Technical Comments

New Zealand Marine Terraces: Uplift Rates

William B. Bull and Alan F. Cooper (*1*) identify as marine terrace remnants 18 "notches" or steps at altitudes up to 1700 m on the ridge crests southeast of the Alpine fault, New Zealand. They infer late Quaternary uplift rates on this upthrown side of the fault at three study areas. Their conclusions are based on (i) morphology of the steps, which are said to resemble eroded marine cliffs and shore platforms; (ii) the presence of quartz beach pebbles on 16 of the 18 steps; and (iii) linear correlation of step altitudes with the sea-level peaks derived from the Huon Peninsula, New Guinea terraces (*2*). These lines of evidence should be critically examined.

With respect to point (i), three-dimensional terrace morphology is not preserved. For the most part the steps occur on narrow, essentially knife-edge ridge crests perpendicular to the Alpine fault and inferred former coastline. The shore-parallel continuity of up to 3 km is not apparent. Step altitudes of the Fox–Franz Josef area listed in table 3 (*1*) appear to have been derived from the peaks on a histogram of all altitudes of steps discernible on a topographic map (*3*). The lack of correspondence between the table 3 altitudes and those of the "type" sections at Stony Creek listed in table 2 (*1*) demonstrates either that this procedure is unreliable or that there is no consistent set of step altitudes in the Fox–Franz Josef area, or both.

The widely scattered rounded quartz pebbles with frosted surfaces and high-energy impact marks (*1, 4*) can equally or preferably be interpreted as (probable Holocene) gizzard stones of one of the eight or nine species of moa (*5*), ostrich-like birds (Order Dinorithiformes) 1 to 3 m tall, formerly widespread in New Zealand, but becoming extinct in the last few hundred years.

The analysis of Bull and Cooper assumes a one-to-one correspondence of erosional marine terraces with the sea-level peaks inferred from the essentially constructional deltaic and coral terraces of New Guinea described by Chappell (*2*), a doubtful proposition as emphasized by Chappell (*6*). High apparent uplift rates of 5 to 8 mm per year, with permissible errors of 30 m or more, lead one to suspect that almost any semiregular sequence of altitudes could be matched "successfully" to the New Guinea sea-level curve. In the present case, the suspicion is compounded by the coincidence of an apparent increase in uplift rate about 135,000 years ago with a marked decrease in sea-level peak spacing in the New Guinea sea-level curve at this time (*2*). This decrease in turn coincides with the shift in the basis of the sea-level curve, from the coral terraces of Sialum and Gitua to the mainly deltaic sequence at Tewai River that more sensitively indicates sea-level change (*2*).

Consideration of the geological setting of the stepped ridges provides more definitive evidence against recognition of the ridge-crest steps southeast of the Alpine fault as marine terrace remnants. In the Last Glaciation, a lobe of the Franz Josef Glacier flowed northeast along the Alpine fault scarp, hard against the spurs flanking Stony Creek. Well preserved moraine ridges northwest of the Alpine fault (*7*) allow clear definition of ice limits and indicate a glacier margin in the last (weakest) advance of the Last Glaciation at least as high as the 503-m step identified by Bull and Cooper, or above the 564-m step allowing for approximately 100 m of Holocene uplift on the Alpine fault (*8*). This implies that at least the lowest six steps identified by Bull and Cooper are nonmarine features of the Holocene age.

A more general implication is that substantial glacial advances throughout the late Quaternary are likely to have destroyed any (hypothetical) marine terraces formed east of the Alpine fault during the preceding 60,000 years or more if the uplift rate is the 7.8 mm per year inferred by Bull and Cooper. In other words, a marine terrace is unlikely to be uplifted beyond the reach of subsequent glacial advances unless the marine terrace–forming sea-level peak is followed by an exceptionally long interval without a substantial glacial advance.

The same arguments apply to the Kaniere area studied by Bull and Cooper (*1*). Late Last Glaciation moraines are at similar altitudes. Glacial advances would have destroyed any marine terraces formed in the preceding 90,000 years if the uplift rate is the 5.5 mm per year inferred by Bull and Cooper. Moraines are not preserved in the Haast study area (*1*), but Last Glaciation ice levels there are unlikely to have been any lower than at Franz Josef and Kaniere.

Where it has been little modified by glaciers, the scarp of the Alpine fault generally rises 600 to 1200 m above the fault trace at average angles of 25° to 35°, close to the angle of repose. At depth, the Alpine fault is a high angle reverse fault, as befitting its role as an obliquely convergent plate boundary. Hence, unless its hanging wall were literally to overhang, major uplift on the fault could not occur without complete collapse of the fault scarp, which would destroy 10 to 15 of the steps interpreted by Bull and Cooper as marine terraces. If the steps were indeed marine terraces, then the present is a unique point in geological history, when the Alpine fault scarp has just reached the state when it is about to collapse for the first time in 200,000 years—not just at a single locality, but simultaneously along a length of 250 km or more. On the contrary, a long history of deep-seated gravitational collapse of the fault scarp is demonstrated by the relatively gentle southeast dip of the fault plane wherever it is exposed (*9*).

Poorly documented marine terraces are present near the modern coast west of Franz Josef (*7, 10*). Cement Hill, the highest known terrace, is 220 m above sea level and 3.5 km inland, 10 km northwest of the Alpine fault. It is of unknown (pre–Last Glaciation) age but likely to be approximately 200,000 years old if the estimates by Bull and Cooper (*1*) of uplift rates west of the Alpine fault are correct. It follows that during the episodes of high sea level in the late Quaternary, when Bull and Cooper infer marine terraces were being cut east of the Alpine fault, that the coast was in fact far to the west. [Only during brief intervals after deglaciation and before alluvial infilling of fiord-like glacial valleys can the sea have penetrated to the Alpine fault (*11*)].

The same argument applies with greater force to the Kaniere study area, 20 to 25 km seaward of which lies one of New Zealand's classic marine terrace sequences spanning at least the Last and Penultimate Interglacials, with intervening glacial outwash gravels (*12*). Degraded sea cliffs associated with these marine terraces closely parallel the modern curvilinear coastline. This argument cannot be directly applied to the Haast study area, where the Alpine fault is separated from the sea by 8 km of low-lying Holocene deposits.

In summary, Bull and Cooper (*1*) appear to have misidentified a collection of steplike geomorphic features as marine terraces and to have incorrectly correlated them with the New Guinea sea-level curve. The inferred late Quaternary uplift rates east of the Alpine fault appear, therefore, to be without foundation.

C. M. Ward
Department of Conservation,
Post Office Box 10420,
Wellington, New Zealand

REFERENCES AND NOTES

1. W. B. Bull and A. F. Cooper, *Science* **234**, 1225 (1986).
2. J. M. A. Chappell, *Geol. Soc. Am. Bull.* **85**, 553 (1974); *Search* **14**, 99 (1983).

3. By analogy with W. B. Bull, in *Tectonic Geomorphology*, M. Morisawa and J. T. Hack, Eds. (Allen & Unwin, Winchester, MA, 1985), pp. 129–152, with particular reference to figure 5 and the study of the Caswell Sound area.
4. A. F. Cooper and D. G. Bishop, *R. Soc. N.Z. Bull.* **18**, 35 (1979); G. J. van der Lingen, *ibid.*, p. 45.
5. A. Hamilton, *Trans. N.Z. Inst.* **24**, 172 (1891); D. R. Gregg, *Rec. Canterbury Mus.* **9**, 151 (1972).
6. J. M. A. Chappell, *N.Z. J. Geol. Geophys.* **18**, 129 (1975).
7. G. Warren, *Geological Map of New Zealand 1:250,000* (Department of Scientific and Industrial Research, Wellington, New Zealand, 1967), sheet 17, Hokitika.
8. J. Adams, *R. Soc. N.Z. Bull.* **18**, 47 (1979).
9. H. W. Wellman, *N.Z. Geol. Surv. Bull.* **48** (1955); R. P. Suggate, *Trans. R. Soc. N.Z. Geol.* **2**, 105 (1963); R. H. Sibson, S. H. White, B. K. Atkinson, *R. Soc. N.Z. Bull.* **18**, 55 (1979).
10. P. Wardle, *Plants and Landscape in Westland National Park* (Department of Lands and Survey, Wellington, New Zealand, 1979).
11. R. P. Suggate, *N.Z. J. Geol. Geophys.* **11**, 345 (1968).
12. ——, *N.Z. Geol. Surv. Bull.* 77 (1965).

20 July 1987; accepted 19 October 1987

Response: Rounded quartz pebbles on accordant steps in the Southern Alps provide clues to uplift rates and crustal plate interactions *if* they are marine-terrace time lines. Ward says that they are not, but does not provide an alternative explanation for round pebbles on flat summits. In this reply, we answer Ward's criticisms and clarify our original position (*1*).

Marine-terrace remnants can be extensive (Figs. 1 and 2). None of our 200 sites of rounded quartz pebbles are on knife-edge ridge crests; they are on flat summits and gently sloping notches on spur ridge crests. The pebbles do not occur on steep valley sides, glacial deposits, and scoured bedrock and are rare or absent on steeply sloping ridge crests between flat terrace remnants. These pebbles are distinct from moa gizzard stones, which have a delicate patina (formed by slow grinding of fibrous plants) that is superimposed on any pre-ingestion high-energy-surface texture (*2*). Electron microscopy by Angus (*3*) of surface textures on 28 quartz pebbles reveals systematic changes with increase in terrace altitude from 830 to 1323 m in the Alexander and Bald ranges. Angus concludes that "quartz pebbles from lower terraces are dominated by mechanical features" and "become progressively modified by a distinctly different chemical etch in the higher terraces" (*3*, pp. 97–103).

Distinctive spacings of inner-edge altitudes allow internally consistent correlations of dated with undated terrace flights (*1*, *4*). Increase of the uplift rate about 135×10^3 years ago is apparent at 14 sites along the Alpine fault. With the same analytical procedure, a contrasting tectonic style of no change in inferred uplift rate is seen in altitudinal spacings of remnants of marine terraces formed during the past 300×10^3 years at Fiordland and at Seaward Kaikoura Range sites (*4*), which are in tectonic settings different from that of the Alpine fault escarpment. Sea-level highstands recorded by coral reefs, deltaic deposits, and shore platforms may result from global climatic changes induced by variations in the earth's orbit (*5*). The "astronomical clock" is a good independent check against the radiometric chronology of New Guinea terraces. The new chronology predicts the same number of global marine terraces, but slightly younger ages for sea-level highstands result in slightly higher inferred uplift rates.

Ward's emphasis on glacial processes seems to preclude consideration of the cutting of marine benches on previously glaciated surfaces. We believe that marine, fluvial, and glacial processes interacted with uplift to create the Alpine front topography of Fig. 2. Glacially smoothed lower slopes contrast with higher rough terrain where streams have cut valleys into rising mountains. Marine platforms with round quartz cobbles and pebbles (*6*) occur as flat summits and accordant benches on spur ridges. Spot altitudes of 834 m, 831 m, 837 m, and 834 m (A on Fig. 2) are on remnants of an extensive, flat marine platform formed 214×10^3 years ago that has a shore parallel continuity of at least 2.5 km to the southwest (*3*) and of 6 km to the northeast of the 837-m spot altitude (*7*). Flat surfaces are typical of shorelines but not of streams or glaciers. This marine terrace has been raised by regional uplift, but has not been faulted or folded, which leads to the conclusion that Ward's postulated collapse of a thrust-fault escarpment has not occurred. Notches at B (Fig. 2) suggest glacial benches, but they also occur at C as ridge-crest notches flanked by fluvial valleys. This suggests that slopes at B and C were smoothed by glacial erosion, raised above subsequent glaciers, notched by several sea-level highstands, and eroded by streams. The upstream increase of valley depth west of C (20 m deep at the 200-m contour, 50 m deep at 300 m, and 95 m deep at 400 m) also supports the idea that recent glacial trimming did not reach the trimlines of earlier glaciers. We agree that in the Fox–Franz Josef area the lowest bench was modified by glaciers (*1*), but believe that higher benches and notches record process interactions similar to those described for Fig. 2.

The terrain northwest of the Alpine fault has been rising out of the sea, so future sea-level highstands will have to be higher than present sea level in order to locally notch schist southeast of the Alpine fault. Previ-

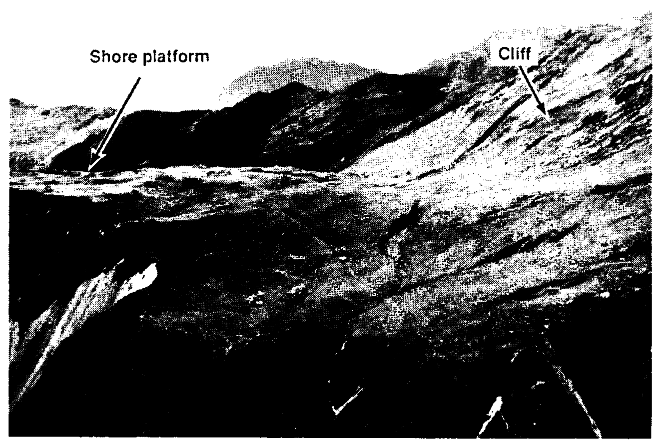

Fig. 1. Encroachment by fluvial erosion into an upland with several levels of extensive marine-terrace remnants with inferred ages of 286×10^3, 305×10^3 and 320×10^3 years ago, respectively (*5*). Arrow points to a terrace at an altitude of 1280 m that was formed 305×10^3 years ago in the Kelly and Bald ranges in the Southern Alps of New Zealand 10 km from the Alpine fault. Rounded quartz pebbles are common on shore-platform remnants, but are absent on the degraded sea cliff.

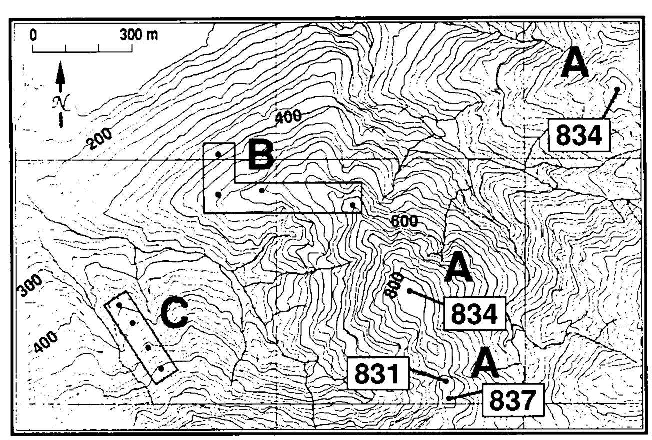

Fig. 2. Topographic characteristics of hillslopes modified by fluvial, glacial, and marine processes in the Alexander Range of the Kaniere study area of the Southern Alps (*7*). Alpine fault is near base of escarpment. Glacial and fluvial slopes have been notched by four sea-level highstands at B and C. The terrace A, formed 214×10^3 years ago, is still flat; it is 834 ± 3 m over a distance of 1.5 km. It extends northeast and southwest for a total distance of at least 8 km (*8*).