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Funeral Arrangements for Plants: An Essay in Organic Geochemistry

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Abstract: Organic geochemistry literally is the dead end of science since it is concerned with the transformation of decaying plant material into humic substances, coal, petroleum and natural gas. The transformation process is primarily controlled by the possible degree of oxidation. Under reducing conditions coal and gas are formed and under oxidising conditions humic material is formed. Not surprisingly, the nature of the input vegetation also has an effect on the type of decomposed organic matter produced. One new finding for oxidising environments, reported here, is the concept of a host-guest structures where smaller molecules reside within a framework of a macromolecular host primarily derived from lignin. The guests within the host cannot be removed by physical separation. The structure of the host can be determined by pyrolysis gas chromatography mass spectrometry and nuclear magnetic resonance techniques. Differential thermal analysis, methylation and gas chromatography mass spectrometry and nuclear magnetic resonance data can be used to identify the guests. Some of the guests are probably held by hydrogen bonding but others are true prisoners in that they are alkanes and hence have no binding sites.

Keywords: Humic substances, Host-guest theory, COSY NMR, Differential thermal analysis

INTRODUCTION

The study of a leaf which is physically connected to a plant, belongs to the discipline of botany. For a few moments after death, while a leaf floats to the ground, the study of the mobile object belongs to the aerodynamicist, but thereafter, the leaf is the property of organic geochemists, the undertakers of the scientific world.

Animals contribute little to decaying matter and it is the major components of plants that are significant. These in order of importance are carbohydrates and lignin, (Figure 1) i.e. the C_3 aryl macromolecular skeletal component containing various amounts of syringyl para-hydroxyphenol or guaiacyl groups, that keeps plants upright. To a lesser extent but still important, are proteins and pigments e.g. chlorophyll (Figure 2), and also tannins and alkadiene polymers. These materials may be transposed by microorganisms and the detritus from microorganisms should not be underestimated; they too have to die.
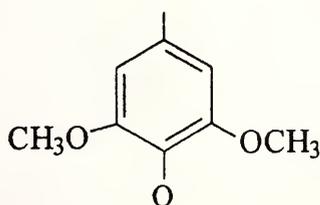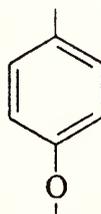
Syringyl   **para-Hydroxyphenyl**   **Guaiacyl**
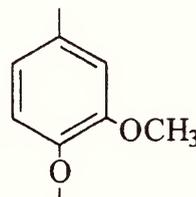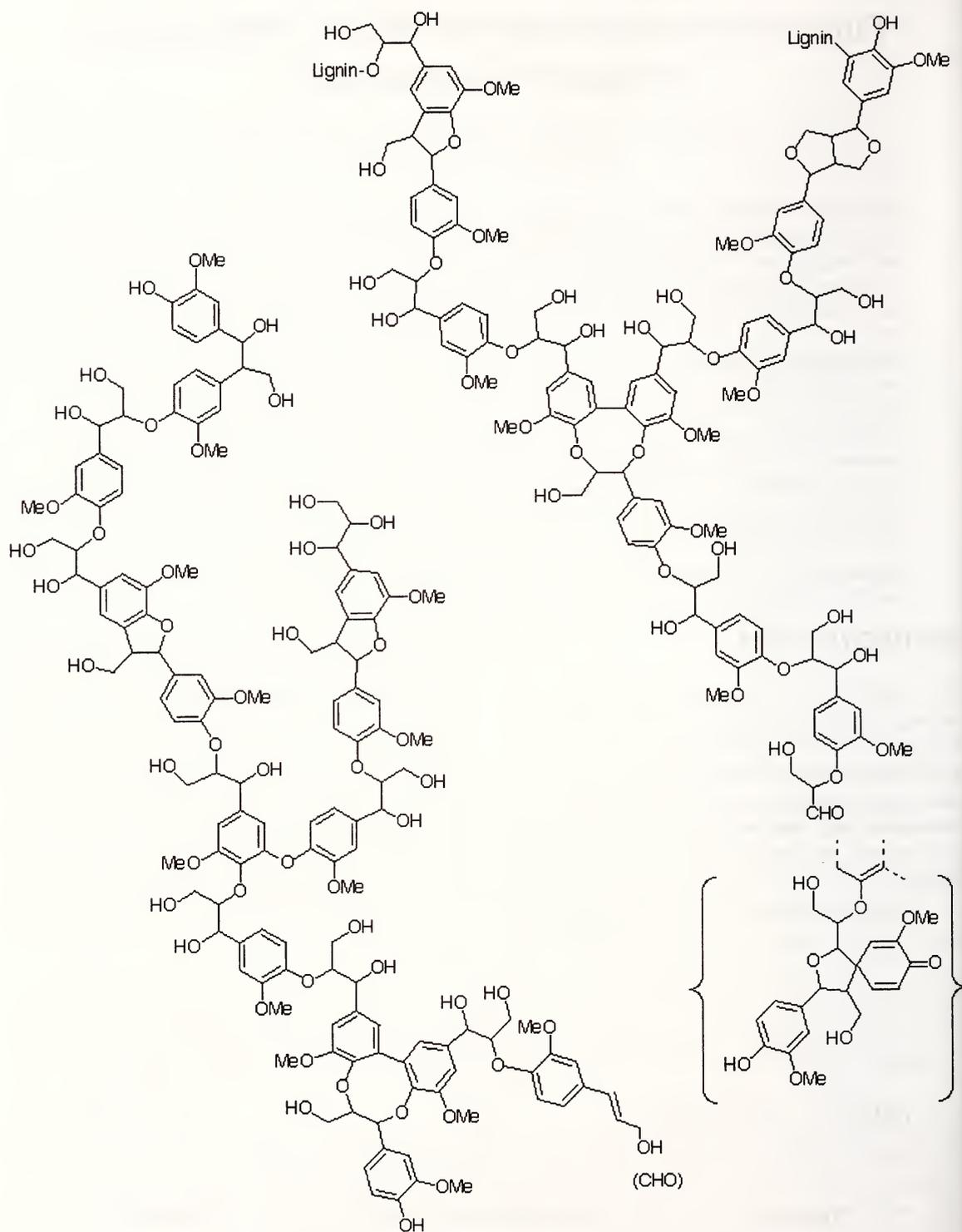
Fig. 1. Typical molecular structure of gymnosperm lignin.

R = CH3 ; Chlorophyll a
R = CHO; Chlorophyll b

Phytol
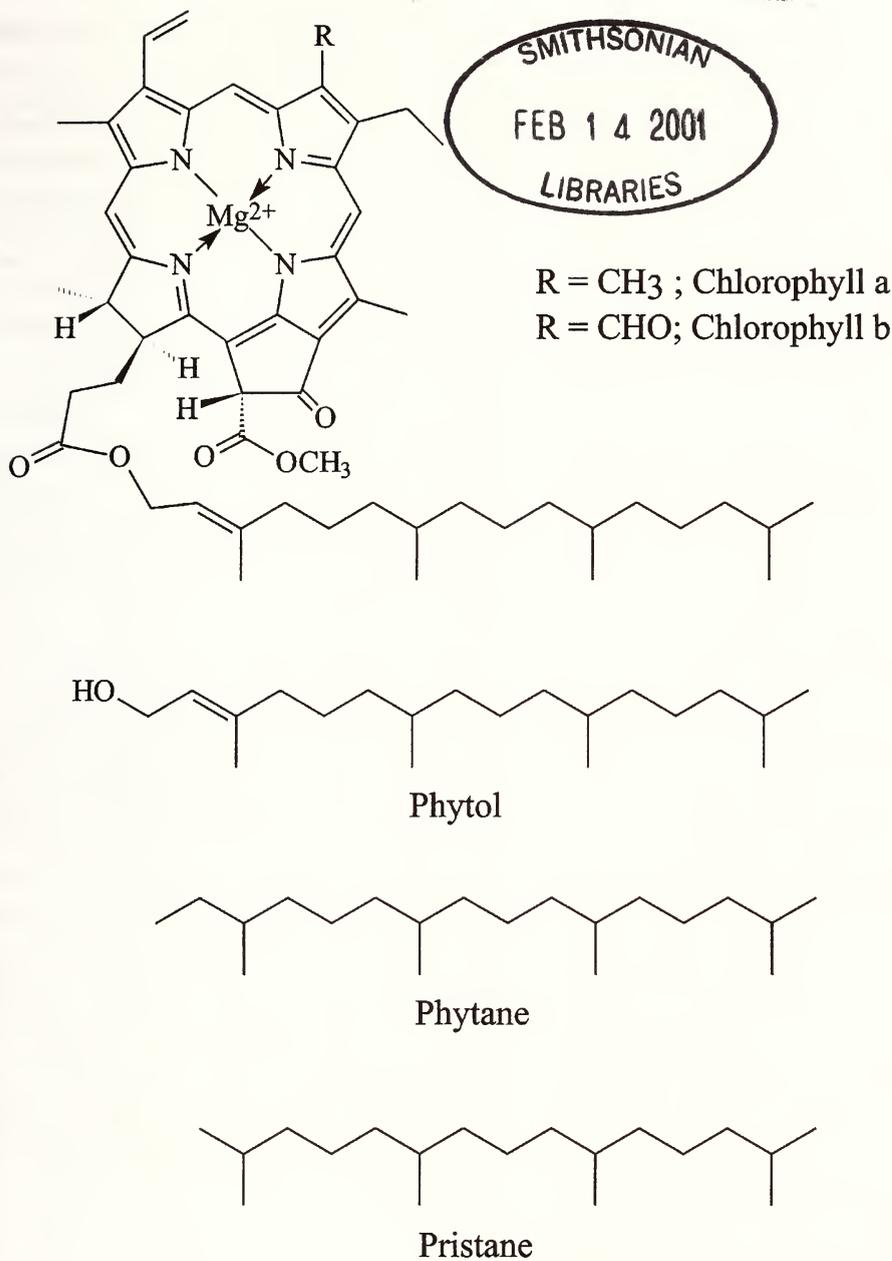
Phytane

Pristane

Fig. 2. Structure of chlorophyll illustrating the phytol chain. On cleavage under reducing conditions phytane is formed but on oxidation one carbon is lost to form pristane.

Once on the ground two things can happen to the leaf. It may be transposed by oxidation or by reduction. These are the great overriding chemical reactions on the planet primarily brought about by the two redox half couples:

$\frac{1}{2} O_2 + 2H^+ \rightarrow H_2O + 2e$ and $2H^+ + 2e \rightarrow H_2$ either directly or through biological activity.
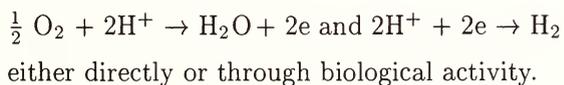
Sometimes cyclic processes, involving both oxidation and reduction in sequence, can ensure that transformations can occur via both routes.

The limiting factor in our understanding of both oxidation and reduction processes has been the lack of methodology available for understanding the molecular structure of amorphous, non crystalline solvent insoluble organic solids. It has only been over the last twenty years with advances in appropriate instrumentation that progress has been made. Major advances have been made because of the development of three techniques. These are :

1) the development of separation methodology for high molecular weight solids (Swift, 1989),
2) the development of solid state high resolution nuclear magnetic resonance spectroscopy (NMR),
3) the development of pyrolysis gas chromatography mass spectrometry (py GC/MS).

Gel permeation chromatography and dialysis have allowed the complex macromolecules that arise from the decomposition of plants to be separated so that they can be studied. They have also allowed assessment of molecular weight and size to be determined which, with structural and elemental data, has allowed constraints on molecular formulae (Sihombing et al., 1996). Laser desorption mass spectrometry can also be useful to obtain molecular weights directly (Wilson et al., 1992). The development of nuclear magnetic resonance spectroscopy (NMR) in geochemistry (Wilson, 1987), particularly solid state NMR (for which myself, Pat Hatcher (now at Ohio State) and Caroline Preston (Forestry Canada) can claim to have contributed) has allowed some understanding of structural group composition and the nature of transformation processes. While the detail obtained on proteins is not present in ^1H or ^{13}C NMR spectra of these materials it is possible to estimate structural group content including the fraction of carbon which is aromatic f_a, the fraction of carbon which is carboxylic (ester or amide have usually been hydrolysed during preparation), and the fraction of carbon which is alcoholic (primarily carbohydrate). Using selected spectral editing techniques it is possible to estimate the fraction of carbon which is aromatic and protonated $f_a^{a,H}$, and the length of the aliphatic chains. The amounts of methoxy, phenolic anchiomeric carbohydrate and ketonic and aldehyde groups are also measurable. Two "typical" analyses are shown in Table 1 for base soluble fractions from the same soil. When combined with elemental data additional constraints on structure are imposed.

Pyrolysis gas chromatography mass spectrometry (Saiz-Jimenez and de Leeuw, 1986) is essential for structural studies because many plant decomposition substances have such high molecular weights that conventional GC/MS is almost useless and only gives us information on a very small amount of organic matter present. Pyrolysis is a method of determining structures that are components of the macromolecules. Structures that are of interest are those which can be recognised as being devised from plant building blocks. The furans derive from carbohydrates while guaiacyl and syringyl groups from lignin structures. By measuring the amounts of these in different molecular weight fractions sequencing information can be obtained.

	f_{COOH}	f_a	$f_a^{a,H}$	f_{OH}	$f_{phenolic}$	f_{OMe}	f_{CH_2}	$f_{aliphatic}$
Fraction 1	0.15	0.35	0.30	0.20	0.05	0.10	0.10	0.10
Fraction 2	0.30	0.15	0.30	0.20	0.05	0.20	0.05	0.10

Table 1: Fractions of carbon types in geo-organic matter produced under oxidising conditions.

REDUCTION PRODUCTS

The loose term kerogen is used to identify products under reducing conditions (Tissot and Welte, 1984). Kerogens are further divided into three groups classified on the basis of the type of organic matter involved in transformation. Type I kerogens are mainly marine algal derived and are the precursors to petroleum which is formed by further geochemical processing. Type II kerogens are from lakes and rivers. Type III kerogens are known as coal (Van Krevelan, 1993).

If the decomposition of organic matter is slowed so that macromolecules build up in the environment rather than being transformed to gas, then reducing reactions occur. Under reducing conditions the organic matter does not decay to carbon dioxide but forms peat, and, given sufficient time and pressure, brown and black coals. As expected, the carbohydrate carbon is first to go and this can be followed by high resolution solid state NMR (Figure 3). The reductive transformation of carbohydrates is complex and is not understood but a strong possibility exists that furans are formed. On reduction carbon and methane alone are not formed but coals. Coals are not carbon, nor are they unmodified plant matter. During reductive transformation of lignin, bridging groups between aromatic rings are formed. On further geological transformation from brown to black coal these bridging groups are lost (Figure 4) and the aromatic rings become less substituted until the product has about 89% carbon content. On further reduction, substantial cross linking occurs to form anthracite and then graphite (Wilson et al., 1984).

200   100
Chemical Shift ppm
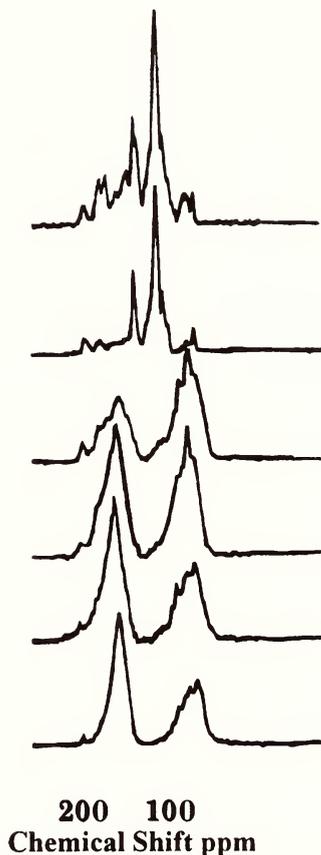
Fig. 3. ^{13}C solid state nuclear magnetic resonance spectra of fossil woods as a function of rank. The uppermost spectrum show carbohydrate resonances at 76 and 102 ppm or thereabouts as the largest two peaks. With increasing rank these are removed. The subbituminous wood (third spectrum) shows only trace amounts of carbohydrate. The lowest three spectra are from wood that is of bituminous coal rank. Note the high aliphatic carbon content centering around 30–40 ppm.
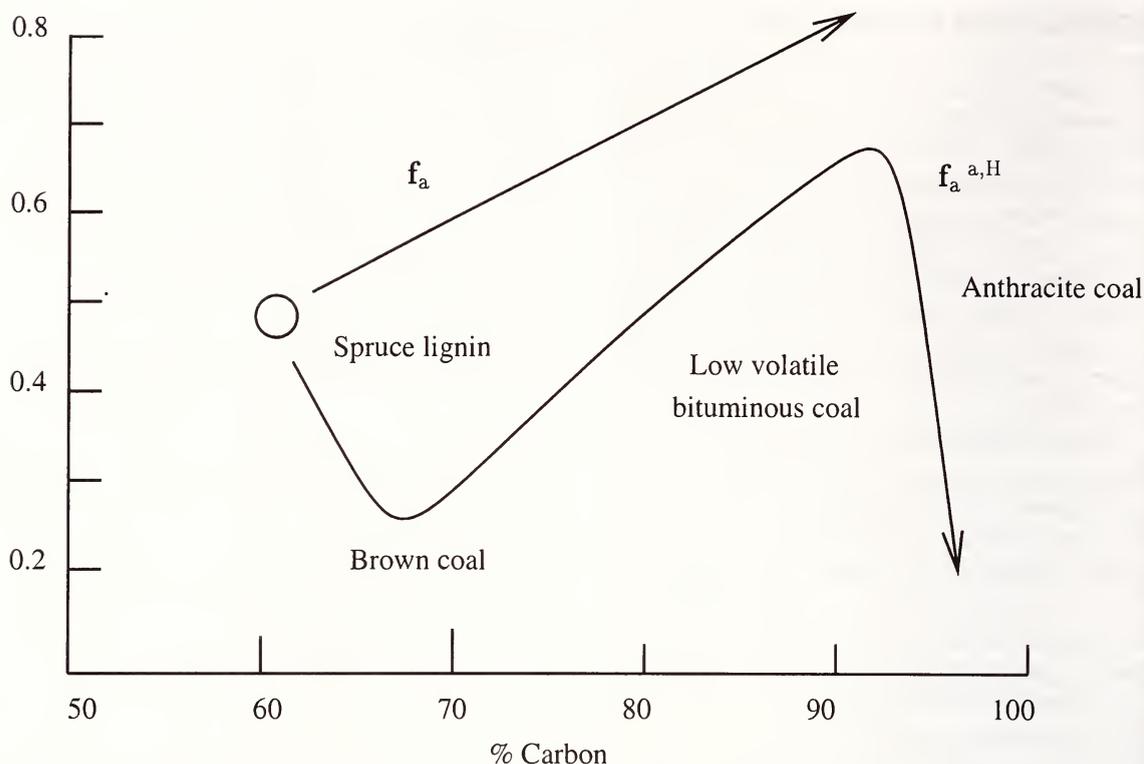
Fig. 4. Diagram to illustrate the effects that occur during coalification. Aromaticity f_a increases but the ring substitution parameter $f_a^{a,H}$ first decreases and then increases before decreasing again.

OXIDATION PRODUCTS

The loose term "humic material" is used to identify products formed under oxidising conditions. Humic materials have a number of beneficial roles in nature. They contain considerable amounts of carboxylic acid functionality, and aquatic humic materials being water soluble, have particularly high carboxylic acid contents. Some aquatic humic materials contain as much as 33% of their carbon in carboxylic acid groups (Wilson, 1987). Such structures are little more than zipped-up carbon dioxide units and it is not surprising that they are such vociferous chelating agents and can be responsible for the transport of a wide range of metal ions in soils and waters. Humic materials affect the availability of a wide range of cations and hence fertility. Their chelating role is significant in preventing run off of cations. Hence humic materials allow soils to store useful cations.

(Stevenson, 1982). Their nutrient value however is restricted to slow release of nitrogen and phosphorus.

Nevertheless, humic materials are not always beneficial in industrial processing. In water they generate colour and affect taste and hence are removed during purification. The removal process can generate chloroform, which is known to be a liver carcinogen and can be present in processed waters in small amounts (Hanna et al., 1991). Furthermore, because of their chelating ability any industrial process that involves surface activity can be inhibited by humic materials. Thus they are very important in alumina processing from bauxite with sodium hydroxide. During the conversion of AlO_4^- to $Al_2O_3 \cdot 3H_2O$, the AlO_4^- ion is converted to octahedral coordination by polymerisation and addition of water groups. Humic materials interfere in this process by chelating across building sites, thereby inhibiting polymerisation and

precipitation. They also inhibit the removal of oxalate, the main degradation product after extensive oxidation (Wilson et al., 1999).

The oxidative transformation of carbohydrates results in carbon dioxide, but during this process carbohydrates are rapidly consumed by microorganisms, which on death leave much of the carbon as polymethylene, presumably derived from the microorganism cell walls. A nice way to demonstrate this (Baldock et al., 1990) is by placing ^{13}C labeled glucose on a soil, and showing that the labeled carbon ends up as $(CH_2)_n$. These are also the thermal transformation products in forest fires. Carbohydrates disappear rapidly on reduction and are not present in Type I, II or III kerogens (Wilson et al., 1987) (Figure 3).

Since lignin is a major component of most but not all decaying vegetation, its transformation is also important. Depending on origin, lignin (Figure 1) may contain syringyl as well as guaiacyl and parahydroxy phenol units. During oxidative decomposition the phenolic ether linkages are believed to be broken. The resulting monohydroxy and dihydroxyphenols are believed to be relatively stable but the trihydroxyphenols can rearrange and the aryl ring can be cleaved. The authors were most surprised to find that aliphatic components are formed in this process including aliphatic carboxylic acids (Pang et al., 1990).

The eventual fate of another major plant component, proteins, is unknown. However substantial amounts of nitrogen heterocycles are found in soils and many of these do not derive from DNA or pigments (Stevenson, 1982). Of course most of the protein nitrogen can be assimilated by microorganisms as amino acids and in oxidised form as nitrates and nitrites. However in due course this nitrogen also must eventually become incorporated in complex molecules or lost to the atmosphere as

NH_3, N_2O, or other gases.

Pigments are of significant interest. They yield phytol which can be transformed under reducing conditions to phytane or lose one carbon atom to form pristane in highly oxidising environments (Figure 2). Hence the pristane to phytane ratio is very useful for determining the degree of oxidation of the sediments (Didyk et al. 1978).

VEGETATION TYPE

Not surprisingly humic structure depends on vegetation type. When lignin is present the product will be quite different from that formed when it is absent. Thus Antarctic humic materials derived from moss are different from those found in dense forests (Wilson et al., 1986). Normally material formed under oak (angiosperm vegetation) differ from that formed under pine (gymnosperm vegetation) because the lignin differs. Thus the origin of the humic material can often be recognised from the macrovegetation on the soil. However if the turnover of microvegetation is more important than that of macrovegetation, microvegetation can be the major contribution to humic material and the lignin origin is unclear from examining the types of trees on the soil (Amalfitano et al., 1995).

In the absence of other factors it is possible to draw illustrative contour plots which demonstrate the effect of climate and hence microbiological activity and input vegetation on the organic matter composition produced (Wilson, 1987) (Figure 5). In principle with increased biological activity, O-alkyl carbon (as in carbohydrates) is less stable than aromatic matter which in turn is less stable than aliphatic chains. As more oxidation occurs more carboxylic carbon is also formed.
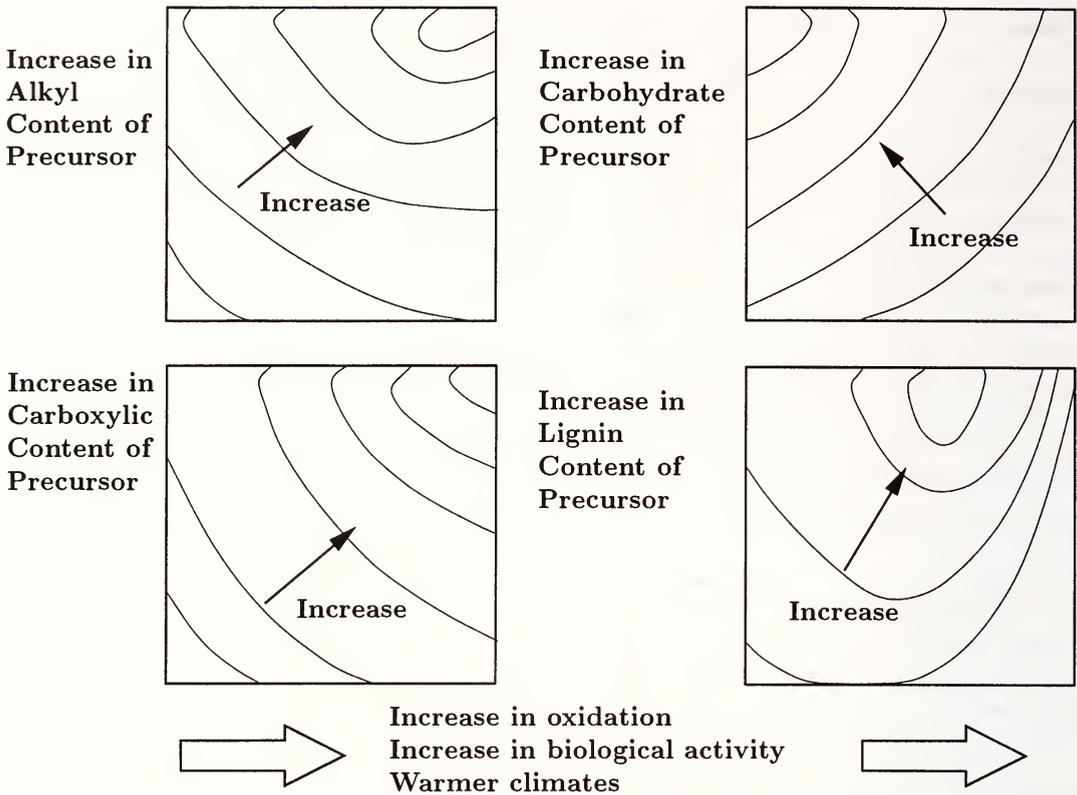
Fig. 5. Diagram to illustrate the change in functional group content of humic material with functional group content of precursor vegetation and microbiological activity.

GEOCHEMICAL PHENOMENA

Soils and sediments act via aluminosilicates and free oxides as chromatographic agents. Hence rainfall and soil composition can greatly affect the types of humic material present. In many soils organic matter is washed through the profile and behaves like eluent from a column used in chromatography. Just as in conventional chromatography, it collects on the column a distance from the initial elution point. This is normally in the B horizon of a soil, and is, in effect, a chromatographic fraction. Under rainfall some humic materials are washed into streams and rivers. That is, they are fully eluted. The process actually fractionates the organic matter.

The pH and E_h (a measure of the reduction potential) of the soil or sediment can be critical in affecting both the microbiological content

as well as the potential for organic substances to be degraded or polymerised. Temperature is important here since it affects transformation rates, but temperature is most significant in fire formation. Fires are common in forests. Fire can affect the composition of humic materials by producing chars of high molecular weight polycyclic hydrocarbons (Skjemstad et al., 1996).

RESYNTHESIS

Not much is known about events immediately after decomposition. Early theories proposed that even under reducing conditions macromolecules were broken down into some sort of organic soup which was then transformed, by addition reactions, to new substances unrecognisable as original plant material. Under reducing conditions this is almost certainly now

known not to be true, and it is believed many of the original macromolecules are polymerised, with and without smaller molecular weight co-reactant material. Under oxidation, the situation is much more complex; probably here initial decomposition is more important, but the degree of repolymerisation is unknown and the amount of direct polymerisation has not been established. (Figure 6).

Plant material

⇓

Biological molecules   ⟹ ║

⇓

Decomposition products ⟹ ║

⇓   ↓

Polymerisation   Polymerisation
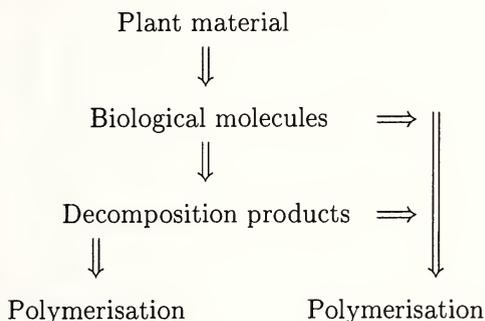
Fig. 6. Polymerisation mechanisms.

HOST-GUEST STRUCTURE

It is clear that a myriad of chemical compounds of different molecular weights compose the organic mixture that makes up the organic matter. Many have extremely high molecular weight. Values for some components as high as 300,000 Daltons have been recorded. It is also clear that this material is intimately bound with structures of relatively low molecular weight. Material of molecular weights of 50,000 Daltons or greater will have voids in its packing quite capable of occluding smaller molecular weight material, so that the smaller material are in fact guests. For organic matter produced in reducing environments ^{1}H NMR evidence was proposed (Given and Marzec, 1988) to show the existence of two groups of molecules in bituminous coals with different molecular rigidities, i.e. rigid large hosts and smaller mobile guests. Evidence for a similar structure for brown coals or lignites is based on solubility and reactivity grounds as proposed by Professor Jackson and his group at Monash University (Redlich et al. 1985). Hence it is not surprising that we have

also found similar evidence for structures produced under oxidising environments.

A good example of this evidence comes from organic matter associated with bauxite which becomes soluble in sodium hydroxide used in the process for producing alumina from bauxite. Despite attempts to remove low molecular weight organic matter by dialysis, specific molecular weight fractions are obtained which still contain low molecular weight organic matter. In differential thermal analysis studies on various dialysed high molecular weight (>25,000 Da) fractions, the loss of mass up to 200°C was attributed to loss of volatile organics as well as surface and bound water (Smeulders et al., 2000). These molecules are trapped in the macromolecular matrix. This mass loss was found to be between 9.3% and 17.6%, depending on which fraction was being examined.

If the amount of water and volatile organics adsorbed on a humic extract solid is calculated and compared with that calculated by summing the amount for each molecular weight fractions adjusted for mass, the numbers differ. This shows that the water and volatile organic holding capacity for the different fractions changes when the different molecular weight materials are separated. It suggests that the various humic molecular weight fractions agglomerate together in structures where some water or volatile organic binding sites on each humic substance are held by other humic species.

This is depicted in Figure 7 (left side), where both water and small organic volatiles (circles) occupy binding sites and the bound molecules can bridge macromolecules (rectangles). After separation by dialysis (Figure 7, right side) the large molecules are separated and this process generates more sites for adsorption of small molecules. Thus the water and volatile content of the unseparated material is not the same as the mass weighted sum of the water content of the separated materials. Mass loss data expressed as first derivative plots (differential thermal gravimetric analysis, (DTG, Figure 8), indicates temperatures at which rapid mass loss occurs which allows further information to be

gathered. Such plots also show that secondary volatile material is present which gives superimposed inflections in DTG plots.
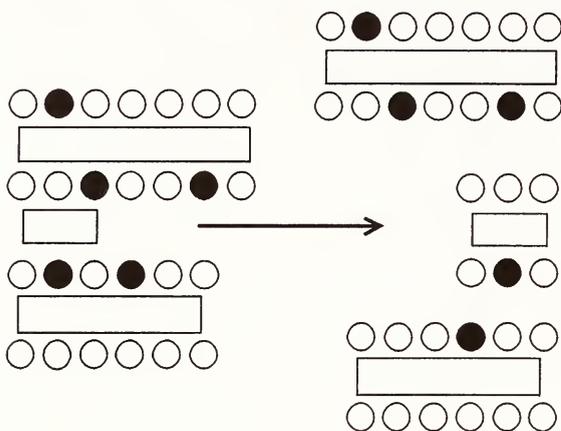

Fig. 7. Model to explain the water and volatile holding capacity of humic substances before and after fractionation. Rectangles = humic substance, length equivalent to molecular weight, o = water, • = organic volatile. The arrow represents the process of dialysis.

With pure compounds enthalpies can assist in identification. However, thermal events are not discrete for geo-organic matter since a variety of materials may be volatilising at the same time or changing phase in some other way. Since the ΔH of vaporisation of water is known (44 kJ mol^{-1}) (Aylward and Findlay, 1991) it should be possible to determine whether the thermal events at lower temperatures are due to loss of water or not.

It is difficult to obtain accurate values for endotherms for individual events but those below 250°C can be summed. Fractionated material produces two separate endotherms at 140°C and 210°C (ΔH = 21.69 kJ mol^{-1} if calculated as water). This is a lot lower than that expected for water (ΔH = 44 kJ mol^{-1}). Moreover a further endotherm was observed at about 250°C–272°C (see arrow Figure 9), a temperature unlikely to be due to volatilisation of bound water, and an event, which in any case, has an inappropriate ΔH. Thus there is considerable evidence for volatile material other than water

being present from enthalpy data. All events are endothermic up to 250°C as expected for evaporation and are not decarboxylation reactions as they proceed well above 250°C (Vassallo and Attalla, 1992; Leinweber and Schulten, 1992). This is additional evidence that the events are evaporations which arise from trapped species and not decompositions. However, it is shown below that most of the trapped species can only be removed by methylation.
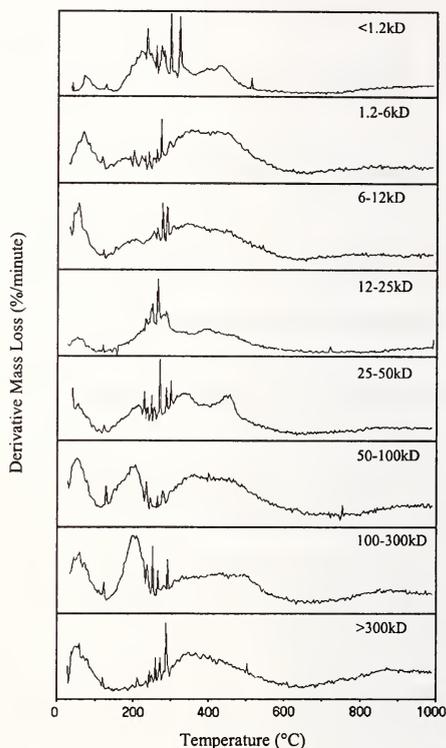

Fig. 8. Differential thermal gravimetric analysis (DTG) plots of humic molecular weight fractions
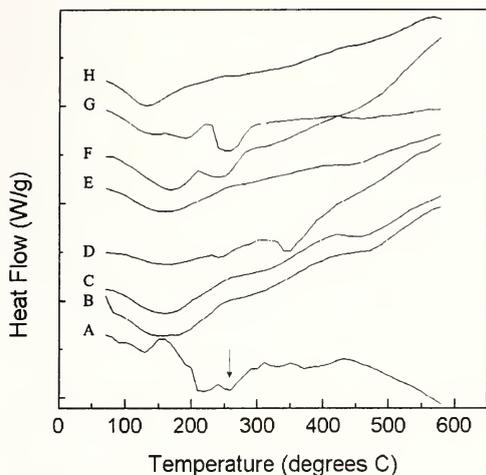
Fig. 9. Modulated Differential Scanning Calorimetry plots for humic molecular weight fractions. A = <1.2 kD; B = 1.2–6 kD; C = 6–12 kD; D = 12–25 kD; E = 25–50 kD; F = 50–100 kD; G = 100–300 kD; H = >300 kD.

^{1}H and ^{13}C NMR analysis of molecular weight fractionated material is very useful in supporting this proposition. Discrete resonances should not be observed for macromolecules, yet they are seen in high molecular weight fractions. In larger molecular weight fractions these are almost all confined to the aliphatic region. The ^{1}H NMR spectrum of all fractions of molecular weight greater than 25 kD fraction showed few discrete resonances in the aromatic region. These fractions appear to form molecular aggregates with alkanes and aliphatic fatty acids. Discrete aromatic resonances were not seen for >300 kD molecular weight fractions indicating the absence of small aromatic compounds in this fraction.

Two dimensional heteronuclear multiple quantum correlation and homonuclear chemical shift correlation spectroscopy (COSY) NMR analysis (Ruiz-Cabello et al. 1992; von Kienlin et al., 1991; Wilker et al., 1993) allowed some further information to be deduced about the fractions and identified some guests. The results from heteronuclear correlation analysis

show several strong couplings in the aromatic region of the spectrum. Coupling in the aromatic region was observed between the carbon at 129.50 ppm with the proton at 8.08 ppm. The ^{1}H and ^{13}C chemical shifts suggest the compound to be benzene-1,4-dicarboxylic acid. The ^{13}C resonance at 120.49 ppm was strongly coupled to the aromatic proton at 7.55 ppm, and the carbon at 121.39 ppm was coupled to the proton at 7.96 ppm. The ^{1}H and ^{13}C chemical shifts suggest the compound to be 5-methylbenzene-1,3-dicarboxylic acid.

In the COSY aliphatic spectrum coupling was observed in the aliphatic region, with the protons in the triplet at 3.20 ppm (J = 7.6 Hz) being coupled to the protons in a quintet at 2.10 ppm (J=7.6 Hz). Integration, coupling and location of the resonances indicate that the compound contains a three-carbon alkyl chain attached to highly electronegative functional groups at each end with the two CH_2 groups adjacent to the electron withdrawing groups being equivalent. This ^{1}H NMR data is thus consistent with the compound 1,5-diphenylpentan-1,5-dione.

Several couplings were observed between protons in the aromatic region. The proton at 7.96 ppm is coupled to the strong resonance at 7.55 ppm (unresolved doublet, J = 1.4 Hz). A J coupling of 1.4 Hz suggests meta coupling. Hence the results indicate that the protons are located meta to one-another in different chemical environments on the same aromatic ring. The coupled protons located at 7.55 ppm and 7.96 ppm were the same protons observed in the ^{1}H-^{13}C 2-D NMR spectrum. The integration results show that there are twice as many protons at 7.55 ppm as there are at 7.96 ppm. The small coupling constant, integration results, and the chemical shifts, like the heteronuclear correlation experiment, also suggest that 5-methylbenzene-1,3-dicarboxylic acid is present in the 12-25 kD fraction.

If the fractions are methylated with tetramethyl ammonium hydroxide (TMAH) (Hatcher et al., 1995) and analysed by GC/MS a wide variety of compounds were identified including

benzenecarboxylic acids, n-alkanes, and fatty acids. These three families of compounds represented the majority of the compounds released by the fractions. Many of the compounds released from the Bayer organic fractions by methylation were analysed as methyl esters, particularly the fatty acids and benzenecarboxylic acids.

A typical GC/MS chromatograph of the methylated Bayer organic fractions is shown in Figure 10. The chromatogram shows the large number of compounds released from the molecular weight fractions when they are methylated. Methylation with TMAH acts to release small molecules trapped in the macromolecules by forming esters and ethers with carboxylic and phenolic groups respectively, thereby breaking the hydrogen bonding that holds the molecules in place. Without methylation the molecules are held tightly in the macromolecules matrix. When the unmethylated fractions are analysed by GC/MS no small molecules are detected (Figure 10A), only the internal standard (C_{20}) is identified. This result indicates that the small molecules are tightly hydrogen bonded in the macromolecule structures by forming molecular aggregates.

With methylation n-alkanes were identified in the chromatograms with carbon chain lengths ranging from C_{11} to C_{29}. n-Alkanes are derived from algal, microbial and higher plant sources. The distribution of the n-alkanes in these fractions suggests that they were derived from the waxes of higher plants.

Fatty acids were found to be one of the main chemical classes released by the methylation of the Bayer organic fractions. Fatty acids with carbon chain lengths ranging from C_7 to C_{22} were identified as products of the fractions. Identified fatty acids were found to have both monocarboxylic and dicarboxylic acids on their structures as well as unsaturations in several of the products. Numerous C_{18} isomers were identified as products from the organic fractions. Numerous substituted benzene mono- and dicarboxylic acid compounds were identified as methylation products from the Bayer organic
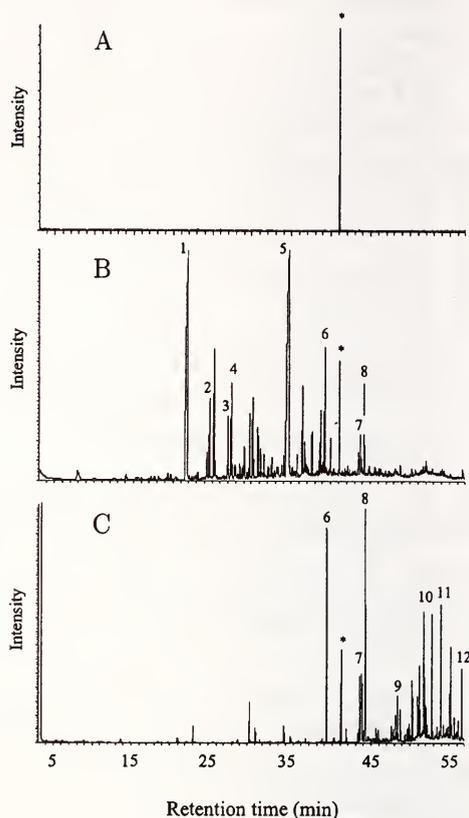
fractions.

Fig. 10. GC/MS spectra of molecular weight fractions A) before methylation B) after methylation of low molecular weight humic material (<1.2 kD) and C) after methylation of high molecular weight humic material (100-300 kD). The numbering of compounds is as follows: 1) 3-Methoxybenzoic acid methyl ester, 2) 1,4-Benzenedicarboxylic acid methyl ester, 3) 1,4-Benzenedicarboxylic acid dimethyl ester, 4) 1,3-Benzenedicarboxylic acid dimethyl ester, 5) 4-Hydroxy-2-methoxy-3,6,5-trimethylbenzoic acid methyl ester, 6) Hexadecenoic acid methyl ester, 7) 7-Octadecenoic acid methyl ester, 8) 1-Octadecenoic acid methyl ester, 9) C23-Alkane, 10) C25-Alkane, 11) C27-Alkane, 12) C29-Alkane. * C20 internal standard.

It is not clear whether these host-guest complexes formed by these highly oxidised humic molecules also exist in solution. The deprotonated conjugate bases, phenoxide and carboxylate would not form strong hydrogen bonds under these conditions due to repulsion forces of similarly charged species under strongly basic conditions but under neutral pH they may still hydrogen bond. In either case, during precipitation intra molecular hydrogen and intermolecular hydrogen bonding may occur. In the process large molecular voids may be formed which could occlude other molecules. It may well be true that some of these occluded molecules also hydrogen bond but the presence of alkanes shows that for some molecules this is not always the case.

These host-guest interactions may occur in a variety of humic macromolecule compounds in the environment. It is also possible that the formation of these host-guest interactions through hydrogen bonding or physical entrapment trap other molecules including organic pollutants. While chelation of metal ions is important this may be a mechanism of breaking hydrogen-bonding intra- or intermolecular interactions which create voids or indeed a mechanism of forming other voids. Thus chelation may release guests or entrap others. The destruction of host-guest complexes might be expected to be achieved more readily than necessary for the breaking of covalent bonds. Indeed it has been demonstrated that UV radiation can degrade humic substances (Schmitt-Kopplin et al., 1998; Ong and Bisque, 1968; Havel et al.,1998; Fetsch et al., 1998; Frimmel 1998) rather than polymerise them. This reaction could be through oxidation of phenols to quinones, breaking hydrogen bonding and then subsequent release of small molecular weight guests.

SUGGESTIONS FOR FUTURE RESEARCH

Isotope ratio gas chromatography mass spectroscopy can lead to important information of the source of geo-organic compounds. A single compound can have a different isotope ratio depending on source or formation mechanism. Solid state 2 and 3 dimensional NMR will enlighten us further on coal and humic structure. New separation methodology is urgently needed.

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Minerals of the Queen Sally Mine, North-west Queensland

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Abstract: The Queen Sally deposit is located near Kajabbi, north-west Queensland. Primary cobalt mineralization comprises cobaltite and glaucodot, an assemblage that is consistent with a hydrothermal origin, possibly associated with the emplacement of the nearby Naraku granite. Oxidized cobalt mineralization consists of cobaltian calcite, erythrite and heterogenite-2H, which is unusual in that it carries up to 2.2% by weight of vanadium. Oxidation of V^{3+} in the lattice to V^{4+} may explain an early report of "blue" erythrite in the oxidized zone of the deposit.

INTRODUCTION

The Queen Sally cobalt deposit, discovered in 1922 (Anon., 1923), is situated (54411280E 7779010N) near Sally Creek, a tributary of Cabbage Tree Creek, some 4 km east of the now abandoned Cloncurry-Dobbyn railway line and approximately 13 km south-east of Kajabbi, north-west Queensland. It is one of only three mines (together with Mount Cobalt and the Success) to have recorded production of cobalt in the Mt Isa Block (Carter et al. 1961). There is little mention of the mineralogy of the Queen Sally deposit in the literature but Rayner (1938) reported the occurrence of erythrite, cobaltite, malachite, azurite, chrysocolla and a cobaltiferous "black oxide." We have had occasion to re-examine the deposit, as part of a more extensive study of the geochemistry of cobalt in the Mt Isa Block.

GEOLOGY

The ore deposit occupies a sub-vertical shear striking 155° in foliated quartzite adjacent to a narrow limestone bed, associated with cross-cutting acid pegmatite veins (quartz + orthoclase + tourmaline). Hornblende schists surround these units, and these are intruded by granite to the east and north-east (Rayner, 1938). Mine workings consist of two shafts c. 20 m deep and several shallow pits.

Primary mineralisation is confined to the pink and green stained foliated quartzite, which is well exposed in the northern shaft, and erythrite is common on a nearby cobbing floor. Quartzite on the dump carries a considerable amount of calcite, some of which is cobaltian. Careful examination of the dumps revealed an abundance of heterogenite in oxidized material and the quartzite on the dump around the southern shaft carries patches of gossan associated with scorodite, erythrite and minor secondary copper minerals.

ANALYTICAL METHODS

Polished sections of primary mineralisation and material bearing crystalline heterogenite were inspected by reflected light microscopy and then carbon coated and analysed using a JEOL JXA-8600 electron microprobe, with a beam current of 20 nA. Three wavelength dispersive spectrometers, controlled by JEOL software, and an energy dispersive spectrometer controlled by Moran Scientific software were employed for the analyses, which were calibrated against kaersutite, marcasite and pure metal standards. X-ray powder diffraction measurements were used to identify individual phases and were carried out with a Philips PW1925-20 powder diffractometer using $CuK\alpha$ radiation.

MINERALOGY

A list of all minerals identified in the deposit is given in Table 1. Some of the occurrences and assemblages are worthy of separate comment.

PRIMARY MINERALS

Cobaltite (analysis 3, Table 2) and related sulfosalts are the most common primary metalliferous minerals. Cobaltite, which occurs massive, in stringers and veins and as disseminated euhedral grains, is commonly associated with chalcopyrite, pyrrhotite (inclusions of which in cobaltite carry some 0.8% Co; analysis 13, Table 2), arsenopyrite, pyrite and glaucodot. Disseminated pyrite crystals are embedded in arsenopyrite and cobaltite, and pyrite is an early formed mineral (as judged by textural relationships), that contains only minor amounts of Co. Covellite carrying trace amounts of Co (analysis 15, Table 2) and chalcocite invade fractures in the primary sulfides where they have been supergene enriched. Fine-grained glaucodot commonly fills cracks in cobaltite and pyrrhotite. The arsenopyrite (analysis 6, Table 2) carries only a trace of cobalt. Chalcopyrite occurs as crystals up to 2 mm across in the foliated quartzite, in veins, as inclusions in cobaltite, and in association with pyrrhotite, included galena blebs and veinlets and disseminated subhedral to euhedral 40 micron crystals of low-iron sphalerite. Analyses of chalcopyrite (analyses 1 & 2, Table 2) indicate at least two generations of mineralisation, one carrying higher amounts of Co than the other. Negligible amounts of Ni are present in this or any other analysed phase. Pyrrhotite inclusions in cobaltite are associated with chalcopyrite and glaucodot. Early molybdenite crystals embedded in cobaltite reach 20 microns in size.

This assemblage is indicative of mesothermal to hypothermal regimes (Park and MacDiarmid, 1970; Vaughan and Craig, 1978), and is consistent with the geological setting. Further, the primary mineralisation is compatible with acid hydrothermal activity, in common with other related deposits of the eastern section of the Mt Isa Block (Nisbet et al. 1983; Wyborn, 1998) and points to the nearby Naraku granite of the Eastern Fold Belt (Perkins and Wyborn, 1998) as the source of the metals. Some of the accessory minerals identified in the lode lend support to this kind of origin, as does the composition of the pegmatite intrusions nearby (Rayner, 1938).

Analyses of cobaltite and glaucodot (analyses 3–5, Table 2) reinforce a number of these conclusions. Two generations of glaucodot are clearly represented in the deposit and both are compatible with temperatures of crystallisation of around 400–500°C, by reference to the geothermometer developed by Klemm (1965), whereas cobaltite analyses suggest a lower temperature of formation of around 200°C. Several pulses of primary mineralization occurred.

ERYTHRITE

Erythrite is the most conspicuous secondary mineral in the deposit and occurs as crusts of acicular crystals to 10 mm on quartzite and heterogenite. Of particular interest is the oxymoronic report of "an earthy blue mineral simulating azurite ... it is an unusual form of the ordinary pink hydrous arseniate (erythrine)" from the Queen Sally (Saint-Smith, 1925). No material fitting such a description was identified. Dehydration of erythrite gives a blue product (Palache, et al. 1951) and it is perhaps possible that this was the origin of the earthy blue mineral noted by Saint-Smith. However, analyses of heterogenite suggest a more plausible explanation (see below).

A. Primary rock-forming and accessory minerals
    Albite $NaAlSi_3O_8$
    Allanite $(Ce,Ca,Y)_2(Al,Fe)_3(SiO_4)_3(OH)$
    Biotite $K(Mg,Fe^{2+})_3(Al,Fe^{3+})Si_3O_{10}(OH,F)_2$
    Calcite $CaCO_3$
    Epidote $Ca_2(Fe,Al)_3(SiO_4)_3(OH)$
    Fluorapatite $Ca_5(PO_4)_3F$
    Orthoclase $KAlSi_3O_8$
    Quartz SiO_2
    Rutile TiO_2
    Titanite $CaTiSiO_5$
    Zircon $ZrSiO_4$

B. Primary metallic minerals
    Arsenopyrite $FeAsS$
    Chalcopyrite $CuFeS_2$
    Cobaltite $CoAsS$
    Galena PbS
    Glaucodot $(Co,Fe)AsS$
    Molybdenite MoS_2
    Pyrite FeS_2
    Pyrrhotite FeS
    Sphalerite $(Zn,Fe)S$

C. Secondary minerals
    Azurite $Cu_3(CO_3)_2(OH)_2$
    Chalcocite Cu_2S
    Conichalcite $CaCu(AsO_4)(OH)$
    Copper Cu
    Covellite CuS
    Erythrite $Co_3(AsO_4)_2\cdot8H_2O$
    Goethite $FeO(OH)$
    Hematite Fe_2O_3
    Heterogenite-2H $CoO(OH)$
    Malachite $Cu_2(CO_3)(OH)_2$
    Scorodite $FeAsO_4\cdot2H_2O$

Table 1: Minerals of the Queen Sally deposit, with idealised formulae.

	1	2	3	4	5	6	7	8
As	< 0.05	< 0.05	43.7	51.0	46.6	45.1	45.16	
S	34.8	34.4	20.1	16.1	17.1	19.9	19.32	34.94
Fe	29.5	29.2	1.3	25.5	15.1	34.2		30.43
Co	< 0.05	1.6	34.1	9.2	20.1	0.1	35.52	
Ni	< 0.05	< 0.05	0.3	< 0.05	0.2	< 0.05		
Cu	34.7	33.3	< 0.05	< 0.05	< 0.05	< 0.05		34.63
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		
Zn	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		
Total	99.0	98.5	99.5	101.8	100.1	99.3	100.00	100.00
	9	10	11	12	13	14	15	16
As	< 0.05		< 0.05		< 0.05		< 0.05	
S	32.3	32.90	54.0	53.45	38.3	36.47	30.1	33.54
Fe	2.4		46.7	46.55	59.4	63.53	0.5	
Co	0.1		0.2		0.8		0.2	
Ni	< 0.05		< 0.05		< 0.05		< 0.05	
Cu	0.7		< 0.05		< 0.05		70.3	66.46
Sb	< 0.05		< 0.05		< 0.05		< 0.05	
Zn	64.3	67.10	< 0.05		< 0.05		< 0.05	
Total	99.8	100.00	100.9	100.00	98.5	100.00	101.1	100.00

Table 2: Analyses of primary ore minerals (wt%), Queen Sally mine. 1: Low-Co chalcopyrite, average of three analyses; 2: high-Co chalcopyrite, average of two analyses; 3: cobaltite, average of 16 analyses; 4: high-Fe glaucodot; 5: low-Fe glaucodot, average of 5 analyses; 6: arsenopyrite, average of 5 analyses; 7: calculated for CoAsS; 8: calculated for $CuFeS_2$; 9: sphalerite, average of two analyses; 10: calculated for ZnS; 11: pyrite, average of nine analyses; 12: calculated for FeS_2; 13: pyrrhotite, average of two analyses; 14: calculated for FeS; 15: covellite; 16: calculated for CuS. Values denoted as < 0.05 are not included in totals.

HETEROGENITE-2H

Heterogenite-2H (confirmed by X-ray diffraction) is very common in the dump and occurs as earthy slugs, masses and coatings, veins and stringers, as well as aggregates of plates up to 3 mm across; it was one of the main Co ore minerals of the deposit (Rayner, 1938). Microprobe analyses (Table) gave an Fe_2O_3 content of no more than 0.6% in the heterogenite, but analyses of crystalline heterogenite revealed unusually high V_2O_3 contents, up to 3.2% by weight. No other phase was detected by X-ray powder diffraction and thus it is concluded that the vanadium is substituted in the heterogenite lattice. Montroseite (VO(OH)), paramontroseite (VO_2) and goethite (FeO(OH)) are isomorphous, space group $Pbnm$, while heterogenite-2H is hexagonal, space group $P6_3/mmc$ (Anthony et al. 1997). While the structures of the CoO(OH) and VO(OH) end-members of the solid solution are different, there is no chemical reason which would serve to prohibit the substitution of some vanadium in the heterogenite lattice. We do not know the origin of the vanadium, and the geochemical association is unusual, although not unprecedented in the Mt Isa Block (Wyborn, 1998).

	1	2	3
Co_2O_3	86.6	86.4	90.20
Fe_2O_3	0.6	0.4	
V_2O_3	2.7	3.2	
H_2O (by difference)	10.1	9.8	9.80
Total	100.0	100.0	100.00

Table 3. Analyses of crystalline heterogenite, Queen Sally mine.
1: Heterogenite; idealised formula $(Co_{0.960}V_{0.033}Fe_{0.007})_{\Sigma1.000}O(OH)$;
2: Heterogenite; idealised formula $(Co_{0.957}V_{0.039}Fe)_{\Sigma1.000}O(OH)$;
3: calc. for $CoO(OH)$.

Oxidation of low-iron montroseite involves oxidation of V^{3+} to V^{4+} accompanied by replacement of OH^- by O^{2-} to form blue paramontroseite (Forbes and Dubessy, 1988). Thus it seems possible that the earthy blue material mentioned by Saint-Smith (1925) was a surface coating of paramontroseite formed as a oxidation product of vanadium-rich heterogenite.

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Thesis Abstract: Physical Activity, the IGF-I Axis, and Body Composition in 55 to 75 Year-old Women

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Similar effects of human growth hormone (GH) deficiency and ageing on body composition suggest that age-related losses of bone and muscle mass and fat accumulation may be caused by reduced GH secretion.

The anabolic effects of GH are partly mediated by insulin-like growth factor-I (IGF-I), released by the liver and other tissues in response to pituitary GH secretion. As both GH and IGF-I increase acutely with exercise, stimulation of the GH/IGF-I axis represents a means whereby regular physical activity can attenuate or reverse the effects of age on bone, muscle and fat. Studies investigating this have, however, produced conflicting findings, and information on postmenopausal women is scarce.

This cross-sectional study investigated the relationships between habitual physical activity, IGF-I bioavailability and body composition in 53 healthy postmenopausal women aged 55 to 75 years. A subgroup of 28 women receiving oestrogen replacement therapy were included, to describe interactions between oestrogen and IGF-I. Subjects underwent a multi-compartment body composition assessment to define water, protein, bone mineral, fat and muscle masses (Hansen et al, 1999). Habitual physical activity pattern was determined by a semi-structured interview. Fasting serum hormone levels (IGF-I, IGF binding protein-3, acid-labile sub-unit, and oestradiol) were determined by radio-immunoassay.

The subjects were representative of Caucasian women of the same age in regard to body composition, IGF-I status, and prevalence of habitual activity. Based on regular involvement in moderate to vigorous activity, the sample was stratified into high (n = 27) and low (n = 26) activity groups. The most common activities pursued were aerobic in nature, including walking, dancing, floor exercises and swimming. Significant (p<0.05) age-related declines were evident in bone, muscle, physical activity, and IGF-I axis parameters. There was some accumulation of central fat with advancing age. Protein, mineral and skeletal muscle fractions of fat-free mass showed an accelerated decline after 65 years of age. Although high activity subjects had relatively more bone and muscle, but less central adipose tissue, throughout the age range, they experienced similar overall rates of change with age to low activity subjects.

Multiple linear regression showed that advancing age, increased adiposity, and a high oestradiol level impacted negatively on IGF-I levels. Physical activity level was *not* a determinant of the IGF-I axis. As expected, oestradiol status and physical activity were both positive, independent predictors of bone mass. Adiposity was also a positive determinant of bone mass. Neither age nor IGF-I were predictors of bone parameters. Both age and physical activity were independent predictors of skeletal muscle mass, such that a highly active 70 year-old had on average the same skeletal muscle mass as a less active 56 year-old woman. However, IGF-I status was *not* related to muscle mass.

These data do not show a hypothesised positive relationship between habitual physical activity and serum IGF-I parameters, or between the IGF-I axis and body composition, in postmenopausal women. The most plausible explanation for this is that *localised* factors, such as target tissue production or modulation of IGF-I, are involved in mediating the effects of physical activity on bone and muscle.

The interaction between oestradiol and IGF-I supports previous claims of a biphasic influence of oestrogen on IGF-I, whereby moderate serum oestradiol levels can increase, but high oestradiol levels can depress, IGF-I axis activity. This phenomenon should be further investigated in a longitudinal study.

The study provides strong evidence that moderate intensity, aerobic type activities can contribute significantly to the maintenance of bone and muscle in postmenopausal women. Such activities are generally acceptable to older women, and the age range studied is known to be characterised by progressive declines in bone and muscle status, with accompanying frailty and loss of independence. These activities should therefore confer significant benefits in terms of what has been coined "successful" ageing (Hansen et al, 2000) - that is, maintaining a high degree of functionality and independence in the latter part of one's life.

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Mathematical and Computer Modelling of the Human Brain with Reference to Cortical Magnification and Dipole Source Localisation in the Visual Cortex

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Mathematical and computer models are important tools that are available to investigate natural phenomena. They can be used to model many systems. In this thesis, mathematical models are developed, implemented and applied to research involving the human brain and in particular, the human visual cortex. The visual cortex constitutes a relatively large part of the cerebral cortex. It is often used in investigations of the human brain because conclusions regarding the visual cortex can be extended to other regions of the brain. Virtually all information from the visual system is recognised as first being processed by the primary visual cortex and is then passed to other regions of the brain involved in more complex processing.

The primary visual cortex has a retinoptic mapping in that one spot in the retinal visual field maps directly to a spot on the primary visual cortex. However, there is disagreement as to the amount of cortex that is allocated to the representation of central vision or other portions of the visual field. A mathematical formulation of this mapping is presented and mapping functions which transform the surface representing the retina to the surface representing the visual cortex are developed.

If the head is modelled as three concentric spherical shells and neural sources of brain activity are modelled as dipoles, then a mathematical model which incorporates biophysical properties can be used to estimate the location of sources which generate a set of electrical potentials measured on the surface of the scalp. This model is known as dipole source localisation. The forward problem, which is the predication of a potential distribution due to a given electrical source is implemented, and the inverse problem, which is to determine a dipole source that is the best generator of a given potential distribution is solved in the least squares sense. Monte Carlo simulations and mathematical analysis show that the optimum reference electrode to use in dipole analysis is a weighted version of the common average electrode. Monte Carlo simulations are also used to investigate the accuracy of confidence regions surrounding the estimated dipole parameters.

Subsequently, a methodology for modelling a region of cortex from magnetic resonance images is developed. This methodology is applied to the calcarine fissure and surrounding grey matter to produce a three dimensional surface reconstruction of the visual cortex. This model is used to provide anatomical constraints in the dipole source localisation model. These models are then applied to visual evoked potential data obtained from an experiment which uses a chromatic grating stimulus. Results reveal that these mathematical and computer models, combined with imaging and experimental approaches, elicit new information and improved results in investigations of the human brain.

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Tectonic Evolution of the Marlborough Region, South Island, New Zealand

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Abstract of Thesis Submitted for the degree of Doctor of Philosophy University of Waikato, New Zealand.

The tectonic evolution of the Marlborough region has been studied by application of fission track thermo-chronology and finite element (FE) methods. The region lying within the Australian-Pacific plate boundary zone is considered to have a transcurrent fault system, known as the Marlborough Faults System (MFS). The MFS is viewed as comprising secondary transforms connecting the Hikurangi subduction margin with the main Alpine Fault oblique-slip boundary. This fault system appears to have developed sequentially towards the southeast during the past 5 million years.

Based on the principles of rock mechanics and FE method, the numerical modelling results reveal that the accommodation percentage of total displacements in Marlborough is about 85% of the total plate motion. The contour of instantaneous displacements estimated by the FE modelling can be compared to the topography of Marlborough. According to the results of the FE modelling cases, the main conclusions drawn are:

- A curved fault (the Alpine Fault) resulted from a change in the plate motion vector.

- The development of the MFS reflects the continuation of tectonic rotations.

- Three secondary faults may have developed within a short period of one another.

- Uplift movements still continue.

- A pre-existing fault offset of the Alpine Fault is not a unique result in the FE modelling.

The extremely young fission track ages (< 10 Ma) in the vicinity of the Alpine Fault bend and Seaward Kaikoura Range coincide with the recent raid uplift/erosion in these areas. All the apatite ages indicate that the host rocks in Marlborough have experienced exposure to elevated temperatures in the zone of partial annealing for apatite, some of them having been reset. Except for the samples in the Marlborough Sounds region, zircon fission track ages are older than 119 Ma, reflecting that the host rocks of the samples have not experienced temperatures in the zircon partial annealing zone since the mid Cretaceous. Apatite fission track ages and mean lengths indicate that there are two major cooling events: one occurring from the early Miocene (20 Ma) and the other in the mid Cretaceous (100 Ma).

The largest amount of rock uplift (11.5 km) occurs in the area of the Alpine Fault bend. The amounts of rock uplift and denudation derived from the fission track parameters are in the range 0.7–11.5 km and 0.6–11.0 km, respectively. In the Seaward Kaikoura Range, high elevation coincides with large amounts of denudation. Compared with the region of continent-continent convergence to the south in Canterbury, the amounts of rock uplift and denudation in Marlborough are relatively small, revealing the differences between a fully developed continent-continent collision zone and the continental transform setting in Marlborough.

The horizontal movements determined by the FE modelling can be converted into vertical movements. Both the FE modelling and fission track results show that the pattern of vertical deformation is consistent with the topography in Marlborough. The FE modelling and fission track results reveal the character of the tectonic evolution of Marlborough and are a step towards its quantification.

Ming-Hung Kao
182 Tramway Road
Hamilton
New Zealand

Biographical Memoirs

Mark Oliphant, AC, KBE, DSc, FAA, FRS, FTS, HonDSc (*Melb,Birm*), HonLLD (*StAndr.*), MA, PhD (*Camb.*)
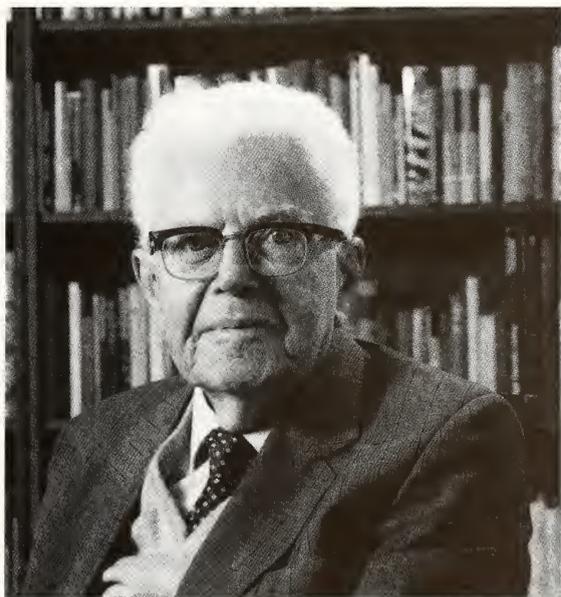
SIR MARK OLIPHANT
A Great Australian Physicist and
Philosopher (1901–2000)

Mark Oliphant, the Adelaide born nuclear physicist, thought carefully before he decided in 1949 to leave his established career in Birmingham and return, in 1950, to Australia and play a major role in the creation of the Australian National University, the establishment of the Research School of Physical Sciences, the founding of the Australian Academy of Science and the development of Canberra.

These new responsibilities left him little time to continue research, in the forefront of physics, such as he had done with Lord Rutherford in the Cavendish Laboratory at Cambridge. Work for which he was already famous and led to his election as a Fellow of the Royal Society in 1937, which, until his death on 14 July 2000, at the age of 98, made him the longest holder of a Fellowship of the Royal Society. His work with Rutherford in 1933 to 1935 had revealed the existence of tritium and helium three and

demonstrated the release of energy in the fusion reaction when deuterons collided at high speed. Shortly before his death in 1937 Rutherford had proposed that Dr. Oliphant be offered the Poynting Chair of Physics at the University of Birmingham. Oliphant was reluctant to leave the then world centre of nuclear physics but was pleased to have the chance to 'run his own show'.

In Birmingham Oliphant decided to build a cyclotron to produce faster ions than any at the Cavendish Laboratory. It would be larger than the one invented by Prof. E.O. Lawrence at the University of California. Since the University could not provide the money needed, Prof. Oliphant sought grants from sponsors. Lord Nuffield gave the amount required. In October 1938 Lawrence provided details of the 60 inch diameter cyclotron that was under construction in Berkeley.

By November 1939 the 60 inch cyclotron at Berkeley was producing 10 million-electron-volt (MeV) protons and Lawrence was awarded the Nobel Prize in Physics. Writing to congratulate Prof. Lawrence, Prof. Oliphant said 'The Prize shows that the technical side of the subject is now recognised as of equal importance to the advances that follow from the use of these techniques'. This was the line Mark Oliphant followed for the rest of his scientific life, designing ever more powerful machines to shed light on the new questions that each advance raised.

Early in 1939 Oliphant was told of the need for powerful radio transmitters with a wavelength of ten centimetres or less for radio direction finding (RDF) equipment (later named radar by American engineers) small enough to fit into fighter aircraft. Because of Oliphant's experience and reputation his team at the Nuffield Laboratory won a contract with the Admiralty to identify or invent a suitable generator and detector of microwaves. Existing

klystrons and magnetrons were low power laboratory devices. In November 1939 it was proposed to buid magnetrons with the tuning cavity cut into the inner copper walls of the valve was proposed. Professor Oliphant allocated the money required to build a demonstration unit. This worked well when tested in February 1940 and by June the first sealed-off magnetrons were available for use in RDF sets. Rapid improvements increased the power to 25 kW pulses so that an airborne set could detect the periscope of a submarine.

Prof. Oliphant concentrated on improving the design of klystrons, which were essential for the local oscillators in the heterodyne microwave receivers of the signals reflected from the target.

Thousands of magnetrons and klystrons were produced in England and then in USA where English designs were improved for use in American radar sets. Detailed information on the design and production was carried by Oliphant himself to America. He crossed the Atlantic several times in the empty, except for extra fuel tanks, bomb-bay of the aircraft.

On a trip in August 1941 he was asked to explore whether any attention had been given to reports from Britain on the use of uranium for the production of power and the possibility of producing a powerful bomb using U^{235}. He found that the Chairman of the 'Uranium Committee' had not read the reports nor distributed them to the committee. He saw that failure to act on the warning that a uranium fission bomb could be built might allow Germany time to do so. Deeply worried he contacted Ernest Lawrence to urge him to convince the 'Uranium Committee' and the USA Government to take immediate action on the production of U^{235} and the development of a fission bomb.

Oliphant also told Lawrence that research at Cambridge had shown that slow neutrons could convert uranium into a new element of atomic number 94 which could be easier to split than U^{235}, thus foreshadowing the possibility of a plutonium fission bomb.

When President Roosevelt, Prime Minister

Churchill and Prime Minister Mackenzie King met secretly in August 1943 to sign an agreement to share all work on the development of nuclear bombs, Dr. Oliphant took a leading role with the team from Britain. Now part of the Manhattan Project, he chose to work with Lawrence in Berkeley on the large scale electromagnet separation of the uranium isotopes. Based on the research at Berekely, the extremely large separators, 'Calutrons', were built at Oak Ridge, to process the uranium in which the proportion of U^{235} had been increased by gaseous diffusion.

The magnets of the calutrons contained over 50,000 tons of steel and since copper was required for other uses, the coils of the magnets were wound, at Oliphant request, with 14,000 tons of silver from Fort Knox. Dr. Oliphant was driven to work relentlessly by the fear that Germany would produce a nuclear bomb before the Allies did, and that England would be forced to surrender to Hitler. Even with the concerted effort of the scientists and industry the isotope separators did not produce much U^{235} until November 1944. It took until June 1945 to produce sufficient to construct a test explosive assembly.

Prof. Oliphant, now back in Birmingham, was informed of the success of the test on 16 July 1945, but having ceased work in the Manhattan Project he could not participate in the final debate on how the weapon would be used. Earlier in the program it was understood that, if and when a nuclear weapon was produced, its existence and devastating power would be demonstrated to the Axis Powers before it was used against a military target, unless the demonstration itself already had lead to a cease fire.

In July 1945 the war in Europe was over, Germany had not produced a nuclear bomb, and Japan had not built one. Many of the scientist with whom Prof. Oliphant had worked were opposed to what had been intended as a defensive safeguard being used as an offensive weapon against a target in a populated area. The act of doing so horrified Oliphant and branded Amer-

ica as the power which set the precedence of using such an inhumane weapon. Throughout the rest of his life Prof. Oliphant advocated, with Lord Russell and many others, effective international agreements and controls to prevent the construction of nuclear weapons.

No doubt Dr. Oliphant had done more than anyone to initiate and drive the effort to build a nuclear bomb before Germany. When that threat had passed the weapons had been used in a way that horrified Oliphant and most people. Early in 1946 the United Nations was to debate the international control of nuclear weapons at a session chaired by the Australian Minister for External Affairs, Dr. Herbert Evatt. Prime Minister Chiffley proposed that Oliphant become a technical adviser to the Australian delegation. When Russia proposed an agreement by all nations not to build nuclear weapons and dismantle all existing ones, Oliphant saw this as a way to stop the threat to mankind that he had helped to create. He, like only one or two others at the conference, knew that only two bombs existed and these could be dismantled and stored under international supervision. They could be reassembled in a few hours if the agreement was not being observed. After the production of the five bombs the production of the necessary isotopes had stopped due to technical problems. The chairman, Dr. Evatt and the conference did not support the Russian resolution and the arms race with the threat to all life on earth, that Oliphant feared, began.

With a depressing feeling of guilt for participating in the horrors of Hiroshima and Nagasaki Prof. Oliphant resumed his scientific career with typical enthusiasm and "innovativeness". Firstly, the cyclotron was to be finished, but more important to him was to find money for building such a machine to accelerate protons to velocities greater than any achieved or being attempted. While working on the Manhattan Project, he worked, in his spare time, on the design of an accelerator, now known as a proton synchrotron. In January 1945, while still in America, Oliphant wrote to the Head of the Tube Alloys project seeking money to build, in England, such a machine to accelerate protons to 1000 MeV. By July 1945 money had been allocated.

In 1944 Veksler published in Russia a paper on such an accelerator for protons and electrons, while in July 1945 in America, Edwin McMillan proposed the same principal for a machine, that he named a synchrotron, to accelerate electrons to 300 MeV. It seems that Veksler, McMillan and Oliphant had each independently invented this form of accelerator but Oliphant was the first to request and receive money to construct one.

In 1946 Prof. Oliphant was invited, as one of four highly qualified Australian academics who were working in England, to form an Academic Advisory Committee to work with the Interim Council of The Australian National University on the establishment of four research schools in this new university. The Advisers met monthly, in England, from August 1947 into 1948. Oliphant ensured that many of the features of the older English universities were adopted in the statutes of the new university and that the independent authority and responsibilities of the Directors of the research schools were established.

During 1947 Prof. Oliphant planned the Research School of Physical Sciences as he saw it and gave an estimate of the cost and running expenses for the first five years. These were high compared with the expenditure of the existing universities, but because of Oliphant's standing and Prime Minister Chifley's personal assessment of him, Chifley said whatever money was needed would be provided by the Government if Oliphant was the Director.

The dominant issue for Oliphant, when deciding to accept the Directorship, and for the Council when making the appointment was his plan to build a cyclo-synchrotron to accelerate protons to an energy of 2000 MeV (2 GeV), twice the energy of protons from the synchrotron that was being built to his design in Birmingham.

Prof. Oliphant obtained funding for the School based on the estimated cost of build-

ing the proposed accelerator and of providing for nuclear physics research using protons and deuterons with energy up to 1.2 MeV from an accelerator powered by a Cockcroft-Walton rectifier which was delivered in November 1951. Thus research, under Prof. Ernest Titterton, started long before building the cyclo-synchrotron started. Prof. Oliphant directed the rapid establishment of the Research School with the creation of Departments of Astronomy, Geophysics, Nuclear Physics, Radiochemistry and Theoretical Physics by October 1952.

By June 1953, when the synchrotron at Birmingham started operating, two others, whose construction started later, were in operation: the Cosmotron at Brookhaven accelerating protons to 3 GeV and the Bevatron at Berkeley reached 5 GeV by March 1954. Typically, Oliphant proposed an innovative change which made use of the work already done on parts of the cyclo-synchrotron to build a synchrotron to accelerate protons to 10.6 GeV. The very small staff, by world standards, set to work on the new proposal. But even with the appointment of extra staff and having made considerable progress by early 1961, it was decided that only the huge machine - a homopolar generator (HPG) with two 40 tonne rotors, being built to supply the 500 MJ of energy required to create the magnetic field for the synchrotron - would be completed. The synchrotron, if built, would not accelerate protons to the energy of those from the machine that was under construction by CERN in Geneva and therefore work on it would stop.

The HPG would be able to generate pulses of current of 1 MA lasting one second, or other wave forms to a series of experiments which would probably include the study of plasma physics. The high energy pulses could be used to produce the high temperature plasma required for nuclear fusion such as observed for the first time by Lord Rutherford and Mark Oliphant when working in the Cavendish Laboratory in 1934. To prepare for this, a small group in Prof. Oliphant's Department started

in 1958 to conduct experiment on the compression of plasmas.

The generator was completed by June 1962 using jets of sodium-potassium alloy (NaK), a metal that is liquid at room temperature, to carry the megamp current from the rotors to the output connections. One half of the machine was tested. It worked without fault supplying a peak current of 1.8 MA. Prof. Oliphant had considered it necessary to use liquid metal jets because experience with solid brushes indicated that the speed of the rotor surface and the massive current would destroy them. Because of the danger of handling NaK (it ignites and produces toxic smoke when exposed to air) and the complications it added to the design, operation and maintenance of the generator, a member of the HPG team decided to test brushes made from sintered copper with about one tenth graphite.

The conditions for the small scale tests matched those in the HPG and the results showed that the copper-graphite brushes could be used. The use of such brushes in the generator required unusual configurations and sophisticated mountings with actuators to apply them to the periphery of the four rotor disks for a few seconds longer than the duration of the pulse of current. They had to make continuous contact with an almost perfect surface moving in either direction at up to 40 m/s, and not be lifted or deflected by the powerful electromagnetic forces on the connections. The brushes were required to contact the rim of the 3.6 m diameter rotor disks in a close-packed ring of 864 brushes with contact face one centimetre square.

Sir Mark Oliphant (Marcus L.E. Oliphant had been created Knight Bachelor in January 1959) approved the redesign of the HPG using copper-graphite brushes and agreed to the cost involved. He designed new bearings more robust and less elaborate than those used previously. The new bearings and brushes were tested early in 1964 and worked very well. Sir Mark must have been relieved to see that the generator was now a reliable working machine which could perform as intended, however he did not comment on the success of copper-graphite brushes. In

July 1963 he had resigned from the position of Director of the Research School of Physical Sciences to be able to devote more time to the Particle Physics Department. In July 1964 he resigned from the position of head of the Department. In an address thirteen years later - after the HPG had been used to power two high field magnets, the larger to 30 Tesla, the most powerful rail gun built to that time and the first tokamak to be built outside the USSR - he said about the brushes "Mr. Marshall has produced a remarkably successful solid-state collecting system, and for that we are very grateful."

Prof. Oliphant had often expressed disappointment at the time taken to complete the work, but he never complained that someone was not working hard enough. He accepted that his estimate of the time that would be required was wrong. He sometimes considered that this error was due to the person responsible making the design too complicated, too sophisticated, or unnecessarily well-made. After commenting to this effect, he would not veto the design but occasionally he would work on a simpler version himself. He was devoted to the maintenance of academic freedom.

As soon as a section of the design was finalised Oliphant would ensure that material and parts that would not be delivered promptly were ordered immediately. Work was rarely delayed because items were not on hand. Construction proceeded as fast as the small number of staff could do it, with no outside place to have the engineering done.

The HPG was used to power tokamaks for plasma research directed towards harnessing the power from the fusion reactions until December 1985 when it was dismantled. It remains the largest homopolar generator ever built. Beautifully engineered, reflecting the skills, ingenuity and perseverance of the men who built it, it was a remarkable achievement.

From 1950 to 1966 Prof. Oliphant did much more than just try to obtain a proton accelerator. A student, and then a member of staff of the Department of Nuclear Physics for most of that time, has written: "Other departments were established and well supported with staff and funds under his selfless guidance. It is testimony to the strength and diversity of the research vigour, within the school he founded, that non-completion of the accelerator had remarkably little effect on the perceptions of either the School or large scale research, to those outside it. While Oliphant's judgement may have been questioned, his scientific credentials, determination and loyalty to the ANU never were."

From the end of the war to the end of his life he spoke with his remarkable skill, authority, and confidence, both in public and personally to many Heads of State, against the manufacture of nuclear weapons and the threat to mankind if they were used. This cause received a major boost in 1955 when Bertrand Russell and Albert Einstein signed a manifesto on 'the tragic situation which confronts humanity' due to the possibility of a nuclear war. The Russell-Einstein Manifesto was signed by eleven world renowned scientists.

In July 1957 Lord Russell invited Oliphant and 21 other leading scientists from ten countries, including the United States, Britain, Russia and Japan, to a conference to debate the manifesto. The conference was hosted by the American millionaire Cyrus Eaton at his birthplace, Pugwash, a small fishing village in Nova Scotia, Canada. Thereafter, similar conferences known as Pugwash Conference on International Affairs were held annually in different countries. Oliphant attended most and by 1960 many governments recognised the independent attitude and constructive intentions of the Pugwash participants and the organisation.

In 1954 Prof. Oliphant initiated discussions by a group of renowned Australian scientists concerning the establishment of an Australian Academy of Science and when it was founded, he was elected "founding president".

In February 1968 Sir Mark Oliphant was asked by the Premier of South Australia, Donald A. Dunston, if he would agree to a recommendation to the Queen to appoint him Gover-

nor of South Australia. After being told that the role of Governor would not prevent him attending international science conferences, Sir Mark agreed . However, Dunston's government lost power and the new government did not agree to the appointment. In May 1970 Premier Dunston returned to office. Shortly later the incumbent Governor died and Sir Mark again was recommended to Buckingham palace. In December 1971 he was sworn in as Governor of South Australia.

As Governor Sir Mark performed his traditional duties with distinction but he continued to speak frankly about the injustice or mistakes he saw in our society. At the same time he used the opportunity to emphasise the need for peace, conservation of resources and species, the protection of the natural environment, the need to improve the conditions of our indigenous people and to respond justly to their request for land rights. In general his expressed views were endorsed by a majority of the population and most were pleased to have a Governor who was willing to speak out on important issues.

Sir Mark Oliphant (Ollie or MLO to his staff) was a modest man. At the end of the war he declined an award for his work on the development of magnetrons. He considered others working under him did more than he did to invent this device which made such a decisive contribution to winning the war.

In 1954, after 4 years in the ANU as the Director of the Research School of Physical Sciences and having taken the initiative in the establishment of the Australian Academy of Science, he considered himself 'a newcomer (the academic scene) to Australia'. This was his reason for declining, when asked if he would consent to a recommendation to the Queen that he be created a Knight Bachelor. Five years later when asked again he consented and so became a KBE in January 1959.

He was a quick thinker. In any debate he would put forward an idea. If a different idea with merit was then proposed he would quickly assess it and support it if he considered it better than his. For example when the cavity mag-

netron was proposed he provided the support required while he continued work on the development of klystrons. He was always thinking far ahead of the people working with him or for him, but he did not veto a proposal made by a colleague. He criticised it as a member of the team and accepted the group decision. If he felt strongly about an idea of his own he went ahead alone and invited others, who could do so, to join him.

All who worked with him were amazed at his broad knowledge of science and his grand expectations of what science could, and in time, would do. As the leader of a team he followed what he had learnt from his famous Professor and master, Lord Rutherford. Prof. Oliphant set the goals, allocated tasks with several options, and expected his men to make a choice and get on with it. Then followed frequent checks on progress and many suggestions to solve any problem.

He was kind and loyal to his staff. On one occasion when the question arose of continuing with a difficult but rewarding program that he had undertaken, he responded with the statement he could not agree to terminating the project and thereby dashing the hopes of the staff who had joined him.

He had great confidence in what science could do for humanity if mankind were cooperative and wise in applying it. To him no 'good idea' or importan⁺ goal was to difficult to implement. Persistence and careful thought would overcome all obstacles.

He was a persuasive speaker. Who else could have convinced the US Treasury to provide 14,000 tons of silver from their reserves to make the conductors for the magnetic isotope separators? His command of the English language was brilliant, unlike many of us with a scientific or technical bent.

He was a risk taker, but he would not risk Germany building the first atom bomb. He risked many bomber flights across the Atlantic; he risked harming his career in nuclear physics by going to Birmingham and again when coming to Australia; he consistently risked his standing

and reputation with outspoken comments on is-
sues that were important to him and knowing
the merit and importance of what he had to say.

This led a colleague to remark, "One is old
when you will no longer take a risk and on that
measure Mark Oliphant will never grow old".
He certainly did not grow old early.

Sir Mark Oliphant did not believe in a God
that did or could influence life, behaviour, or
well-being of people or the occurrence of natu-
ral events. He did consider the energy and the
infinite extent in time and space of the universe
a phenomenon the existence of which could not
be explained by our present knowledge and as
such was a godlike phenomenon. He did not be-
lieve there is life after death. He did considered
'life' was a wonderful and precious thing to be
cared for most diligently. He was a vegetarian.
He admitted that he had made mistakes, and
some may hold them against him. He hoped
he would not be remembered for them, but for
what he had achieved for science.

After Lord Rutherford died in October 1937,
Oliphant was asked, in March 1938, to address a
memorial gathering at Trinity College, Dublin.
His eulogy began:

> 'We have all endured the death
> of the greatest figure of our age.

Newton, Faraday, Maxwell, Kelvin,
Rutherford... his name belongs with
theirs. His pupils feel that they have
lost more than a master. We have
lost a friend, a confidante, a fatherly
adviser. Indeed many of us feel we
have lost a father'.

Now we have lost one of the sons who had
followed the fatherly advice. During Oliphant's
life he was too modest to agree that his name
should be added to the list. Perhaps we could
do so now.

Many of the dates and facts quoted above
were confirmed by reference to the book
'Oliphant', published by Stewart Cockburn and
David Ellyard in Association with Axiom Books
Pty Ltd in 1981. The research for this book was
most comprehensive and the results well doc-
umented. It contains much more information
about the remarkable life of Sir Mark Oliphant.

E.K.I.

Sir Mark Oliphant was elected Honorary
Member of the Royal Society of New South
Wales in 1948 and was awarded the Society's
Cook Medal in 1974. He was born on 8th Oc-
tober 1901 and died on 14th July 2000.

JAMES LANGFORD GRIFFITH
1910–1999

James (Jim) Langford Griffith, a life member and past president of the Society, died on May 12, 1999 in retirement after a long and distinguished career in teaching, research and service to the Society. He was born in the Sydney suburb of Longueville on May 17, 1910 and attended North Sydney Boys High School proceeding to Sydney University where he first graduated B.Sc with first-class honours in mathematics (1931). He subsequently qualified for the awards of Dip.Ed and M.Sc and later the B.A. from that same institution. In those times, the N.S.W. Department of Education facilitated the university education of many able students inducting them into the N.S.W. high school teaching service. Jim served with the N.S.W. Department of Education from 1932 to 1945, and lectured at the Sydney (1938–39) and Armidale (1940–44 part-time) teachers' colleges. He became a Sydney Technical College lecturer in mathematics with the Department of Technical Education in 1946 and on the formation of the now University of New South Wales transferred to the new body. He remained with the University of N.S.W. until his retirement in 1974 as Associate Professor in the School of Mathematics.

In the early days of the University he was largely responsible for the design of the many courses in mathematics, especially pure mathematics, and was, and remained, a key staff member. In those times there was no strong research tradition in some disciplines of the technical college schools. Jim has the distinction of championing research in pure mathematics in an institution otherwise having a strong applied bias. His research was concerned primarily with integral transform theory, most of his papers were published in the Society's *Journal and Proceedings* and he received the Ollé prize in 1964. He served as a consultant to the Australian Atomic Energy Commission 1967–71 and was Visiting Associate Professor at the University of Kansas 1964–65.

He joined the Society in 1952 and served on Council 1954–63, 1966–70, 1974–75, 1981–83 and was Hon. Secretary 1955–57, 1966–68, Hon. Librarian 1981-85. He was President in 1958. His contribution to the Society cannot be overstated. He was a major influence over many years and served well into retirement. He was awarded the 1971 Society medal for his contributions to science, education and the Society.

His long and varied career provided him with numerous stories from the past. Many were unusual and often they were humorous, and he told them with great relish. He was always willing to share his long experience with both colleagues and students. He was survived for a time by his wife Elsie Anne, and by his daughter.

W.E.S.

JAMES LEE HERON
1939–2000

Mr James Lee Heron, a member of the Society since 1998, died on 23rd October 2000, aged 85. Jim Heron was born in Bundaberg, Queensland, and educated in Brisbane. At the outbreak of War in 1939 he, with a group of 20 other young Australians, joined the Royal Air Force to become a Pilot. He served throughout the War in Coastal Command, operating from airfields in the UK and in Iceland and recently published a history of those other 20 young Australians.

After the War James was accepted into the fledgling British Overseas Airways Corporation, and served as a Captain. On cessation of his flying years he served the airline in a number of senior administrative posts in post-colonial

Africa and in Bangladesh.

James was an Upper Freeman of the London Guild of Air Pilots and Air Navigators, and an Associate of the Royal Aeronautical Society. He and his wife frequently attended lectures arranged by the Royal Society of NSW, both in the Southern Highlands and in Sydney.

D.R.

The Royal Society of New South Wales Council's Financial Report

Your Council members submit the following financial statements of the Society for the year ended 31 December 1999.

COUNCIL MEMBERS

The names of Council Members throughout the year and as at the date of this report are:

Prof. A.T. Baker   Dr E.C. Potter
Dr D.F. Branagan   Dr A. Shannon
Miss P.M. Callaghan   Prof. W.E. Smith
Dr P.R. Evans   Dr F.L. Sutherland
Mr J. Hardie   Prof. D.J. Swaine
Mrs Krysko v. Tryst.   Prof. R. Vernon
Dr M. Lake   Prof. P. Williams
Dr D.J. O'Connor   Prof. M.A. Wilson

PRINCIPAL ACTIVITIES

The principal activities of the Society during the year were: organisation of meetings; publication of the Journal & Proceedings and the Bulletin; organisation of a Summer School for Secondary Students.

SIGNIFICANT CHANGES

No significant change in the nature of these activities occurred during the year.

OPERATING RESULT

The surplus for the year amounted to $2768.

Signed in accordance with a resolution of the members of the Committee.

President   [Original signed by D.J. O'Connor (Vice-President)]

Hon. Treasurer   [Original signed by P.R. Evans]

Dated this 29th day of March 2000

The Royal Society of New South Wales Statement by Members of the Council

In the opinion of the committee the financial statements:

1. present fairly the financial position of The Royal Society of New South Wales at 31 December 1999 and the results for the year ended on that date in accordance with Australian Accounting Standards and other mandatory professional reporting requirements.

2. at the date of this statement, there are reasonable grounds to believe that the Society will be able to pay its debts as and when they fall due.

This statement is made in accordance with a resolution of the council and is signed for and behalf of the Council by:

President   [Original signed by D.J. O'Connor (Vice-President)]

Hon. Treasurer   [Original signed by P.R. Evans]

Dated this 29th Day of March 2000

The Royal Society of New South Wales Independent Audit Report to Members

SCOPE

I have audited the financial statements, being the Statement of Income and Expenditure, Balance Sheet and Notes to and forming part of the financial statements of The Royal Society of New South Wales for the year ended 31 December 1999. The Council is responsible for the financial statements. I have conducted an independent audit of these financial statements in order to express an opinion on them to members.

My audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the financial statement are free of material misstatement. My procedures included examination on a test basis of evidence supporting the amounts and other disclosures in the financial statements and the valuation of accounting policies and significant estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the financial statements are presented fairly in accordance with Australian Accounting standards and other professional reporting requirements so as to present a view which is consistent with my understanding of the Society's position and the results of its operations.

The audit opinion expressed in this report has been formed on the above basis.

AUDIT OPINION

In my opinion, the financial statements present fairly in accordance with Australian Accounting Standards and other mandatory reporting requirements the financial position of The Royal Society of New South Wales as at 31 December 1999 and the results of its operation for the year then ended.

[Original Signed by Mr B.E. Holden 29 March 2000]

B.E. Holden FCA
Chartered Accountant
Chatswood

The Royal Society of New South Wales
Income & Expense at 31 December 1999

	1999 $	1998 $
INCOME		
Membership Subscriptions	15,712	14,240
Applications for Membership	152	164
Journal Subscriptions	5,581	5,139
Reprints and Other Publications	525	545
Investment Income	6,681	5,904
Summer School	1,445	2,796
Annual Dinner	(268)	177
Other	35	0
TOTAL INCOME	29,863	28,965
EXPENSES		
Accounting and Auditing Fees	575	4,765
Bank Charges and Government Duties	118	150
Bulletin	1,765	2,121
Depreciation	474	436
Insurance	842	787
Journal & Proceedings Publication and Distribution	10,901	10,228
Miscellaneous	14	13
Monthly Meetings	727	389
Office	837	842
Provision for Doubtful Debts	1,743	1,955
Rent	2,000	2,000
Salaries	6,184	7,319
Superannuation	508	201
Telephone	407	439
TOTAL EXPENSES	27,095	31,645
SURPLUS (LOSS) FOR THE YEAR	2,768	(2,680)
Balance at 1 January	112,704	115,384
Balance at 31 December	115,472	112,704

The Royal Society of New South Wales
Balance Sheet at 31 December 1999

	Notes	1999 $	1998 $
ASSETS			
CURRENT ASSETS			
Cash	2	11,409	13,758
Receivables	3	420	1,871
Investments	4	5,641	183
TOTAL CURRENT ASSETS		17,470	15,812
NON-CURRENT ASSETS			
Investments	4	132,000	132,279
Property, Plant, & Equipment	5	17,481	15,565
TOTAL NON-CURRENT ASSETS		149,481	147,844
TOTAL ASSETS		166,951	163,656
LIABILITIES			
CURRENT LIABILITIES			
Creditors and Accruals	6	4,098	6,033
Other	7	2,701	2,624
TOTAL CURRENT LIABILITIES		6,799	8,656
NON-CURRENT LIABILITIES			
Creditors and Accruals	7	7	23
TOTAL NON-CURRENT LIABILITIES		7	23
TOTAL LIABILITIES		6,806	8,679
NET ASSETS		160,145	154,977
MEMBERS' FUNDS			
Library Reserve	8	7,311	7,311
Library Fund	9	13,909	13,173
Trust Funds	10	22,588	22,788
Studentship Fund	15	865	0
Accumulated Funds		115,472	112,704
TOTAL MEMBER'S FUNDS		160,145	154,977

The accompanying notes form part of these financial statements.

The Royal Society of New South Wales
Notes to and Forming Part of the Accounts for Year Ended 31 December 1999

1 Statement of Accounting Policies These financial statements are a special purpose financial report prepared for use by the council and members of the Society. The council has determined that the Society is not a reporting entity.

The statement has been prepared in accordance with customary accounting practices on an accruals basis and on historic costs, taking no account of changing money values, or, except where specifically stated, current valuations of non-current assets.

Where required, comparative figures have been adjusted to conform with changes in presentation for the current financial year.

	1999 $	1998 $
2 CASH		
Cash on Hand	28	68
Cash at Bank	11,381	13,690
	11,409	13,758
3 RECEIVABLES		
Debtors for contributions towards printing Journal & Proceedings	420	1,871
Membership Subscriptions in Arrears	3,834	2,653
Less Provision for Doubtful Debts	(3,834)	(2,653)
	420	1,871
4 INVESTMENTS		
Current		
Deposits at Call	5,641	183
Non-Current		
St George 551324554	0	77,571
St George 551555467	132,000	0
Westpac Variable	0	54,708
	132,000	132,279
5 PROPERTY, PLANT & EQUIPMENT		
Office equipment and furniture - at valuation of	12,390	10,000
less accumulated depreciation	8,519	8,045
	3,871	1,955
Library - at 1936 valuation	13,600	13,600
Pictures - at cost less depreciation	10	10
	17,481	15,565

	1999 $	1998 $
6 CREDITORS & ACCRUALS		
Sundry Creditors & Accruals	4,098	6,033
7 OTHER LIABILITIES		
Current		
Life Members subscriptions prepaid	16	16
Membership subscriptions paid in advance	133	30
Journal & Proceedings subscriptions paid in advance	2,552	2,578
	2,701	2,624
Non-current		
Life Members subscriptions - prepaid	7	23
8 LIBRARY RESERVE		
Balance at 1 January	7,311	7,311
Movement for year	0	0
Balance at 31 December	7,311	7,311
9 LIBRARY FUND ACCOUNT		
Balance at 1 January	13,173	12,325
Donations and interest	774	868
	13,947	13,193
Library purchases and expenses	(38)	(20)
Balance at 31 December	13,909	13,173
10 TRUST FUNDS		
Included in Trust Funds are:		
Clarke Memorial Fund (11)	3,291	3,166
Walter Burfit Prize (12)	7,350	7,552
Liversidge Bequest Fund (13)	3,101	3,557
Ollé Bequest Fund (14)	8,846	8,513
Total Trust Funds	22,588	22,788
11 CLARKE MEMORIAL FUND		
Capital	5,000	5,000
Revenue		
Income	134	146
Expenditure	(10)	(7)
Surplus (Deficit)	124	139
Balance at 1 January	(1,833)	(1,973)
Balance at 31 December	(1,709)	(1,834)
Total fund capital and revenue	3,291	3,166

	1999 $	1998 $
12 WALTER BURFITT PRIZE FUND		
Capital	3,000	3,000
Revenue		
Income	308	350
Expenditure	(510)	
Surplus (Deficit)	(202)	350
Balance at 1 January	4,552	4,200
Balance at 31 December	4,350	4,550
Total Fund Capital and Revenue	7,350	7,552
13 LIVERSIDGE BEQUEST FUND		
Capital	3,000	3,000
Revenue		
Income	143	166
Expenditure	(598)	(43)
Surplus (Deficit)	(455)	123
Balance at 1 January	557	434
Balance at 31 December	101	557
Total fund capital and revenue	3,101	3,557
14 OLLÉ BEQUEST FUND		
Capital	4,000	4,000
Revenue		
Income	333	412
Expenditure	0	(500)
Surplus (Deficit)	333	(88)
Balance at 1 January	4,513	4,601
Balance at 31 December	4,846	4,513
Total fund capital and revenue	8,846	8,513
15 STUDENTSHIP FUND		
Revenue		
Income	1,865	0
Expenditure	(1,000)	0
Surplus (Deficit)	865	0
Balance at 1 January	0	0
Balance at 31 December	865	0

Membership List

The year of election is given in brackets; an asterix indicates pre-paid Life Membership. Assoc. = Associate Member. The number of papers published in the *Journal* is indicated by P. Degrees and diplomas are listed in order of seniority, with awarding institution, where known.

HONORARY MEMBERS

BENNETT, J.M. Emer. Professor AO, BE(Civ), BE(Med & Elect), BSc Qld, PhD(Camb), FACS, FBCS, FIEAust, FIMA, FRSS, MACH, MIFF, MORSA, MASOR, ACS(Hon.Life), FIS Balgowlah NSW (1978; Hon.Memb. 1995)

CAREY, S.W. Emer. Professor AO, FAA, DSc(Syd), HonDSc(PNG, FNAI, FGS Sandy Bay TAS (1938; Hon.Memb. 1976; P.2)

CORNFORTH, J.W. Emer. Prof. Sir AC, Kt, CBE, Nobel Laureate, FRS, DPhil(Oxf), MSc(Syd) Sussex England (1977)

CRAIG, D.P. Emer. Professor AO, FAA, FRACI, FRS, DSc, PhD(Lond), HonDSc, MSc(Syd),HonDrChem(Bologna), FRSChem. Canberra ACT (1941; Hon.Memb. 1985; P.7)

FIRTH, R.W. Emer. Professor Sir Kt, MA, PhD (Lond), DSc FRS England (Hon.Memb. 1952)

McCRACKEN, K.G. Dr AO, FAA, FTS, DSc, PhD, BSc, FAusIMM Mittagong NSW (1973; Pres. 1979; Hon.Memb. 1995)

NAPPER, D.H. Professor MSc(Syd), PhD(Camb), FAA, FRACI University of Sydney NSW (1973)

NOSSAL. Sir Gustav AC, Kt, CBE, FAA, FTS, FRS, HonDSc, MB, B, BScMed(Syd),HonDSc(ANU), PhD(Melb), FRACP, FRCP, FRSE Parkville VIC (Non.Memb. 1986)

ROBERTSON, R.N. Emer. Professor Sir AC, Kt, CMG, FAA, FRS, DSc(Syd), PhD(Camb). The Aust. National Univ. Canberra ACT (Hon.Memb. 1985)

STANTON, R.L. Professor FAA, PhD, MSc(Syd), HonFIMM, HonFGSAm, MAusIMM Canberra ACT (1949; Hon.Memb. 1988; P.2)

WILD, J.P. Dr AC, CBE, FAA, FTS, FRS, ScD, MA(Camb), HonDSc(ANU) Ann Arbor Michigan USA (Hon.Memb. 1990)

YERBURY, D. Emer. Professor AM, LLB(Lond), PhD(Melb), DipTechSci(Manc). Macquarie University NSW (Hon.Memb. 1996)

MEMBERS

ADRIAN, J. BSc(Syd). Blackheath NSW (1970)

AMBLER, E.P. Dr BSc(Hons) PhD. Mittagong NSW (1996)

AMBLER, W.L. BSc, LLB. Mittagong NSW (1996)

ANDERSON, G.W. BSc, BE. Lane Cove NSW (1948)

ARDITTO, P.A. BSc, MSc, Dip.Ed. Ivanhoe Vic (1981)

ARROLD, N.P. Dr BSc(Agr) PhD(Syd). Mittagong NSW (1998)

AULD, J.E. Wingello NSW (1999)

AULD, W.T.M. Wingello NSW (1999)

BADHAM, C.D. Dr MB, BS, DR(Syd), FRACR, BSc(NSW). Paddington NSW (1962)

BAGGS, S.A. Dr BArch, DipArch, MArch(NSW), Grad.Dip. Land Des, PhD. Newport NSW (1989)

BAGGS, D.W. B.Arch (Hons) NSWIT. Castle Hill NSW (1992)

BAKER, A.T. A/Prof. BSc(NSW), PhD(NSW), FRACI, C.Chim. Oatley NSW (1997; Pres.

1999)

BAKER, N.J. Oatley NSW (1999)

BANFIELD, J.E. Dr MSc, PhD Melb. Armidale NSW (1963)

BASDEN, A.M. BSc (Hons). Winston Hills NSW (1999)

BASDEN, H. BSc, Syd, DipEd Syd, MAppSci UTNSW, Collaroy Beach NSW (1970)

BASDEN, K.S. Dr BSc NSW, PhD NSW, MRACI MAusIMM, CChem, MIEAust, ASTC, CPEng, FInstE, FAIE. Lawson NSW (1951)

BEAN, J.M. Dr PhD Trangie NSW (1975)

BEAVIS, F.C. Emer. Prof. MA Camb, BSc Melb, LLB NSW, FGS, PhD Melb. Cowra NSW (1973; Pres. 1978)

BENNETT, M.R. Prof. FAA. Sydney NSW (1993)

BHATHAL, R. Dr CertEd, BSc, PhD, FS M S. Georges Hall NSW (1982; Pres. 1984)

BILLS, R.M. MB,BS Syd, Queanbeyan NSW (1982)

BINNIE, A.E. MSc(Hons), BSc, DipEd; East Ryde NSW (1998)

BINNS, R.A. Dr BSc Syd, PhD Camb, North Ryde NSW (1964)

BLACK, D.St C. Prof. MSc Syd, PhD Camb. AMusA, FRACI. Sydney NSW (1983)

BLACK, L. Broken Hill NSW (Assoc. 1975)

BLACK, P.L. OAM, BSc(NSW) Broken Hill NSW (1975)

BLANKS, F.R. AM, BSc, Greenwich NSW (1948*)

BLAXLAND, D.G. Dr MB, BS Syd, FRCPA. Wagga Wagga NSW (1977)

BRAKEL, A.T. Dr BSc, PhD Newc. Canberra ACT (1968)

BRANAGAN, D.F. Dr MSc, PhD Syd, FGS. HonMGSAus Northbridge NSW (1967; Pres. 1995)

BRIERLEY, A.J. BSc., Dip Tech., M.B.A. Lidcombe NSW (1999)

BROWN, D.J Dr DSc, DPhil O'Connor ACT (1942*)

BROWN, H.E. MSc Epping NSW (1975)

BROWN, L.M. Dr PhD, BSc(Hons). Thirlmere NSW (1999)

BURGESS, J.R. Dr B.Med.Sci, M.B., B.S., M.D., FRACP. Hobart TAS (1999)

BURNS, OBE B.B. OBE, MDS Syd, FICD. Collaroy NSW (1961)

BURNSTEIN, K. M. Des Bowral NSW (Assoc. 1997)

BURNSTEIN, R. M.Sc M.B.A. Bowral NSW (Assoc. 1997)

CALLAGHAN, P.M. Bsc Syd, MSc Melb, ALAA North Sydney NSW (1984)

CALLENDER, J.H. BSc NSW, MSc(Hons), Woll'g, Wahroonga NSW (1969)

CAMPBELL, I.G.S. BSc, Wahroonga NSW (1955)

CAMPBELL, K.S.W. Emer. Prof. MSc, PhD Qld, FAA. Campbell ACT (1975)

CAMPBELL, M.T. Dr Picton NSW (1994)

CAVILL, G.W.K. Emer. Prof. Seaforth NSW (1944)

CHAFFER, E.K. Chatswood NSW (1954*; Pres. 1975; P.1)

CHALMERS, R.O. ASTC. Cleveland QLD (1933*)

CHATFIELD, S.P. Lane Cove NSW (1988)

CHAUDHRY, T.M. Minto nSW (1996)

CHOPIN, L.K Dr BVSc(HONS), AMusA., PhD Oakey QLD (1997)

CLANCY, B.E. Dr MSc, PhD NSW, DipEd Syd, Lugarno NSW (1957)

CLEMENTS, M.A. Dr Chisholm ACT (1997)

COENRAADS, R.R. Dr BA (Hons) Macq, MSc Brit.Columbia, PhD Macq, Frenchs Forest NSW (1991)

COLE, E.R. Dr MSc Syd, PhD NSW, FRACI. Eastwood NSW (1940)

COLE, J.M. BSc(Hons) Syd, Eastwood NSW (1940)

COLE, T.W. Professor FTS, BE WA, PhD Camb, FIEAust, University of Sydney NSW (1978)

COLLETT, G.W. BSc, DipEd Syd, ARACI. Cherrybrook NSW (1940)

COOK, J.L. Dr BSc, MSc, PhD NSW, FAIP, MAPS. Caringbah NSW (1990)

COPLAND, B.J. Moss Vale NSW (1994)

CORBYN, J.A. Dr PhD Lae PNG (1999)

COX, C.D. BSc, DipEd Qld, Forestville NSW (1964)

CRADDOCK, D.A. BSc (Eng) Epping NSW (1999)

CRASS, J.K. Dr MAppSc, PhD(UTS), West Pymble NSW (1998)

CREELMAN, R.A. Dr BA, MSc(Hons), PhD Macq, Epping NSW (1973)

CROOK, K.A.W. Dr MSc Syd, PhD NE, BA ANU. Hawaii USA (1954)

DAGGETT, C. Moss Vale NSW (Assoc. 1998)

DAGGETT, D.G. Moss Vale NSW (1998)

DAVIES, AO L.W. Prof. AO, BSc(Syd), DPhil(Oxon),FIEEE,FTSE, FAA. Picton NSW (1997)

DAVIS, B.J. B.A.(Syd), Diplome de Medaille d'or Brussels. Neutral Bay NSW (1998)

DAY, A.A. Dr BSc Syd, PhD Camb, FGS, FAusIMM. Lindfield NSW (1952; Pres. 1996)

DOWNES, S.J. BSc (Hons) Univ. Melb University of Sydney NSW (1999)

DRAKE, L.A. Dr BA (Hons), BSc Melb, MA, PhD CALIF, LA PAZ, Bolivia (1962)

EMMETT, A.J.J. Dr MB. BS. FRCS. FRACS.. Bowral NSW (1999)

ENGEL, B.A. Dr MSc NE, PhD, Uni. of Newcastle NSW (1961)

EVANS, P.R. Dr BA Oxf, PhD Brist, MAIG. Turramurra NSW (1968)

FACER, R.A. Dr BSc(Hons), PhD Syd, FausIMM, MGSAus, MAGU. North Turramurra NSW (1965)

FELTON, E.A. Dr BSc ANU, FGM. Eden NSW (1977)

FENTON, R.R. Dr BSc (Hons) Macq, PhD Macq Padstow Heights NSW (1985)

FERGUSSON, C.L. Dr BA (Hons) Macq, PhD NE. Wollongong NSW (1980)

FEWELL, M.P. Dr BSc (Hons), PhD ANU Armidale NSW (1988)

FINLAY, C.J. BSc Syd, North Ryde NSW (1975)

FOLDVARY, G.Z. BSc, MSc NSW Sydney NSW (1965)

FORD, G.W.K. MBE, MA Cantab, Jannali NSW (1974)

FROST, J.P. BA, DipEd, Quakers Hill NSW (1977)

GEORGE, C.R.P. St Ives NSW (1995)

GIBBONS, G.S. Dr MSc Syd, PhD NSW FAIG. Stanmore NSW (1966)

GILLESPIE, T.R. BSc Syd, Artarmon NSW (1986)

GLEN, R.A. Dr BSc(Hons) Syd, PhD Adel, St.Leonards NSW (1983)

GOLDRICK, R.B. Dr M.D. BS (Syd) F.R.A.C.P. Burradoo NSW (Assoc. 1998)

GOLDRICK, V.M. M.B., BS(Syd), DCH (Land.) Burradoo NSW (1998)

GOULD, R.E. Dr BSc, PhD Qld, Clayfield QLD (1973)

GOW, N.N. BSc (Hons) Ontario Canada (1966)

GRAHAM, I.T. Dr BAppSci(Hons) AppGeol NSW. Kingsford NSW (1987)

GRANT, A. Dr MBBS(Syd) BHA(NSW), DDR(Syd), FRACR McMahons Point NSW (1999)

GROVER, C. Belrose NSW (Assoc. 1991)

GROVER, OBE J.C. BE(Hons), MSc(Syd). Belrose NSW (1990)

GUY, B.B. Dr BSc, PhD(Syd). Bayview NSW (1968; P.2)

HADLEY, M. North Sydney NSW (1997)

HANCOCK, H.S. MSc Syd. Wahroonga NSW (1955; Pres. 1989)

HARDIE, J.R. BSc, FGS, MACE. Edgecliff NSW (1979)

HARDWICK, R.L. MEd, BSc, GradDip Hydrogeology Qld. via Leyburn QLD (1968)

HARDY, C.J. Dr BSc (Hons), PhD, DSc, CChem, FRIC, MAusIMM. Hurstville NSW (1976)

HARRISON, P.L. Dr Lismore NSW (1994)

HERON, H.M. MA, DipEd. Burradoo NSW (1998)

HERZ, A.J. Dr Bowral NSW (1996)

HIBBERD, F.H. Dr Armidale NSW (1993)

HOGG, G.R. Dr Molong NSW (1994)

HOLMIK, I. Moss Vale NSW (1999)

HOSKING, A.D. BE, DIC, FGS, MIEAust. Bermagui NSW (1988)

HOSKINS, D.G. Mittagong NSW (1997)

HOUGHTON, R.C.C. Turramurra NSW (1996)

HUMPHRIES, J.W. BSc NZ, CPhys, MInstP (Lond) AIP Killara NSW (1959)

HUNT, D.C. Assoc. Professor BSc (Hons) Syd, MSc, PhD(Warwick). Sydney NSW (1986)

IRWIN, D.M. Marsfield NSW (1994)

JENKINS, T.B.H. Dr BSc, PhD Wales, FGS. Lindfield NSW (1956)

JOASS, G.G. MAppScMinGeomech(NSW), BAppScHons, DipTech(NSWIT). Collie WA (1975)

JONES, The Honorable B.O. AO MHR, FTS, FAHA. HonsDSc(Macq), MA, LLB(Melb). Melbourne VIC (1984; P.1)

KELVIN, N.V.P. Dr BE(Hons) NSW, MS, MPhil, PhD(Yale). Lavender Bay NSW (1990)

KERSAITIS, C.J. BSc(Macq). Pendle Hill NSW (1994)

KHOO, C.S. Dr BSc, MCHEM, PhD(NSW). Campbelltown NSW (1994)

KIDD, S.E. Dr BA, DipEd. Turramurra NSW (1984)

KLINE, P.W BDSc, MDSc, FRACDS Bowral NSW (2000)

KLINE, R.J McMahon's Point NSW (Assoc. 2000)

KLINEBERG, I.J. Prof. BSc PhD(Lond) MDS, FDSRCS (Eng), FRACDS, FICD Westmead NSW (1999)

KNUCKEY, G.J. BA(Hons) Dept. of Archeology & Paleoanth., Univ. of New England. Armidale NSW (1995)

KOCH, L.E. Dr DPhil, habil, Dr(Cologne). Lindfield NSW (1948; P.5)

KRYSKO, von TRYST M. BSc, GradDip (MinTech) NSW, MAusIMM. Epping NSW (1959)

KRZYSZTON, A.J.M. Dr MB, BS, BSc(Med) Springwood NSW (1985)

LAKE, M. Dr BSc PhD(Syd). Thornleigh NSW (1994)

LAMPERT, R.J. Dr PhD, FAHA, FSA. Bowral NSW (1995)

LANDER, J. Dr MB, BS, BSc (Med), PhD, FFA, RACS Bondi NSW (1977)

LASSAK, E.V. Dr MSc, PhD, ASTC, FRACI. Westleigh NSW (1964; P.8)

LAU, H.P.K. MB, BS, FRCPA. Townsville QLD (1979)

LAWRENCE, L.J. Dr DipCom Syd, PhD NSW, DIC, DSc Syd, FAusIMM. Epping NSW (1951)

LEAVER, G.E. BSc Wales, DipEd, FGS (Lond). Wahroonga NSW (1961)

LEE, G.F. Penshurst NSW (1994; P.1)

LEMANN, F.M. Bowral NSW (Assoc. 1994)

LEMANN, J.A. DipEd. SKTC, Hort.Cert. Bowral NSW (1994)

LINDLEY, I.D. Dr BSc(Hons) NSW, PhD NSW. Yass NSW (1980)

LINDOY, L.F. Dr PhD DSc(NSW) FRACI Sydney NSW (1999; P.1)

LOMB, N.R. Dr BSc, PhD. Haymarket NSW (1980; P.5)

LOUGHNAN, F.C. Dr BSc Syd, PhD, DSc NSW, MausIMM. Narraweena NSW (1979; P.7)

LOW, C.Y.D. Dr GRAD. CERT. MATH Sc(UTS), BDS(Syd), MSc Dent(Syd). Hong Kong (1999)

LOWENTHAL, G.C. Dr Chevalier de l'O. Nat. Mérite, France, BA, BSc, DipPubAdmin(Melb), MSc NSW, PhD NSW, FAIP, MInstP. Cremorne NSW (1989)

LOXTON, E.H. Dr MB, BS, DObsRCOG. Burradoo NSW (1995)

LOXTON, J.H. Emer. Prof. PhD(Camb), MSc(Melb). Deputy Vice-Chancelor (Academic) , Macquarie University NSW (1974; Pres. 1985; P.1)

LOXTON, S. Dr MB, ChB, DPH, MFCM. Burradoo NSW (Assoc. 1995)

LYONS, M.T. DipTech(Sc) NSWIT, MChem NSW. Miranda NSW (1974; P.1)

MacLENNAN, A.S. Bowral NSW (1998)

MAHER, B.J. BminEng MELB. Bowral NSW (1999)

MAHER, P.M. Bowral NSW (1999)

MARTIN, P.M. Prof. BSc Agr(Hons) MScAgr, PhD, DipEd(Syd), FLS(Lond), FAIAS. Pymble NSW (1968; P.1)

MARTIN, P.R. Prof. BSc(Hons), Bristol, Dip.Clinical Psychology, Dphil.Oxford. Armidale NSW (1997)

MAWSON, R. A/Prof. BA, PhD Macq, Macquarie University NSW (1974)

McAULEY, Capt. R.A.E. W.J.W., MSc(NE), FAusIEnergy. via Womboota NSW (1975)

McCLEAN, L.H.G. Allambie Heights NSW (1993)

McGHEE, M.E. MinCom(SES) NatMedal. Wentworth Falls NSW (1975)

McKERN, H.H.G. MSc, ASTC, FRACI. Roseville NSW (1943*; Pres. 1963, P.12)

McNAUGHTON, J.E. AM. FISAust. Newcastle NSW (1982)

McNAUGHTON, P.M. AMusA. Merewether, NSW (Assoc. 1989)

MELLOR, R.W. Dr PhD, AM(Harv), BA(Syd). Dept. Math Sciences, Univ. West. Syd. Macarthur NSW (1994)

MITCHELL, G.A. Jindera NSW (1995)

MOORE, F.H. BSc, MSc(N.Z.), D.Phil(Oxford). Mittagong NSW (1998)

MOORE, S.M. BSc. Mittagong NSW (1998)

MORSE-EVANS Capt. D.W. Moss Vale NSW (1994)

MURPHY, A.B. Dr BSc(Hons), PhD. Lindfield NSW (1995)

NASHAR, B. Emer. Prof. OBE, BSc(Syd), PhD(Tas), DipEd(Syd), HonDSc(Newc), MAusIbM. Adamstown Heights NSW (1946; P.3)

NEEF, G. Dr BSc, PhD(Well. N.Z.). Sydney NSW (1989)

NEELY, D.F. Dr PhD, BAHons, DipEd(Macq), ASTC, MAIP. Bradbury NSW (1994)

NEUHAUS, J.W.G. PhD, MSc(Melb), MEc(Syd). Baulkham Hills NSW (1943*; Pres. 1969; P.1)

O'CONNOR, D.J. Dr Castle Cove NSW (1993, Pres. 1999; P.1)

O'KEEFFE, E.D. BSc, DipEd Syd, MSc Macq. Eastwood, NSW (1984)

ORGAN, M.K. BSc.(Hons) Wollongong, DipArchAdmin(NSW). Woonona NSW (1999)

OSBORNE, R.A.L. Dr MSc, DipEd PhD Syd. Harbord NSW (1984; Pres. 1993; P.4)

O'SHEA T. Dr MSc NZ, BVSc Syd, PhD Syd. Armidale NSW (1973)

OXENFORD, R.A. BSc Syd, MPhil Camb. McCrae VIC (1950)

PARSONS, P.A. Emer. Prof. ScD, PhD (Camb), MSc(Melb), BAgSc(Adel), FLS, FIAM AAS Unley SA (1997)

PARTRIDGE, A.D. BSc Syd, MSc NSW. MacLeod VIC (1977)

PERKINS, D.A. DipPharm(Syd). Bundanoon NSW (1995)

PERRY, H.R. BSc(Syd). Bowral NSW (1948)

PICKETT, J.W. Dr MSc NE, DrPhilNat Frankfurt/M. McMahon's Point NSW (1965; Pres. 1974; P.3)

POGSON, R.E. DipTechSc (NSWIT), BAppSc (Hons) NSWIT, MAusIMM. Panania, NSW (1979)

PORRITT, P.M. Nth Wahroonga NSW (1987)

POTTER, E.C. Dr PhD, DIC(Lond), FRSC, FRACI. Kariong NSW (1988; Pres. 1991, 1997)

POTTER, M.P. Kariong, NSW (Assoc. 1997)

POWER, P.A. Dr LLM(UTS), MSc(NSW), BSc(Syd), CChem, CBiol, ARACI, MRSC, MAIBiol, MIBiol, AIPAA, AIArb.A. Bondi Junction NSW (1980)

RAMM, E.J. MSc, Dip Chem & Met PTC. CEng, ARACI, MAustIMM, MIM, FICeram, FIMMA. Lilli Pilli NSW (1959)

REDFERN, Esq. N.R. ACertCM, GCMLond, BSc(Syd), BMin, MChMus, MHlthSc(OHS) ECowan[c] MGCM (UK), ASIA, H (Eng), MIAG, MRIPHH, ATRACI. Five Dock NSW (1999)

RICE, T.D. BSc, MSc(Syd), GradDipEd(NE). Katoomba NSW (1964)

RICHMOND, A.G. Bowral NSW (Assoc. 1998)

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