *Aerosol Measurement, Principles, Techniques and Applications*, Eds: Klaus Willeke and Paul A. Baron. Van Nostrand Reinhold, New York p 34.

[6] Bonwick, J. and Ellis, R. (1985) "New Caves for Old: Cleaning, Restoration and Redevelopment of Show Caves." IN: *Cave Management in Australasia VI Proceedings of the Sixth Australasian Conference on Cave Tourism and Management*, Waitomo Caves, New Zealand ED: Williams, D.R. and Wilde, K.A.. pp 134 - 153.

[7] Bonwick, J.; Ellis, R. Bonwick, M. (1986) "Cleaning, Restoration and Redevelopment of Show Caves in Australia." IN*: Proceedings of the Ninth International Congress of Speleology*, Spain. 1st to 7th August 1986 Barcelona pp 221 - 223.

[8] Michie, N.A.. (1997) "The threat to caves of the human dust source." IN*: Proceedings of the 12th International Congress of Speleology*, La Chaux-de-Fonds, Switzerland. 10th - 17th August 1997 International Union of Speleology/Swiss Speleological Society La Chaux-de-Fonds, Switzerland. Vol. 5 pp 43 - 46.

[9] Christoforou, C.S.; Salmon, L.G. and Cass, G.R. (1994) "Deposition of Atmospheric Particles within the Buddhist Cave Temples at Yungang, China." *Atmospheric Environment* Vol. 28 No. 12 pp 2081 - 2091.

[10] Salmon, L. Christoforou, C. S. and Cass, G. R. (1994) "Airborne Pollutants in the Buddhist Cave Temples at the Yungang Grottoes, China." *Environmental Science and Technology* Vol. 28 No. 5 pp 805 - 811.

[11] Salmon, L.G., Christoforou, C.S., Gerk, T.J., Cass, G.R., Cassucio, G.S., Cooke, G.A., Leger, M. and Olmez, I. (1995) "Source Contributions to Airborne Particle Deposition at the Yungang Grottoes, China." *Science of the Total Environment* Vol. 167 No 1 pp 33 - 47.

[12] Pashchenko, A., Dublyansky, Yu. & Andreichuk, V. (1993). "Aerosol study in the Kungur Ice Cave (Urals, Russia)." IN: *Proceedings of the XI International Congress of Speleology*, Beijing. International Union of Speleology. pp 190 - 192.

[13] Carey, W.F. (1959) "Atmospheric Deposits in Britain—A Study of Dinginess." *Intern. J. Air Poll*. Vol. 2 pp 1-27.

[14] Hancock, R.P.; Esmen, N.A. and Furber, C.P. (1976) "Visual Response to Dustiness." *Journal of the Air pollution Control Association* Vol. 26 No. 1 pp 54 - 57.

[15] Nicholson, K.W. (1988) "The dry deposition of small particles: A review of experimental measurements." *Atmospheric Environment* Vol. 22 No. 12 pp 2653 - 2666.