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CONTEMPORARY ^{14}C LEVELS AND THEIR SIGNIFICANCE TO SEDIMENTARY HISTORY OF BEGA SWAMP, NEW SOUTH WALES

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ABSTRACT. Atmospheric ^{14}C variations in nature, as previously documented for the Southern Hemisphere by studies carried out in South Africa and New Zealand, were supplemented by ^{14}C concentration measurements of wheat-grain samples collected in southeastern New South Wales. Our measurements cover the critical period of 1945/46 up to 1956/57, and span the transition of Suess and atom-bomb effects. The observed variations can be followed quite precisely in the peat deposits of the Bega Swamp, New South Wales, and indicate that vertical mixing of organic components within the peat is negligible. Pollen analytical data covering the last 400 years also show that the peats act as efficient traps; thus, time-precise zonations can be identified, and historically documented man-induced changes in pollen assemblages can be correlated with ^{14}C ages in recent times.

INTRODUCTION

Anthropogenic ^{14}C concentration changes in the earth's atmosphere, such as the dilution of ^{14}C by fossil fuel combustion followed by the atomic weapons induced enrichment of atmospheric ^{14}C, offer an opportunity to test whether these changes are recorded faithfully in recently deposited plant material. Should the record of changes in the last 100 years be preserved in detail, one could then test if the well-established, dendrochronologically documented, changes up to ca 7000 ^{14}C years BP (*cf* Olsson, 1970) could also be dated. The exciting exercise of detecting and documenting changes beyond that time would then follow. Lake sedimentation rates and lake varve chronology have already provided information on long-term atmospheric ^{14}C changes (eg, Stuiver, 1970; Vogel, 1970). This study presents the first series of ^{14}C and palynologic data available for the Bega Swamp, New South Wales, Australia. The choice of a peaty swamp to define a long-term sedimentation and climatic history stems from our belief that this swamp has deposited and accreted autochthonous organic matter since the onset of favorable climatic conditions about 13,500 ^{14}C years ago.

The Bega Swamp

Physiography

The Bega Swamp lies at the eastern edge of the Southern Tablelands, about 20km northeast of Nimmitabel in southeastern New South Wales (36 31′ S, 149 30′ E). The swamp (ca 1080m altitude) appears to have originated as a valley fill on a gently sloping surface in the Bega granite along the watershed between Yankee Creek and the Bemboka River (fig 1). Rainfall figures from the Brown Mountain region show that the swamp receives a mean annual rainfall of 800 to 1200mm. The swamp is surrounded predominantly by several tree eucalypt species commonly described as a 'wet sclerophyll forest'. It is thickly overgrown with several aquatic and semi-aquatic plant species, the most conspicuous belonging

to the genera *Calorophus, Restio,* and *Lepidosperma* (Restionaceous rushes).

Field and laboratory work

A monolith of restionaceous rush-peat, approximately 30cm × 30cm and 56cm deep, was dug from a hummock close to the point where radiocarbon determinations had been made in 1973 from a 3m core sample (ANU-1213 to ANU-1216, table 1). A hummock was selected instead of a trough so as to avoid contamination either through trampling by kangaroos, horses, and cattle, or through excessive sedimentation of

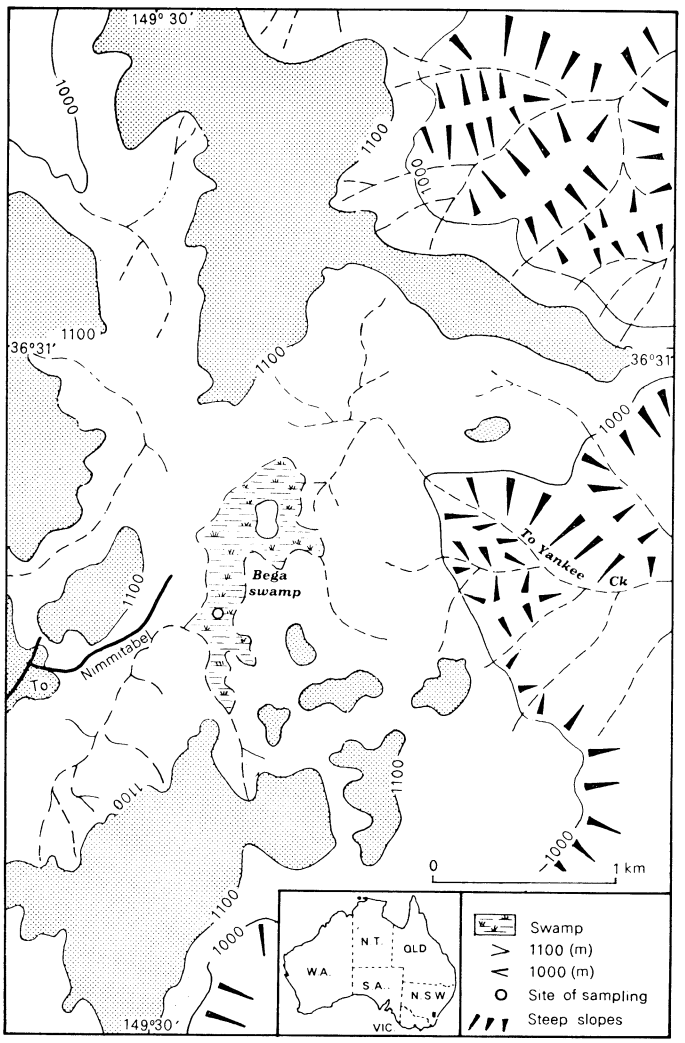

Fig 1. Location of Bega Swamp showing the local topography of the site. Contours shown are in meters above sea level.

TABLE 1

Carbon isotopic (^{13}C and ^{14}C) abundances of Bega Swamp peat samples (arranged in order of increasing depth through profile)

ANU-code	Depth (cm)	Fraction	$\delta^{13}C \pm$ error		$\delta^{14}C \pm$ error		$\Delta^{14}C \pm$ error	
1655A	0.0- 1.0	Rushes	−30.2	2.0	340.5	12.1	354.4	13.4
1655C		NaOH Sol	−28.3	2.0	215.2	27.1	223.2	27.7
1655D		NaOH INSOL	−27.1	2.0	295.2	14.7	300.6	15.6
1656C	1.0- 2.0	NaOH Sol	−28.3	2.0	273.9	14.4	282.3	15.4
1656D		NaOH INSOL	−24.8	0.4	353.9	6.6	353.4	6.7
1755C	2.0- 3.0	NaOH Sol	−28.3	2.0	322.6	9.8	331.3	11.2
1755D		NaOH INSOL	−27.1	2.0	402.1	6.9	408.0	8.9
1654C	4.0- 5.0	NaOH Sol	−28.3	2.0	239.1	9.9	247.3	11.1
1654D		NaOH INSOL	−27.1	2.0	291.7	7.8	297.1	9.4
1653A	6.0- 7.0	Coarse as is	−30.9	2.0	121.5	5.4	134.7	7.1
1653B		Fines as is	−29.5	2.0	131.8	7.9	142.0	9.2
1877C	7.0- 8.0	NaOH Sol	−28.3	2.0	91.3	9.3	98.5	10.3
1877D		NaOH INSOL	−27.1	2.0	87.9	10.5	92.5	11.4
1757C	8.0- 9.0	NaOH Sol	−28.3	2.0	44.0	8.7	50.9	9.7
1757D		NaOH INSOL	−27.1	2.0	−33.3	8.6	−29.2	9.2
1758C	9.0-10.0	NaOH Sol	−28.3	2.0	31.7	7.4	38.5	8.5
1758D		NaOH INSOL	−27.1	2.0	45.2	9.7	49.6	10.6
1759C	10.0-11.0	NaOH Sol	−28.3	2.0	60.9	20.9	67.9	21.5
1759D		NaOH INSOL	−27.1	2.0	−45.4	7.6	−41.4	8.5
1878C	11.0-12.5	NaOH Sol	−28.3	2.0	−6.2	5.6	0.4	6.9
1878D		NaOH INSOL	−27.1	2.0	27.0	5.5	31.3	6.9
1879C	13.5-15.0	NaOH Sol	−28.3	2.0	−2.5	6.9	4.1	8.0
1879D		NaOH INSOL	−27.1	2.0	−40.9	5.4	−36.9	6.6
2009C	13.5-15.0	NaOH Sol	−28.3	2.0	−7.7	10.8	−1.2	11.6
2010C	15.0-16.5	NaOH Sol	−28.3	2.0	−33.0	11.0	−26.6	11.7
2010D		NaOH INSOL	−27.1	2.0	13.0	7.0	17.3	8.1
2239A	16.7-17.8	Coarse as is	−30.7	0.4	141.0	12.8	154.0	13.0
2239B		Fines as is	−29.5	0.4	2.0	9.2	11.0	9.3
2094C	10.0-21.0	NaOH Sol	−27.7	0.4	74.2	12.0	80.0	12.1
2094D		NaOH INSOL	−27.9	0.4	118.7	17.8	125.2	17.9
2095C	25.0-26.0	NaOH Sol	−29.2	0.4	20.2	12.3	28.8	12.4
2095D		NaOH INSOL	−27.3	0.4	71.3	13.4	76.2	13.5
2240A	26.1-27.2	Coarse as is	−31.1	0.4	15.1	8.7	27.5	8.8
2240B		Fines as is	−29.4	0.4	71.7	11.7	81.1	11.8
2096C	30.0-31.0	NaOH Sol	−29.5	0.4	6.1	12.3	15.2	12.4
2096D		NaOH INSOL	−29.0	0.4	141.0	18.5	150.1	18.7
2097C	34.0-35.0	NaOH Sol	−27.6	0.4	−58.2	16.1	−53.3	16.2
2097D		NaOH INSOL	−27.4	0.4	309.6	30.6	315.9	30.8
2190C	35.0-36.0	NaOH Sol	−26.9	0.4	−21.7	8.3	−18.0	8.4
2190D		NaOH INSOL	−24.4	0.4	71.4	10.8	70.1	10.8
2191C	43.1-43.8	NaOH Sol	−28.8	0.4	−73.5	8.5	−66.5	8.6
2191D		NaOH INSOL	−30.2	0.4	21.7	14.6	32.3	14.8
2192C	52.8-53.7	NaOH Sol	−28.7	0.4	−109.4	8.9	−102.8	9.0
2192D		NaOH INSOL	−26.1	0.4	106.8	14.6	109.2	14.7
1213	75.0-85.0	As is	−30.2	2.0	−257.7	11.9	−250.0	12.4
1214	175-185	As is	−30.2	2.0	−607.7	7.5	−603.6	7.7
1215	250-260	As is	−30.2	2.0	−780.0	11.9	−777.7	12.1
1216	266-270	As is	−30.2	2.0	−813.8	6.5	−811.9	6.6

Note: All fractions were acidified after separation.

allochthonous materials in the trough. The monolith was frozen immediately after extraction in order to stop bacterial alteration of its constituents. While still frozen, the monolith was cut on an electric bandsaw into 5mm-thick horizontal slices following the bedding planes, and defrosted just prior to laboratory pretreatment and analysis.

Radiocarbon age determinations

Godwin and Willis (1959) were perhaps the first to demonstrate successfully the reliability of radiocarbon age determinations of peat by checking the age of peat/wood sample pairs. They showed that contamination in a fast-growing peat bog can be negligible. Many later researchers also did not subject their peat samples to physical and chemical pretreatment (eg, Grant-Taylor and Rafter, 1971; Polach, Head, and Gower, 1978) and obtained acceptable results. The question of contamination, however, could not be altogether precluded, and some related wood or charcoal and peat age differences were also cited. Our own experience confirms that false ages are sometimes indicated, and Geyh and Morgenthal (1970) suggested that humic acids should be discarded. Goh (1978) subjected peat samples to a wide range of chemical treatment in a step-wise procedure and obtained a significant increase in age, particularly after treatment with 70 percent HNO_3.

To test the validity of our own ^{14}C age determinations of the Bega Swamp peat samples, and recognizing the limitations of any treatment we might wish to apply, we decided to date the following fractions: 1) NaOH soluble (acid precipitated); 2) NaOH insoluble (acid washed); 3) 'coarse', and 4) 'fines', the last two being acid-washed sieve fractions. 'Coarse' represents matter retained on 50-micron size sieves, whilst 'fines' would pass it. All work was done quantitatively, within reason (losses were minimized), and a record of pH, dry treated sample weight, and CO_2 yield were kept. ^{14}C measurements were carried out in a liquid scintillation spectrometer (Polach, 1969) using ANU Sucrose Secondary International ^{14}C Dating Standard, the activity of which was correlated with NBS Oxalic (Polach, in press; Currie and Polach, ms in preparation). Mass-spectrometric $^{13}C/^{12}C$ determinations were carried out on key samples.

The results listed in table 1 are arranged in depth sequence and referred to in terms of ^{14}C depletion (–) and enrichment (+) wrt 0.95 NBS Ox. The oxalic values were standardized to the base of delta $^{13}C = -19‰$ and sample values to the base of delta $^{13}C = -25‰$. The $D^{14}C$ (D for capital delta) values are in parts per thousand. The calculations and annotation procedures follow recommendations by Stuiver and Polach (1977). Conventional ages BP are not given at this stage. We are satisfied that observed ^{14}C concentration differences are not statistical aberrations in count rate but are an indication of the samples' ^{14}C activity within the statistical uncertainty, which is given as one standard deviation. Where fraction pairs of the same sample, therefore, indicate a trend (fig 2), it is interpreted by us as being significant.

In the samples measured to a depth of 54cm, a strong modern atmospheric atom bomb ^{14}C component appears in the first 12cm. Sample ANU-2010C (15 to 16.5cm) could represent the Suess effect (see next section). Beyond this depth and certainly up to 31cm, the increase in ^{14}C activity in all fractions dated indicates post-depositional contamination. Nevertheless, the NaOH soluble fraction ages converge with the postulated 'true age' regression slope, meeting with it at some as yet undetermined point. The observed pattern has a physical meaning, perhaps reflecting the mobility of organic matter within the peat, making absolute dating at this stage an elusive proposition.

Composition changes of samples were as follows: the NaOH insoluble fraction was present at highest concentration and exhibited smallest variance (66 ± 10 percent) and ranged from ca 78 percent near the surface to ca 60 percent at a depth of 54cm, as expected. This fraction represents visible fragments of undecayed matter whose presence

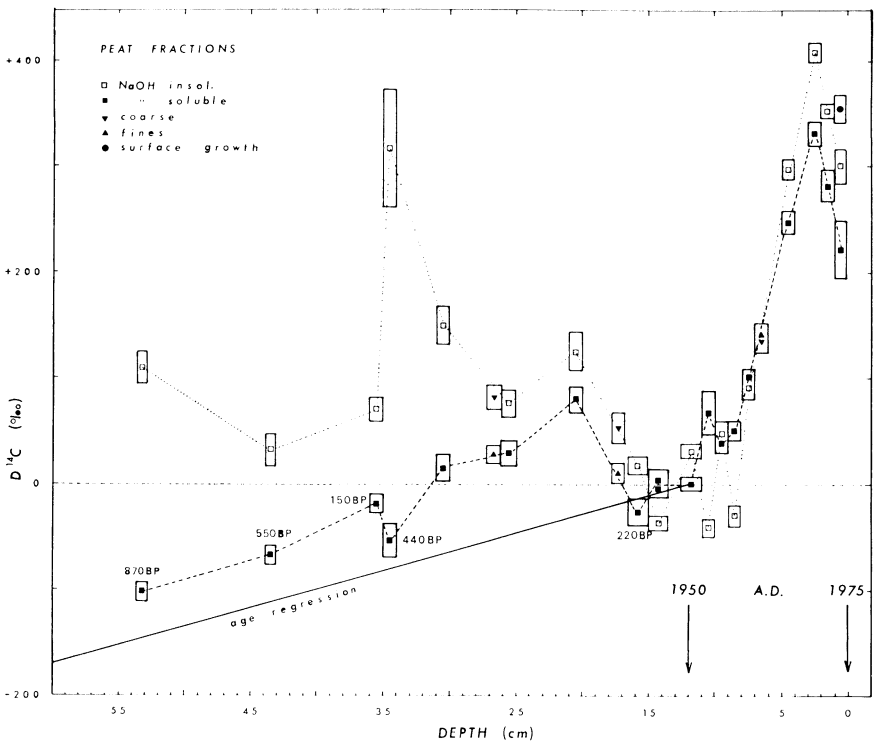

Fig 2. Bega Swamp, NSW peat samples, collected in 1975, deep frozen *in situ* and dated in 1cm spits as acidified fractions: NaOH soluble (■); NaOH insoluble (□); coarse (▼); fines (▲). (●) at 0cm is determination for surface plant in summer of 1975/76. Atom bomb and Suess effect are followed up to a depth of ca 15cm, then lateral root penetration of plant material growing during period of ^{14}C atmospheric increase contaminates all fractions to a depth of 55cm. The solid line is postulated 'age regression' line on which uncontaminated results should lie (*cf*, fig 5). Extrapolation of ^{14}C results to solid line is the basis of Assigned Ages BP* listed in table 2.

diminishes at depth. Conversely, the total OH soluble matter represents 34 ± 9.6 percent of the profile, and ranged from 22 percent near the surface to 40 percent at a depth of 54cm. The carbon content of both fractions, the NaOH soluble and insoluble, varies considerably. It is highest in the NaOH soluble fraction at 47 ± 12 percent C and lowest in the NaOH insoluble matter at 27 ± 12 percent C. The trends indicate a fairly smooth transition from surface to 54cm of all system components (fig 3). Certainly, the contamination peak, obvious in figure 2, between 15 and 35cm, cannot be correlated with fractional composition or carbon concentration changes, suggesting that the contaminants may not be readily isolated (hence, eliminated) by physical or chemical means.

Southern NSW atmospheric ^{14}C variations

Atmospheric pre-bomb ^{14}C levels were tested by collecting ripe wheat-grain samples from the NSW wheat belt. Growing plants represent a convenient average sample of carbon dioxide in the air. Thus, we can compare the changes of ^{14}C concentration of local atmosphere in the summer growing period. The results are illustrated in figure 4 (dotted line) and are added to ^{14}C atmospheric variations in the Southern Hemisphere as given by Vogel (1972) (solid line). Additional points at the contemporary end are tree leaves, ANU-Sucrose and ANU-1655A (table 1). The results are not tabulated here, as this study is incomplete, and only the trends indicated are pertinent to the Bega Swamp stratigraphy and interpretation of results. The most significant observations that can be drawn from figure 4 are that the atmospheric ^{14}C depletion in the region is larger than anticipated by previous workers, extending up to the summer of 1955/56. Both the atom bomb and Suess effect appear in

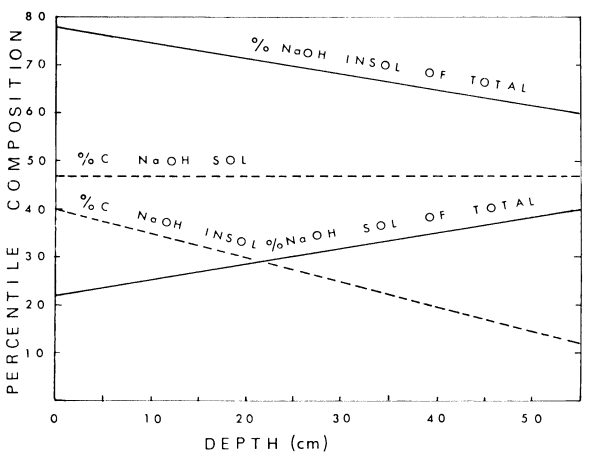

Fig 3. Peat organic fraction relationship up to a depth of 55cm. Total OH' insoluble matter was largest component throughout profile, although degrading from 'coarse' on the surface to 'fines' at depth. Postulated lateral intrusion of rootlets, giving rise to observed contamination due to atom bomb effect (figs 2 and 5, tables 1 and 2) is not associated with a physical or chemical change of constituents in the peat bog profile.

the Bega Swamp samples in cm by cm layers up to a depth of 15cm. This suggests absence of vertical mixing in the profile. The ^{14}C decrease with depth of the NaOH soluble extract attests to the datability of the peat by this fraction, a contention which needs further testing.

Interpretation of ^{14}C results

Despite the established contamination of samples to a depth of 54cm, it is possible to evaluate the age structure of the Bega Swamp. This is done in figure 5 where only results based on NaOH soluble and 'fines' are given. The four samples taken from 80, 180, 255, and 268cm were assigned conventional ^{14}C ages based on their determined $D^{14}C$ depletion figure. The solid line drawn from 180cm to the 12cm depth, where we postulate AD 1950 to lie, intercepts precisely the $D^{14}C$ determinations at 80cm, suggesting that a linear regression is justified. The convergence at ca 80cm of the dotted contamination line and the solid postulated age-regression line also indicates that atom bomb ^{14}C ceases to play any role at this depth. Figures 2 and 5 illustrate clearly that contamination has reached the depth of 40 ± 20cm laterally, but not vertically. In the absence of any indicated or observed water movement, this contamination must be by lateral penetration of roots from distant plants living at a time when ^{14}C atmospheric activity was rising in the Southern Hemisphere. This lateral root penetration, if applicable today, must also be assumed to have been present in the past. However, we suggest that the effect of such past 'contamination' by lateral penetration is not within the resolution of ^{14}C dating because the ^{14}C concentration changes in the past were induced either by radioactive decay (*ie*, age difference) or by ^{14}C variation in nature, neither of which gave rise to an increase (or decrease) in ^{14}C activity of the magnitude observed since 1950.

Based on the ^{14}C results of datable peat fractions we suggest that the 'true' ages will lie along the regression line (solid), as indicated in figure 5 and presented in table 2 which lists 'Assigned' ages in years BP* for all samples below 12cm. Table 2 also gives determined apparent ages BP, which we have shown to be false.

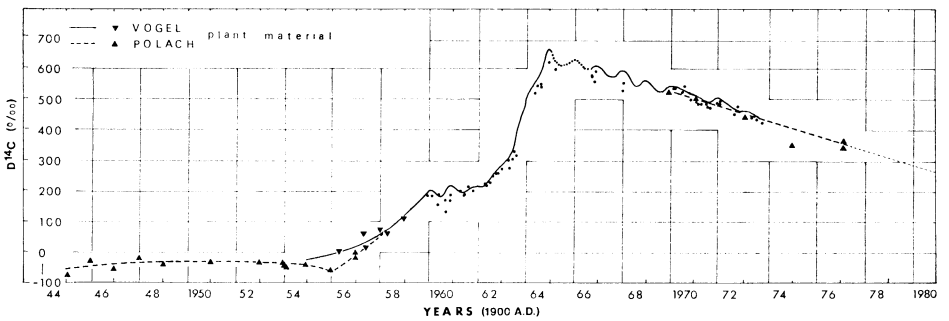

Fig 4. Suess and atom bomb effect in Southern Hemisphere. Data (solid line) taken from Vogel (1972) is supplemented by our own measurements (dotted line) extending determination of plant material collected during summers of each year from 1944/45 and 1975/76 in Southern New South Wales, Australia.

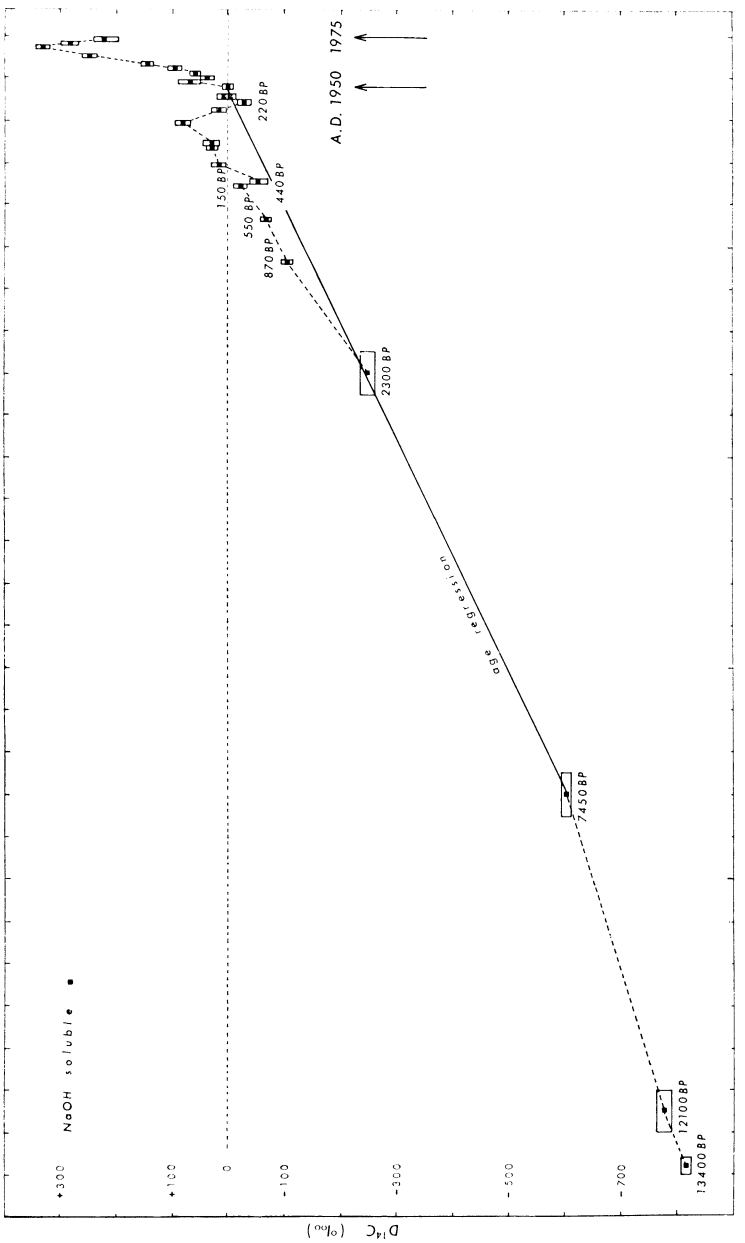

Fig 5. Age/depth relationship of NaOH soluble fractions (C) of samples listed in table 1. At depth of 80cm and beyond, these were considered to be valid. Above 80cm depth and up to 12cm, contamination due to lateral root penetration is postulated. Above 12cm depth up to surface, atom bomb effect response is apparent. Sample at 13cm giving an apparent age of ca 220 BP could be indicative of Suess effect in the Southern Hemisphere (*cf* fig 4).

Palynologic and historic evidence

The final palynologic data now being compiled from spectra taken at 5mm intervals are not yet available. However, an initial investigation at wider intervals provides a means of assessments of the proposed ^{14}C chronology of the upper peat layers (fig 6). For the present discussion, only the aggregate pollen data are being considered in the form of relative percentages of trees, shrubs, and herbs because it is felt that various qualitative plant assemblages represented in the pollen diagram will only confuse the main thrust of this contribution and should, therefore, be presented elsewhere.

According to both the historic records of forest fires (Duggin, 1976) and the accounts rendered by local property owners, there have been only two fires in the Bega Swamp area, one in 1951-52 and the other in 1968-69. The one in 1951-52 is generally believed to have been the biggest on record. The charcoal curve in figure 6 shows the absolute abundances of charcoal per unit volume of sediment and exhibits two peaks at the 2cm and 11cm levels, the last corresponding to an assigned age of 1950 (table 2).

The logging operations and the clearing of land for pasturage has been more intense in post-World War II years, especially in the 1960's and 1970's, than pre-World War II. These developments show clearly in the decrease of tree and shrub pollen and in decreasing pollen influx at the 0 to 11cm levels. The same conclusion is borne out by the increasing number of pine pollen grains appearing in the samples between the 0 and 11cm levels showing the effects of plantations established partly in the 1930's and after the Second World War. Probably the fall in the

TABLE 2
Assigned ages BP* and determined apparent ages BP, Bega Swamp

ANU-code	Depth (cm)	Assigned age years BP*	Determined apparent age years BP
1878C	11.0-12.5	0	Modern
1879C	13.5-15.0	65	Modern
2009C			
2010C	15.0-16.5	109	220 ± 95
2239B	16.7-17.8	153	> Modern
2094C	20.0-21.0	249	> Modern
2095C	25.0-26.0	399	> Modern
2240B	26.1-27.2	434	> Modern
2096C	30.0-31.0	553	> Modern
2097C	34.0-35.0	677	440 ± 135
2190C	35.0-36.0	709	150 ± 70
2191C	43.1-43.8	965	550 ± 80
2192C	52.8-53.7	1289	870 ± 80
1213	75.0-85.0	2250	2300 ± 130
1214	175-185	7433	7450 ± 155
1215	250-260	NA	12,100 ± 425
1216	266-270	NA	13,400 ± 280

Note: NaOH soluble fraction 'C' and Fines 'B', both acidified, are listed as these were considered to be datable. Corrections are applied to ages BP from 80cm depth up to surface using the postulated age regression line in figure 5. All ages are in conventional radiocarbon years using 5638 yr ^{14}C half-life; they are normalized to delta ^{13}C = 25 percent wrt PDB.

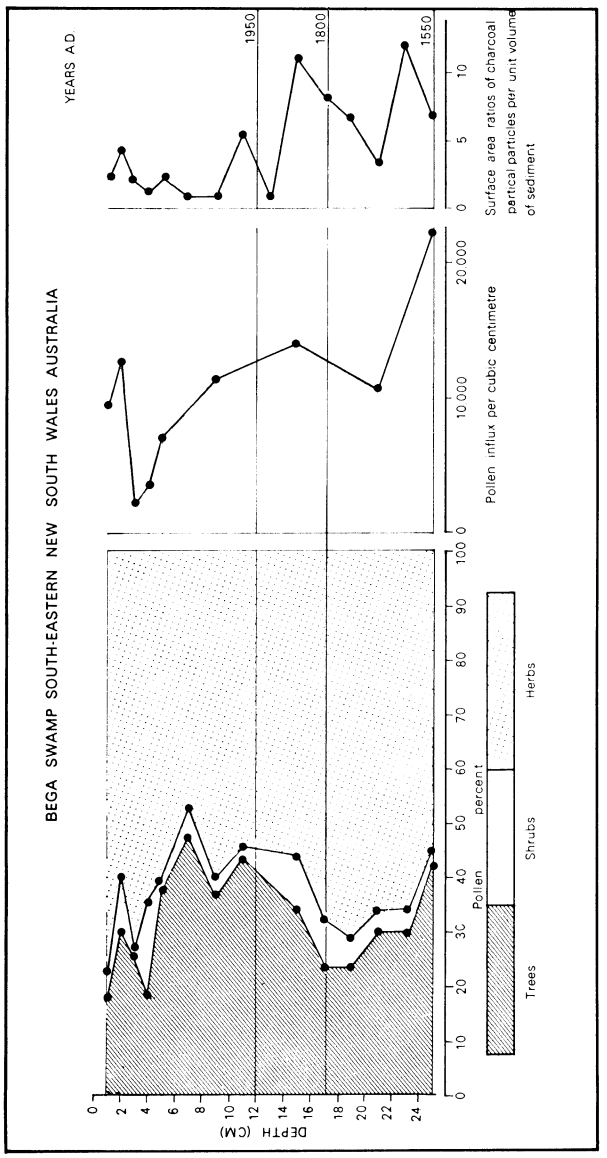

Fig 6. Summary pollen diagram from Bega Swamp showing relative percentages of trees, shrubs and herbs, pollen influx per cubic centimeter and surface area ratios of charcoal particles per unit volume of sediment. The calendar years given are derived from Assigned Age Years **BP*** (fig 5, table 2).

pollen influx was partly caused by drought in the late 1960's, but confirmation will only be available after the palynologic data have been scanned at 5mm intervals. Similarly, the period before 1950 will be dealt with only after detailed analysis of the pollen data has been completed. However, the falls in values of the tree and shrub curves and the pollen influx curve between 25 and 17cm may reflect the 'little ice age'. The estimated age bracket for this section of profile falls approximately between AD 1550 to 1800.

CONCLUSION

The absence of a reliable chronologic method to date undisturbed organic sediments at short-term intervals during the span of available historic and meteorologic records has, so far, not allowed precise correlation of known events. Such events include short-term changes in vegetation resulting from forest successions, clear felling, fires, droughts, exceptionally good years of rainfall, or other small-scale climatic change, with palynologic records from sedimentary profiles. Detailed pollen and ^{14}C time-precise zones in the Bega Swamp peat deposits are indicated by the data presented. Issues applicable to problems of successional and paleoclimatic reconstruction and ^{14}C variations beyond 7000 years BP and up to ca 13,500 years BP may be resolved by further study of the Bega Swamp peat profile.

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DISCUSSION

Mook: Your age regression line can be influenced by changes in ^{14}C concentration in the atmosphere and by compression and/or changes in sedimentation rates. The parameters which can add to each other or (partially) cancel each other will interfere with your study of atmospheric variations. How do you propose to distinguish between them?

Polach: We propose to follow ^{14}C changes down the profile. So far, we have documented that atmospheric changes can be detected in an attenuated form for the period 1950 to present. Our next task is to verify if changes documented by tree-ring studies can be also detected further down the peat profile.

Goh: The results, as presented by Dr Polach, could be better interpreted if effective fractionation techniques for separating mobile and inert fractions were applied.

Polach: We are aware of Professor Scharpenseel's and your approach, using intensive acid hydrolysis. Data on carbon mobility and concentration presented in the paper, however, does not indicate that such an approach would work in the peats under study.

Srdoč: Do you think that the phenomena and data you have presented are typical of any peat bog, regardless of climatic conditions, geographic location, and other factors that may influence the peat formation?

Polach: The only requirement, to my knowledge, is that the peat must build up in an autochthonous manner. This, of course, needs to be tested for a given climate or geographic location. We used the recent (1950 to present) atom-bomb-induced changes to test this.

Olsson: I saw from the slide that your swamp was covered by grass, but I never heard how you describe it in geologic terms. I often work with raised bogs, and in my experience, they are, so to speak, 'living'. They are continuously developing and changing. Often, we find *Sphagnum* remains that seem unaltered deep in the bog, with material that has decayed at other levels. Thus, you can expect the accumulation rate (as you see it now, cm/year) to vary in the core. This would preclude the study of past atmospheric $^{14}C/^{12}C$ variations in peat deposits.

Polach: You are correct in all your comments: 1) I did not describe the geologic conditions in my talk; they are given in the paper; 2) we agree with your statement of 'living' bog and, hence, have set out to test organic matter mobility through the profile. We found the intrusive contamination did occur. Nevertheless, we suggest an interpretation of the results; 3) the project has two aims: one is to document climatic history of the region, and two is to find out if ^{14}C variations in nature are preserved. The next stage of our work will give us answers to both these points.