PART

~~████████~~ A. METHODS AND SUPPLEMENTAL DATA FOR EDM

THEODOLITE SURVEYS

Rossmore Stream, Lake Jasper

Over 210 points on the terrace surfaces were surveyed from instrument

stations on both ends of an 171.5 m long survey baseline (A-B in Fig. 10a).

Elevations and coordinates on this map are relative to point "A".

Repeated shots of this baseline indicate a precision of ±1 mm (1σ) in laser

distance measurements, and of ±5 sec. for angles. These correspond to an

overall survey precision of <±5 mm at the 1σ level. The grid azimuth of

the baseline (244.5±0.5) was determined by repeated compass observations

from both ends of the baseline, assuming a local magnetic declination of

22.1° E (D. McKnight, pers. commun., 1995). The inset (Fig. 10b) was made

by interpolating survey elevations at a 5 cm spacing using a spherical

kriging routine, and then contouring the resultant grid on a 50 cm

interval.

Grey River

A primary instrument station and local coordinate origin was established

at IGNS Grey River survey monument "11a" (Blick and Moss, 1981). A

retroreflector was placed at monument "10," fixing the opposite end of a

597 m long survey baseline, the azimuth of which is known from celestial

observation (Blick and Moss, 1981). Repeated observations of the baseline

indicate a length precision of ±3 mm (1σ) over this distance, and an

angular precision of ±5 sec. Most shots were <650 m long, yielding an

overall survey precision of <±2 cm at the 1σ level. Points on the lowest

terrace riser were surveyed from a secondary instrument station tied into the baseline (Fig. 11a).

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~~━━━━~~B. SUPPLEMENTAL DATA ON THERMOLUMINESCENCE (TL) DATING METHODS, RESULTS, AND INTERPRETATION

As loess is readily datable by thermoluminescence (TL) procedures that exploit the sensitivity of TL to resetting by sunlight exposure (Aitken, 1985), we applied TL sediment dating techniques to two loess samples in the lower Awatere Valley region, including SEDN95-1. During sample collection, we took precautions to avoid sediment near modern rootlets and other evidence of potential contamination of original beds with younger grains of silt (Pillans et al., 1993; Berger et al., 1996). From the interior of block samples polymineralic (feldspar dominant) fine grains (4-11 micron diameters) were prepared in the usual way (Wintle and Huntley, 1980) for TL dating using the partial-bleach (R-beta) method (Aitken, 1985; Berger, 1988, 1996; Berger et al., 1992, 1994; Berger and Busacca, 1995). From TL measurements equivalent-dose (D_E) values were determined from extrapolation to the intersection of dose-response curves as a function of readout temperature (Fig. ia). From a plot of D_E against temperature (D_E-T plots, Figs. ib and ic), we calculated a plateau D_E value representing thermally stable or long-lived TL signals. Divided by a calculated effective dose rate, D_R (Berger, 1988, 1996) for each sample, the plateau D_E gives a TL age estimate (Table 3).

Sample SEDN95-1 yielded a TL age estimate of 15.2 ±1.3 (1σ) (Table 3). We interpret this result as closely post-dating the time of abandonment of the Stb_1 terrace surface by the Awatere River.

MRMA95-1 yielded a TL age of 58.2 ±6.9 ka. This age contradicts the internally consistent set of late Quaternary age constraints provided by the stratigraphic position of the Kawakawa tephra, the radiocarbon ages, and

the SEDN95-1 TL date in loess for the minimum age of the older and higher Stb_1 terrace. We conclude that the dated MRMA95-1 silt sample contains or is dominated by fluvial silt derived by recycling of older terrace deposits. Slumping of older loess is observed along the modern river, especially during floods. In such a situation, resetting (zeroing) of TL by sunlight exposure during floods would be hindered by water turbidity (Berger, 1990) and rapid overbank burial of the silt. Berger (1990, Fig. 24) and Berger and Easterbrook (1993) provide examples of overbank (non-eolian) silt and silty clay that retain most of the pre-depositional or relict TL signal. In one example (Berger and Easterbrook, 1993, sample DEMG-3), a ~13-ka overbank deposit in a relatively high-relief region yielded a TL age of 57 ±13 ka. On the other hand, other overbank silty clay deposits in a low-relief, broad floodplain in the same region yielded correct TL ages.

Fig. i. TL analytical data for samples SEDN95-1 and MRMA95-1 (see also Table 3). (a)-- Dose-response curves for SEDN95-1 and equivalent-dose (D_E) value at the 290-300 °C slice of the readout curves. Top curve results from laboratory beta dose added to unirradiated subsamples (N). Partial bleach (PB) used is specified in footnote to Table 3. Preheating was for 4 days at 130°C and only blue-emissions signal was acquired (through a 5 mm thick Copp optical glass filter, CS-560). (b)-- D_E-T plot of PB data from Fig. ia. A plateau indicates stable TL for age calculation. (c)-- D_E-T plots for MRMA95-1. TB is total-bleach procedure, in which a subgroup of only the N subsamples is bleached for a long time, with a full-spectrum Hg-vapor lamp in this example. The subtraction of this remaining light-insensitive TL from the N+beta data yields a D_E value. No significant difference is seen between the TB and PB results, thus the age estimate in Table 3 used only the TB plateau. TB and PB bleach parameters are specified in a

footnote to Table 3. The same preheating and readout were used here as for SEDN95-1.

PART C. SUMMARY OF NEOTECTONIC DATA FOR THE EASTERN PART OF AWATERE FAULT, NEW ZEALAND

Active coastal section of the Awatere fault and the Vernon fault

The near-coastal part of the Awatere fault has minor topographic and geologic expression. East of Boundary Stream, the fault dips NW at ~80°. Here the scarp strikes 060-063° and is typically upthrown on the NW side, causing 1-3 m of relief on hillslopes and late Quaternary terraces. West of Highway 1, the fault plane strikes ~065°, dips ~85° NW, and offsets hillslopes in a down-to-the-NW sense. There, the fault plane is exhumed by erosion, in part by numerous small landslides.

A conglomeratic sequence of Late Miocene-Early Pliocene deep-marine rocks is present on both sides of the fault. Offset of this sequence is <1 km vertically, and <4 km dextrally, as inferred from offset of the gently dipping Miocene-Pliocene unconformity across the fault (Little and Jones, in press), a conclusion that accords with the lack of a measurable gravity anomaly change across the fault (Hunt, 1969). Coastal hills are 250-350 m high on both side of active Awatere fault, which is a subdued topographic feature, whereas an older inactive scarp, down-thrown to the SE, is sharply defined by a break in topography along the northern edge of the Awatere Valley. Seismic reflection data suggest that the coastal section continues offshore as a steeply dipping fault bending to an easterly strike in Cook Strait, where Neogene sediments of the Wairau Basin are downthrown on the north side of the fault (Carter et al., 1988; Uruski, 1992; Henrys et al., 1995). Ridge spurs cut by the coastal section of the Awatere fault are displaced dextrally by 70, 60, and 40-50 m between Stafford Creek and Highway 1, and by 25-40 m between Highway 1 and the coast (e.g., Fig. 4). A small deeply incised stream gully east of Stafford Creek is dextrally offset

by 5 ±2 m (Table 2). The surface trace of the active coastal strand, especially between Toe Toe and Stafford Creeks, consists of a grassy, poorly drained trench or furrow, 60-150 cm wide and ~30 cm deep, that has the appearance of an in-filled fissure or rent.

Several kilometers north of the Awatere fault, the Vernon fault occurs as two discontinuous scarps near the southern margin of Wairau Lagoons (Fig. 2). The northern scarp is upthrown 1-3 m to the south, but locally by <1 m to the north; stream channels are dextrally offset by 2-3 m on the northern trace, and by up to 40 m on the southern one (P. R. Wood, unpub. data). Hunt (1969) noted closely spaced, linear gravity contours parallel to this fault which he attributed to >300 m of downthrow of the lagoon block relative to the Vernon Hills.

Inactive coastal section

To the west of Black Birch Stream, where it emerges out of a complex zone of fault splays and ridge rents on the southern slopes of the Black Birch Range, the main Awatere fault system bifurcates eastward into two strands (Fig. 2). The northern of these two strands is the active coastal section of the Awatere fault (above). The southern one coincides with the inactive Fuchia fault, which juxtaposes Mesozoic basement greywacke to the north against Late Miocene strata to the south (Little and Jones, in press). Farther east, this strand of the Awatere fault is concealed beneath Quaternary river terraces (Eden, 1989), but appears to coincide with a steep gravity anomaly gradient diverging eastward from the main Awatere fault– a gravity change that suggests the presence of an extra ~0.5 km of Neogene sediments abutting the south side of the concealed fault (Hunt, 1969). The bed of the modern Awatere River also deflects eastward away from the north wall of the valley in this region (Fig. 2). Near the coast, the older

strand is expressed by ~300 m topographic break between the flat, terraced floor of the Awatere Valley and the Vernon Hills to the north.

Dumgree Station section

This 3 km-long section strikes ~035°, defines a ~1 km-wide double restraining bend between the Nina Brook and active coastal sections, and includes two oblique-thrust splays (Fig. 2). These splays separate rugged hills, >500 m high, of basement greywacke on their uplifted NW side, from late Quaternary alluvial terraces (including the Downs and Stb_1 terraces of Eden 1989) on their SE side. The Stb_1 terrace is displaced 3-5 m vertically across the southern fault splay and hillslopes are offset ~7-8 m vertically across the northern splay. The northern fault splay dextrally offsets a ridge spur west of Kennel Creek by ~13 m and a stream channel east of Kennel Brook by ~8 m (Table 2). Between Lake Jasper and Kennel Brook, the southern fault splay dextrally offsets a bedrock ridge flanked by Downs terrace remnants by ~400 m. At the Dumgree Station west of Kennel Brook, the southern strand offsets an alluvial fan downlapping onto the Stb_1 terrace by ~112 m away from its source gully (Table 2). A nearby streamlet to the east is offset dextrally by 6 m across the southern fault splay (Table 2), whereas an adjacent, abandoned channel of this same stream on the SE side of the fault is offset a further 8 m to ~14 m, suggesting the cumulative effects of two surface rupturing events. West of Dumgree Station, the southern splay displaces streams and ridge spurs 40-50 m dextrally and ~30 m vertically (P. R. Wood, unpub data). East of it, active streams cut into the Stb_1 terrace are dextrally offset by 40-50 m across a single, reunited strand of the Awatere fault.

Nina Brook section

Well exposed in the canyon of Nina Brook, this ~4-km long section strikes ~065°, dips ~85° northwest, and is continuous with the Dumgree Station

section to the east. Farther west, it bounds the southern margin of the Lake Jasper pull-apart structure. The Nina Brook fault scarp is sharply defined and steep, causing ~10 m of relief on the Stb_1 terrace surface near Taylor Pass Road. This section is downthrown on its NW side (normal dip-slip), in contrast to the adjoining Blairich and Dumgree sections, which are both up-to-the-northwest.

Blairich River section

The ~15 km-long Blairich River section of the Awatere fault strikes ~055-065° and forms the northern boundary of the Lake Jasper pull-apart structure. Just west of Lake Jasper, the fault dips 65° NW and uplifts the Stb_1 terrace on its NW side with ~3.3 m of reverse dip-slip (see below). Farther west, younger terraces are upthrown to the NW by 0.2-1.9 m, and a relict channel is dextrally offset by ~52 m (Lensen, unpub. data). The fault is exposed in Blairich River where it dips 78-81° NW, and places Mesozoic basement rocks against Pliocene mudstone to the south. West of Blairich River, the fault is complicated by several restraining bends and local strike changes, reversals in the sense of throw, fragmentation into discontinuous traces off the main fault, and a westward divergence into splays on to the Black Birch Range. Lensen (unpub. data) measured a dextral-slip of ~92 m and NW-up vertical slip of 0.8 m for an offset terrace riser footed by the Stb_1 terrace. West of Black Birch Stream, the sense of throw on the Awatere fault becomes consistently SE-up. Lensen (unpub. data) noted dextral-slip of 90 m and a SE-up vertical-slip of 5 m on a ridge spur near Altimarloch Station.

Grey River section

This section links discontinuously with the Blairich River section across a zone of horse-tail splays on the southern flank of the Black Birch Range (Fig. 2). The Grey River section is expressed as a conspicuous furrow along

the northern wall of the Awatere Valley as it continues southwestward from the horse-tail zone for ~28 km. The fault displaces steep hillslopes with a SE-up sense of dip-slip to cut an up-hill facing scarp (ridge rent), typically 3-6 m high. Shutter ridges occur locally on SW-facing slopes due to lateral displacement of bedrock spurs, and have locally resulted in damming to form small ponds along the scarp (e.g., Gosling Creek, NZ grid ref. P29 800392). P. R. Wood (unpub. data) has observed a dextrally offset spur of ~40 m, and several stream offsets of 70-80 m between Black Birch Stream and Ring Creek. From precise mapping of the fault trace across six 100-250 m deep gorges, the fault plane strikes 057±4° and dips 50 ±8° NW. Immediately north of the Awatere fault trace, several discontinuous fault sections striking 20-30° clockwise from the main trace occur near Grey River (Lensen, 1963).

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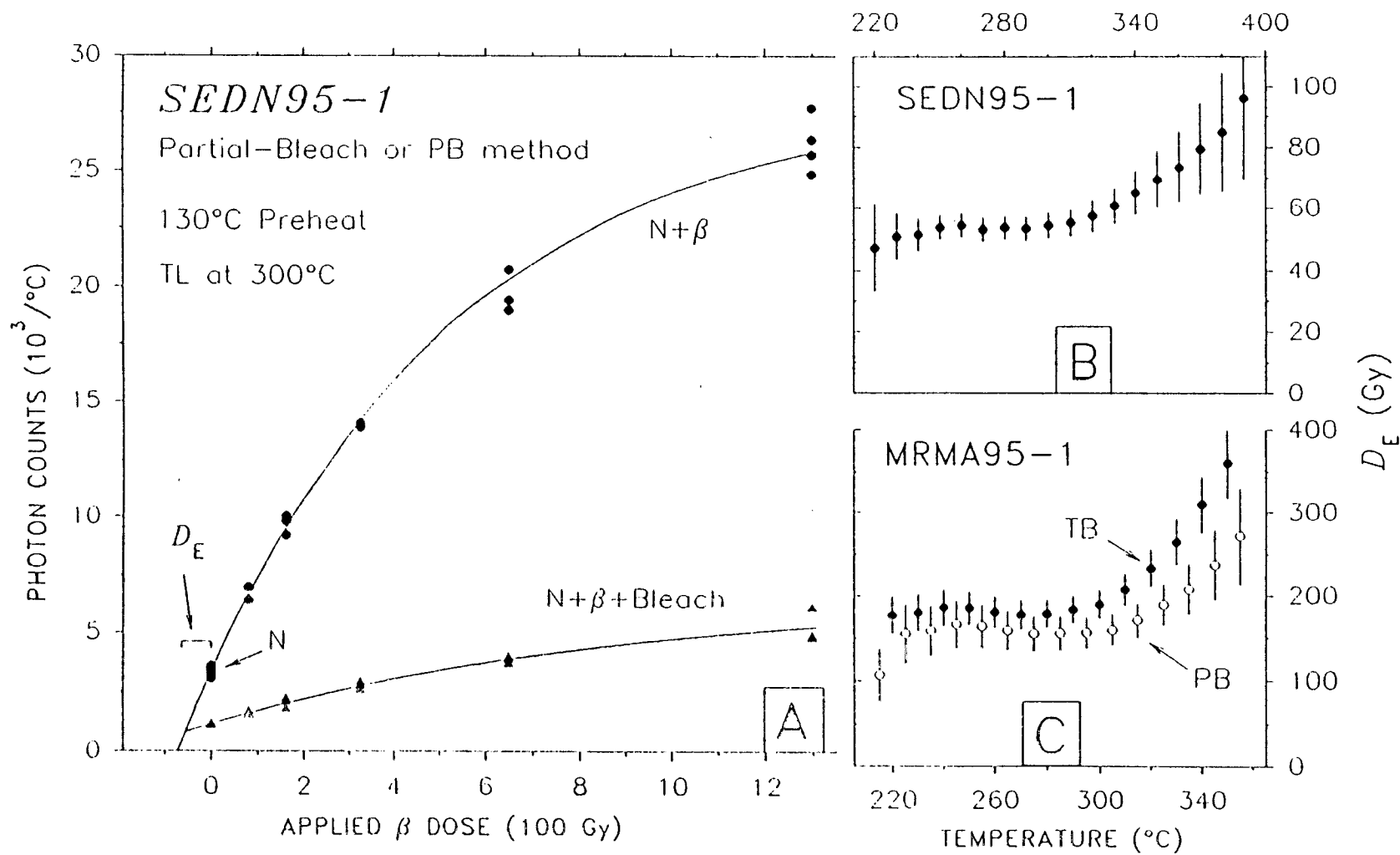## D. INTERPRETATION OF PEBBLE WEATHERING-RIND AGES

The following observations are consistent with our conclusion that pebble weathering rind ages are prone to underestimating terrace ages in the Awatere Valley. Knuepfer (1988, 1992) obtained a pebble rind age of 3900 ±480 yr B.P. for the SG terrace at Grey River, but concluded from soil development that the actual age was probably 5-10 ka, and we correlate SG with the regionally extensive, ~15 ka Stb$_1$ aggradation surface. At Saxton River, the last glacial aggradation terrace is constrained by ^{14}C dating to an age of 9.4-12.6 ka (McCalpin, 1992b, McCalpin, 1996). Two corresponding pebble weathering rind ages are younger, at 9.4±1.6 ka and 7.9±3.8 ka (Knuepfer, 1988). Also, our pebble rind age of 400 ±70 yrs for the t$_3$ terrace (Fig. 10a) seems improbably young for a terrace located ~6m above a stream incised into greywacke bedrock.

Pebble weathering-rind ages may underestimate actual surface ages because: (1) some surface clasts, originally buried by loess, are later

exhumed by deflation, and (2) rather than simply thickening with time, rinds also spall or disintegrate, a "saturation" effect that makes pebbles >10 ka especially prone to age underestimation (Whitehouse et al., 1986; McCalpin, 1992a; McCalpin, 1992b; McSaveney, 1992).