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Applications of Radiocarbon Dating in Victoria, Australia

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Abstract: A brief outline of the radiocarbon method of dating is followed by a list of all the known datings of samples from Victoria. Literature references are given, but many datings are published for the first time. Illustrations are provided of how this form of dating has put perspective into geologic and archaeologic researches in Victoria. In conclusion, its value is assessed, and the need to distinguish varying purposes and degrees of reliabilitiy in dating are stressed.

THE RADIOCARBON METHOD

As animals living on the floor of the sea are thereby protected from the direct effects of solar radiation, so we and all other living things on the surface of the earth are protected by the atmosphere from the direct effects of cosmic radiation. However, the upper atmosphere is so affected, and one result is the changing of nitrogen 14 into carbon 14 which is 15 per cent heavier than normal carbon 12. The transmutation of elements that was for so long denied as being impossible takes place continuously in this way.

Scientific methods are often devised, and then later the fundamental processes involved are elucidated, but the existence of radiocarbon was worked out theoretically by Professor W. F. Libby, who then made a search for it. Likewise its mode of origin was worked out theoretically and then established with the aid of high-flying balloons. Libby also deduced that the radiocarbon cycle of formation, of assimilation in all living things, and then decay back to nitrogen could be used as a timepiece for dating the past. The proliferation of radiocarbon dating laboratories from one in 1950 to over 80 in 1968 (many with multiple apparatus) is witness to the high value of this method for certain fields of scientific endeavour, as also is the considerable literature on the subject, and a special publication (*Radiocarbon*) for reporting results. It has dramatically brought into perspective the geologic, geomorphic, archaelogic and biologic history of the past 40,000 years.

When a radiocarbon atom changes back to nitrogen it emits an electron, and a radiocarbon dating machine counts the flow of these electrons. The number per minute per gram of carbon allows the age to be calculated. The electrons punch a time clock, so to speak. Even in the richest material, the natural radiocarbon is remarkably scarce, having a concentration of only 10^{-12}, so in ancient specimens the activity is extremely low. This low level counting is difficult and expensive. Minute amounts of contamination can spoil the count.

Having invented a new timepiece, Professor Libby had to calibrate it, and he did this by the radiocarbon dating of materials of known age. He used wood from an ancient Californian redwood (*Sequoia*), historically dated Egyptian wood, and such like (Libby 1955). There was sufficient correlation between the historic ages and the radiocarbon ages to indicate that a valuable tool for chronology had been discovered. Professor Libby's method was to reduce the sample to pure carbon, but later this was replaced by a gas (such as carbon dioxide) which provides (1) greater equality of opportunity for disintegrations to be recorded, and (2) the opportunity to alter the concentration of the disintegrations by increasing the pressure of the gas. The latter is an advantage where the sample is ancient and the disintegrations relatively fewer. Since the method was invented in 1950, many refinements have been made and corrections applied. Two major alterations of the natural level of radiocarbon have been discovered, viz:

(1) That the Industrial Revolution resulted in vast quantities of dead carbon dioxide being poured into the atmosphere. This has diluted the concentration of ^{14}C.

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(2) That atom bombs have raised the level of ^{14}C in the atmosphere so that the level is now 60 per cent greater than before they were exploded.

Air enriched in radiocarbon by an atom bomb can be traced, and so the speed of mixing of air measured. It takes only 5-10 years to spread through the earth's atmosphere. However, it takes thousands of years for complete mixing in the oceans. For example, Pacific waters decrease in ^{14}C below 1000 m, and Antarctic waters upwelling from depth give an age of about 1800 years because they are deficient in radiocarbon (Rafter 1968). These deficiencies can be used for tracing the movements of bodies of oceanic water. Waters from two sites in the NE. Pacific Ocean at 2000 m gave dates of 2194 and 1480 y respectively (Williams et al. 1969).

Until recent years it was taken for granted that the rain of neutrons on the earth generating radiocarbon was constant, but it is now known that this is not so. Variations have been traced by counting tree rings back to 7100 years in redwoods and bristle cone pines (Ferguson 1968), then comparing the dendrologic age with the radiocarbon age (Damon et al. 1966, Dyck 1966, Jansen 1962, 1965, Kigoshi 1965, Suess 1967, Lerman et al. 1969, and others). Green (1968) queried my interpretation of radiocarbon dates from Aitape in New Guinea as a measure of the mean rate (he misquoted me as stating 'a sustained and constant rate') of tectonic uplift, but as the age is within the range checked by dendrologic chronology, there is insufficient reason for questioning the validity of the method. The effects of the sunspot cycle and geomagnetic variations are being studied (Libby 1965, 1967, Schell et al. 1965). The half-life of radiocarbon has not yet been finalized (Godwin 1962) so that a date $\times$ 1·03 is probably more correct. So there are many refinements needed, but Walton and Baxter (1968) consider that we are not yet at the stage where these can be satisfactorily applied.

There are other problems in radiocarbon dating (e.g. Shotton 1967). It has been found that plants growing in a lake which draws carbon from an ancient limestone in its floor can give dates of up to 2000 years, which is two millenia too old. Living plants growing at the sites of fumaroles, and of springs in ancient limstones, can give ^{14}C dates up to 20,000 years too old. On the other hand, carbonates as in mollusc shells can be dissolved and reprecipitated using carbon dioxide from the atmosphere, so that the age is diluted, and the result is too young.

Enough has been stated here to given an indication of the nature and the measure of the problems in the radiocarbon dating method. It will be clear that one cannot take a sample, put it in a machine and obtain a reliable answer. How good then is the radiocarbon dating method? Have we overrated it? Dyck (1967) reviewed the method and stated, 'The radiocarbon cycle, like all natural phenomena, deviates from the ideal; but until more sophisticated dating methods are discovered, it will remain the best timepiece for the most recent past in spite of its imperfections.' He further commented that 'a value in error even by 10-20 per cent is better than a thousand intelligent guesses'.

Nevertheless, the method is being improved all the time. Originally, 1-2 pounds of sample was asked for, but now a date can be done (if necessary) on 5 g of carbon. The range of materials that can be dated has been considerably extended. For example, at first bone was considered unsuitable, but then it was found that a reliable date could be obtained from the organic fraction (essentially the collagen). However, this disappears in most places within 5000-6000 years. Now a method has been discovered for using the carbon from the bone apatite (Berger et al. 1964, Haynes 1968). Similarly the organic component of shell (conchiolin) as well as the carbonate can be dated. Sea water can be dated by extracting its carbon dioxide. Ice from ancient glaciers can be dated in the same way, but about a metric ton is required to produce enough carbon dioxide (Oeschager et al. 1967). Even iron can be dated by the small amount of carbon present (Van der Merwe and Stuiver 1968), and this has opened up new possibilities for dating Iron Age sites.

This introduction provides a very brief account of the existing status of the radiocarbon dating method in so far as it is relevant to the present purpose. The most important thing in this method is to know what is being dated, i.e. to understand the origin of the carbon that is assayed. Results from the dating of Victorian samples will now be listed, and then their meaning discussed.

RADIOCARBON DATES ON SAMPLES FROM VICTORIA

All dates are B.P. (before 1950), and hereafter will be quoted in this paper by their list number. The date is followed by a brief description of the sample and note of its origin. If the collector's name is given, it follows in brackets; then the literature reference (if any) is provided. Some dates are published here for the first time. Some dates are different from those originally published because the laboratories concerned re-calculated them before publication in *Radiocarbon*. The differences are usually small.

1. **Modern (NZ-32).** Wood from central, most-decomposed part of root of standing *Eucalyptus oleosa* of 'Bull-mallee' habit about 4 ft in diameter, 40 ft high on Research Farm of Victorian Department of Agriculture (A. B. Costin). Grant-Taylor and Rafter 1963.

2. **170 ± 80 y (GaK-987).** Heartwood of large red gum, Victoria Valley, Grampians (L. K. M. Elmore).

3. **240 ± 84 (V-37).** Wood near base of soil profile in exposed bank of eroded creek on Kelleher property about 250 yd S. of Mt. Buller Rd. (A. Rundle). *Radiocarbon* 8: 510.

4. **260 ± 51 (ANU-30).** Charcoal from narrow vertical concentration (1 in. x 8 in.) in stream bed gravels beneath 78 in. of younger sediments of Campaspe prior stream exposed in gravel pit 6.5 miles NE. of Rochester (J. M. Bowler). *Radiocarbon* 10: 181. Date confirmed by N-294 225 ± 110 y.

5. **290 ± 50 (V-38).** Wood near base of soil profile in exposed bank of eroded creek on Graves property about 200 yd N. of Mt. Buller Rd. (A. Rundle). *Radiocarbon* 8: 509.

6. **370 ± 45 (NZ —).** Charcoal 6 ft from surface in centre of aboriginal rock shelter in dune limestone near mouth of Aire River. Mulvaney 1962.

7. **492 ± 36 (NZ —).** Fossil plant material (mostly reeds) from dark reddish-brown clayey zone 2 ft 6 in.–2 ft. 10 in. from surface, NE. corner of Lake Watt Watt, Snowy River Delta, Gippsland (E. D. Gill).

8. **538 ± 200 (C-601).** Charcoal from aboriginal midden in upper soil layer, Tower Hill Beach, between Warrnambool and Port Fairy. Libby 1955. Solid carbon method.

9. **760 ± 90 (GaK-965).** Shells of *Anadara trapezia* from slightly emerged shellbed on protected W. side of Point Henry, Corio Bay, Geelong (E. D. Gill).

10. **1020 ± 80 (GX-148).** Fossil wood from alluvium of Maribyrnong River at Braybrook exposed 2 ft from surface in a soil pit on E. side of Milleara Rd. and S. of Clarendon St. Gill 1966a.

11. **1177 ± 175 (C-600).** Charcoal from aboriginal midden at Goose Lagoon, W. of Port Fairy. Libby 1955; Gill 1955.

12. **1190 ± 90 (GaK-1059).** Organic fraction of aboriginal bones from Shire of Ararat gravel pit accompanied by mortar made from basalt. Gill 1969.

13. **1300 ± 250 (W-1478).** Fine carbonaceous matter from top of hardpan of soil in Port Campbell Project Square E5, 14.5-16.5 in. from surface. Gill 1965.

14. **1750 ± 115 (GX-60).** Marine shells from aboriginal midden in upper soil horizon, Tower Hill Beach, between Warrnambool and Port Fairy. Gill 1967a.

15. **1781 ± 115 (NZ —).** Carbonate from Green Gully human bones. Macintosh 1967, Mulvaney et al. 1970.

16. **1855 ± 85 (Y-150-1).** Charcoal from a second aboriginal midden at Goose Lagoon W. of Port Fairy. Gill 1955.

17. **1865 ± 85 (GX-149).** Small branch of red gum (*Eucalyptus camaldulensis*) of large tree exposed by the lowering of the level of Lake Bullenmerri, near Camperdown. The tree was in position of growth in a peaty soil (E. D. Gill).

18. **2370 ± 100 (GaK-2149).** Bore 1 through landward edge of sand barrier NE. of Seaspray, carbon of swamp deposit 8 ft 3 in. to 8 ft 7 in. Gill 1970b.

19. **2800 ± 100 (GaK-611).** Charcoal from aboriginal midden in the upper soil at Tower Hill beach. Gill 1967a.

20. **3010 ± 160 (W-125).** Charcoal from aboriginal fireplaces, Medway Golf Links, Braybrook, in wash with low dip overlying Doutta Galla Silt, revealed in soil pit section. Gill 1970a.

21. **3060 ± 100 (GaK-681).** Charcoal from aboriginal midden at excavation 5, site 9A, Yanakie, Wilsons Promontory. Coutts 1967.

22. **3145 ± 95 (V-78).** Charcoal on fire-burnt surface 8 ft beneath surface Maribyrnong Terrace near Green Gully, S. of Keilor. Bowler 1970.

23. **3480 ± 90 (GaK-970).** Charcoal from aboriginal midden in excavation 6, site 9A, Yanakie. Coutts 1967.

24. **3560 ± 100 (GaK-1060).** Marine shells 16-18 in. from surface in emerged stillwater marine deposit under Howe Flat, E. of Mallacoota Inlet, cf. 25 (E. D. Gill).

25. **3780 ± 100 (GaK-842).** Marine shells 28-36 in. from surface at Howe Flat, E. of Mallacoota Inlet, cf. 24 (E. D. Gill).

26. **3880 ± 250 (W-1477).** Resin of fossil grass-tree in situ from 10-11 in. below ground surface in Port Campbell Project Square R18, Port Campbell. Gill 1965.

27. **3920 ± 90 (GaK-968).** Aboriginal midden excavation 1, site 11, Yanakie. Coutts 1967.

28. **3980 ± 150 (GX58).** Marine shells 10-21 in. from surface and resting on marine aeolianite platform, SE. of Moulden's Quarry, Dennington. Gill 1967a; this date has also been published as 3750 ± 150 y.

29. **4100 ± 110 (GaK-2150).** Seaspray bore 1, organic carbon in sediment with vertical plant roots and freshwater sponge spicules, 11 ft to 11 ft 5 in. Gill 1970b.

30. **4170 ± 200 (GaK-1432).** Organic fraction of aboriginal bone from site 6, Keera Station, W. of Merbein (Chowilla Project, National Museum).

31. **4230 ± 65 (NZ).** Marine shells (*Katylesia peroni*) from emerged shellbed at Andersons Inlet. Gill 1966b.

32. **4315 ± 195 (GX59).** Marine shells from aboriginal midden in lower soil horizon at Tower Hill beach between Warrnambool and Port Fairy. Gill 1967a.

33. **4400 ± 220 (GaK-1433).** Organic fraction of aboriginal bones from site 6, Keera Station, W. of Merbein (Chowilla Project, National Museum).

34. **4440 ± 100 (V-77).** Fragment of *Eucalyptus camaldulensis* in MMBW trench 22 ft below surface, Maribyrnong Terrace near Green Gully. Bowler 1970.

35. **4510 ± 80 (NZ).** Marine shells *(Anadara trapezia)* from thin mud layer at top of sandy shellbed exposed in drain from Seaspray to Lake Reeve, Gippsland Lakes. Gill 1966b.

36. **4550 ± 120 (GaK-2518).** *Coxiella* shells in parna with fossil kangaroo, *Macropus* (*Megaleia*) *rufus*, at outlet of Lake Gnapurt to Lake Corangamite (H. E. Wilkinson).

37. **4750 ± 200 (PIC-8).** Marine shells (*Anadara trapezia*) from shellbed exposed in long drain running S. from Telegraph Road, Hedley, Gippsland, from 2.5-3 ft below surface. Parish of Welshpool, sect. 34 of B. *Radiocarbon* 7: 203; Gill 1966b.

38. **4820 ± 200 (W-170).** Wood of *Eucalyptus* bored by marine borers from marine shellbed 2.4 ft above LWM. on N. bank of Maribyrnong River at Brunel St., Essendon. Rubin & Suess 1955; Gill 1968a.

39. **4830 ± 250 (W-1476).** Charcoal 8-10 in. below surface and above australite in situ, Port Campbell Project Square H3, Port Campbell. Gill 1965.

40. **4910 ± 85 (NZ).** Marine shells from emerged shellbed at Foster Beach, Corner Inlet. Gill 1966b.

41. **5120 ± 120 (GaK-610).** Charcoal from aboriginal midden in lower soil horizon at Tower Hill Beach between Warrnambool and Port Fairy. Gill 1967a.

42. **5350 ± 90 (GaK-1431).** Organic fraction of aboriginal bones from site 6, Keera Station (Lybra Paddock), W. of Merbein (Chowilla Project, National Museum).

43. **5350 ± 350 (W-1473).** Charcoal 12-13 in. below surface and below level of australite in situ, Port Campbell Project Square L18, Port Campbell. Gill 1965.

44. **5400 ± 80 (NZ-196).** Wood from bore at pumping station on S. bank of Murray River at Psyche Bend, Mildura. Depth 35 ft from surface = 83 ft above sealevel (F. Penman, C.S.I.R.O., states drilling method ensures this depth correct for origin of sample). Ferguson and Rafter 1959.

45. **5540 ± 200 (GaK-705).** Organic fraction of aboriginal bones from carbonate zone at base of granitic talus apron overlying pediment 5 ft 6 in. from surface, Mitiamo. Gill 1967b.

46. **5560 ± 80 (NZ —).** Marine shells (*Katylesia rhytiphora*) from excavation for culvert, Miller's Road, Altona. Gill 1964.

47. **5590 ± 350 (W-1474).** Charcoal 10-11 in. below surface and above australite in situ, Port Campbell Project Square L19, Port Campbell. Gill 1965.

48. **5620 ± 90 (NZ-279).** Marine shells from emerged bed overlying freshwater Lara Limestone bored by marine molluscs, right bank Hovell Creek where crossed by Princes Highway N. of Geelong. Gill 1961.

49. **5700 ± 350 (W-1475).** Charcoal 11-12 in. below surface at level of australite in situ, Port Campbell Project Square L17, Port Campbell. Gill 1965.

50. **5840 ± 90 (GaK 1429).** Charcoal from among three aboriginal skeletons at site 1, Brown's Paddock, Keera Station, W. of Merbein (Chowilla Project, National Museum).

51. **5850 ± 320 (PIC-9).** Marine shells (*Homalina deltoidalis*) from excavation 26, Lake Pertobe, at foot of Cannon Hill, Warrnambool, from depth of 22 in. (Gill 1953, *Radiocarbon* 7: 203).

52. **5900 ± 550 (GaK-1430).** Aboriginal bones from site 5, Lybra Paddock, Keera Station, W. of Merbein (Chowilla Project, National Museum).

53. **5990 ± 105 (V-75).** Charcoal from lower part of the low terrace on right bank of Maribyrnong River near Green Gully tributary (J. M. Bowler).

54. **6010 ± 100 (GaK-1100).** *Eucalyptus* wood from 8 ft below surface in excavation in Power Street, S. Melb., associated with estuarine shells, and collected in 1900. Gill 1968a.

55. **6010 ± 110 (GaK-971).** Aboriginal midden on Cape Liptrap, Gippsland. Coutts 1967.

56. **6140 ± 150 (GaK-2155a).** Organic carbon from dark gray clayey silt, Bore 8, 9 ft 11 in. to 10 ft 8 in., Seaspray. Gill 1970b.

57. **6230 ± 430 (PIC-7).** Marine molluscs from depth of 4 ft in emerged shellbed covered by peat of swampy flat in research area of Department of Botany, University of Melbourne, near Tidal River, Wilsons Promontory. Gill 1967c; *Radiocarbon* 7: 203.

58. **6235 ± 120 (GX150).** Peat from Condah Swamp, 5-6 ft below surface, and near top of underlying basalt flow. Gill and Gibbons 1969.

59. **6330 ±.180 (GaK-2154b).** Marine shells in grey clayey silt from Bore 8, 8 ft to 8 ft 10 in., Seaspray. Gill 1970b.

60. **6360 ± 150 (GaK-2154a).** Same sample as 59 but date on marine shells. Gill 1970b.

61. **6435 ± 110 (GX152).** Carbonate from marsupial bones under parna dune on E. shore of Lake Weeranganuck 5 miles NE. of Camperdown (E. D. Gill, see 101).

62. **6450 ±.130 (GaK-2153).** Marine shells from Bore 1, 10 ft 10 in. to 12 ft 3 in., Seaspray. Gill 1970b.

63. **6450 ± 140 (GaK-2155b).** Marine shells from Bore 8, 9 ft 11 in. to 10 ft 8 in., Seaspray. Gill 1970b.

64. **6460 ± 190 (NZ —).** Bone collagen from fossil human remains, Green Gully, S. of Keilor. Macintosh 1967a, b; Mulvaney et al. 1970.

65. **6500 ± 200 (PIC-10).** Stratified marine shells *(Homalina deltoidalis)* from W. bank of Merri Canal, 1 chain downstream from Warrnambool Woollen Mill and near HWM., Warrnambool. Gill 1966b; *Radiocarbon* 7: 204.

66. **6550 ± 100 (GaK-683).** Charcoal from aboriginal occupation underlying GaK-681-2, excavation 5, site

9A, Yanakie, Wilsons Promontory. Coutts 1967; *Radiocarbon* 9: 56.

67. **6605 ± 190 (GX151).** Fragments of marsupial bones from Merri River, Bushfield, N. of Warrnambool. Gill 1967a.

68. **6630 ± 140 (GaK-2152).** Marine shells from Bore 1, 4 ft 8 in. to 5 ft 2 in., Seaspray. Gill 1970b.

69. **6810 ± 130 (GaK-2151).** Marine shells from Bore 1, 13 ft 10 in. to 14 ft 1 in., Seaspray. Gill 1970b.

70. **7040 ± 180 (GaK-1061).** Wood from emerged marine shellbed, Millers Road, Altona. Gill 1964.

71. **7360 ± 105 (NZ).** Chips of pedogenic calcite forming encrustation 1-2 mm thick on Keilor Cranium. Gill 1966a.

72. **7380 ± 250 (W-1336).** Humified fragments of stems (not roots) in top of carbonaceous hardpan on which australites are left following deflation. Site on old coastal road a short distance W. of country road to Loch Ard Gorge. Gill 1965; *Radiocarbon* 7: 395.

73. **7700 ± 140 (GaK-966).** Charcoal from possible aboriginal fireplace in Doutta Galla Silt on N. bank of Maribyrnong River upstream from Green Gully (E. D. Gill).

74. **7710 ± 150 (GaK-985).** Charcoal from possible aboriginal fireplace, N. bank of Maribyrnong River in Doutta Galla Silt upstream from Green Gully, near 73 (E. D. Gill).

75. **8155 ± 130 (V-63).** Charcoal a few inches above Green Gully burial, near Keilor. Mulvaney et al. 1970.

76. **8155 ± 130 (V-65).** Charcoal from tree root burnt in situ c. 3 ft below Green Gully burial. Mulvaney et al. 1970.

77. **8300 ± 210 (Y-151).** *Eucalyptus* wood from stump in position of growth found 63 ft below LWM. at S. abutment of Spencer St. Bridge, Melbourne. Gill 1968a.

78. **8330 ± 190 (GaK-1065).** Peat of bog moss *Sphagnum cristatum* at level of *Eucalyptus* stump in position of growth (77) under S. abutment of Spencer St. Bridge, Melbourne. Gill 1968a.

79. **8500 ± 250 (W-169).** Charcoal from 2 ft. 6 in. above diastem in Doutta Galla Silt near bottom of quarry on S. bank of Maribyrnong River, Braybrook. Gill 1956.

80. **8780 ± 200 (W-95).** Another part of the fossil *Eucalyptus* stump listed number 77. Gill 1968a.

81. **8990 ± 150 (V-64).** Charcoal c. 4 ft below top of Green Gully burial, near Keilor. Mulvaney et al. 1970.

82. **9340 ± 200 (Anon).** *Eucalyptus* wood from bore testing foundations of new Art Gallery in S. Melbourne, from 93 ft below surface (= 64 ft below LWM.). Gill 1968a.

83. **9650 ± 100 (GaK-1066).** *Eucalyptus* wood from bore testing foundations for new Art Gallery, S. Melbourne. Gill 1968a.

84. **11,030 ± 140 (V-74).** Fragments of root charcoal from excavation at junction of Keilor and Intermediate Terraces on right bank, Maribyrnong River, near Green Gully (J. M. Bowler).

85. **11,250 ± 240 (GaK-1062).** Selected thick pieces of well preserved *Velesunio* shell from base of large aboriginal midden on right bank of Murray River, Redcliffs (H. F. Thomas).

86. **12,810 ± 210 (GaK-1101).** *Eucalyptus* wood from 93-94 ft in bore testing foundations of King St. Bridge, Melbourne. Gill 1968a.

87. **12,900 ± 210 (GaK-742).** Marine shells from E. Australian Continental Shelf at 70 fathoms (C. V. G. Phipps). Gill 1967c.

88. **13,500 ± 700 (ANU-29).** Charcoal from alluvial silt later buried by overbank deposition to depth 116 in. below present surface, exposed in left bank Goulburn River 9.5 miles ENE. of Echuca (J. M. Bowler). *Radiocarbon* 10: 181.

89. **13,700 ± 250 (Y-170).** Brackish water gastropod shells (*Coxiella*) from marsupial bone bed on E. side of Lake Colongulac, near Camperdown. Gill 1963; Barendsen, Deevey, and Gralenski 1957.

90. **14,600 ± 200 (GaK-1064).** Carbon from podsolic hardpan 2 ft 6 in. from surface thereof where pan 5 ft thick in road cutting at top of hill W. of Sherbrook River on Ocean Road, E. of Port Campbell. Gill 1970c.

91. **14,940 ± .500 (V-79).** Wood charcoal from section through Keilor Terrace exposed on right bank of Maribyrnong River upstream from junction with Green Gully, near Keilor (J. M. Bowler).

92. **15,000 ± 1500 (NZ-366).** Small sample of charcoal in Keilor Cranium Quarry from about the level from which the cranium came. Because sample so small, carbonate not removed.

93. **15,200 ± 320 (GaK-509).** Bones from stratified layer, McEacherns Cave, 5 miles N. of Nelson. Wakefield 1967.

94. **17,300 ± 300 (V-73).** Charcoal from extensive surface with oxidized silts, Green Gully excavations (J. M. Bowler). Mulvaney et al. 1970.

95. **17,800 ± 600 (GaK-2516).** Charcoal from near base Doutta Galla Silt, Keilor Cranium site, Gallus sample KA395.

96. **18000 ± 500 (NZ-207).** Charcoal from aboriginal fireplace 5 ft 9 in. below level of cranium from Keilor Cranium Quarry in Doutta Galla Silt where Dry Creek enters Maribyrnong River. Gill 1967a.

97. **19,300 ± 600 (GaK-2517).** Wood from gravel with marsupial bones under 112 ft of basalt, Ettrick Bore 3 (Geological Survey of Victoria).

98. **20,100 ± 500 (NZ —).** Earthy charcoal near beach level in gray parna with reddish soil (interpreted as burnt ground) immediately underneath, the structure dipping lakewards at 30°, SE. shore Lake Colongulac near Camperdown (E. D. Gill).

99. **22,850 ± 750 (GaK-1067).** Marine shells from emerged shellbed under peat, Goose Lagoon, W. of Port Fairy (E. D. Gill).

100. **24,000 ± 3,300/5,700 (ANU-81).** Charcoal from Gallus excavation at Keilor Cranium site, about 40 in. from ANU-65. *Radiocarbon* 10: 189.

101. **25,300 ± 1,200 (GaK-986).** Brackish water gastropod shells (*Coxiella*) from bone bed below parna dune at Lake Weeranganuck (E. D. Gill, see 61).

102. **28,240 ± 1,100 (Y-230).** Brackish water shells (*Coxiella*) from parna dune on E. shore of Lake Corangamite near Cundare, Beeac, Military map 628, 956. Barendsen, Deevey and Gralenski 1957.

103. **>30,000 (W-185).** Marine shells from deposit of Port Fairy Calcarenite on emerged shore platform at Two Mile Bay W. of Port Campbell. Baker and Gill 1957.

104. **30,700 ± 1,850 (V-76).** Charcoal fragments from MMBW trench across Maribyrnong River near Keilor, from W. bank in soil developed in material of Arundel Terrace (J. M. Bowler).

105. **>31,000 (V-23).** Wood of *Eucalyptus camaldulensis*, Murmungee 38, Ovens Valley (B. R. Thompson). *Radiocarbon* 8: 509.

106. **31,600 ± 1,100/1,300 (ANU-65).** Charcoal from third of four strata about 40 in. beneath face of Keilor Terrace in Gallus excavation, Dry Creek, Arundel. *Radiocarbon* 10: 189.

107. **>35,000 (W-195).** Marine shells from Port Fairy Calcarenite (Gill 1956). Dated 120,000 years by Valentine, using ionium method.

108. **>41,000 (GaK-2045).** Wood from Moray St. Gravels in foundations (pier 15) of Lower Yarra Crossing (A. E. Makram, Victorian Mines Dept.).

109. **41,700 ± 1,900 (GaK-890).** Humified wood from sand 158-192 ft in. bore 11.5 miles S. of Benetook, NW. Victoria (F. N. Bethune).

INTERPRETATION OF RADIOCARBON DATES

With the half life of radiocarbon still not finalized, and with a number of corrections still to be applied, the accuracy of radiocarbon dating is not that which is suggested by the form in which it is expressed. Dates often conclude in numbers less than ten, so that the figures have the appearance of an accuracy they do not possess. To express the figures as dates AD or BC likewise gives the impression of an accuracy which does not apply. On the other hand, radiocarbon dates fix time with an accuracy which has not hitherto been possible. An outstanding advantage is that they come from a different discipline, and so act as a check on deductions from the earth sciences. There is no easy way or comfortable short cut to dating the past. All the evidence available needs to be brought together and the results checked inductively. The ideal is a self-checking network of dates determined on the most reliable materials such as wood or charcoal. Samples for such a network are seldom available, and even when they are, the cost is often too high. In all radiocarbon dating the geochronologist should consider (a) what in fact he has dated, and (b) what is the order of accuracy attained.

A radiocarbon assay sometimes raises a problem instead of solving one. Thus an assay of charcoal from a camp site of the extinct Tasmanian Aborigines gave a date in the future, which is obviously incorrect. Another example is the effort to age the sediments in Lake Eyre in Central Australia. In preparing a report for INQUA on the Holocene of Australia, the literature on Lake Eyre was studied. King (1956) showed that a freshwater limestone underlay the area, and that over this was a series of layers which indicated, in general, an increase in salinity. His geological section of Sulphur Peninsula showed a bed of sulphur nodules 26-27 ft 6 in. from the top of this horizontal series of layers. The nodules included organic matter that gave a radiocarbonage of 19,200 ± 500 years. Apart from some windblown sand, the top bed in the section is one rich in the shells of *Coxiella*, which grows in brackish lake waters. Since this bed was emplaced, it appeared, the present basin of Lake Eyre had been scooped out, leaving cliffs of former lake sediments now standing 36 ft above the present lake floor. As the lake floor is below sealevel, the only means of erosion appears to be the wind. The question arose as to whether in a drier postglacial period, the area had dried up, the lake floor was desiccated, and the present basin eroded. If this were so, the shellbed would provide a maximal date for this important event. With the co-operation of Mr. R. C. Sprigg, a large sample of the shells was obtained. A part was analysed by the Chief Government Chemist in Melbourne, and a part sent for radiocarbon assay to Dr. Athol Rafter in New Zealand where the sulphur nodules had been dated. The analysis revealed the following percentages—calcium 13·3, carbonate 12·5, sulphate 11·9, silica 54·4—so the calcium carbonate constituted about 20·8 per cent of the sample and gypsum 16·8 per cent. Since the shellbed apparently superposed the nodule bed, a date considerably less than 19,000 years was expected, but the date obtained was 39,200 ± 1300 years. Thus the age obtained was of a magnitude of about 6 times greater than was expected, i.e. too old to be explicable by contamination. As a check, another part of the same sample was sent to New Zealand for radiocarbon dating, and this gave an age of 32,200 ± 1450 years. This comparable age showed that the bed was definitely older instead of younger than the bed with the sulphur nodules.

Johns (1962) re-studied Lake Eyre geologically, and suggested two possible solutions of this problem raised by the radiocarbon date for the shells (the second date had not been obtained then), viz:

(1) Superposition does not apply. The sulphur nodule bed may be alongside instead of stratigraphically below the shellbed.

(2) The sulphur nodules used for dating were taken from the lake floor where they had suffered aerial contamination.

Point (1) is important, and can be checked by boring. Point (2) provides an inadequate explanation because the material used for dating was the biologic carbon of recently living species, so contamination of this order is very unlikely.

I offer for investigation a third possibility:

(3) The greater age of the shellbed could be due to shells being excavated from the lake floor and blown up on to the peninsula during a dry period. The age obtained would then be the age of the material and not the age of its emplacement.

Sedimentary structures in the bed could probably prove how it was emplaced, and its relationship to the bed below reveal whether it is part of an uninterrupted sedimentary sequence. Subsequent filling of the lake could cause cliff cutting with removal of the ramp up which the shellbed material blew, and thus the formation of the present cliffs. The appreciable difference in age obtained by radiocarbon assay for the shells (32,200 and 39,200) could be explained if the material is a mixture of shells removed from the floor of the lake. A radiocarbon dating of material from the bed below the shell layer would also assist elucidation of the chronology.

So the attempt to date the Lake Eyre sediments did not provide an answer but only a new problem. However, this is itself helpful, and in due course the problem will be solved.

INTERPRETATION OF VICTORIAN RADIOCARBON DATES

The two samples (8, 11) sent to Professor W. F. Libby were the first specimens from Australia to be dated by this new method. Since then there has been a progressive interpretation of those results, both because of greater knowledge of the radiocarbon method, and because of growing knowledge of the environment from which the samples came. So it is with all radiocarbon dates. There is a growing appreciation of what a dating means and what can justifiably be read from it. For many years no funds were available locally for radiocarbon dating, and those done were by the kindness of the laboratories, or in exchange for services. Thus for a long time only spot dates here and there could be assayed, but they were nevertheless very helpful in giving some idea of age. As adequate resources for full radiocarbon dating are still not available, it will be some time before we can say that any event or process has been adequately dated. Thus the applications of dating which will now be outlined should be considered as in the nature of first approximations. However, the differing purposes of radiocarbon dating should be recognized: for example, the purpose of the geologist carrying out a reconnaissance survey and wanting some idea of age would differ from that of an archaeologist working inch by inch through a cave deposit and seeking refined dating.

RADIOCARBON AND ABORIGINAL ANTIQUITY

The discovery of the Keilor Cranium in 1940 (Mahony 1943a, b) stimulated the study of the Maribyrnong River Valley. Keble and Macpherson (1946) gave a thalassostatic interpretation of the fluviatile terraces of the Maribyrnong River Valley, and on this basis dated the Keilor floodplain as Würm 1. When the writer succeeded Keble at the National Museum, Keble strongly recommended that the study of the Maribyrnong River Valley and the Keilor Cranium be continued, and so this was done. However, a different interpretation of the terraces was reached because they were regarded as fluviatile in origin. The terrace of yellow silt that contained the Keilor Cranium was traced down the valley and these compacted oxidised sediments were seen to descend below sealevel and to be covered by the unoxidised uncompacted sediments of the Flandrian Transgression (Gill 1962). The terrace was thus graded to a lower sealevel, earlier than the Postglacial sediments. It was therefore dated as Late Glacial. This is about as far as one could go without isotopic dating. The formation characterized by yellow silt (in which the Keilor Cranium was found) is the Doutta Galla Silt, and its surface is the Keilor Terrace (Gill 1962). The upper part of the terrace is an unusual sediment. It is fine grained and exceptionally well sorted, so much so that overseas visitors usually take it for loess. The quartz grains are of the size carried by the winds, and it is considered that this was a windblown deposit later washed into the river valley, because it has sedimentary structures and it does not extend up the valley walls. A few deposits of this kind have been found in hollows in the basalt plain above the valley. It is this fine grained material that has been worked commercially for non-ferrous castings. In such a quarry the Keilor Cranium was found, and this explains why the quarry was no deeper than it was. Any sediment from below the level of the floor of the quarry was rejected by the foundries. Samples so far dated from this upper part of the terrace range from 6460 to 8990 years. The top of the terrace has not yet been dated, but it is older than 4400 years. A sample from the level of the Cranium dated 15,000 years, but was too small for precise dating. However, it gives the order of age, which is the maximal radiocarbon date for human skeletal material found in Victoria up to the present, although some may well be older. The relatively poorly sorted sediments below this level, often current bedded, date up to 18,000 years (95, 96), which must be near the maximal date of the deposit. Sample 95 dated 17,800 years came from only 5 in. above the basal gravel. A midden of similar age (18,200 ± 800, GaK-2514) has been found at Lake Victoria in NSW, not far from the Victorian border. From the bottom of this terrace have come the oldest dated Aboriginal implements, universally accepted as such, at Keilor. Bones, scattered charcoal and chipped stones excavated by Dr. A. Gallus and members of the Archaeological Society of Victoria are dated as 24,000 and 31,600 years. The detailed evidence of these ancient sites is awaited with interest. The writer interprets the matrix as slumped material from the Arundel Formation. It contains extinct giant marsupials while only extant species are known from the Doutta Galla Silt. Similar material at the Green Gully site was dated 30,700 years. Thus in the Maribyrnong River Valley radiocarbon has given much more precision to dating, and has made possible correlation from one part to another.

The radiocarbon dating of carbonate encrustation from the Keilor Cranium illustrates the problem of knowing what exactly has been dated. Chips 1-2 mm thick from the skull gave an age of 7360 years. What does this date? X-ray determination at the Institute of Nuclear Sciences in New Zealand showed the material to be calcite, the more stable form of calcium carbonate. On the other hand, the mineral deposit was thin, and chalky on the outside. Some exchange with soil air since it was deposited is likely. The date is minimal for the Cranium, but how far from the real date? The Cranium came from the B-horizon of a paleosol, and so the carbonate was derived from the leaching of the ground above. As the soil profile dried out, the carbonate was deposited, utilizing the air in the soil. Thus after the Keilor Cranium was deposited by the river, at least two ft of sediment were deposited above it, and a soil profile gradually developed therein, so reducing its thickness. By analogy, it is estimated that this would take at least 2000 years. The Cranium is therefore older than 7360 years by the time taken to deposit 2+ ft of sediment, by the time taken to develop the soil profile (so depositing the carbonate), and by the amount of age dilution that has occurred since. Thus the ^{14}C date is the age of the soil air used to precipitate the carbonate plus any age dilution that has occurred in the meantime.

By contrast we may consider a site where the geology is not known, e.g. an extensive aboriginal midden at Redcliffs on the Murray River (85). Mr. H. F. Thomas of Mildura and his associates found this midden and asked for advice about dating it. Some thought it to be historically recent, but there was reason for believing it to be older because of its compaction, and its relationship to the erosion of the high river cliffs upon which it stands. The radiocarbon date was determined on mussel shell (*Velesunio ambiguus*) which was thick and well preserved, and from which the outer surface had been stripped. However, the date of 11,250 years was a surprise. There is no reason to doubt this date for the base of the midden, and indeed it could be younger than the real age in that the material assayed is carbonate. Other middens in the region have since been dated as 15,300 ± 500 (GaK-2515) and 18,200 ± 800 (GaK-2514) y BP.

Control on radiocarbon datings on freshwater mussel shells (*Velesunio ambiguus*) consists so far of the following assays:

1. Shells with soft parts collected in 1934 (before atom-bomb contamination) by Messrs E. Le G. Troughton and H. O. Fletcher on Avon Downs Station, Queensland, gave a date of —8·3 ± 4 years (DSIR Institute of Nuclear Sciences, NZ) which Dr. T. A. Rafter states 'is a very good zero for pre-bomb fresh water mussels. Its ^{14}C activity corresponds almost exactly to the ^{14}C activity of the atmosphere here in 1934 due to the Industrial Effect depletion since 1890'.

2. Shells collected near Tartanga on the River Murray in S. Australia by Dr. N. B. Tindale in 1953 gave a date of —39 ± 14 years (Broecker and Olson 1959, p. 128).

3. Shells collected by me in Dalrymple Creek near the Talgai Cranium site on the Darling Downs, Queensland in 1963 have suffered contamination (presumably from atom bombs) and gave a future date, viz. —850 ± 170, GX-62).

As yet we know little of the prehistory of Vic toria. Radiocarbon datings have been obtained for cultural objects, but these are unlikely to be the earliest occurrences. Nevertheless, the few dates obtained have already helped perspective in our prehistory.

RADIOCARBON AND THE LONGEVITY OF NATIVE TREES

In 1895, people passing over the Black Spur to Healesville in the daily Cobb and Co. coaches saw 'Uncle Sam', a giant *Eucalyptus* over 250 ft high (measured by theodolite) given variously as 36 ft and 40 ft in diameter 6 ft from the ground (Caire 1905). One and a half miles away they could see the stump of 'Big Ben' felled for the Paris Exhibition and measuring over 250 ft high with a circumference of 57 ft. After it was felled, the rings were counted and found to be 1200 in number. The 'Neerim Giant' was measured by the Government Surveyor as 325 ft high and 48 ft in circumference. Many of these great trees were killed by the 1902 bushfires and other fires later. Many have been felled. Few people nowadays have seen such trees. How old were these trees, and to what age do our native trees grow? It has been claimed that the red gum (*Eucalyptus camaldulensis*) grows to over 1000 years old. A similar claim has been made for the grasstree (*Xanthorrhoea australis*) and the bull-mallee (*Eucalyptus oleosa*). Radiocarbon dating can provide some real information on this subject. A botanist chose from the huge lignotuber of a big bull-mallee a sample which it was thought would indicate the age of this tree, but the wood gave a modern date. One has often been pressed to make a radiocarbon assay of grasstrees, but when one notes how quickly they regenerate after a bushfire, and that the specimens planted by Guilfoyle in the Royal Botanic Gardens between 1870 and 1880 are now 10 to 15 ft high, it would not appear that they have a great antiquity. So far the funds have not been available for testing grasstrees, but radiocarbon could provide an answer. The Southern Beech (*Nothofagus*) in New Guinea was dated on heartwood at 550 ± 85 years. The heartwood of a red gum (*E. camaldulensis*) from the SE. of S. Australia gave a qualitative date of 950 years. The laboratory concerned made a rapid test and not a definitive assay, but the order of age is of great interest. Having asked Mr. L. K. M. Elmore of Hamilton to watch for any particularly large red gum being felled in his district so that the heartwood could be dated by radiocarbon, he obtained such a sample from what appeared to be a very old tree. It was growing within 30 ft of the vertical banks of Dwyers Creek, which revealed 8 ft of sandy silt overlying ferruginous clay. At ground level the tree had a circumference of 53 ft 6 in., at 4 ft from the ground a circumference of 40 ft, at 14 ft from the ground 27 ft, and the sample was taken from the apex of the hollow inside the tree at about 16 ft above the ground. The rings of *Eucalyptus* are not laid down regularly and so cannot be used for determining the age of a tree, so it was hoped that the present sample would date the antiquity of this big red gum. It was collected in 1962 from the property of Mr. D. McArthur in the Victoria Valley in the Grampians. The age obtained was 170 ± 80 years, which was less than expected. The matter was submitted to Dr. M. R. Jacobs, Director-General of the Commonwealth Forestry and Timber Bureau, who stated that 'the wood of all hardwood trees matures from the cambium in quite strong tangential compression and severe longitudinal tension. In the case under discussion tangential compression would be the important factor atlhough the longitudinal tension can crush the interior cells and make them more susceptible to attack by fungi'. He stated that as the tree is narrow above the spread hollow part of the trunk, the date appears to be quite reasonable. He provided a photograph of a red gum planted E. of the Andes in Argentina and quoted as 30 years old, but a large tree of the order of five feet in diameter. The tree could not be much older than 60 years. So it is possible for red gum trees to grow very rapidly. Thus the red gum in the Victoria Valley appeared to be a very old tree but it was only of the order of 170 years old. The centre had failed and the tree had expanded to give the appearance of a tree of great antiquity. The samples of *Eucalyptus camaldulensis* were determined by Mr. H. D. Ingle of CSIRO Division of Forest Products.

Thus very little has been done to test by the effective radiocarbon dating method the longevity of our native trees. This question has interest for the geologist because on dating a piece of wood from a geologic formation he wishes to know the biologic age of the sample he has dated, and what is the maximal age for the species concerned. For example, when the foundations of the new Art Gallery beside St. Kilda Road in Melbourne were being tested, wood was obtained at 94 ft from the surface in one of the bore holes. The site is that of an ancient course of the River Yarra, and the level from which the wood came was 64 ft below sea level. The age obtained was 9340 ± 200 years. Is this approximately the age of the sediment at that level, or is this a piece of wood of a 1000 year old tree? Judging by dates obtained for other levels in the delta, the tree is probably not so old. However, this indicates the type of problem which can arise, i.e. the biologic age of a piece of wood dated from a geologic formation.

RADIOCARBON AND THE AGE OF AUSTRALITES

At the request of the National Aeronautics and Space Administration, and with financial assistance from them, australites were sought in situ for dating. When did our planet sweep up this shower of glassy tektites from space? With the help of a group of university students, an archaeologic type of excavation was dug at Port Campbell and 14 australites discovered in place. The site revealed 10-12 in. of sandy topsoil, under which was a hardpan consisting of sand cemented with humic matter and iron. Although this appeared to be a normal soil profile, it was discovered that the lowest 2-3 in. of the topsoil contained an increased percentage of heavy minerals, the australites, aboriginal artifacts, some buckshot gravel, and charcoal. Winnowing concentrated these materials at this level, and later the topsoil was reconstituted. This in itself was a useful discovery. When did it occur? Humified pieces of plant stem (not roots) in the top of the hardpan dated 7380 years. Samples of charcoal in the lowest 2-3 in. of the topsoil gave dates from 4830 to 5700 years. Just above this level, in the sand of the reconstituted topsoil, a ring of grasstree resin gave a date of 3880 years. Thus between 4000 and 6000 years ago this topsoil was winnowed during a time of greater soil instability. There is widespread evidence of a small climatic change at this time, including the evidence of marine fossils. In this same area a place was found where the hardpan was exceptionally thick, and in the middle of it (2 ft 6 in. from the top of the hardpan) a sample was obtained that gave a date of 14,600 years. The relationship of this hardpan to present sea level, and the fact that it runs down the walls of quite young valleys, shows that it is fairly recent geologically. It belongs to the cooler and presumably wetter conditions of the Last Glacial. Radiocarbon has thus dated the time of emplacement of the australites where they were discovered, but how is this related to the time of fall? In this situation, the hardpan appears to provide a maximal date for the australites, but if the buckshot was washed in from some other site, perhaps the australites were also washed in. Thus a search is being made for any older formation from which they could come.

RADIOCARBON AND CLIMATIC CHANGE

Because of the considerable range of weather in a single day, the considerable climatic change over the yearly seasonal cycle, and the larger cycles of drier and wetter years, all enveloped in the bigger cycles of major climatic change, it is difficult to trace with assurance the climatic changes of the past. The gross change of climate between the mid-Tertiary and now is obvious. In the shorter range of Quaternary time there have been changes, but they are not so apparent. Because the investigation is difficult, some abandon it. Some will accept only that minimal amount of change that can be fully proved, but this is not the product of a balanced judgement. By considering patterns of change over wide areas of country, the small local changes can be smoothed out, and the general direction of change discerned. We plot change against time, and isotopic dating is the best way to determine the time factor. As examples, let us consider three types of regional pattern that have changed with time.

1. SOILS: The terrain has experienced successive periods of stability and instability as Butler, Churchward, Walker, Galloway, Bowler and others have described. Changes in regional subaerial conditions have brought about these and other changes in the nature of the landscape. Thus the terrain is covered by a patchwork of soils not due simply to differing substrates and differing degrees of development (cf. Gibbons and Gill 1964). As a starting point let us note that in the Pliocene lateritic soils were developed in both N. and S. Victoria. This was before the main uplift of the Dividing Range during the Kosciusko Epoch. The formation of laterite depends on alternate wet and dry seasons as in a monsoon area. To have laterites develop over both N. and S. Victoria proves that the climatic conditions were different from the present. However much time were allowed, laterites could not be formed under present conditions, which are not such that the soil could be leached to the depth, and with the severity, that occurs in lateritisation. Conversely, would it not be a surprising thing if the uplift of the Dividing Range caused no difference in climate? Subsequent to the laterites in S. Victoria krasnozems and red earths were formed, followed by podzolic types. In N. Victoria the laterite was followed by a soil in which silicified sandstone, silcrete, or common opal was formed. This was followed by a series of carbonate-bearing soils with intercalated periods of soil destruction. That the soils mobilised iron, then mobilised silica, and later carbonate, indicates changes in climatic conditions. The amount of rainfall, the degree of leaching, and the geochemical conditions are different for each of these types of soil. The geologic and pedologic evidence indicates that there were at least three

cycles of carbonate soil formation. Radiocarbon shows that one is late Pleistocene to Holocene, one is Last Glacial, and one is beyond the time range of the method.

2. DUNE SYSTEMS: In N. Victoria and the adjacent parts of New South Wales and South Australia there is a very extensive system of E-W. dunes. During the 1945 and recent droughts, terrain instability increased (with development of dust storms) and the crests of some of the dunes began to move. Nevertheless, as a system, these dunes are dead. Paleosols within them show that there were stages in their construction, i.e. oscillations of climate. An auger hole was sunk through one of these dunes on Berribee Station in the extreme NW. of Victoria. In addition to the carbonate horizon of the present soil at the surface there were two other carbonate horizons. The bore traversed more carbonate-impregnated sediment than carbonate-free sediment. So much carbonate could not be produced from the sediments themselves and so must have been blown in, presuming dust storms. The dating by radiocarbon of the paleosols in this dune system is now being attempted. This system is built over the Last Glacial terrain, and radiocarbon is our only means at present of dating the climatic changes that brought about these geomorphic changes.

3. SEALEVELS: Quaternary changes of sealevel are associated with changes in climate. These will be discussed in a separate section.

RADIOCARBON AND SEALEVELS

One of the surprising results of modern science is that sealevel is so mobile. It is only about 7000 years since Port Phillip Bay and all the harbours of Victoria were mostly dry land. Radiocarbon dating has contributed in a major way to the study of sealevels. Emerged marine beds of Holocene age have long been observed in Victoria, but their dating was generalized, correlation from place to place was hazardous, and international correlation impossible. Usually the more recent a process, the more accurately it can be traced, and the more fully understood, but with sealevels it is not so. The changes over the past 11,000 years are the subject of symposia in various parts of the world, and there is major disagreement as to what happened. For instance, some believe there was a stand or stands of the sea up to 10 ft higher than now in the last 6000 years, while others deny this. It may well be that there is some factor involved not recognized before, or inadequately assessed. However, if in each area of the world the evidence is recorded and dated by radiocarbon, then it will be possible to think more objectively on this matter. Insufficient data and too few dates are the present limiting factors.

The coast of Victoria is essentially E.-W., and extends for 500 miles of latitude. Emerged marine shell beds are common. As is to be expected, they occur more widely in flat country, but they also occur in mountainous areas in estuaries and such places. A research project on this subject has been concentrated on stratified stillwater marine beds that have been laid down behind coastal sand barriers. Such beds are deposited below low water mark, so to survey from the top of such a deposit to present low water mark provides a measure of the minimal amount of sealevel fall since the bed was emplaced. This has been done in many places in Victoria and the figure is always of the order of 6 ft in spite of various tidal ranges. In some places the shell bed is overlain by muddy estuarine deposit with such species as *Anadara trapezia* in position of growth (e.g. Seaspray, Gippsland). Stillwater marine beds are low energy deposits, and so there are no problems such as shells thrown up by storm waves.

The coast of Victoria is crossed by six tectonic provinces consisting of alternative negative structures (basins) and positive structures (horsts). From W. to E. the structures are the Otway Basin, the Otway Horst, the Central Sunklands (Port Phillip, Western Port), the S. Gippsland Horst, the Gippsland Basin, and the E. Gippsland Horst. Whether the emerged beds are on horsts or in basins, they are at about the same level and contrast with those of Last Interglacial age which in some areas have suffered deformation. While it is possible that the 500 miles of coast has moved as a unit, this is not likely, as there are active faults bordering most of these structures. However, what is found here is not found all over the globe, e.g. on the coast of California such emerged beds are not apparent as they are in Victoria.

Radiocarbon dating shows that these Postglacial emerged marine shell beds in Victoria belong mostly if not altogether to the period of 4000 to 6000 years ago. Such chronometric dating allows comparison with events on land, and with shoreline structures in distant places.

RADIOCARBON AND THE YARRA DELTA

The River Yarra has had many deltas according to the position of sealevel. The present delta is a late Quaternary structure consisting of soft gray unoxidised silt that infills Last Glacial channels and spreads over the surrounding flat areas to a few feet above present high water level. Its lack of compaction has caused many problems for bridge and harbour engineers. At the base of this Coode Island Silt is the gravel that accumulated when the rejuvenated river was running in the floors of the channels. When the oil wharf at Williamstown had to be extended to accommodate bigger oil tankers, a difficulty existed in that it had already been built to the edge of a Pleistocene channel, infilled with sediments of inadequate bearing strength. The problem was solved by excavating the sediments to 60 ft by deep dredging, and infilling with sand from near the Brighton coast, then building the wharf on the new substrate.

The deep dredging over this considerable area revealed that the mollusc *Anadara trapezia* occupies a zone at the top of the delta and does not extend to great depth. This is not surprising because this species is at the extreme of its range in Port Phillip at present, and instead of occurring in great numbers between tide marks (as in Port Jackson for example) it occurs only in small numbers at or below low tide. So the enormous numbers of *Anadara*, their growth to such large size (up to 5 in. wide) and their position at the top of a formation rising above present sealevel indicate conditions a little warmer than at present.

At Altona the shell beds and associated sediments overlie a thick basalt flow, so minimal compaction is involved. At the base of these sediments is swamp mud, followed by beach sand over which is a marine shell bed, which passes up into beach sands again and the present swamp. Shells from the marine shell bed gave a radiocarbon date of 5560 years while a piece of wood from the base of the bed gave a date of 7040 years. This shell bed is widely spread through the delta and extends up both the Maribyrnong and Yarra Rivers into tracts which were occupied by fresh water under natural conditions. At Brunel Street, Essendon, a piece of red gum wood bored by marine borers was found in a stratified shell bed and gave an age of 4820 years. Just across the river excavations showed the extension of these shell beds over a considerable area and *Anadara trapezia* was common. The bones of a porpoise were also found there. The top of the Brunel Street shell bed is 2·4 ft above low water (MMBW datum) where the present tidal range is only six inches. As this stratified bed was deposited below low water, emergence is indicated. Estuarine muds with *Anadara* on the opposite bank rise above this level. At Power Street, South Melbourne, an excavation revealed an old channel of the Yarra with marine shells and drift wood that dated 6010 years. These dates agree with those obtained for similar emerged marine shell beds in many other parts of Victoria. The Coode Island Silt occupying the channels is of course older. Thus a tree stump found under the S. abutment of the Spencer Street Bridge at 63 ft below low water, and peat at the same level, gave radiocarbon dates ranging from 8330 to 8780 years. Wood from 64 ft below low water mark in the new Art Gallery foundations (bore 23) gave a date of 9650 years while bore 10 on the site of the King Street Bridge yielded at 93 ft a piece of wood which gave a date of 12,810 years. At a depth of 60 ft in the channel that was excavated at the oil wharf, a diatom flora was found which is unlike that at present in the bay, but is comparable with the assemblage at Hobart where the average temperature is 5°C cooler.

Underlying the unoxidised and uncompacted Coode Island Silt is another formation that is a close parallel to it—the Fishermans Bend Silt. However, this silt was exposed during the last low sealevel with the result that it was drained, oxidised, and in places leached. This formation has not yet been directly dated. However, the Victorian Mines Department obtained a radiocarbon date on wood from the Moray Street Gravels at their base of >41,000 years. The Fishermans Bend Silt also contains *Anadara trapezia*, and is thought to be Last Interglacial in age. This species has not been seen in any older formation.

RADIOCARBON AND EXTINCT MARSUPIALS

The first dating of a site with extinct marsupials in Australia was at Lake Colongulac in Western Victoria (Gill 1953). The sample consisted of over one pound of the small brackish water gastropod *Coxiella*, each carefully cleaned inside and out. The shells were from a fossil beach deposit comparable with the banks of shells to be seen at certain times on present lake shores. Only complete or nearly complete shells were accepted so as to avoid re-cycled material. Bones of extinct kangaroos and other marsupials were found in the same deposit. It took about one hundred man hours to prepare this sample, and members of the Field Naturalists' Club of Victoria assisted with it. In those days large samples were needed because the solid carbon method was employed. It was a disappointment that after so much work the dating was spoilt by an early atom bomb test, but when the gas method of radiocarbon dating was invented, the sample was re-prepared and a date obtained, viz. 13,700 years. This dating was the first indication in years of the age of these deposits, and was very welcome, although it had the obvious defects of being an isolated determination, and based on thin shells which could have suffered exchange on their extensive shell/air interfaces. The date was therefore a minimal one (Gill 1968b). In spite of extensive search over many years no wood or charcoal was found in this shell bed, in the overlying tuff, or in the parna dune above, until recently when in the Colongulac Parna about 3 in. above beach level in a layer dipping lakewards at 30° there was found burnt soil, bones and charcoal, the last giving an age of 20,100 ± 500 years. The bone bed is a little older. It was from this locality in 1842 that fossils were sent to Professor Sir Richard Owen at the Royal College of Surgeons in London, resulting in the first descriptions of extinct marsupials from Victoria. In spite of considerable effort over 20 years, this important site is still not accurately dated.

AGE OF MURRAY RIVER SKELETONS

Because of the low rainfall and the alkaline nature of the soil, numerous aboriginal skeletons have been preserved in the Murray River Valley between Mildura and the S. Australian border. The high frequency of skeletal remains has been used as an argument for large populations of Aborigines in this district. This argument is only valid if the skeletons were emplaced over a short period of time, but actually no one has had an adequate idea of the range of age of these aboriginal remains. During the Chowilla Project of the National Museum of Victoria, a series of skeletons was excavated on Keera Station W. of Merbein. Some considered that this effort was of little value because the skeletons were only 'a century or two old', but five radiocarbon dates showed that the skeletons fell within the period of 4000 to 6000 years ago. Four of the dates were on the organic fraction of bones while the other was on charcoal disseminated between skeletons in a multiple burial. The skeletons thus proved to be much older than had been accepted. Interments usually took place in sandy ground where it was easy to dig, and the severe erosion that has followed the introduction of domesticated animals has caused the widespread destruction of these human remains. The evidence is being rapidly lost but it would take considerable financial resources to collect all these evidences of human occupation and date them by radiocarbon. However, a programme of sample dating being carried out at present should provide basic information about the times and places in which these Aborigines were buried.

DATING VOLCANIC ERUPTIONS

When Professor Libby discovered radiocarbon dating, news of it came to me through Dr. K. P. Oakley of the British Museum, and I was invited to submit two samples of 1-2 lbs of charcoal for assay by the solid carbon method. As the study of the Warrnambool district was in progress, samples were collected from aboriginal middens in that area. One was taken from Tower Hill beach, and the other from Goose Lagoon. The beach deposit overlies tuff from the Tower Hill volcano, and the date obtained was 538 ± 200 years, rather young for the method at that stage. Since then methods have been refined, and the stratigraphy done in more detail. A series of dates on both marine shells and charcoal has now been obtained (Gill 1967a), and the oldest of these is a charcoal date of 5120 years for the lowest soil in the series. The charcoal was from an aboriginal midden incorporated in that soil. Underneath it is dark grey sand which overlies the Tower Hill Tuff. The eruption of this volcano has always been considered a fairly recent event, and estimates of the order of 2000 years have been given. The walls of the craters are still very sharp geomorphologically, and the ash from the volcano overlies all formations except the very recent sand dunes of the coast. A long search was made of the well exposed layers of volcanic ejectamenta, but no samples could be found within these materials by which the eruption could be dated. Absence of soil layers within the ejectamenta indicates that the eruption took place over a comparatively short period of time, so that there was no opportunity for the formation of soils between phases of activity. An effort was therefore made to obtain radiocarbon dates above and below the ejectamenta in order to define more closely the time of eruption. As the date of 5120 years is for material separated from the tuff by the dark grey sand, the time of eruption is earlier. Five miles N. of Warrnambool in the valley of the Merri River, a site was already known where an aboriginal camping place existed below the tuff. An aboriginal axe was found there in an excavation, and the accompanying bones of food animals had been turned black by the conditions of chemical reduction. A large sample of bone fragments from this site was submitted for radiocarbon dating, but there was an insufficient percentage of organic fraction for an adequate date. A 'qualitative date' of 5085 ± 800 years was obtained by the laboratory that carried out the assay, but that laboratory considered that a date on the carbonate was 'far superior'. The latter gave the figure of 6605 ± 90 years. The date on the organic matter is too young because the charcoal overlying the ash is older. For the time being we can regard this eruption as being something like 5500 to 6000 years ago. This example illustrates the difficulties that attend radiocarbon dating: firstly, the difficulty of obtaining suitable materials for dating, and secondly the methodological problems. Nevertheless, the estimate of age on geological evidence was out by the order of three. Thus radiocarbon dating is able to achieve closer definition of age in spite of its difficulties. Although there is not yet a good bracket of dates below the tuff to give the maximal age, there is a good bracket above to give the minimal age.

Because Aborigines occupied this site when Europeans came, it was thought that the middens were very recent, probably not more than a few hundred years old. There are actually two well preserved occupation layers, one of the order of 5000 years ago (with hearths, bone and stone implements), and one of the order of 2800 years. As the older formation contains the bones of animals no longer in the district (Gill 1953, 1967a), important faunal changes are indicated. Our knowledge of this site has been considerably advanced, largely due to the questions raised by radiocarbon dating. The more we discover, the more we see there is to discover.

CONCLUSIONS

Just as the faintest ink is better than the best memory, so radiocarbon dating is far better than 'a thousand intelligent guesses'. Although the amount of radiocarbon dating done in Victoria is small, it has revolutionized late Quaternary geology and archaeology; it could do the same for geomorphology, pedology (e.g. Campbell et al. 1967a, b) and some other sciences. Radiocarbon dating has created a perspective not otherwise possible at present, and has allowed correlations both near and far.

In evaluating radiocarbon dating, it is helpful to:

1. Distinguish reconnaissance dating from precision dating. Most geologic dating in Victoria so far belongs to the former category. Precision dating is illustrated by the archaeologist's series of datings through a finely stratified sequence. Reconnaissance dating grades into precision dating, but the distinction is useful.

2. Recognize grades of reliability in dating. With respect to samples, carbon is usually more reliable than carbonate, and bone collagen than bone carbonate. Thick shells are better than thin shells, and shells from an aquiclude better than those from an aquifer. Most bone collagen disappears after 5-6000 years, so that assays of older bone are likely to be negative, and those nearing the limit less reliable. When the aboriginal bone samples from the Murray River valley (30, 33, 42) were selected, a younger age than received was anticipated, with the result that the samples were too small. Gak-1431 was measured under low pressure, and 1432-3 were diluted with dead carbon. Thus the samples were of minimal size and two methods were used, so the results cannot be taken strictly at face value. They may well be nearer the same age than the figures suggest. However, in the excavation, the sample GaK-1432 was above GaK-1433, so younger, and the radiocarbon dates were in the correct order, viz. 4170 and 4400 y respectively.

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