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Age of the raised beach ridges at Turakirae Head, Wellington: A reassessment based on new radiocarbon dates

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Revised ages for the five raised beach ridges at Turakirae Head, based on new radiocarbon dates, indicate that the highest and oldest ridge was uplifted between 5500 and 6500 years B.P., and possibly close to 6000 years B.P. (or *c.* 4900 B.C.). (Dates given in radiocarbon years, old half-life). Uplift of the second youngest raised beach is thought to have occurred about 450 years B.P., or around 1500 A.D. The two intervening beach ridges, dated only by indirect methods, were probably elevated about 2900-3400 years B.P. (*c.* 1460 B.C.) and 4600-5400 years B.P. (*c.* 3700 B.C.). These ages are similar to those estimated by Wellman (1967, 1969).

The raised beach ridges at Turakirae lie close to the axis of the Rimutaka Range, which has risen at an average rate of 3.9 m/1000 years over the past 6000-7000 years. Based on the assumption that this rate will continue, the next major (>2 m) uplift at Turakirae (and, by inference a destructive earthquake in the Wellington area) could be in about 800 years time, although smaller (<1-2 m) uplifts may occur before then.

Keywords: Raised beaches; radiocarbon dates; Holocene; Quaternary; tectonic uplift; earthquakes; Turakirae Head; Wellington.

INTRODUCTION

The sequence of raised Holocene marine beach ridges at Turakirae Head, at the southern end of the Rimutaka Range, provides a unique record of tectonic uplift in the Wellington region, since each of the five beach ridges is thought to have been elevated almost instantaneously during a major earthquake (Wellman, 1969; Fig. 1). The youngest beach was raised by about 2.5 m in 1855.

Stevens (1969) considered the second youngest raised beach was uplifted during the Haowhenua earthquake of Maori tradition, said to have occurred around 1460 A.D. (Best, 1918). A 15th to 16th century date for this earthquake (uplift) has been confirmed by Moore and McFadgen (1978).

The "ages" of the three higher beach ridges have been estimated by indirect methods (Wellman, 1967, 1969). The formation of the highest ridge was considered to have begun about 6500 years ago, and ceased upon initial uplift close to 5600 years ago.

It is important for earthquake prediction studies in particular that the time of uplift of the series of beach ridges at Turakirae Head be dated as precisely as possible. The aim of this paper is to reassess the times of uplift of the raised beaches using the 22 radiocarbon dates now available (see Table 2), to establish approximate limits on uplift times, and provide some estimate of when the next *major* uplift at Turakirae (and therefore a major earthquake) may be expected.

The raised beaches at Turakirae are well preserved, and have been described and illustrated in some detail (*e.g.* Stevens 1975). In Fig. 1, the beach ridges (BR) are numbered from youngest to oldest; BR1 is the 1855 beach ridge, and BR5 the highest, and oldest, recognised. The modern beach ridge (BR0), formed since 1855, will ultimately be uplifted and preserved if present trends continue.

Quaternary geological features of the area have been mapped by Ota *et al.* (1981).

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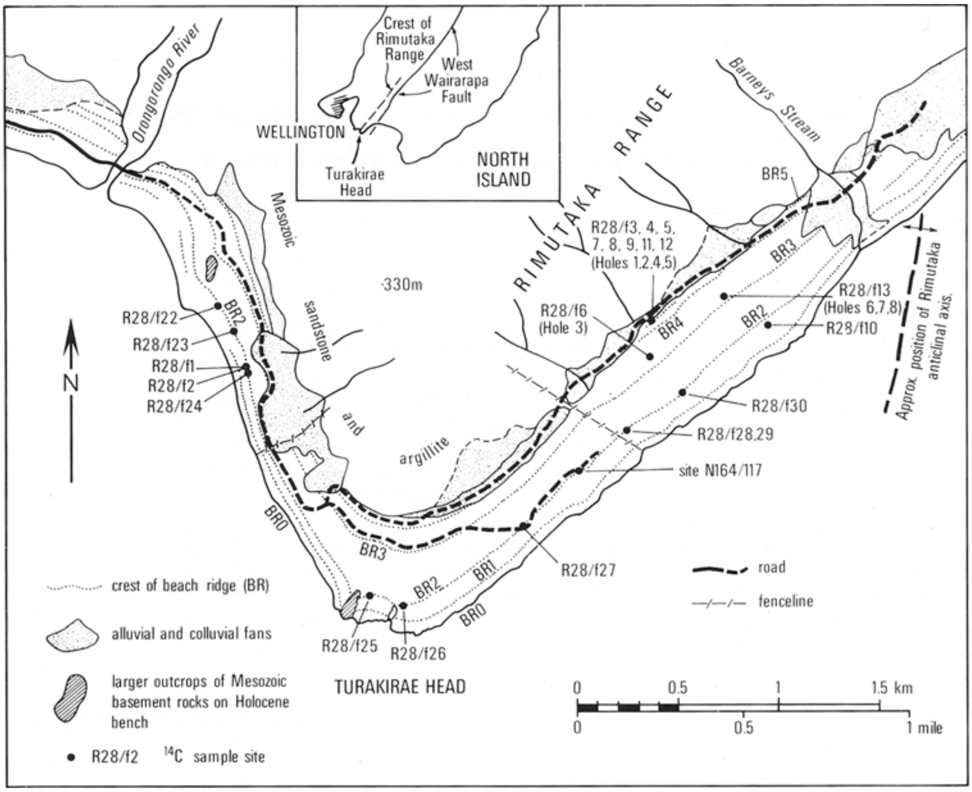

Fig. 1 — Simplified geological map of the Turakirae area showing sequence of raised beach ridges (BR1-BR5), sampling sites, and approximate position of Rimutaka anticlinal axis (from Wellman, 1969). Geology largely from unpublished map by D. N. Williams. For stratigraphy of holes 1-8 see Fig. 2. Inset: southern tip of North Island.

SAMPLING

Shell material incorporated within BR2 (Fig. 1) was observed in 1975 during an assessment of the gravel resources of the area (Moore, 1975), and first collected in November 1976 at grid ref. R28/696739 (R28/f1, f2) (grid references from metric NZMS260). In August 1976 a shell midden situated on top of BR2 was excavated in order to obtain material for radiocarbon dating, and thus provide a minimum age for uplift of the beach ridge (Moore and McFadgen, 1978). Then in 1977, with the assistance of Messrs D. N. Williams and R. G. Bagnall, a series of holes was dug into peat deposits on the landward side of beach ridges BR3 and BR5 (Fig. 1) using a post-hole auger and 4 cm diameter corer. Peat, wood and freshwater shell samples were obtained for ^{14}C dating. Marine shell deposits present both within and on top of BR2 were extensively sampled in February 1980.

INTERPRETATION OF THE BEACH RIDGES

The stranded beach ridges at Turakirae are former storm beaches, consisting mainly of well-rounded, pebble to cobble-sized gravel. The ridges are sub-triangular in cross-section with irregular bases and generally steep (20-30°) seaward-facing slopes. With the exception of BR5, each beach ridge was formed during a period of relative still-stand between major tectonic uplifts.

The berm crest of the present day beach ridge (BR0) is generally about 1 m above MHWM, but just south of the Orongorongo River mouth where sedimentation rate is high the crest is 2-3 m above MHWM (J. G. Gibb, *pers. comm.* 1980). Here, BR0 has overtopped the uplifted 1855 ridge (BR1) to form a combined 1855-modern storm beach. Thus uplifts of 2-2.5 m or less (such as occurred in 1855 in the vicinity of the river mouth) may be insufficient for raised beach ridges to be completely isolated from the sea, and it follows that a single ridge could form as the result of a series of small (< 1-2 m) uplifts over a considerable period of time. Consequently it might be possible to "miss" one or more uplifts, and by inference several major earthquakes, in interpreting a sequence of raised beach ridges. Small uplifts may leave no physiographic record, although some evidence could be preserved within beach ridges. The beach ridges at Turakirae Head were presumably stranded only as a result of *major* (> 2-2.5 m) uplifts, and minor uplifts (if any) are not distinguishable.

The fact that the 1855 beach ridge is being locally overtopped also has a bearing on the interpretation of dated material obtained from behind (landward of) beach ridges. Wood found behind the 1855 beach undoubtedly includes material stranded there up to 100 years before the 1855 uplift, and very recently, and some driftwood will continue to be stranded until the next major uplift. It is important to take this into account in establishing the time of uplift of BR5 in particular.

AGES OF BEACH RIDGES

Wellman's (1967, 1969) estimated times of uplift of the beach ridges at Turakirae Head (Table 1) were based on a eustatic sea level curve, the assumption that sea level had remained essentially static for the past 6000-7000 years, and that the average rate of uplift was constant. Duration of beach ridge formation was determined from relative cross-sectional area. These ages have been widely accepted (*e.g.* Stevens, 1975; Ghani, 1978), although Wellman's "600-year" beach ridge was later correlated with the "1460 A.D." Haowhenua earthquake by Stevens (1969).

Wellman (1967, 1969) provided no estimate of errors for his ages. The cross-sectional area is not likely to be a reliable criterion for measuring the duration of beach ridge formation, since the supply of gravel was probably higher during the formation of BR5 (from screes), and also BR1 and BR2 (from deforestation and inferred development of alluvial fans). Cross-sectional area is also difficult to determine (Moore, 1975).

Stevens (1969) also made no allowance for error in applying Best's (1918) "1460 A.D." date (which was based on tradition related to Best by Wairarapa Maoris) to BR2, and assumed that the earthquake took place in exactly 1460 A.D. (or 514 years before 1974; Stevens, 1975). The absence of stated errors implies an accuracy that has not, in fact, been attained.

Ward (1971) calculated altimetric ages for the beach ridges at Turakirae Head on the basis that BR2 (C) was equivalent to the stage of high sea level dated at 1540 yrs B.P. by Schofield (1960) from the Firth of Thames. This gave mean ages (but not times of uplift) of: BR1—460 yrs B.P.; BR3—2822 yrs; BR4—3551 yrs; and BR5—4366 yrs B.P. The calculated ages implied that ridges D and E (BR3, 4) were contemporary with high sea levels established from the Firth of Thames. However, this gave an age for BR5 which was much too low, and instead Ward (1971: 715) favoured equivalence of ridge F with the *c.* 6000 yr high sea level indicated for Poverty Bay.

In this paper the ages of beach ridges are inferred from radiocarbon dates, and indirect methods. All radiocarbon dates are quoted in terms of the old (or Libby) half life of 5568 ± 30 years, and ages are in radiocarbon years B.P. (before 1950) unless otherwise indicated. Table 1 provides a comparison between the revised ages (this paper) and those estimated by previous workers. Details of radiocarbon dates are given in Table 2. All dates were determined by the N.Z. Radiocarbon Dating Laboratory, Institute of Nuclear Sciences, Lower Hutt.

Age of beach ridge 2 (BR2, Fig. 1)

Best (1918) considered the Haowhenua earthquake occurred about 1460 A.D., based on Maori tradition which related that the event took place in the time of Te Ao-haere-

Table 1 — Time of uplift of the raised beaches at Turakirae Head according to various authors years. Beach ridge A (=BRO) is forming at the present day.

Beach ridge	Height above MHWM†	Wellman (1967, 1969) (years B.P.)	Stevens (1969) (years before 1969)	Stevens (1975) (years before 1974
A	c. 1 m	—	—	—
B	2.5 m	100 (1855 A.D.)	114	119
C	9 m	c. 600	509 (1460 A.D.)	514
D	18 m	c. 3100	c. 3100	c. 3100
E	24 m	c. 4900	c. 4900	c. 4900
F	27 m	c. 5600	c. 5600	c. 5600

* See also Table 3

† Heights of ridge crests measured near axis of Rimutaka anticline (see Fig. 1). Data from Wellman (1969).

tahi, 18 generations before 1918. He does not mention exactly how the *c.* 1460 date was arrived at, and in a later work (Best, 1923) simply stated that the earthquake occurred sometime in the 15th century.

Thirteen radiocarbon dates have now been obtained for BR2, one of which (NZ4229) came from a Maori shell midden (site N164/117) situated on top of the beach ridge (Moore and McFadgen, 1978). Six of the dates are in the 400-500 year range, while a further six have ages of <300 years B.P. (Table 2). NZ5103 (R28/f24; 344±34) could be included in either group.

The minimum age of 430±40 years B.P. for BR2 obtained from archaeological site N164/117 makes it most unlikely that BR2 was uplifted later than 350 years B.P., and by "bracketing" of the six dates (assuming NZ4278 and 4279 to be maximum ages), BR2 was almost certainly uplifted sometime between 350 and 550 years B.P. The actual time of uplift could be close to the mean age (450 years B.P.) of the six oldest dates, which in calender years is about 470 BP or 420 BP, depending on whether a −55 year correction to the Marine Shell Standard (McFadgen, 1982) is applied or not (Table 3).

Regarding the group of younger dates, it is important to note that the dated samples came from a variety of situations: shell concentrations on top of the ridge (f25, f26), "caches" of shells wedged under boulders near the berm crest (f10, f27), and shelly layers 20-30 cm beneath the berm crest (f22, f23, f24?). There are two possible explanations for these very young dates: either the sea swept over the beach ridge one or more times (possibly as tsunami) long after BR2 had been uplifted, or the shell concentrations represent Maori middens. Of the two alternatives the latter is more acceptable because it is difficult to see how older shell deposits, particularly on the seaward face of the beach ridge (*e.g.* f28, f30), could remain intact if tsunami or unusually high storm waves washed over the ridge at a much later date.

Although it could be argued that all the older dates are also from archaeological contexts, there is little doubt that at least some of the shell deposits (f1, f2, and probably f29, f30) are natural. Uplift of BR2 about 450 years B.P., therefore, is quite reasonable, especially when considered in relation to other independent evidence (*e.g.* Moore, n.d.). It also agrees reasonably well with Best's (1918) estimate from traditional sources.

A maximum age limit can be established for BR2 from the abundant pumice incorporated in the ridge. The pumice is considered to be derived from major eruptions in the Taupo region about 1800 years B.P. (Stevens, 1969), and therefore BR2 could not have been stranded above sea level before this date.

Age of beach ridge 5 (BR5)

A eustatic sea level curve constructed by Gibb (1979, fig. 6.3) indicates that sea level rose at 10 m/1000 years from about 12,000 years B.P. to 6500 B.P. Between 6500 years

Note that some ages are expressed in calendar

This paper (1987)*		
(calendar years)	(radiocarbon years B.P.)	
–	–	BR0
132	–	BR1
c. 420-470 (B.P.)	c. 450	BR2
c. 3400	c. 3100	BR3
c. 5680	c. 5000	BR4
c. 6900	c. 6000	BR5

and present day his curve shows sea level to be essentially static, with minor oscillations in the order of ±1 m. If the Rimutaka Range was rising at a rate of only 4 m/1000 years (Wellman, 1969), no beach ridges would be preserved until sea level had stabilised, or at least assumed a rise of less than 4 m/1000 years. If Gibb's sea level curve is correct, and 500 years for the formation of the beach ridge is assumed, then the initial uplift of BR5 could not have occurred until about 6000 years B.P.

On the landward side of BR5 at R28/715740, up to 1 m of calcareous silt overlain by 1.4 m of peat was cored and material obtained for radiocarbon dating (Fig. 2). Four of the dates fall within the range 5700-6500 years B.P. (±2 standard deviations) with a mean of about 6000 years. The date of 10,050±100 years B.P. (R28/f4, NZ4415) obtained from sand-sized freshwater shell material is excluded because of the possibility that older carbon was incorporated in the shell structure.

The four closely grouped dates were obtained from wood near the base of the calcareous silt, which directly overlies gravel and boulders of the stranded beach ridge (Fig. 2). Two of the dated samples (NZ4549, 4550) were probably from the outer part of large logs, and two (NZ4416, 4420) consisted of small pieces of wood <6 cm diameter, probably a mixture of driftwood and material washed in from the nearby hills. Since the wood appears to consist predominantly of podocarp species (mainly totara?), in common with pollen and other plant material from the calcareous silt (Mildenhall and Moore, 1983), it is possible that most of the wood was locally derived. This may mean the logs had not drifted in the ocean for any great length of time.

There are two ways the dates can be interpreted: either (a) the wood was stranded up to several hundred years before uplift of the beach ridge (by analogy with the modern beach ridge BR0), in which case it gives a *maximum age* or (b) much of the wood, particularly smaller pieces, was washed down from the dearby hillside after the beach ridge was uplifted. In this case, the wood will provide a *minimum age* for uplife.

It is most unlikely that the dated material was stranded behind the beach ridge just prior to uplift, and it must also be accepted that large logs in particular could have been several hundred years old by the time they were washed up by the sea. Small pieces of wood could easily have accumulated behind the beach ridge after uplift. Hence the dates do not provide a precise age for the uplift of BR5, but it is reasonable to assume that it was uplifted sometime between 5700 and 6500 years B.P., and probably close to 6000 years B.P. (mean age of 4 dates). In calendar years this is about 6900 B.P.

Age of ridges 3 and 4 (BR3, BR4)

In the absence of material suitable for radiocarbon dating, only indirect methods can be used to determine the times of uplift of BR3 and BR4. Figure 3 is based on Wellman's (1969) approach—that the approximate time of uplift can be determined if the elevation of each beach ridge is known, the average uplift rate is assumed to be constant, and the duration of beach ridge formation is estimated. Reasonable ages (times of uplift) for BR3

Table 2—Radiocarbon dates from Turakirae Head. See Fig. 1 for location of

Beach ridge	Locality	^{14}C Nos	Radiocarbon age	Material
BR2	R28/f1	NZ4278A	470 ± 40	shell (paua)
		NZ4278B	490 ± 40	
BR2	R28/f2	NZ4279A	530 ± 40	shell (paua)
		NZ4279B	550 ± 40	
BR5	R28/f3	NZ4414A	4100 ± 80	peat
		NZ4414B	4220 ± 90	
		NZ4414C	4760 ± 90	
BR5	R28/f4	NZ4415A	10050 ± 100	freshwater shell
		NZ4415B	10350 ± 150	
BR5	R28/f5	NZ4416A	5840 ± 90	wood (small pieces)
		NZ4416B	6010 ± 100	
		NZ4416C	6700 ± 100	
BR3	R28/f6	NZ4417A	1450 ± 50	peat
		NZ4417B	1490 ± 60	
		NZ4417C	1410 ± 50	
BR5	R28/f7	NZ4418A	modern	peat
		NZ4418B	modern	
BR5	R28/f8	NZ4419A	2980 ± 70	peat
		NZ4419B	3070 ± 80	
		NZ4419C	3240 ± 120	
BR5	R28/f9	NZ4420A	6360 ± 80	wood (small pieces)
		NZ4420B	6540 ± 90	
		NZ4420C	7180 ± 50	
BR2	R28/f10	NZ4530A	260 ± 40	shell (paua)
		NZ4530B	270 ± 40	
BR5	R28/f11	NZ4550A	6060 ± 100	wood (logs?)
		NZ4550B	6240 ± 100	
		NZ4550C	6940 ± 120	
BR5	R28/f12	NZ4549A	5960 ± 90	wood (logs?)
		NZ4549B	6130 ± 100	
		NZ4549C	6820 ± 120	
BR3	R28/f13	NZ4548A	270 ± 60	peat
		NZ4548B	280 ± 60	
		NZ4548C	380 ± 50	
BR2	R28/f22	NZ5101A	modern (<250)	shell (paua)
BR2	R28/f23	NZ5102A	276 ± 57	shell (paua)
		NZ5102B	285 ± 59	
BR2	R28/f24	NZ5103A	344 ± 34	shell (paua)
		NZ5103B	354 ± 35	
BR2	R28/f25	NZ5104A	259 ± 24	shell (paua)
		NZ5104B	267 ± 25	
BR2	R28/f26	NZ5105A	modern (<250)	shell (paua)
BR2	R28/f27	NZ5106A	modern (<250)	shell (paua)
BR2	R28/f28	NZ5107A	410 ± 45	shell (paua)
		NZ5107B	422 ± 46	
BR2	R28/f29	NZ5108A	493 ± 30	shell (paua)
		NZ5108B	507 ± 31	
BR2	R28/f30	NZ5109A	453 ± 42	shell (paua)
		NZ5109B	466 ± 43	
BR2	N164/117*	NZ4229A	430 ± 40	shell (paua)
		NZ4229B	440 ± 40	

*N.Z. Archaeological Association site number sample sites.

Comments
Secular correction applies only if peat derived from material that grew within c. 4000 years
Secular correction meaningful only if peat formed from material that accumulated within few decades
Secular correction applies only if peat derived from material that grew over <1500 years.
Sample from outer part of logs?
Sample from outer part of logs?
Sample possibly from shell midden.
Shell midden?
Shell midden?
Sample possibly from shell midden.
Sample possibly from shell midden.
Sample from shell midden; minimum age of BR2

Table 3—Estimated, radiocarbon, and approximate calendar age for uplifts of beach ridges.

Beach ridge	Estimated time of uplift (from Fig. 3) (age limits in brackets)	Mean ^{14}C age (old T½)	Approx. secular correction*	Approx. calendar age (age limits in brackets)
BR1	—	—	—	1855 A.D.
BR2	450 yrs B.P. (300-600 yrs)	450 yrs B.P.	+17 yrs	c. 1480 A.D. (1380-1580) or 1530 A.D.** (1430-1630)
BR3	3100 yrs B.P. (2900-3400 yrs)	—	+340 yrs	c. 1460 B.C.
BR4	5000 yrs B.P. (4600-5400 yrs)	—	+680 yrs	c. 3700 B.C.
BR5	6000 yrs B.P. (5500-6500 yrs)	6000 yrs B.P.	+880 yrs	c. 4950 B.C.

* Based on secular correction table distributed by Michael and Ralph at the 8th International Radiocarbon Conference, Lower Hutt, 1972 (as used by N.Z. Radiocarbon Dating Laboratory).

** Based on new half-life and correction of −55 years to Marine Shell Standard (McFadgen 1982).

and BR4 can be obtained if it is accepted that BR5 was uplifted about 6000 years B.P. and BR2 about 450 years B.P. (Fig. 3).

Beach ridge 3 (BR3)

The oldest date obtained for peat behind the beach ridge is 1450 ± 50 years B.P., which indicates that this ridge cannot be younger than 1350-1550 years B.P. (NZ44174 ± 2 S.D.). The apparent absence of pumice strongly suggests that formation and uplift of the beach ridge predates major eruptions of pumice from the Taupo Volcanic Zone about 1800 years B.P. Thus it is fairly certain that BR3 was uplifted before 2000 years B.P., and from Fig. 3, probably sometime between 2900 and 3400 years B.P. If BR5 was uplifted about 6000 years B.P., then BR3 could have been raised close to 3100 years B.P., which is identical to Wellman's (1969) estimate.

Beach ridge 4 (BR4)

There is no direct evidence for the age of BR4, although a date of 4100 ± 800 years B.P. (NZ4414) for the base of the peat sequence behind BR5 may be significant (Fig. 2). The contact between the peat and underlying calcareous silt is sharp, and could be related to a sudden change in elevation of BR5. If so, the date might provide a minimum age for the uplift of BR4.

From Fig. 2 it is likely that BR4 was uplifted sometime between 4600 and 5400 years B.P., possibly about 5000 years B.P.

Summary

The estimated times of uplift of each of the five raised beach ridges, based on radiocarbon dates and heights of uplift and duration of beach ridge formation (Fig. 3), are listed in Table 3. It should be emphasised that these ages are merely the "best estimates" possible on the evidence available, and that the calendar dates for uplifts (*c.* 1480-1530 A.D., *c.* 1460 B.C., *c.* 3700 B.C. and *c.* 4950 B.C. for BR2, 3, 4, 5 respectively) are approximate only. However, despite the errors involved, the beach ridges were almost certainly uplifted within the time limits shown.

RATE OF UPLIFT

It we accept that sea level in the New Zealand region has remained essentially static (within ± 1 m) for the past 6000-7000 years B.P. (Gibb, 1979), and that BR5 was uplifted

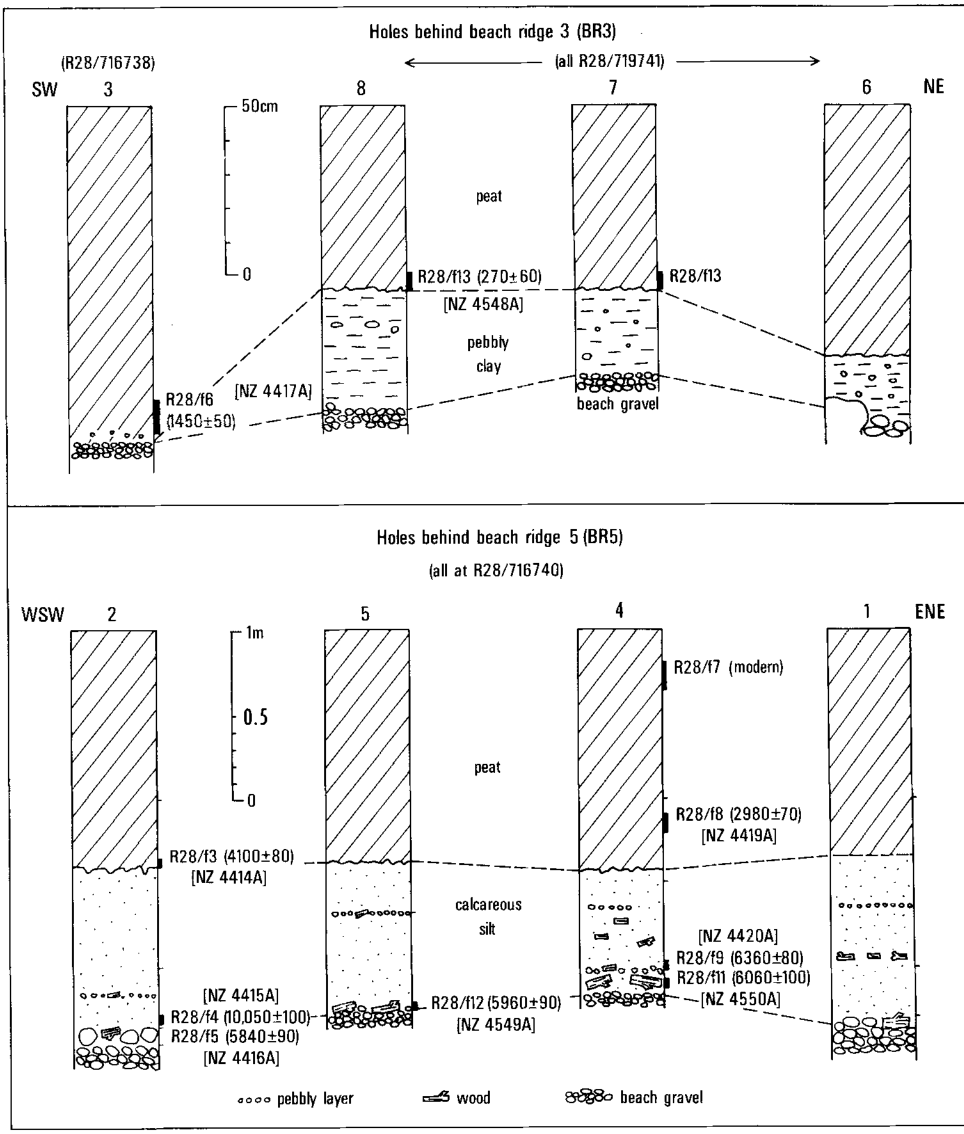

Fig. 2—Stratigraphic columns for holes dug on the landward side of beach ridges 3 and 5, showing position of radiocarbon-dated samples. Location of holes indicated on Fig. 1 (grid references in brackets).

about 6000 years ago B.P., then the average rate of uplift at the Rimutaka Axis is about 4 m/1000 radiocarbon years, or 3.9 m/1000 calendar years. At least, it probably exceeds 3 m/1000 years (Fig. 3).

In the last 500 years there has been 9 m of uplift at this point on the Rimutaka Axis, equivalent to 18 m/1000 years (B.P.). This rate cannot be typical (see also Stevens, 1974: 253), and future uplifts should be of such a magnitude and spacing as to restore a rate of uplift of close to 4 m/1000 years (B.P.).

DISCUSSION AND CONCLUSIONS

The times estimated for the main uplifts of beach ridges 3-5 depend to some extent

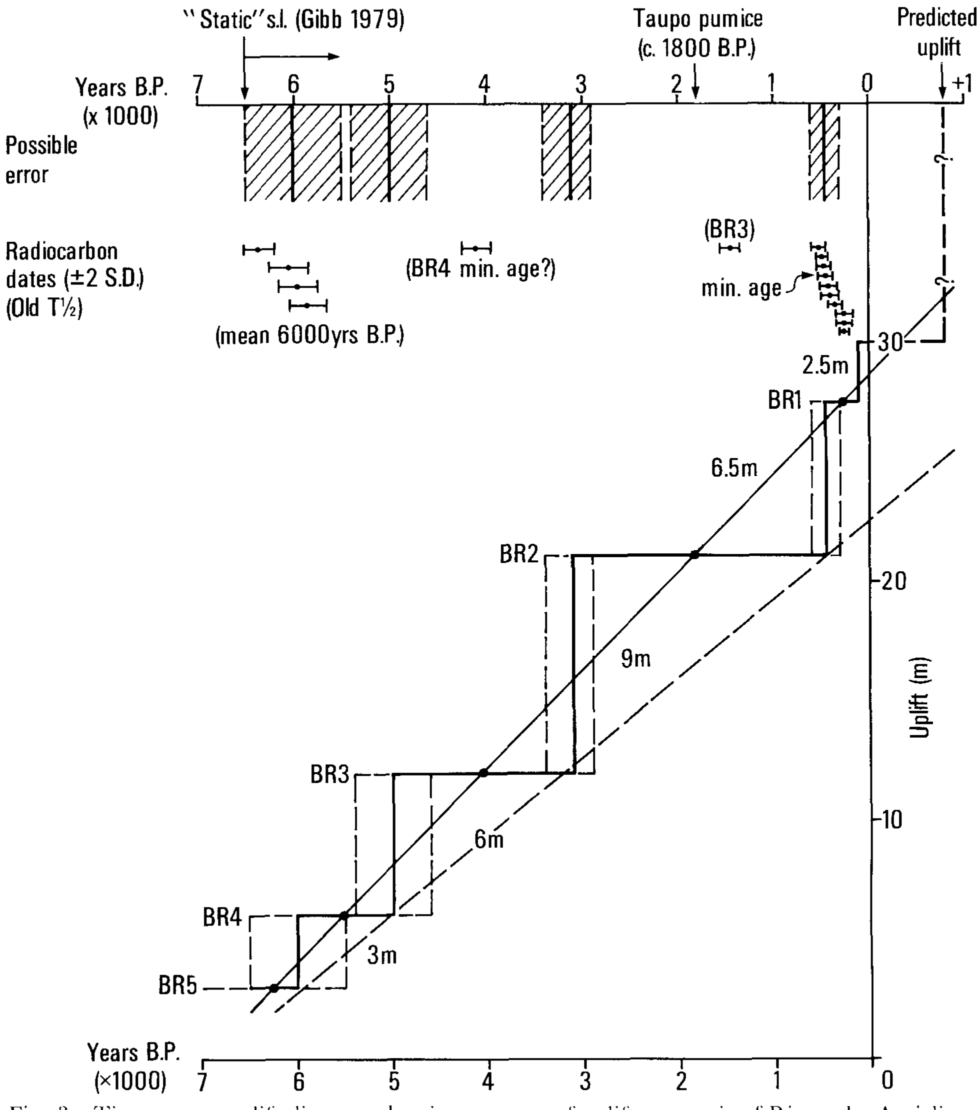

Fig. 3—Time versus uplift diagram showing amount of uplift near axis of Rimutaka Anticline (see Wellman, 1969) and approximate age of beach ridges, assuming uniform average uplift rate and 500 years for the formation of beach ridge 5. Limits on time of uplift indicated on upper ordinate (shaded areas). Line through mid-point of formation time of beach ridges gives average uplift rate (4 m/1000 years B.P.); probable minimum rate (3 m/1000 years) indicated by dashed line joining base of "steps". Duration of beach ridge formation estimated from cross-sectional areas (Moore 1975).

on the age of the post-glacial maximum (when uplift rate exceeded eustatic sea level rise). In many parts of the world the rate of sea level rise declined markedly between 5000 and 7000 years B.P. (Bloom, 1977), and at places with little or no glacio-eustatic effect (*e.g.* Japan, southeast Australia), about 6000 years B.P. Ghani (1974) constructed a eustatic sea-level curve based largely on New Zealand data which suggests a Holocene sea-level maximum about 6000 ± 200 years B.P. The more recent curve drawn by Gibb (1979), and his analysis of radiocarbon-dated Holocene shorelines, indicates a maximum about 6500 years B.P.

It is fairly certain, therefore, that BR5 did not begin to form until somewhere between 6000 and 6500 years B.P., or 7000 years B.P. at the earliest. Based on the present rate of growth of the modern storm beach (BR0), at least 200 years would be required to form BR5 (taking into account a possibly higher accumulation rate). Therefore the estimate of 6000 ($\pm$500) years B.P. for the time of uplift of BR5 is reasonable.

The greater certainty with which the time of uplift of BR5 (and also BR2) is known, the more reliable are the age estimates for BR3 and BR4 (provided uniform, long-term uplift is accepted). Considering the limitations of the method the age ranges determined for BR3 and BR4 are probably acceptable, for despite the difficulty in determining cross-sectional area of beach ridges, mean areas calculated for BR2, 3 and 4 (Moore, 1975) are roughly proportional to the "duration of formation" (or stillstand) times predicted in Fig. 3. This assumes that the rate of formation of the beach ridges has been similar for the last 7000 years, which may not be true (due to variation in sediment supply and the effects of minor eustatic fluctuations).

The average rate of uplift of 3.9 m/1000 years for the Rimutaka Axis calculated from data presented in this paper is not significantly different from that estimated by Wellman (1969) and Ghani (1974). The actual rate could be slightly higher but probably does not exceed the 4.5 m/1000 years estimated from summit height accordance (Ghani, 1974). However, if a rate close to that for the last 500 years (*i.e.* 18 m/1000 years) did persist, we could expect a major uplift ($>$2 m) any time in the next few hundred years.

If the average rate of uplift remained close to 4 m/1000 years, then the next major uplift at Turakirae might not occur until about 800 years from now (Fig. 3; *c.f.* Wellman 1969). This does not mean that Turakirae (and Wellington) will not experience a destructive earthquake, or small ($<$1-2 m) uplifts, before then.

Although the 1855 uplift at Turakirae and western Wellington was associated with movement on the West Wairarapa Fault (Stevens, 1969), future uplifts at Turakirae might not be. Uplift and westward tilting in the past may have been caused, at least in part, by movement on other faults east of West Wairarapa Fault. It is essential, therefore, that similar sequences of raised beaches in Wairarapa be dated as precisely as possible so that the tectonic history of the Wellington region as a whole can be more thoroughly documented, and used to make more reliable predictions on the timing and magnitude of future uplifts and major earthquakes.

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REFERENCES

Best, E., 1918. The land of Tara and they who settled it. *Journal of the Polynesian Society* 27: 49-71.

——— 1923. Miramar Island and its history. *Transactions of N.Z. Institute* 54: 779-791.

Bloom, A. L., (compiler) 1977. *Atlas of sea-level curves.* IGCP Project 61.

Ghani, M. A., 1974. *Late Cenozoic vertical crustal movements in the central part of New Zealand.* Unpublished Ph.D. thesis, Victoria University of Wellington.

——— 1978. Late Cenozoic vertical crustal movements in the southern North Island, New Zealand. *N.Z. Journal of Geology & Geophysics* 21: 117-125.

Gibb, J. G., 1979. *Late Quaternary shoreline movements in New Zealand.* Unpublished Ph.D. thesis, Victoria University of Wellington.

McFadgen, B. G., 1982. Dating New Zealand archaeology by radiocarbon. *N.Z. Journal of Science* 25: 379-392.

Mildenhall, D. C., and Moore, P. R., 1983. A late Holocene pollen sequence at Turakirae Head, and climatic and vegetational changes in the Wellington area in the last 10,000 years. *N.Z. Journal of Science* 26: 447-459.

Moore, P. R., 1975. Gravel resources at Turakirae Head. *N.Z. Geological Survey Report* M68.

——— n.d. Age of raised beach ridges at Turakirae Head based on weathering rate of limestone pebbles. Unpublished report, N.Z. Geological Survey.

Moore, P. R., and McFadgen, B. G., 1978. Excavation of a shell midden at Turakirae Head, near Wellington, and a date for the *Haowhenua* earthquake of Maori tradition. *Journal of the Polynesian Society* 87: 253-255.

Ota, Y., Williams, D. N., and Berryman, K. R., 1981. Part Sheets Q27, R27 and R28 — Wellington (1st ed.). Late Quaternary tectonic map of New Zealand 1: 50 000. DSIR, Wellington, N.Z.

Schofield, J. C., 1960. Sea level fluctuations during the last 4,000 years as recorded by a chenier plain, Firth of Thames, New Zealand. *N.Z. Journal of Geology and Geophysics* 3: 467-485.

Stevens, G. R., 1969. Raised beaches at Turakirae Head, Wellington. *New Zealand Science Review* 27: 65-68.

——— 1974. *Rugged landscape. The geology of central New Zealand.* A. H. & A. W. Reed, Wellington.

——— 1975. *Wellington's restless coast: changes in land and sea at Turakirae Head.* Geological Society of N.Z., Guidebook.

Ward, W. T., 1971. Postglacial changes in level of land and sea. *Geologie en mijnbouw* 50(5): 703-718.

Wellman, H. W., 1967. Tilted marine beach ridges at Cape Turakirae, New Zealand. *Journal of Geosciences, Osaka City University* 10: 123-129.

——— 1969. Tilted marine beach ridges at CapeTurakirae, N.Z. *Tuatara* 17: 82-93.

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