

OVER A DECADE OF FINE SOIL MEASUREMENTS AT SELECTED AUSTRALIAN AND ASIAN SITES BY ANSTO.

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INTRODUCTION

The Australian Nuclear Science and Technology Organisation (ANSTO) has been using accelerator based Ion Beam Analysis (IBA) techniques to quantify and characterise fine particulate (PM_{2.5}) air pollution since the late 1980s [1-9]. These techniques provide quantitative information on over 20 different chemical species from hydrogen to lead [1-3] in just a few minutes of analysis. Fig. 1 shows a typical Particle Induced X-ray Emission (PIXE) spectrum from a fine particulate filter collected over a 24 hour period. Each peak represents an element present and the area under that peak its concentration on the filter. It clearly demonstrates Al, Si from windblown soils, S from coal combustion, K from biomass burning, heavy metals from industrial sources and Pb and Br from leaded petrol. Hence a detailed measurement of the various components can provide actual pollution source contributions [4,8,9].

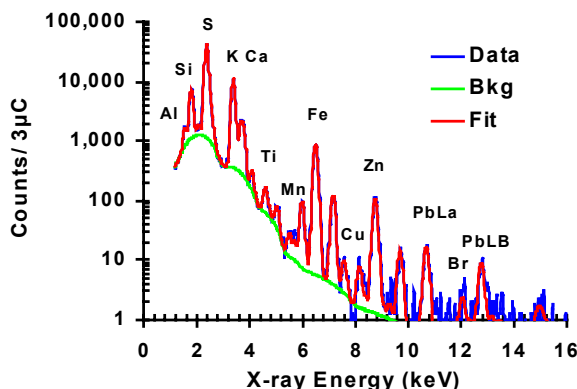


Fig. 1 Typical X-ray spectrum for PM_{2.5} Teflon filter.

SOIL ESTIMATES AND FINGERPRINTING

Soil is one of the easier components to estimate on filter papers using these standard IBA techniques. Correlations plots of key expected soil components like Al, Si, Ca, Ti and Fe show strong associations (see Fig. 2) in fact defining the soil component. This strong inter-elemental association continues for both the fine (PM_{2.5}) and the PM₁₀ fractions as shown by Figs.3 and 4. These inter-elemental correlations for soil and indeed other sources can be extracted in an unbiased way using standard statistical techniques such as Principal Components Analysis (PCA) [10]. Fig. 5 shows a PCA analysis of fine particle data near an open cut mining operation in the Hunter Valley of NSW. Two factors are plotted here showing elements associated with motor vehicles (high Factor 2 loadings, near 1.0 on the vertical axis) and soil (high Factor 1 loadings, near 1.0 on the horizontal axis).

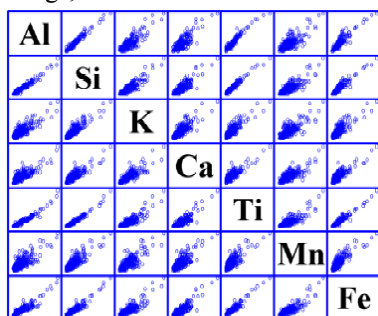


Fig. 2. Correlation plots for key soil components.

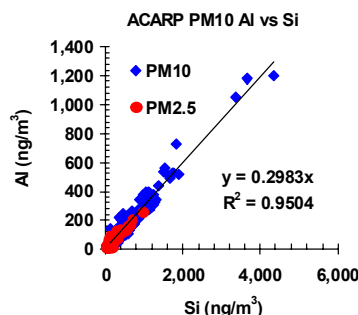


Fig. 3. Al vs Si for fine and coarse soils in NSW.

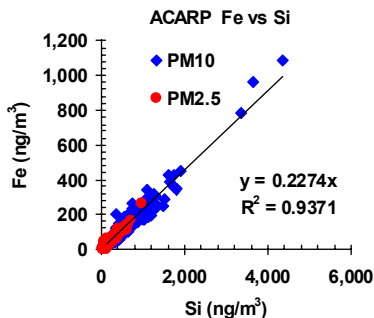


Fig. 4. Fe vs Si for fine and coarse soils in NSW.

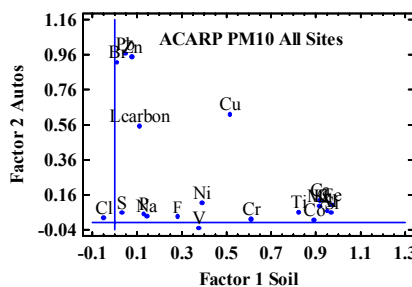


Fig. 5. PCA factor loading plot for soil and autos.

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Having established inter-element associations for soil we can define soil fingerprints, unique to the sites at which the data were collected, by using the gradients of plots like those of Figs. 3 and 4. Fig. 6 is such a soil fingerprint for 5 different sites around NSW. The cleaner rural sites like Cape Grim in NW Tasmania have fingerprints typical of normal crustal material with industrial or urban sites like Wollongong, Newcastle and Mascot have fingerprints with more anthropogenic components like heavy metals. Fig. 7 also shows that there are no significant differences, within the errors, between fine (PM_{2.5}) and coarse (2.5-10µm) sized particles as far as the soil fingerprints are concerned.

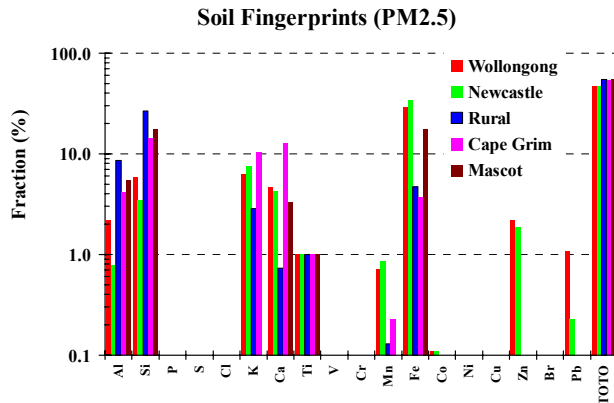


Fig. 6. Soil fingerprints for 5 different Australian sites.

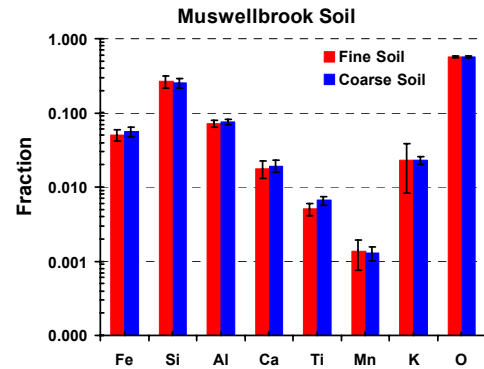


Fig. 7. Soil fingerprints for fine and coarse soils.

FINE PARTICULATE WINDBLOWN SOIL IN AUSTRALIA

Over the past decade or more ANSTO has been routinely measuring and characterising fine particulate air pollution for local Councils and industry groups around NSW. In particular the urban site at Mascot in Sydney, the industrial sites at Mayfield in Newcastle north of Sydney and Warrawong in Wollongong south of Sydney have been sampling twice a week since 1992. Fig. 8 shows the average monthly PM_{2.5} total mass loading for these three sites from February 1992 to June 2004. The Warrawong site was inoperative for several months during 1994, hence the zero mass readings. The horizontal dotted line shows the current US EPA annual average goal of 15 µg/m³ for fine particles. Currently NSW does not have a PM_{2.5} mass goal but the Federal Government is looking to introduce one of 8 µg/m³, which is significantly lower than the US EPA goal. Generally the average monthly PM_{2.5} masses range from around 5 to 20 µg/m³ being 2-3 times higher in the winter months than the summer months.

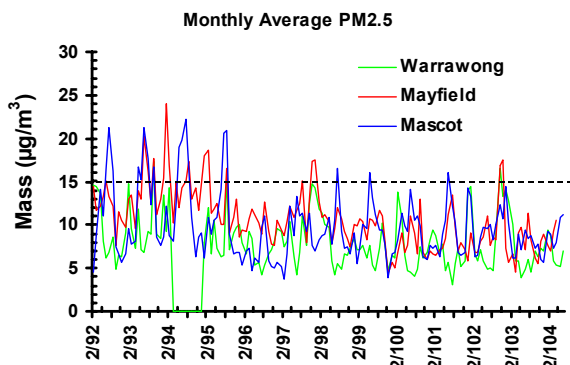


Fig. 8. Average monthly PM_{2.5} masses at 3 NSW sites.

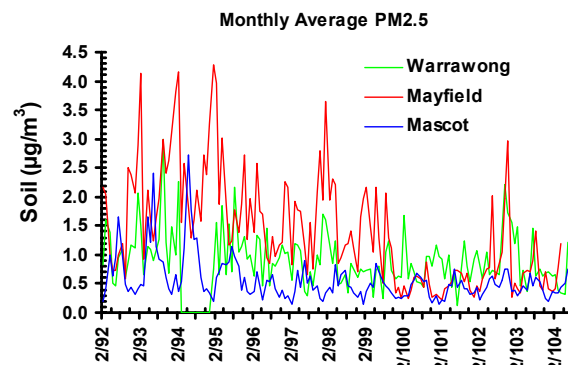


Fig. 9. Average monthly PM_{2.5} soil at 3 NSW sites

Using the elemental fingerprints described about we can extract soil estimates from these total masses for each site. Fig. 9 shows the estimated average monthly PM_{2.5} soil content for the three sites over the same study period as given in Fig. 8. Table 1 shows the PM_{2.5} twelve year average mass, soil and percentage soil for the three sites whose data are given in Figs. 8 and 9. These long term averages are typical for most Australian sites with fine windblown soils typically contributing between 5% and 15% of the total mass.

1992-2004 Site	PM _{2.5} Mass (µg/m ³)	PM _{2.5} Soil (µg/m ³)	% Soil
Warrawong	8.2±3.2	0.94±0.46	11.5±5.6
Mayfield	10.7±3.4	1.42±0.94	13.3±8.9
Mascot	9.8±3.8	0.56±0.38	5.7±3.8

Table 1. Fine PM_{2.5} mass and soils for 3 NSW sites from 1992 to 2004.

Interestingly the industrial site of Mayfield had a significantly higher fine soil fraction than the Warrawong industrial site or the Mascot urban site up until late 1999 when there were significant reductions in industrial activities in the Mayfield region.

Measuring on a long term continuous basis allows us to pick up major events like the dust storms of October 2002 which covered parts of NSW and Queensland (see NASA satellite photo of Fig. 10). Fig. 11 shows the total daily PM_{2.5} mass for the period 1 July 2002 to 30 June 2003 for the Richmond site west of Sydney, the Muswellbrook site hundreds of kilometres north of Sydney and the Queensland University of Technology site in Brisbane, a 1000 kilometres north of Sydney. All three sites show mass peaks well over 20 µg/m³ during the dust storm episode. Using the fingerprint previously discussed the soil estimates for the same period at the same sites are shown in Fig. 12. The site at QUT was affected worst with nearly 20 µg/m³ of fine soil, while Richmond and Muswellbrook both had fine soil values above 5 µg/m³.

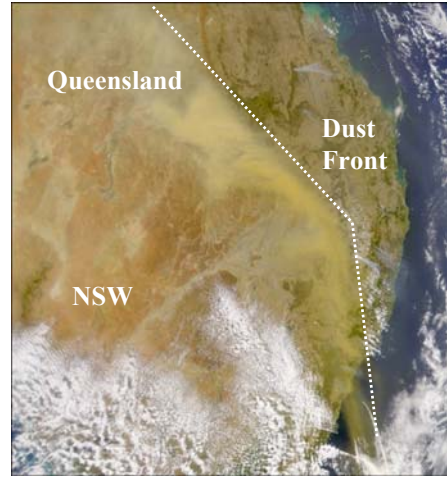


Fig. 10. NASA photo of dust off eastern Australia 23 October 2002.

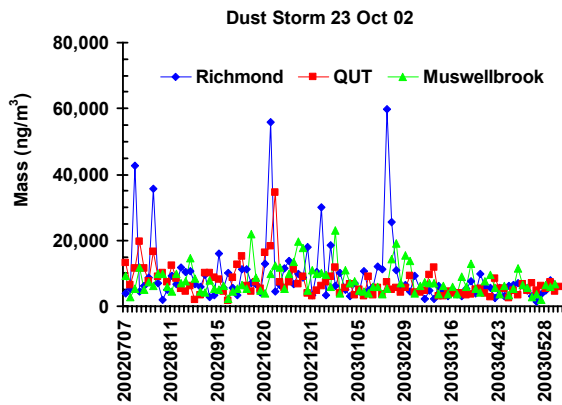


Fig. 11. PM_{2.5} Mass from July 2002 to June 2003.

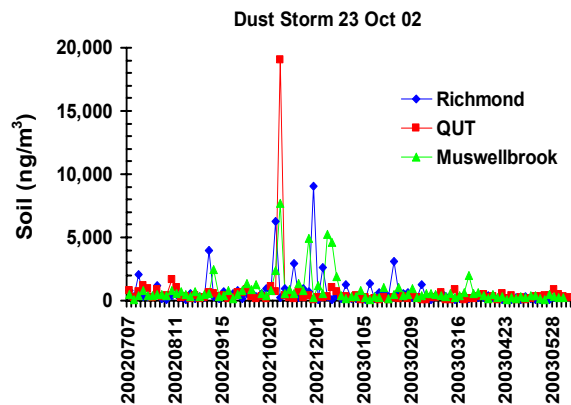


Fig. 12. PM_{2.5} Soil from July 2002 to June 2003

DUST IN ASIA

Since January 2001 we have also been measuring and using IBA techniques at ANSTO to characterise PM_{2.5} and PM₁₀ particulate air pollution at five key sites in Asia associated with the Aerosol Characterisation Experiment in Asia (ACE-Asia). More comprehensive results and discussions for the first few years of sampling have already been published in the literature [7-9]. Fig. 13 shows the site locations in Asia and Fig. 14 shows a NASA satellite image of large dust movements moving across Korea and Japan in April 2002.



Fig. 13. Map of 5 ACE Asia Sites

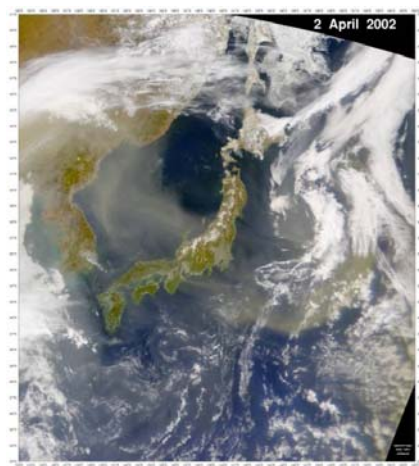


Fig. 14. NASA satellite photo of dust over Japan 2 April 2002.

These large dust events are common for the region generally each springtime between March and May. This is well demonstrated by the fine mass box and whisker plot of Fig. 15 for daily data acquired at the Cheju Island site off southern Korea.

The IBA techniques described above allow us to estimate the average PM_{2.5} composition (see for example Fig. 16 for Cheju Island) for each site and hence the percentage soil contributions. The box and whisker plot of Fig. 17 shows the percentage soil for Cheju Island corresponding to the mass plot of Fig. 15. Generally windblown soils are around 5% to 10% of the total fine mass, however at certain times of the year these increase to well over 15% of the fine mass. Fig. 18 shows these large soil events correspond to major windblown soil events originating from the Gobi desert regions in northern China and Mongolia and being transported thousands of kilometres across Korea and Japan.

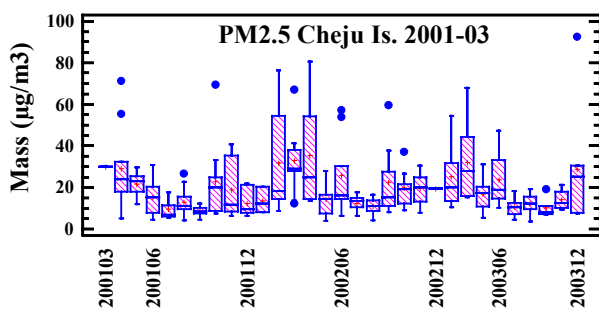


Fig. 15. Fine mass at Cheju Island off South Korea for 2001 to end of 2003.

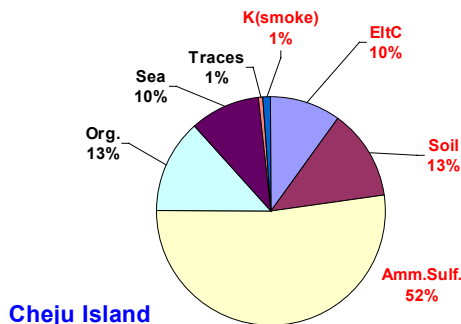


Fig. 16. Average fine particle composition for Cheju Island off South Korea.

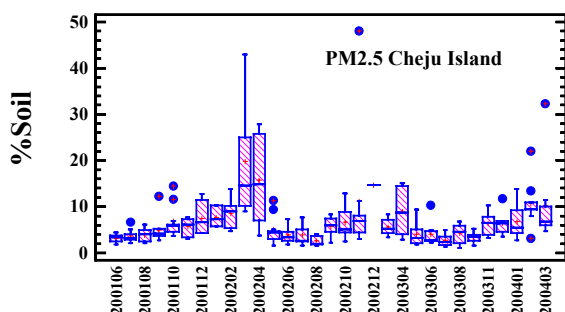


Fig. 17. Percentage fine soil at Cheju Island off South Korea for 2001 to end of 2003

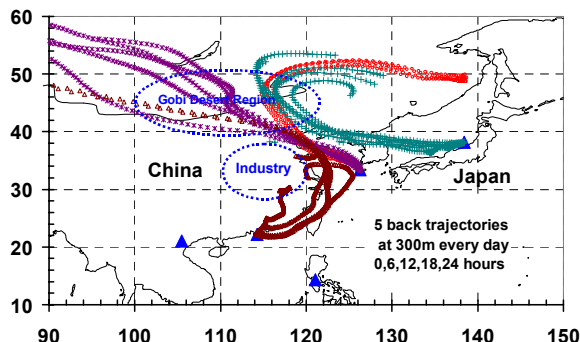


Fig. 18. 5 day back trajectories for Hong Kong, Cheju and Sado Island sites for 10-17 April 2002.

SUMMARY

Soil contributions in both the PM_{2.5} and PM₁₀ size fractions have been successfully estimated using IBA techniques at ANSTO over many years and across a wide range of sites from global baseline site in Tasmania to very heavy polluted sites across Asia. Similar but different fingerprints for rural, urban and industrial soils have been obtained, allowing quantitative fine and coarse fraction soil estimates to be obtained for these regions. Fine soils typically contribute between 5% and 15% to the total PM_{2.5} mass fraction. However this can increase to 40% or 50% under extreme dust storm events as seen in certain parts of east Asia particularly during springtime each year.

ACKNOWLEDGEMENTS

We would like to acknowledge the help of all local staff at each of the sampling site locations for regular filter changes throughout these local, regional and global studies. We are also indebted to all the 3 MV Van de Graaff accelerator staff at ANSTO for assistance with all the IBA measurements. This research was supported by ANSTO, Hong Kong Polytechnic University, the Research Grants Council of the Hong Kong Special Administrative Region (Project No. 5063/01E).

REFERENCES

- [1]. D.D. Cohen, Applications of simultaneous IBA techniques to aerosol analysis. Nucl. Instr. and Methods, B79(1993)385-388.
- [2]. David D. Cohen, Bailey G.M. and Kondepudi R., Elemental Analysis by PIXE and Other IBA Techniques and their Application to Source Fingerprinting of Atmospheric Fine Particle Pollution, Nucl. Instr. and Methods, 109 (1996) 218-226.
- [3]. David D Cohen. Characterisation of Atmospheric Fine Particle Using IBA Techniques. Nucl. Instr. and Methods, 136B (1998) 14-22.
- [4]. David Cohen, Seasonal and regional variations in ambient fine particle concentrations and sources in New South Wales, Australia: A seven year study. Proceedings of International Congress of Biometeorology and International Conference on Urban Climatology, Sydney, Australia, 8-12 November 1999, pp607-612
- [5]. David D. Cohen, D. Garton, E. Stelcer. Multi-elemental methods for fine particle source apportionment at the global baseline station at Cape Grim, Tasmania. Nucl. Instr. And Methods 161 (2000) 775-9.
- [6]. David D. Cohen, Ed Stelcer, David Garton, Ion beam methods to determine trace heavy metals concentrations and sources in urban airsheds. Nuclear Instruments and Methods in Physics Research B190 (2002) 466-470
- [7]. David D. Cohen, David Garton, Eduard Stelcer, Olga Hawas, Tao Wang, Steven Poon, Jiyoung Kim, Byoung Cheol Choi, Sung Nam Oh, Hye-Jung Shin, Mi Young Ko, Mitsuo Uematsu, Multi-elemental Analysis and Characterisation of Fine Aerosols at Several Key ACE-Asia Sites. Journal of Geophysical Research, 109 (2004) D19S12, doi:10.1029/2003JD003569.
- [8]. David D. Cohen, Ed Stelcer, Olga Hawas, David Garton, IBA Methods for Characterisation of Fine Particulate Atmospheric Pollution: A local, regional and global research problem. Nucl. Instr. and Methods B219-220 (2004) 145-152.
- [9]. David D. Cohen, David Garton, Eduard Stelcer, Olga Hawas, Accelerator Based Studies of Atmospheric Pollution Processes. Radiation Physics and Chemistry, 71 (2004) 759-767.
- [10]. P.K Hopke, Receptor Modelling for Air Quality Management, Elsevier Science, Amsterdam, (1991).