

# Liversidge Research Lecture

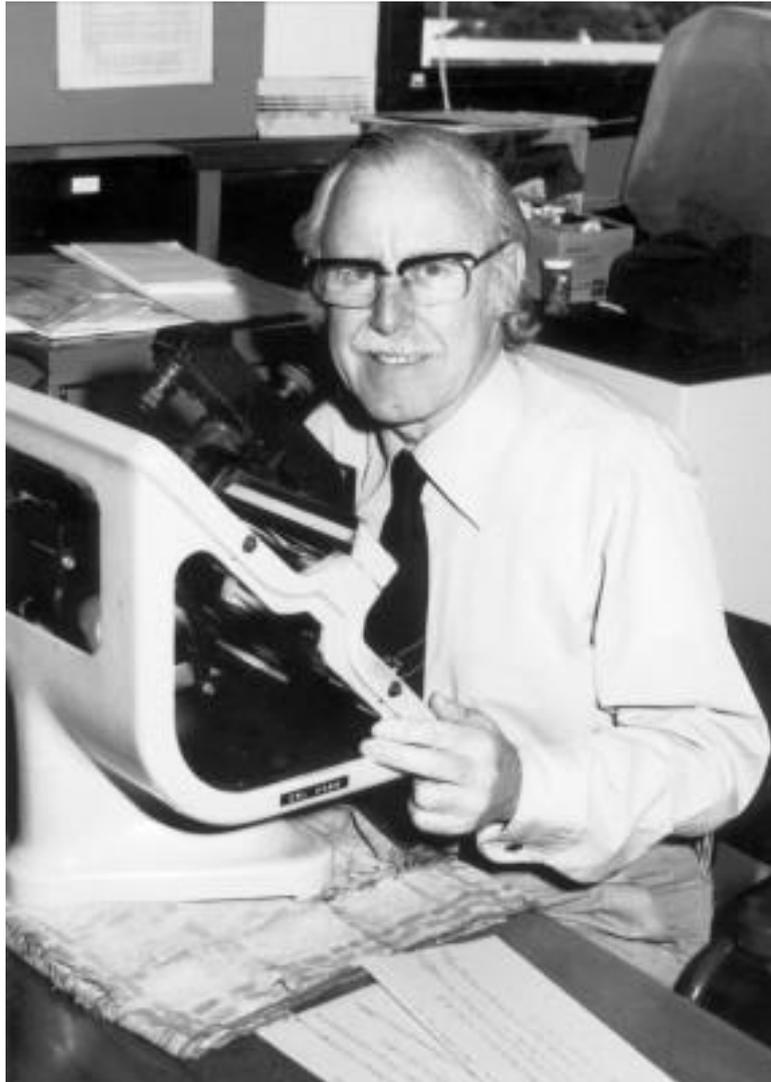
No. 30  
1996

TRACE ELEMENTS IN COAL SCIENCE

D.J. SWAINE



The Royal Society of New South Wales



**Dalway John Swaine**

### **DALWAY JOHN SWAINE 1920 –2013**

**Dalway John Swaine** was born on 23 January 1920 in Sydney. After secondary education at Xavier College, Kew (Victoria), he attended the University of Melbourne part-time during 1940-44 while working as an Assistant Research Officer at the newly established CSIR Lubricants and Bearings Section that was located within the University of Melbourne (see 'Francis Philip Bowden 1903-1968', Liversidge Research Lecturer No. 5). He graduated B.Sc. (1945), and then he worked under the supervision of Mr. G.A. Ampt on the longevity of galvanised roofing sheets and fencing wire, and graduated M.Sc. in 1947 with the award of the Professor Kernot Research Prize. He continued working in the Chemistry Department as a Senior Demonstrator while carrying out further research on analytical methods relevant to geochemistry. In 1949, with the award of a British Council Travel Grant and the Sir John and Lady Higgins Research Scholarship he proceeded to the University of Aberdeen where he worked under the supervision of Dr. R.L. Mitchell on the distribution of trace elements in soils, and graduated Ph.D. in 1952. During 1952-1959 he worked as a Senior Research Officer at The Macaulay Institute for Soil Research at Aberdeen where he carried out research on trace elements in soils and rocks. In 1959 he was appointed as Senior Research Scientist at the CSIRO Division of Coal Research, Ryde (NSW), where he was promoted to Principal Research Scientist in 1966, and then to Senior Principal Research Scientist and Head of the Geochemistry Section, CSIRO Division of Mineralogy in 1972. In 1977 he became Group Leader of the CSIRO Fuel Geoscience Unit, of which he became Acting Officer-in-Charge in 1980. For the period 1980-1985 he was Chief Research Scientist and Leader of the Geoscience Section of CSIRO Division of Fossil Fuels. Since 1985 he has been Honorary Research Fellow of the CSIRO Division of Coal and Energy Technology, and since 1984 he has been a Professorial Fellow in The University of Sydney. From 1990 to 1995 he was Visiting Scientist at the Institute of Sedimentary and Petroleum Geology at Calgary, Canada, and since 1994 he has been Senior Scientific Advisor to the Centre of Excellence on air Toxic Metals, EERC, University of North Dakota, Grand Forks, USA. Other overseas institutions where he has spent time as Visiting Professor or its equivalent (several since formal retirement in 1985) are:- University of Kansas, Lawrence; University of California, Riverside; Pennsylvania State University; University of Heidelberg; Charles University, Prague; Ben Gurion University, Israel; Vernadsky Institute, Moscow; Akadengorok Institute of Inorganic Chemistry, Novosibirsk; University of Kentucky, Lexington; Swedish Academy of Engineering Science, Stockholm; Woods Hole Oceanographic Institute; US Geological Survey, Reston and Denver; St. Francis Xavier University, Antigonish, Nova Scotia; Geological Survey of Canada, Calgary. He has actively collaborated with several overseas scientists, and has been an invited speaker at numerous Australian and overseas conferences.

Dal Swaine was a Member of Council, International Confederation for Thermal Analysis (1968-1971), and a Member of the Standards Association of Australia (1964-1978); he was President of the Royal Society of NSW in 1976. He was a Member of the Editorial Board of *Geochimica et Cosmochimica Acta* (1961-1966), the *Journal of Thermal Analysis* (1968-1974), the *Journal of the Science of the Total Environment* (1979-1987), *Environmental Geochemistry and Health* (1985-), and Associate Editor, *Theophrastus' Contributions to advanced Studies in Geology, Athens* (1995-). He has served as Chairman or as a member of several national and international committees concerned with science and the environment.

His main research interest has been in the trace element geochemistry of soils, rocks and coal, and he has been the author or co-author of several books: 'The Trace-Element Content of Soils' (1955), 'The Trace-Element Content of Fertilizers' (1962), 'Biogeochemical Cycling of Mineral Forming Elements' (with P. Trudinger, 1979), 'Trace Elements in Coal' (1990), 'Greenhouse and Energy' (Editor, 1990), and 'Environmental Aspects of Trace Elements in Coal' (with F. Goodarzi, 1995). He has been the author of chapters in numerous other monographs.

### **Honours and Awards (Pre-2001)**

- 1957 FRACI (Fellow of the Royal Australian Chemical Institute)
- 1972 Hartung Youth Lecturer, RACI
- 1978 Fellow, Australian Institute of Energy
- 1980 Nyholm Youth Memorial Lecturer, RACI
- 1980 Merrill W. Haas Award, University of Kansas, USA
- 1982 Archibald Ollé Prize, RACI
- 1985 Medal of the Royal Society of New South Wales
- 1993 Life Member, Sydney University Chemical Society
- 1993 Medal, Clemson University, South Carolina, USA
- 1996 Liversidge Research Lecture, Royal Society of New South Wales
- 1998 P.H. Given Award, Pennsylvania State University, USA
- 2000 Excellence Award, Energy and Environmental Research Center, University of North Dakota, USA.

### **Biographical Source**

1. Personal communication
2. 'Who's Who in Australia 2000', Information Australia Group Pty Ltd., Melbourne, 1000.

### **Scientific Publications of D.J. Swaine**

Up to the year 2000 D.J. Swaine has been the author / co-author of 86 research papers, 6 reviews, 17 book chapters, and 6 books.

## TRACE ELEMENTS IN COAL SCIENCE\*

D.J. SWAINE

*CSIRO Division of Coal and Energy Technology, North Ryde, N.S.W.  
School of Chemistry, University of Sydney, N.S.W.*

**ABSTRACT.** Trace elements are relevant to several aspects of coal science. Five topics are dealt with in detail, namely, the occurrence of trace elements, boron as an indicator of marine influence, boiler deposits, fluorine in coal, and the deposition of trace elements from the atmosphere. There is an increasing interest in the fate of trace elements from the combustion of coal for power production, especially environmental aspects of trace elements from the atmosphere and from ash disposal areas. Several suggestions for future work are outlined.

### Introduction

It is a pleasure to thank the Royal Society of New South Wales for the invitation to give the Liversidge Research Lecture and the Sydney University Chemical Society for arranging the joint meeting for the presentation. Professor Liversidge directed in his Will that the lecture should cover the results of the lecturer's recent research. Some of Liversidge's early work dealt with coal, for example, gold in the coal measures and coal from the Wallerawang area. Hence, my topic is relevant. In 1872 Liversidge left England to fill the position of Reader in Geology and Demonstrator in Practical Chemistry at The University of Sydney. In 1882 he was appointed Professor of Chemistry and Mineralogy. He was a pioneer in setting up courses in chemistry and influenced greatly the progress of science, in particular, encouraging women to study science. Relevant information on Liversidge's activities at The University of Sydney and in The Royal Society of New South Wales is given by LeFèvre (1968) and by Branagan and Holland (1985). Liversidge was primarily a chemical mineralogist whom I regard as Australia's first geochemist.

There are several aspects of trace elements in coal science that are noteworthy, for example:

- During coalification
- Occurrence (speciation), especially with mineral matter
- Effects of marine influence
- Changes during mining
- Use for seam correlation
- During beneficiation (coal cleaning)
- Boiler deposits
- Analytical methodology, especially at trace and ultratrace levels
- Redistribution during combustion for power production
- Association with flyash
- In stack emissions from power stations

---

\*Liversidge Research Lecture delivered before the Royal Society of New South Wales, 12th June, 1996. Reproduced by permission of the Royal Society of New South Wales from *J. Proc. Roy. Soc. N.S.W.*, 1996, **129**, 139-148.

In deposition from the atmosphere around power stations  
 Rehabilitation after mining  
 Possible health effects  
 As a source of metals and non-metals.

Five of the above topics which are part of my research will be discussed.

Nowadays the stress is on environmental aspects of coal usage. This gives trace elements a major role which is generating a mass of applied and basic research, notably in the USA (Swaine and Goodarzi, 1995).

### Occurrence of Trace Elements

As well as knowing the concentrations of trace elements in coal, it is important to ascertain how they occur (speciation). Much work has been and is being done on speciation which is difficult because so many elements are present in different forms and at parts per million (ppm) and sub-parts per million levels. The total content of a trace element in coal is made up of two main components, namely, organic and mineral, each having several possible forms. For example, the organic may be intrinsic (derived from the early stages of coalification) and adsorbed (gained during the later stages of coalification), the association being with carboxylic acid and phenolic hydroxyl groups and possibly with mercapto and imino groups (Swaine, 1977). Trace element-organic associations are prevalent at the early stages of coalification but less so as the rank of coal increases, possibly because the increase in aromaticity with rank lessens the binding power of fundamental groups (Swaine, 1992a). There is more information about the associations with mineral (inorganic) matter, where trace elements occur as discrete minerals, as replacement ions in major minerals and adsorbed, for example on clays (Swaine, 1990).

During my initial incursion into trace elements in coal, it seemed sensible to apply Goldschmidt's rules, based on the size and charge of ions, to some coal minerals. Carbonate minerals, namely siderite ( $\text{FeCO}_3$ ), calcite ( $\text{CaCO}_3$ ) and ankerite [ $\text{Ca}(\text{Fe,Mg,Mn})(\text{CO}_3)_2$ ] showed relatively high concentrations of manganese (Brown and Swaine, 1964). Table 1 gives results for Mn in these minerals, showing that 1% Mn or more occurs in some samples.

TABLE 1.  
*Manganese in Carbonate Minerals in Coal (as ppm Mn).*

-----	
Siderite-( $\text{FeCO}_3$ )	
Tongarra	3000
Benley Tops	10000
Calcite-( $\text{CaCO}_3$ )	
Queensland	2240
Wallarrah	10000
Hunter Valley	4650
Ankerite-[ $\text{Ca}(\text{Fe,Mg,Mn})(\text{CO}_3)_2$ ]	
New South Wales	500-17700 (mean 7500)
-----	

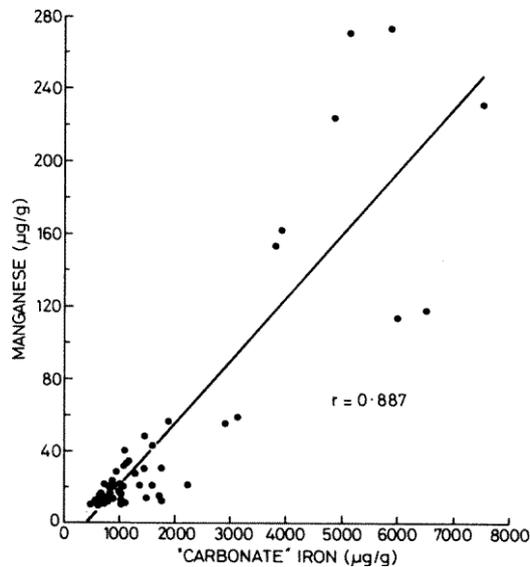


FIGURE 1. The correlation between manganese in siderites, from the Lithgow seam, New South Wales, and "carbonate" iron.

It is suggested that this is because  $Mn^{2+}$  replaces some  $Fe^{2+}$  in siderite and some  $Ca^{2+}$  in calcite. In ankerite, the question may be posed - is Mn replacing some Fe or Ca or both? A study of 56 coal samples from the Lithgow seam, New South Wales, gave indirect evidence for the association of Mn with siderite from the good linear correlation ( $r = 0.89$ ) between Mn and carbonate iron (that is, total iron less pyritic iron), as shown in Figure 1. In low-rank coals, where there are no carbonate minerals, for example, Victorian Latrobe Valley coals, Mn, Sr, Zn and some other elements are associated with carboxylic acid groups in the organic coaly matter (Swaine, 1992a). As coal matures, these carboxylic acid groups disappear and hence also this cation-organic matter association.

### Boron as an Indicator of Marine Influence

Seawater contains 4.6 ppm B compared with less than 0.1 ppm B in most terrestrial waters. This is the basis for using boron to indicate the extent of marine influence on sediments. Initially, boron in clays, especially illite, was used. My attempts to use boron in clays associated with coals were only partially successful and hence boron in coal was investigated. The ranges and mean values for boron in coals from the Sydney Basin are shown in Figure 2 (Swaine, 1962a). Clean-coal composites were used, that is, samples

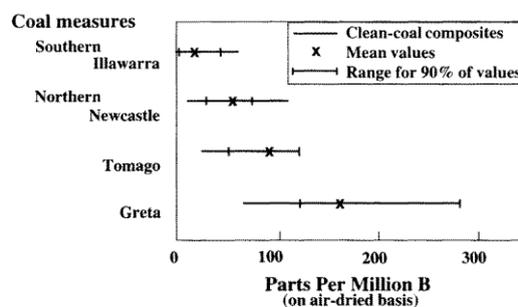


FIGURE 2. Contents of boron in coals from the Sydney Basin, New South Wales (based on Swaine, 1962a).

prepared from sub-samples having ash yields of less than 35 per cent. The Illawarra coals are known to have been exposed to freshwater conditions only, whereas the Greta coals have been exposed to marine influences. These effects probably occurred during the early stages of coalification when the organic matter could have retained boron probably by chemical fixation - or adsorption. On the basis of boron values it was predicted that the Tomago samples had been exposed to mildly brackish conditions. This led to a detailed geological examination which confirmed the boron-based postulate. An extensive study of Queensland coals indicated that most had only been exposed to freshwater conditions, the exceptions being coals from the Nipan-Theodore area of the Bowen Basin, where it is suggested that they had been exposed to mildly brackish to brackish conditions (Swaine, 1971). After a lapse of about 30 years, this use of boron in coal to indicate marine incursions during coalification was tested extensively on a wide range of Canadian coals, in collaboration with F. Goodarzi, Institute of Sedimentary and Petroleum Geology in Calgary. The assessments were carried out in conjunction with geological information on conditions during coal formation, especially changes in the depositional environment (Goodarzi and Swaine, 1994a). An exception was found by Beaton, Goodarzi and Potter (1991) during research on some lignites from Saskatchewan, where high values for boron were not associated with seawater incursions. High concentrations of boron in these coals deposited under freshwater conditions probably depend on secondary enrichments arising from groundwaters leaching evaporites and associated with extensive fault systems (Goodarzi and Swaine, 1994a). This exception stresses the need to confirm boron values by ascertaining the relevant geological features.

In most coals boron is predominantly associated with the coaly organic matter, clays and sometimes tourmaline. The main evidence for organic boron comes from shortfalls in boron in mineral matter and from the inverse relationship between boron in ash and ash yield (Figure 3). Any boron added to the coal swamp from seawater is invariably diluted to brackish water and boron taken up by the coal is considered to be organically bound.

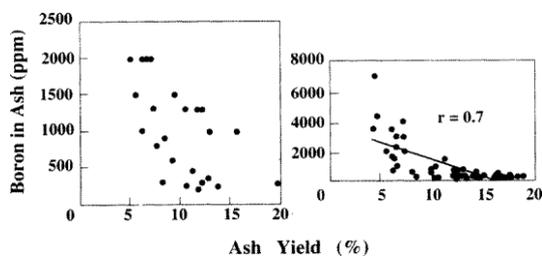


FIGURE 3. Boron contents in ash versus ash yield for coals from the Theodore district, Queensland (on the left) and from the northern part of the Sydney Basin, New South Wales (Goodarzi and Swaine, 1994a).

As a result of the studies of the Canadian coals, the suggested ranges for freshwater, mildly brackish and brackish influences were modified slightly as follows:

	<u>original</u>	<u>final</u>
Freshwater	<40 ppm B	<50 ppm B
Mildly brackish	40-120 ppm B	50-110 ppm B
Brackish	>120 ppm B	>110 ppm B

The original values are based on studies of Australian coals (Swaine, 1962a) and the final values are based on a reappraisal of Australian and Canadian coals (Goodarzi and Swaine, 1994b).

### Boiler Deposits

A study of several deposits from the fireside of boilers, using spreader-stokers and chain-grate stokers, showed the presence of very high concentrations of several elements, notably phosphorus, boron and arsenic. Some results for the inner layer (1-2 mm thick) and from the outer layer of a deposit on a superheater tube are shown in Figure 4 (based on Brown and Swaine, 1964). There are marked enhancements above coal ash for phosphorus, arsenic, boron, lead and thallium, but not for vanadium. This was the first evidence for the presence of thallium in an Australian coal. Later, improved methods of

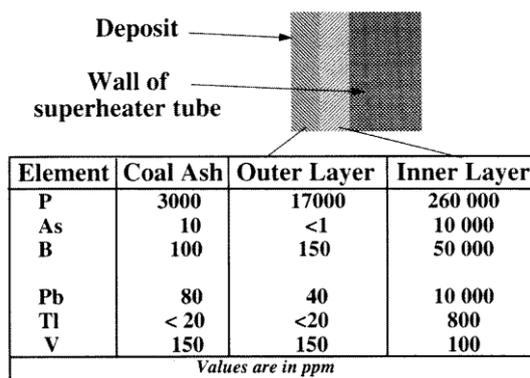


FIGURE 4. Contents of some elements in a deposit on a superheater tube (based on Brown and Swaine, 1964).

analysis showed that most Australian coals had up to about 3 ppm Tl, with a mean of less than 1 ppm (Swaine, 1990). X-ray diffraction identified boron phosphate ( $BPO_4$ ) in the sample from the inner layer. Further work showed that some deposits contained boron arsenate ( $BAsO_4$ ) in solid solution in boron phosphate (Swaine and Taylor, 1970). These two compounds have not been found in nature. As predicted by Goldschmidt they are isostructural with  $\beta$ -cristobalite. Phosphate-rich deposits are not found in modern boilers using pulverised coal burnt with excess oxygen. It seems that these deposits are only formed under certain conditions when lump coal is fired relatively slowly. During combustion an initial reaction between quartz, fluorapatite and coal could yield phosphoric acid ( $P_2O_5$ ) which could react with boron oxide ( $B_2O_3$ ) to produce boron phosphate.

### Fluorine in Coal

As I.P. Pavlov has aptly stated "No matter how perfect a bird's wing may be, it could never lift the bird to any height without the support of air". Facts are the air of science. In environmental science, facts, that is, proper results, are paramount, and hence much attention has been paid to the sampling and analysis of coals for trace elements mostly present at ppm or sub-ppm levels. As an example of the vigilance required to ensure the attainment of proper results, we found that the standard method for determining fluorine in coal (ASTM, 1979) gave low and sometimes very low results for Australian and overseas bituminous coals. This led to the development of a new method (Godbeer and Swaine, 1987) in which the coal sample is mixed with finely ground silica and pyrolysed in a silica furnace at about 1200°C in an atmosphere of oxygen and water vapour, the resulting gases

being passed into a sodium hydroxide solution. The absorbed fluoride is determined by an ion selective electrode or by ion chromatography. This pyrohydrolysis method is the basis of the current Australian Standard Method (AS, 1989) and of the proposed International Standards Organisation method.

Why does the ASTM method give low results? In the ASTM method coal is combusted in an oxygen-charged calorimeter bomb, so it seems that not every fluorine-containing mineral is decomposed. Certainly fluorapatite, which is the main source of fluorine in most coals, and probably clays release their fluorine in the bomb, but resistant minerals, for example, fluorite, tourmaline and topaz, may not be completely decomposed. However, these minerals would release their fluorine in the pyrohydrolysis method which is also used to determine fluorine in rocks.

The pyrohydrolysis method has been used to determine fluorine in representative samples of Australian (Godbeer and Swaine, 1987) and Canadian coals (Godbeer, Swaine and Goodarzi, 1994). It is suggested that the range of values for most coals is 20-500, with a mean of about 150 ppm F (Swaine, 1990).

### Deposition from the Atmosphere

Deposition refers to the amounts of elements reaching the earth's surface from the atmosphere. The most important aspect of trace elements in coal is their relevance to environmental matters, especially those connected with the combustion of coal for power generation. Of the twenty five trace elements regarded as being of environmental interest, twelve are included in the list of hazardous air pollutants under investigation by the US Environmental Protection Agency. Hence, it is necessary to measure the amount of trace elements in deposition in the environs of power stations. When coal is burnt in a pulverised-coal-fired power station most trace elements are released and then redistributed into bottom ash, flyash (removed by particle attenuation) and fine flyash. The properties of flyash (formation, mineralogy and composition) are reviewed by Swaine (1995). The fine flyash particles, emitted with the stack gases, are dispersed into the atmosphere where chemical changes and agglomeration of the finest particles take place. Deposition from the atmosphere occurs by wet and dry processes. In the case of dry deposition, turbulence and other effects complicate the accession to the earth's surface. The overall situation is shown in Figure 5 (Swaine, 1994).

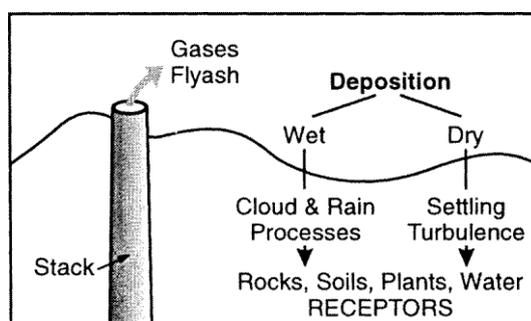


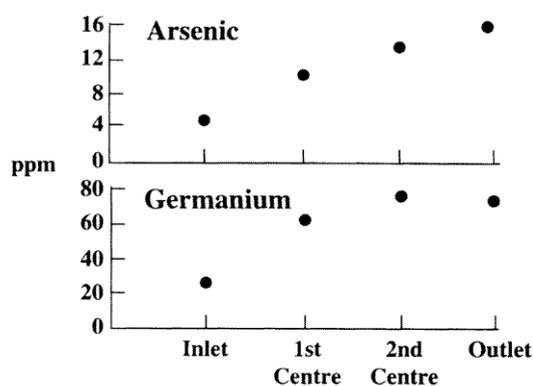
FIGURE 5. Schematic of the fate of trace elements in stack emissions (reprinted from Swaine (1994) with kind permission from Elsevier Science, Amsterdam).

Measurements of the trace-element contents in deposition from the environs of a modern coal-fired power station were carried out for four years. The power station is at

Wallerawang, New South Wales, situated in a mostly wooded area about 120 km northeast from Sydney. The total installed capacity is 1240 MW produced by pulverised coal firing. Particle attenuation is by electrostatic precipitation. The bituminous feed-coal is from the Lithgow seam with low total sulfur content (0.6% S). The deposition was collected using cleaned *Sphagnum cristatum* moss held in flat, fine-mesh envelopes which were mounted in aluminium frames attached to aluminium stakes so that the frames were 2 m above ground. Locations were chosen at different distances and aspects from the power station. Full experimental details are given by Swaine, Godbeer and Morgan (1989) and by Godbeer and Swaine (1995).

An important property of flyash is that the concentration of many trace elements increases with decrease in particle size (Figure 6). Samples of flyash removed by the electrostatic precipitators at Wallerawang power station showed increases in concentration for arsenic and germanium with distance from the boiler with maxima at the outlet to the stack (Figure 6; Swaine, 1994). The maximum values are clearly because of the high content of  $-2.3 \mu\text{m}$  particles. This means that many trace elements in the stack emissions have higher concentrations than in bulk flyash.

#### Trace Elements in Flyash



#### Trace Elements in Flyash Size Fractions

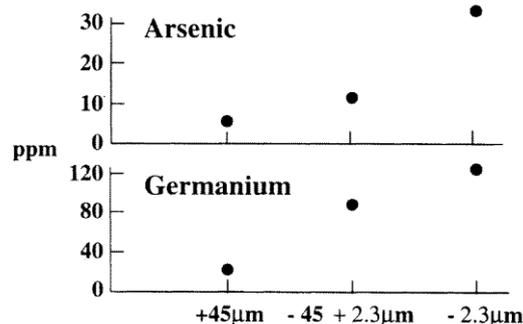


FIGURE 6. Contents of Arsenic and Germanium in flyash size fractions and in samples from different electrostatic precipitators. (Reprinted from Swaine (1994) with kind permission from Elsevier Science, Amsterdam.)

The results of the Wallerawang investigation showed that

(a) The amounts of trace elements in deposition samples decreased with distance from the power station.

(b) The amounts of trace elements deposited at different locations vary significantly with the time of sampling, as shown in Figure 7 for lead at Location A (1.8 km from the power station) and at Location P (27.4 km to the north). Location P is taken as background, that is, virtually unaffected by power station emissions. The patterns of results depend on the distance and aspect from the power station.

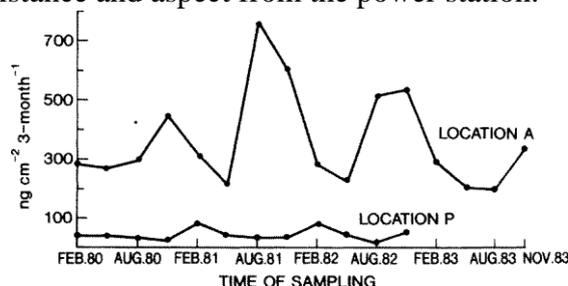


FIGURE 7. Temporal variations in the deposition of lead at Location A (1.8 km from Wallerawang power station) and at Location P (27.4 km to the north).

These results stress the importance of the time of sampling at any location and that meaningful results cannot be obtained by short-time sampling.

(c) Wind direction and strength, topography and micrometeorological factors are probably the main determinants for the different results at various locations.

(d) The validity of the method was confirmed by the close agreement between the sum of two 3-month results and one 6-month result at particular locations. This confirms the efficiency of moss as a collector, the retention of trace elements by the moss and the precision of the analytical results.

Although it was known that moss has a definite cation exchange capacity, how it retains fine particles had to be ascertained. This was shown by scanning electron micrographs of moss before and after exposure (Figure 8) where the particles of flyash (spherical) and soil/rock (angular) are sited in holes and folds in the moss structure. It was pertinent to ask the question "can we estimate the proportions of flyash and soil in samples of deposition?" This was achieved by using the concentration of germanium in the samples of deposition, on the basis of the difference in the concentrations of germanium in emitted flyash (75 ppm Ge) and in soil/rock particles (1-2 ppm Ge). Using this ratio as a correction factor, the proportions of trace elements in flyash in deposition samples were calculated and compared with the total deposition, for example, for zinc (Figure 9; Godbeer and Swaine, 1995). It was found that the proportions of flyash in deposition varied greatly at any location. For example, at 1.8 km from Wallerawang, flyash varied from 7-80, with a mean of 40%, and at 5.3 km the proportions were <1-5, with a mean of 2.5% (Swaine, 1994).

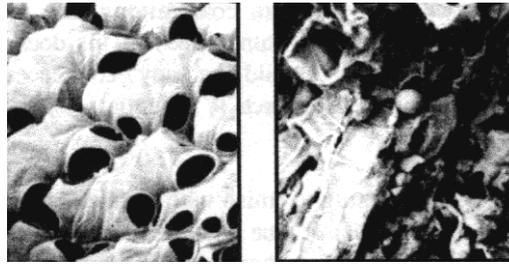


FIGURE 8. Scanning electron micrographs of the surface of moss before exposure (on the left) and after exposure (on the right). Note the spherical particles (flyash) and the angular particles (soil/rock). Scale: 7 mm = 10  $\mu$ m. (reprinted from Godbeer and Swaine (1995) with kind permission from Kluwer Academic Publishers, Dordrecht).

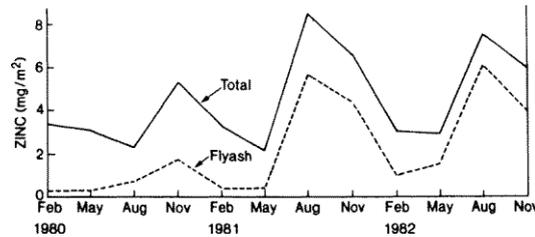


FIGURE 9. Temporal variations in the deposition of zinc, showing the totals and the proportions in flyash (reprinted from Godbeer and Swaine (1995) with kind permission from Kluwer Academic Publishers, Dordrecht).

TABLE 2.  
*Annual deposition in area around Wallerawang power station compared with annual inputs from rock weathering, litter decay and fertilisers (as mg/m<sup>2</sup>).*

Element	Distance from power station (km)	Deposition	Rock weathering	Litter decay	Fertilisers
Arsenic	1.8	0.80	0.04	0.20	2.4
	6.6	0.12			
	27	0.08			
Cadmium	1.8	0.09	0.003	0.15	0.02
	6.6	0.06			
	27	0.04			
Copper	1.8	6.4	1.3	8	0.16
	6.6	2.3			
	27	0.7			
Selenium	1.8	0.42	0.00013	0.02	0.05
	6.6	0.22			
	27	0.14			

The assessment of results and their relevance are very important in environmental science. Results for trace elements in samples of deposition can be put into perspective by comparing them with the amounts contributed by rock weathering (Bowen, 1979), litter decay (Bowen, op. cit.) and fertilisers (based on Swaine, 1962b). Data for arsenic,

cadmium, copper and selenium are given in Table 2. For trace elements, atmospheric deposition in the Wallerawang area is not the major source, except for selenium. Selenium is one of the few elements reaching the atmosphere from coal burning in amounts that should be taken into consideration in an environmental assessment.

### **Concluding Remarks**

It is clear that coal will be used increasingly as a major source of power for at least the next decade and hence more attention will be paid to environmental and health aspects (Swaine, 1992b). In this connection, the role of trace elements is important especially in the areas of combustion and waste disposal. In his Will, Liversidge stated that the most important part of the Lecturer's duty shall be to point out in which directions further researches are necessary. Here are some suggestions for future work:

1. Speciation of trace elements, especially those of environmental significance, for example, beryllium, boron, chromium, molybdenum and vanadium.
2. The determination of the isotopic ratios of  $^{10}\text{B}$  to  $^{11}\text{B}$ , as a refinement of the use of boron in coal as an indicator of marine influence.
3. The associations of trace elements in bottom ash and flyash in order to assess leaching from power station wastes.
4. Speciation in flue gas and stack emissions, especially for arsenic, chromium, mercury and selenium.
5. More data on trace elements in deposition in the environs of power stations.
6. Investigations of the fate of trace elements in bottom ash-flyash disposal areas in relation to nearby underground and surface waters.
7. Possible health effects from trace elements during the mining and usage of coal.

Although these matters are of great practical interest, indeed concern, the answers will need good research using sophisticated methodology. This is the interface between basic science and technology, the key to successful outcomes in practical problems. It is clear that many tasks in geoscience and environmental science need chemistry for successful conclusions. Emotional statements about possible health effects related to trace elements should be avoided. It is pertinent to keep in mind the sixteenth century dictum of Paracelsus "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy". The essentiality of many elements is of paramount importance and must be considered together with the possibility of toxicity.

It is clear that trace elements have, and will continue to have, a prime niche in coal science and technology, especially the environmental aspects. If proper care is taken, then it seems most unlikely that trace elements from coal mining and usage should be harmful (Swaine 1989). This does not mean that there should be any complacency. Indeed, continued research is essential, especially on new coals.

It seems fitting to finish with a statement from Nikos Kazantzakis "True teachers use themselves as bridges over which they invite their students to cross; then having facilitated

their crossing, joyfully collapse, encouraging them to create bridges of their own". A plea is made for there to be some memorial to Liversidge in the School of Chemistry at The University of Sydney.

### Acknowledgements.

It is a pleasure to acknowledge the help of my coworkers the late Marie Clark, Bill Godbeer, Ken Riley, Noel Morgan, Professor Roy Filby (Washington State University), John Fardy and the late Ray Porritt.

### References

- AS, 1989. Methods for the analysis and testing of coal and coke. Part 10.4 - Determination of trace elements - coal, coke and flyash - determination of fluorine content - pyrohydrolysis method. *Standards Association of Australia*, AS 1039.10.4 - 1989, 14 pp.
- ASTM, 1979. Standard test method for total fluorine in coal by the oxygen bomb combustion/ion selective electrode method. *American Society for Testing and Materials*, D3761-79, 4 pp.
- Beaton, A.P., Goodarzi, F. and Potter, J., 1991. The petrography, mineralogy and geochemistry of a Paleocene lignite from southern Saskatchewan, Canada. *International Journal of Coal Geology*, **17**, 117-148.
- Bowen, H.J.M., 1979. *Environmental Chemistry of the Elements*. Academic, London, 1st edition, 333 pp.
- Branagan, D. and Holland, G., 1985 (Eds.). *Ever Reaping Something New - a Science Centenary*. University of Sydney, 1st edition, 256 pp.
- Brown, H.R. and Swaine, D.J., 1964. Inorganic constituents of Australian coals. *Journal of the Institute of Fuel*, **37**, 422-440.
- Godbeer, W.C. and Swaine, D.J., 1987. Fluorine in Australian coals, *Fuel*, **66**, 794-798.
- Godbeer, W.C. and Swaine, D.J., 1995. The deposition of trace elements in the environs of a power station. In *Environmental Aspects of Trace Elements in Coal*, pp. 178-203 (D.J. Swaine and F. Goodarzi, Eds.). Kluwer, Dordrecht.
- Godbeer, W.C., Swaine, D.J. and Goodarzi, F., 1994. Fluorine in Canadian coals. *Fuel*, **73**, 1291-1293.
- Goodarzi, F. and Swaine, D.J., 1994a. Paleoenvironmental and environmental implications of the boron content of coal. *Geological Survey of Canada, Bulletin*, **471**, 76 pp.
- Goodarzi, F. and Swaine, D.J., 1994b. The influence of geological factors on the concentration of boron in Australian and Canadian coals. *Chemical Geology*, **118**, 301-318.
- Le Fèvre, R.J.W., 1968. The establishment of chemistry within Australian science - contributions from New South Wales. In *A Century of Scientific Progress*, pp. 332-378, Royal Society of New South Wales, Sydney, 1968.
- Swaine, D.J., 1962a. Boron in New South Wales coals. *Australian Journal of Science*, **25**, 265-266.
- Swaine, D.J., 1962b. *The Trace-Element Content of Fertilizers*. Commonwealth Bureau of Soils, Harpenden, 306 pp.
- Swaine, D.J., 1971. Boron in coals of the Bowen Basin as an environmental indicator. *Geological Survey of Queensland, Report* **62**, 41-48.
- Swaine, D.J., 1977. Trace elements in coal. In *Trace Substances in Environmental Health - XI*, pp. 107-116. D.D. Hemphill (Ed.), University of Missouri, Columbia.

- Swaine, D.J., 1989. Environmental aspects of trace elements in coal. *Journal of Coal Quality*, **8**, 67-71.
- Swaine, D.J., 1990. *Trace Elements in Coal*. Butterworths, London, 294 pp.
- Swaine, D.J., 1992a. The organic association of elements in coals. *Organic Geochemistry*, **18**, 259-261.
- Swaine, D.J., 1992b. Guest editorial: Environmental aspects of trace elements in coal. *Environmental Geochemistry and Health*, **14**, 2.
- Swaine, D.J., 1994. Trace elements in coal and their dispersal during combustion. *Fuel Processing Technology*, **39**, 121-137.
- Swaine, D.J., 1995. The formation, composition and utilisation of flyash. In *Environmental Aspects of Trace Elements in Coal*, pp. 204-220. D.J. Swaine and F. Goodarzi (Eds.) Kluwer, Dordrecht.
- Swaine, D.J. and Goodarzi, F., 1995 (Eds.). *Environmental Aspects of Trace Elements in Coal*. Kluwer, Dordrecht, 324 pp.
- Swaine, D.J. and Taylor, G.F., 1970. Arsenic in phosphatic boiler deposits. *Journal of the Institute of Fuel*, **43**, 261.
- Swaine, D.J., Godbeer, W.C. and Morgan, N.M., 1989. The deposition of trace elements from the atmosphere. In *Trace Elements in New Zealand: Environmental, Human and Animal*, pp. 1-10. R.G. McLaren, R.J. Haynes and G.P. Savage, (Eds.). New Zealand Trace Elements Group, Lincoln.