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Title of article Estimating Ages of Late Quaternary Stream Terraces From Analysis of Weathering Rinds and Soils

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ESTIMATING AGES OF LATE QUATERNARY STREAM TERRACES FROM ANALYSIS OF WEATHERING RINDS AND SOILS, by Peter L. K. Knuepfer

APPENDIX A--WEATHERING RIND CALIBRATION SITES

Four sites are added to the calibration sites described by Chinn (1981) and Whitehouse and others (1986), and data from the Buller River site discussed by Whitehouse and others (1986) are treated differently here. Locations of these sites are compiled in Table A.

Buller River Aggradation Terrace. Weathering rinds were collected from a prominent outwash aggradation terrace near the head of the Buller River. Moar (1980) reported radiocarbon dates between 18,350 and 19,800 yr on organic muck and carbonaceous silt from a corelative terrace about 5 km and 7 km downstream of the rind-study site. Both dated horizons are overlain by aggradation gravels, so the top of the aggradation surface must be somewhat younger. An age of 18 ka (1 ka = 1000 yr) is here assigned as a likely maximum age. This is less than the 20 ka age used by Whitehouse and others (1986), who assumed that the two oldest radiocarbon ages obtained by Moar (1980) date the terrace surface.

Lake Rotoiti Moraine. Whitehouse and others (1986) obtained weathering rinds from the outer of two late-glacial moraines that dam Lake Rotoiti at the head of the Buller River. They grouped these data with the Buller River data, although the two data sets have distinct modes (Table 1; cf. Knuepfer, 1984). I treat the Lake Rotoiti data as a separate calibration point. The last major glacial advance in New Zealand (the Otiran) had been assigned an age of 18 ka by Suggate and Moar (1970), but recent dating (Mabin, 1983) suggests that the main late-glacial advance in the Southern Alps south of Lake Rotoiti culminated about 14 ka ago. This younger age accordingly is used here.

Old Rainbow Station Homestead Moraine. A remnant of a late-glacial terminal moraine occupies half of the upper Wairau Valley about 1 km north of the old

Rainbow Station homestead. Suggate (1965) assigned the moraine to the late Otiran main advance, so an age of 14,000 yr is used here. Although ages for both the Old Rainbow and Lake Rotoiti moraines are known only approximately, these data can be used as calibration points with uncertainties that reflect the possible age ranges.

Lake Chalice Landslide. A large rock avalanche dams the upper reaches of the Goulter River north of the Wairau Valley and forms Lake Chalice. Adams (1981) reports corrected radiocarbon dates of 2170 ± 70 and 2160 ± 80 from drowned trees preserved on the lake bottom that closely date the landslide event. The source rocks are weakly-foliated Torlesse-equivalent chlorite schists, but the weathering-rind data are similar to those from the less metamorphosed greywacke from other sites.

Hope River Bridge Landslide. A small landslide that originated in terrace deposits and underlying sheared greywacke some 100 m above the river is preserved on a low terrace of the Hope River at Glynn Wye Station. A radiocarbon date of 850 ± 50 ^{14}C yr B.P. (NZ-39; Grant-Taylor and Rafter, 1963) obtained from wood buried by this deposit closely dates the age of the landslide event. Source rocks are Cretaceous (?) Torlesse greywacke.

Charwell Fan. A small alluvial fan deposited on the first degradation terrace of the Charwell River (grid reference S48/667919) preserves disseminated charcoal in a layer 1 m below the surface that was dated at 840±60 yr b.p. (A-3536). This provides a minimum age for the fan surface. Source rocks for rinds are Cretaceous Torlesse greywacke.

APPENDIX B--SOIL MORPHOLOGIC PROPERTIES

Most of the soil morphologic properties used here were described by Harden (1982) and Harden and Taylor (1983). Several additional properties--cobble coatings, cobble weathering, and mottling--are described here. In addition, pH decrease is used to measure progressive changes in soils, rather than pH increase as used in most previous studies, with points assigned as in Harden (1982).

The thickness and continuity of cobble coatings (generally silt and clay particles adhering to cobble surfaces) were measured. Point assignments for coating thickness are 0 points for none, 10 points for thin (< 1 mm), 20 points for medium (1-2 mm), and 30 points for thick (> 2 mm); discontinuous coats receive an additional 10 points, continuous coats an additional 20. A total of 50 points thus is possible.

With increasing soil age schist and greywacke cobbles are increasingly weathered to greater depths in Westland soils. Degrees of weathering range from none to extreme, following a classification by Bull (unpublished). Slight weathering (10 points) includes cobbles with minor spalling and cracking that retain their original hardness. Moderately-weathered rocks (20 points) are easily broken by a hammer and are usually cracked along fractures. Highly-weathered rocks (30 points) commonly can be disintegrated by hand and are generally disaggregated along fractures. Extremely-weathered rocks (40 points) are completely weathered, and only the outline of cobbles may remain.

Mottling involves the development within a soil horizon of areas of different color. Progressively greater mottling was observed in progressively older Westland soils. Perhaps mottling increases as soil drainage is lessened with time. Points are assigned for increases in abundance from none--0 points, to few (less than 10% of soil horizon composed of mottles)--10 points, to common (10%-25% mottles)--20 points, to numerous (> 25% mottles)--30 points; and degree of change in color from surrounding soil material, from weak (10 points) to strong (30 points).

Harden (1982) assigned maximum values for soil morphology properties based on studies of Quaternary soils in California. Although these maxima may not be appropriate for soils formed only during the last 20,000 yr in humid New Zealand, insufficient data were available to redefine the index maxima for the New Zealand soils. Thus Harden's maxima are used here. The resulting index values may be less sensitive to changes occurring in New Zealand soils than if the weighting scheme were completely redesigned.

APPENDIX C--RESOLUTION OF CONFLICTING AGE ESTIMATES

The main text of the paper discusses the similarities and differences among age estimates from terraces of the Branch River, Saxton River, and Charwell River in Marlborough and the four Westland sites. For most of the other Marlborough sites, the composite age estimate reported in Table 4 of the main paper derives directly from the weathering rind mode age estimate. However, in several cases not otherwise discussed in the main text, rind data and soils data are in conflict; these cases are discussed below. In addition, locations of the study sites are compiled in Table A.

Clarence River terraces. Three terraces were studied on both the west and the east bank of the Clarence River. The first terrace on each bank probably is the same surface, most likely a latest Pleistocene aggradation surface (Kieckhefer, 1979). The soil from this Terrace 1 on the west bank of the river is similar in morphology to the Ben Ohau 9 ka soil, and its morphology regression age is some 9.7 ka (Table 4, main text). The weathering-rind age from Terrace 1 east bank (ca. 8.5 ka) thus is probably applicable for both east and west bank (despite anomalously low rind ages for the west bank). The three terraces on the west bank also have been significantly affected by deflation, and many of the cobbles on the surface at present have been exhumed from beneath the original terrace surface. The rind mean age estimates for the west bank yield ages consistent both with terrace position and the limited soils data obtained.

Grey River. Three post-glacial terraces from the Grey River were examined in this study. Weathering rinds yield inconsistent results from these terraces. Soil morphologic data from terraces 3 and 4 yield regression ages that are more consistent with the positions of these terraces relative to terraces of the Awatere River (cf. Lensen, 1964). Thus these age estimates from soils probably are more reliable than the rind ages. Terrace 2 thus is assigned an age greater than 5 ka and probably less than 10 ka, despite its relatively youthful rind age, in order to preserve relative terrace ages from this site.

Other sites. At a few other sites, age estimates from weathering-rind means were used in the composite age estimates because of local site conditions. Numerous samples obtained from Hope River T2 and Kakapo Brook T2 were broken rocks, like the samples from Saxton River T1. These rind populations yielded younger rind-mode ages than expected for surface high above the present-day streams that have been incised a small amount into late-glacial aggradation surfaces. In both cases the rind mean yields a significantly older age, so the rind mean values were chosen for the composite ages.

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TABLE A. SITE LOCATIONS

	Site Name	Location
1	Buller River	S33/186682
2	Old Rainbow Homestead	S33/257430
3	Lake Rotoiti	S33/218665
11	Lake Chalice	S27/640927
13	Hope River Bridge	S53/882699
19	Maruia River	S46/653002
20	Branch River	S27/540812
21	Waihopai River	S28/------
22	Saxton River	S41/500305
23	Grey River	S35/889537
24	Waiau River	S47/000885
	Edwards River	S47/025899
25	Clarence west bank	S47/174938
	Clarence east bank	S47/160934
26	Glynn Wye	S53/858691
	Manuka Stream	S54/927701
	Kakapo Brook	S53/837657
27	Charwell River	S48/669919
28	Hapuku River	S49/976028
29	McLean Stream	S42/111294
30	Red Lakes Stream	S74/099808
31	Wanganui River	S64/177138
G	Moeraki River	S87/116240
H	Mahitahi River	S78/320385
I	Toaroha River	S58/665333

NOTE: Site locations are referenced to the New Zealand topographic map series NZMS 1, scale 1:63,360 and are keyed to Figure 1, main text.