New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzg20

# Sea caves, relict shore and rock platforms: Evidence for the tectonic stability of Banks Peninsula, New Zealand

Adriaan A. Bal

**To cite this article:** Adriaan A. Bal (1997) Sea caves, relict shore and rock platforms: Evidence for the tectonic stability of Banks Peninsula, New Zealand, New Zealand Journal of Geology and Geophysics, 40:3, 299-305, DOI: 10.1080/00288306.1997.9514762

**To link to this article:** http://dx.doi.org/10.1080/00288306.1997.9514762

*New Zealand Journal of Geology and Geophysics, 1997, Vol. 40*: 299–305
0028–8306/97/4003–0299 $7.00/0 



# Sea caves, relict shore and rock platforms: evidence for the tectonic stability of Banks Peninsula, New Zealand

ADRIAAN A. BAL
Department of Geological Sciences
University of Canterbury
Private Bag 4800
Christchurch, New Zealand*

*Present address: Z & S (Asia) Ltd., 46 Ord St., West Perth 6005, WA Australia.

**Abstract** Well developed but partially exposed shore platforms at 6–8 m above mean sea level (m.s.l.) on the southwestern flanks of Banks Peninsula have been considered previously as evidence for either general tectonic stability or differential subsidence of the peninsula. These platforms probably formed during an interglacial high sea-level stand, c. 120 000 yr ago or earlier. Banks Peninsula has been assumed to be differentially subsiding, since comparable platforms have not been identified on the northern flanks, and adjacent late Quaternary marine and fluvial sediments of the Canterbury Plains are unequivocally subsiding. However, an alignment of coastal erosional features at Cave Rock and Sumner Head, Christchurch (northwestern flank of Banks Peninsula), may represent a relict shore platform 5–6 m above m.s.l.

These erosional features are interpreted to be correlatives of the platforms described on the southwestern flank, and therefore suggest Banks Peninsula is not differentially subsiding. By implication, wide (kilometre-scale) subsurface (c. –50 to –100 m below m.s.l.) rock platforms, recently mapped by others, are interpreted to be the product of early Pleistocene multiple glacio-eustatic sea-level falls and/or rises. The presence of this subsurface platform, and possible submarine correlative, suggests Banks Peninsula may have been tectonically stable for much of the mid–late Quaternary.

**Keywords** shore platform; rock platform; sea caves; glacio-eustacy; sea stack; plunging cliffs; coastal erosion; strato-shield volcano; Quaternary; Banks Peninsula; Canterbury

## INTRODUCTION

Discontinuous shore platforms, +6–8 m above mean sea level (m.s.l.), have been identified on the southwestern flanks of Banks Peninsula, South Island, New Zealand (e.g., Jobberns 1928; Speight 1930, 1943; Thomson 1964; Suggate 1968; Armon 1970). Lawrie (1992, 1993) showed that the partially exposed platforms probably formed during the last interglacial ($\delta^{18}O$ stage 5e). More recently, thermoluminescence dates of loess deposits believed to postdate the platform, show the platform could have developed up to 200 000 yr ago (J. Soons pers. comm. 1996). The platforms are best developed on volcanic rock spurs along 18 km of the northern shore of Lake Ellesmere, where they are now protected from open oceanic conditions by Kaitorete Barrier (Fig. 1).

Lawrie (1992, 1993) concluded that Banks Peninsula, as a block, was either stable or subjected to very low rates of movement since the time of platform formation. Although Brown & Weeber (1994) accepted that the southern margin of Banks Peninsula is stable, they suggested that the northern margin is subsiding, and therefore implied that Banks Peninsula is differentially subsiding.

New observations presented here describe coastal erosional features (5–6 m above m.s.l.) at Cave Rock, on

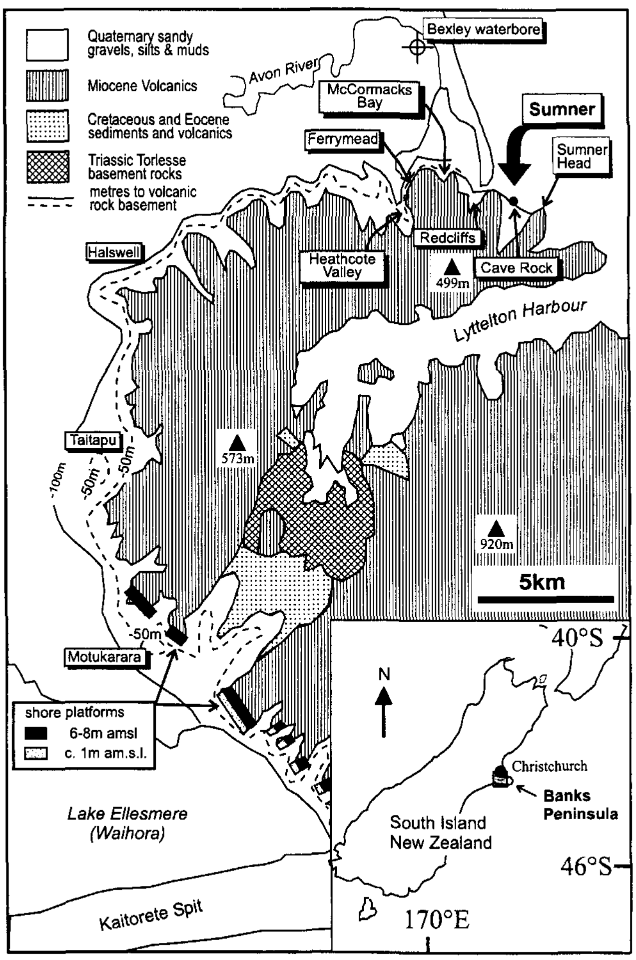


**Fig. 1** Location map showing key features referred to in the text. Metres to volcanic rock basement is after Brown & Weeber (1994) and shore platforms are after Lawrie (1992). Geology is simplified from Sewell et al. (1992).

G96045
*Received 3 December 1996; accepted 10 April 1997*

the northern margin of Banks Peninsula at Sumner, Christchurch. The primary purpose is to resolve the conflict that exists in the literature as to whether Banks Peninsula is stable or differentially subsiding. The features described are at the same level as the platforms described by Lawrie (1992, 1993) and others. If they are correlatives, Banks Peninsula has not been differentially subsiding. The scope also includes the general assessment of rock platforms, now below sea level, as part of the basic data used to evaluate hypotheses of stability and differential subsidence.

## TERMINOLOGY

"Shore platform" is a non-generic term used to describe a gently sloping to near-level coastal erosional feature cut into rocks (Trenhaile 1980, 1987). The processes involved in the development of these features are generally more varied and complex than simply wave cutting. In this paper, I make the distinction between (1) **shore platforms** that develop between and/or a bit above the tide range of elevations during a relatively stable sea level (i.e. sea-level stillstand) and (2) **rock platforms** that are here interpreted to have developed under either rising or falling sea levels (transgression or regression).

In the case of (1), shore platforms attain a state of dynamic, quasi-, or static equilibrium, depending largely on changes in rock type as the platform develops (Trenhaile 1983). Trenhaile argues that most present-day shore platforms have already attained their equilibrium, or are close to it, as a consequence of the past 6500 yr of sea-level stability. The width scale of these platforms is measured in metres, up to c. 500 m (Trenhaile 1983, 1987).

In the case of (2), very wide (kilometre scale) and extensive platforms can develop. On the basis of modelling, Trenhaile (1989) shows these wide platforms may develop during sea-level fall and/or rise. As in (1) it is only the near-intertidal zone that is actively developing as a platform. However, a wide rock platform develops through planation as this zone moves up or down in response to sea-level rise or fall. These rock platforms can have substantial relief between the outer and inner edge (up to 50 m or more) and in profile have the morphology of a gently sloping ramp. To avoid ambiguity and to make a distinction from (1), I will refer to these wide platforms as rock platforms.

## METHODS

Cave Rock (Fig. 1, 2) was visited and photographed during July, August, and October 1996, at both high and low tide periods. Methods used in studying Cave Rock involved field observations, mapping, use of photo mosaics, and surveying. The heights of key features were surveyed relative to a benchmark located at the top of the rock (13.29 m above m.s.l. relative to Lyttelton Datum). Interpretations based on photo mosaics were verified in the field.

Particular attention was paid to erosional features: benches, ledges, notches, and caves. These features either (1) reflect differences in susceptibility to erosion between layers, (2) truncate the layers or structural grain, or (3) are a combination of (1) and (2). The first may be attributed to general weathering processes. However, truncation (especially if horizontal) must be attributed to more aggressive "cutting" processes. Many of the features observed truncate underlying beds and the structural grain.

## GEOLOGICAL SETTING

Banks Peninsula is a large Cenozoic alkalic intraplate volcanic promontory (c. 1500 km$^2$) comprising two large strato-shield volcanoes, Lyttelton Volcano and Akaroa Volcano, and numerous small parasitic cones (Sewell et al. 1992). Lyttelton Volcano is symmetrical and sits on a basement fault block comprising Torlesse metasediments up to 150 m above m.s.l. but c. 1000–1500 m above surrounding basement (Wood et al. 1989; Sewell et al. 1992). Volcanic activity started c. 15 m.y. ago and continued for c. 10 m.y. through to 5.8 m.y. ago (Sewell et al. 1992).

The sandy-gravel Canterbury Plains prograded eastwards mostly during the Quaternary ice ages, connecting Banks "island" to the mainland by the middle Pleistocene (Field et al. 1989; Wood et al. 1989; Brown & Weeber 1994).

## SUMNER BAY, CAVE ROCK, AND SUMNER HEAD

### Wave climate and tidal range

The Sumner Bay wave climate is dominated by northeasterly winds and swells. Semidiurnal tides dominate with a c. 2 m range (microtidal). The spring/neap tide effects are relatively small compared to the monthly perigean/apogean effects (D. Goring, NIWA, pers. comm. 1996). Precise data on storm surge effects in Sumner Bay are not available. Although storm surges in New Zealand have been estimated to be limited to 0.8 m above m.s.l. (Heath 1979), this value is probably significantly underestimated, since Heath did not account for wave setup and interaction with tides (Kirk 1979).

### Cave Rock

Cave Rock is a 13.29 m high sea stack, covering c. 0.1 km$^2$, located in Sumner on the northern margin of Banks Peninsula (Fig. 1, 2A). The stack is now connected to land but was referred to as "Cave Island" on early charts (Macpherson 1978). There are some human modifications and possible excavations, including flat-lying concrete foundations. Construction of a sea wall to prevent coastal erosion at Sumner, reclamation for road building, and a consequent change in the Avon-Heathcote estuary flood-ebb channel, have resulted in alternating periods of aggradation and progradation of the adjacent Clifton Beach (Macpherson 1978; Findlay 1984).

The Cave Rock stack comprises two aa basalt lava units separated by a marked orange-brown tuffaceous bed up to 60 cm thick. The lower unit appears to have been an eroded remnant of a local high, which was mantled by the basalt flows of the overlying unit. Consequently, the layers in the upper unit have variable strikes and dips, but there is a general dip 30–60° to the north (Fig. 2B, C). Individual flows are commonly massive and separated by clinker, agglomerate, blocky, or tuffaceous layers and lenses.

A small (100 m$^2$) shore platform exists on the northeastern aspect (Fig. 2B), facing directly into the prevailing waves. The junction between the cliff and the shore platform is at the high-tide level. From here, the platform slopes

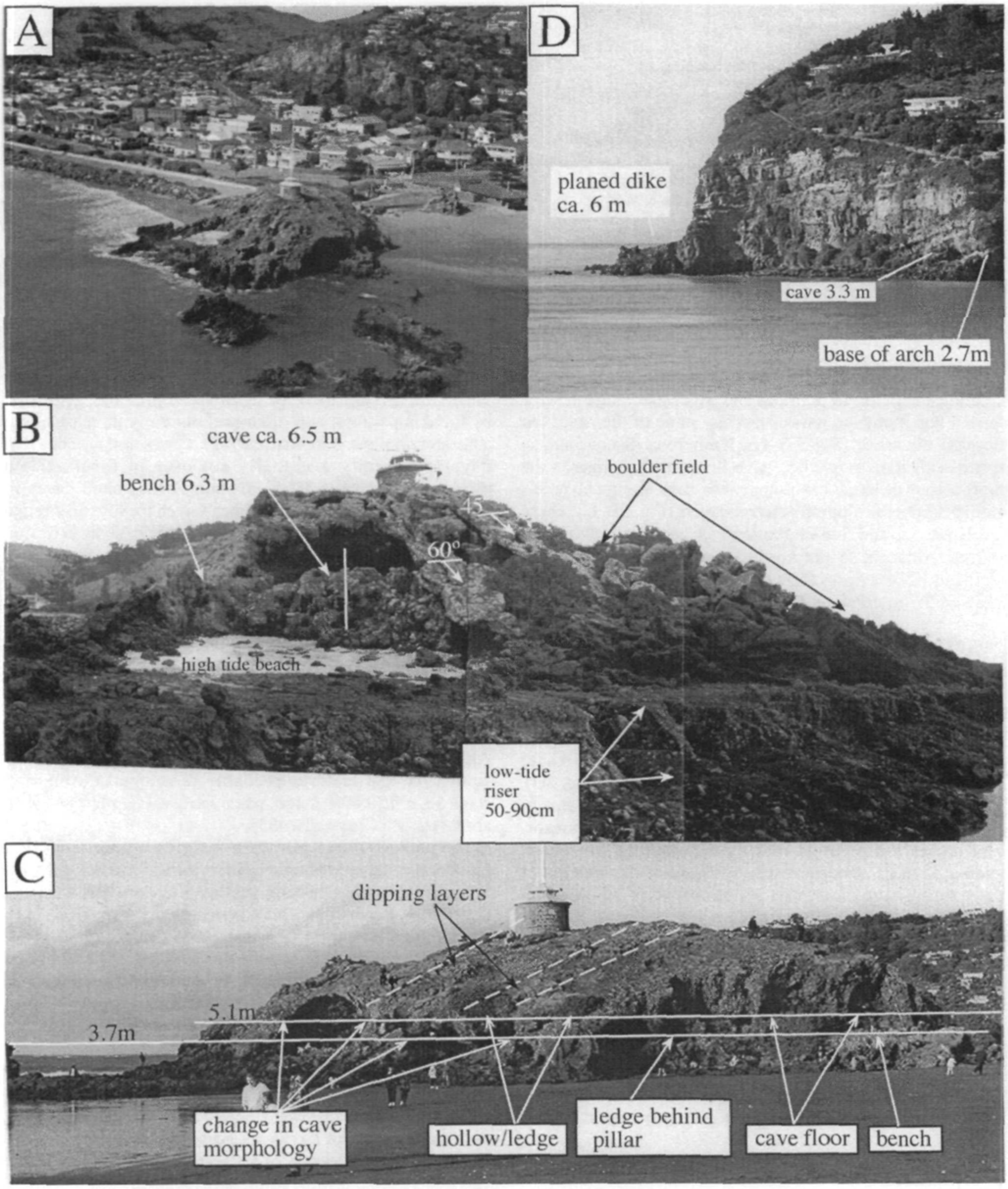


**Fig. 2** **A**, South-facing view of Cave Rock and Sumner *(Photo: D. L. Homer, reproduced from Brown & Weeber 1992)*. **B**, Northeast-facing aspect of Cave Rock showing active shore platform, boulder field, and sea cave (photo taken 0.5 h after low tide). **C**, Cave Rock, western aspect, showing alignment of erosional features described in text. **D**, Prominent planed dike at Sumner head and cave viewed from Cave Rock (houses on Scarbough Hill for scale). The location of a tunnel, and inferred incipient sea arch, is marked.

seawards c. 1° for c. 17 m to a low-tide riser ranging 50–90 cm in height (Fig. 2B, 3). From the low-tide riser, the platform is bevelled and disappears below a sandy substrate exposed at low tide. A pile of large, interlocking, blocky boulders, with long axes ranging 1.5–2.5 m, is on the northeastern margin at a height of 1–8 m above m.s.l. (Fig. 2B). These boulders are angular, and no significant transport was involved in their emplacement.

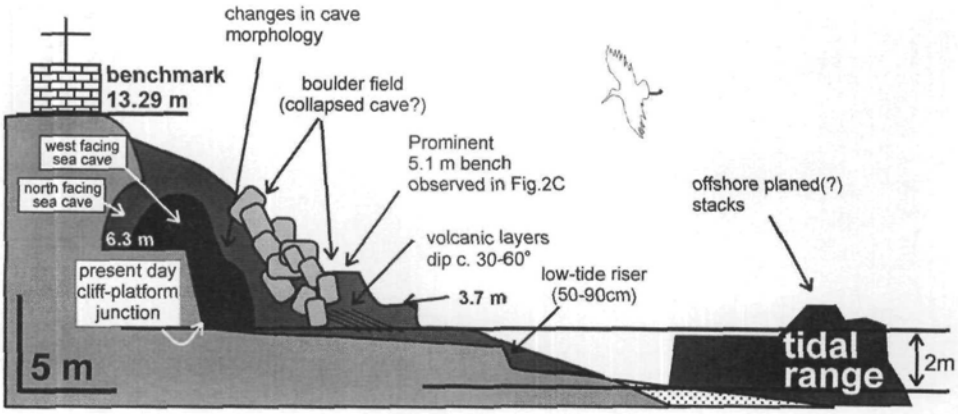


**Fig. 3** Schematic summary of key morphological features that together provide evidence for higher former sea-level stand(s).

The agglomerate layers are exploited by wave energy, creating a network of potholes and caves that range in scale from a few metres to tens of metres; some of the caves cut through the stack (Fig. 2A–C). Numerous discontinuous, metre-scale ledges, notches, cave floors, and changes in the morphology of larger caves appear to align along two levels cutting across the dipping volcanic layers (Fig. 2B, C). These levels are 3.7 and 5–6 m above m.s.l. relative to Lyttelton Datum. Adjacent to the northeastern side of Cave Rock, remnants of lava flows form two offshore platforms, planed at 2 and 3.7 m above m.s.l. (Fig. 2A).

### Sumner Head

At Sumner Head, a 3–5 m wide volcanic dike(?) forms a conspicuous bench that slopes northwards at c. 10°, terminating at a cliff that rises from a present-day active platform (Fig. 2D). This bench is estimated to be c. 6 m above m.s.l. and protrudes c. 30 m out from the cliff. About 300 m south of the head there is a high-level cave (Fig. 2D). The floor at the mouth of the cave (4.3 m above m.s.l.) appears to have been raised by c. 1 m and infilled by humans. This makes it difficult to reliably ascertain the floor level relative to m.s.l. A conservative estimate of the location of the natural cave floor was 3.3 m above m.s.l. A small "tunnel", with dimensions of 2 × 1 m and c. 2 m deep, penetrates the volcanic rock spur that separates the beach with the cave from the access beach to the south at Scarborough. The tunnel floor is flat and ranges between 1.9 and 2.7 m above m.s.l., as is a pronounced notch in the spur. There is no evidence for artificial excavation, which indicates the tunnel is probably a natural feature: possibly an incipient, now abandoned, sea arch.

All these described features are well above the high-tide mark and there is no evidence of presently active marine erosion.

### Interpretation

The coastal features described above and summarised in Fig. 3 are typical of eroding rocky shorelines (Trenhaile 1987; Griggs & Trenhaile 1994). The small shore platform morphology and height above m.s.l., described on Cave Rock (Fig. 2B), is compatible with the present-day intertidal range and wave environment and is therefore interpreted as an active shore platform. The boulder field probably represents the debris of a collapsed large ledge or cave.

Although caves and associated ledges can and do develop within and along volcanic layers by normal weathering or volcanic processes, sea-caves and ledges usually develop under the driving force of hydrostatic pressure generated by breaking waves, and often preferentially develop along a horizontal plane (Trenhaile 1987). Caves and notches that develop laterally eventually coalesce to form narrow platforms (Trenhaile 1987). Cotton (1967) cited caves in basalt developing in such a manner. Given the low tidal range at Banks Peninsula, and descriptions of rocky shores (Cotton 1967; Trenhaile 1987; Griggs & Trenhaile 1994), it is unlikely that the features aligning at 5–6 m above m.s.l. are a product of coastal processes at present-day sea level.

Following the same arguments presented by Lawrie (1992, 1993) when considering the age of shore platforms on the southern margin of Banks Peninsula, the above-described features must be attributed to the last interglacial sea-level highstand or earlier. They are probably poorly preserved relict shore platform-cliff junctions and sea caves. Although it is not possible to determine an absolute date of formation, the features probably developed during $^{18}O$ stage 5e, c. 120 000 yr ago, when sea level was last at c. 6 m above m.s.l. (Chappell 1983).

Expected shore-platform heights under different (assumed constant) tectonic uplift or subsidence regimes can be modelled using eustatic sea-level curves derived from the Huon Peninsula (New Guinea), calibrated with astronomically tuned $^{18}O$ isotope data (Imbrie et al. 1984; Bull 1984; Chappell & Shackleton 1986). If the 120 000 yr age of formation is accepted, in agreement with Lawrie (1992), then modelling shows the northern margin of Banks Peninsula has probably been relatively stable since the last interglacial. Moreover, modelling shows that possible rates of tectonic movement are very tightly constrained. For example, last interglacial platforms would be expected at 18–22 m below sea level if Banks Peninsula were subsiding at the rate of 0.2 m/ka, as suggested by Wellman (1979). Even a slow subsidence of 0.05 m/ka would result in the 120 000 yr old platform being at present-day sea level, and not the +5–6 m observed. This modelling is equally applicable to the +6–8 m platforms described by Lawrie (1993) on the southern margin of Banks Peninsula.

## DISCUSSION

Lawrie (1992) also noted the presence of high (4–6 m) notches along the cliffs of Sumner, most east-facing bays (e.g., Okains Bay), and on the southern side of Banks Peninsula east of Kaitorete Barrier (Fig. 4). Though

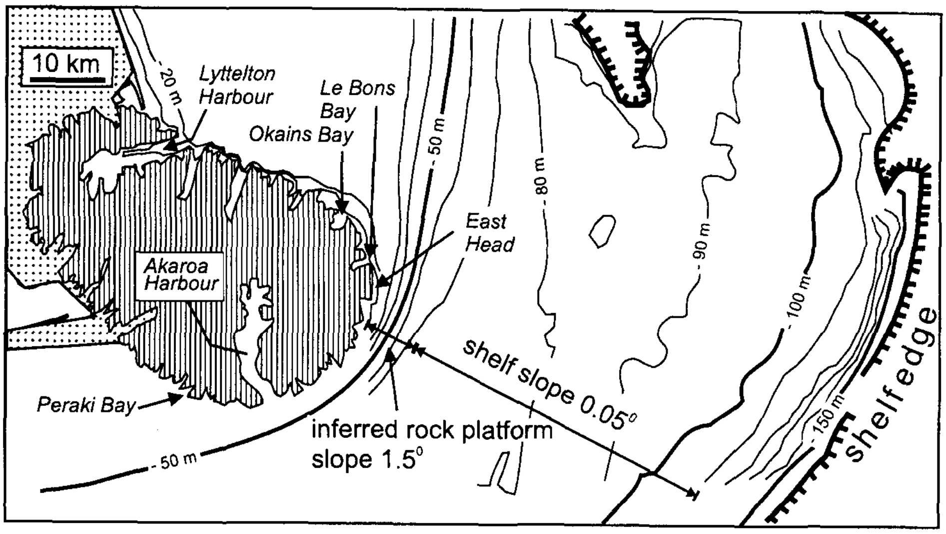


**Fig. 4** Locations referred to in the text and bathymetry around Banks Peninsula (after Herzer 1980; Herzer & Carter 1983). Shelf edge marks post c. 600 000 yr glacial lowstand shore line.

equivocal, Lawrie suggested these notches indicate a former higher sea level and also provide "evidence that the peninsula is not tilting as they show no significant variations in elevation" (1992, p. 73). High-level erosional features between Sumner and Cashmere are equivocal today largely because of extensive housing and infrastructure development on the northwestern flanks of Banks Peninsula. However, an early description makes it clear that,

"Banks Peninsula ... shows by the configuration of its base that an oscillation averaging about 20 feet in vertical height has taken place, the country being depressed and afterwards raised to about the same altitude again. This line is well visible travelling round Banks Peninsula ... the signs of a former submersion disappear below the newer fluviatile and lacustrine deposits." (Haast 1874, p. 55).

Today, the oscillation that Haast refers to would be interpreted as a rise and fall in sea level and not landmass. Furthermore, as argued by Suggate (1968), Lyttelton Volcano's symmetry suggests the edifice has not been subjected to significant differential subsidence since formation c. 10 m.y. ago.

The evidence presented here, together with the past observations of other workers, strongly suggests the northern margin of Banks Peninsula is stable and has not been differentially subsiding since the early last interglacial.

Using borehole data, Brown & Weeber (1994) contoured the inferred contact between sediment and volcanic rock at –50 and –100 m below m.s.l. (Fig. 1). They call this surface a "rock platform" and interpret the morphology, gradient between the contours (c. 1–3°), and the spatial distribution of depth to volcanic rock as a reflection of the "intensity of coastal processes" (p. 181). The width of the rock platform is measured at the kilometre scale, up to 4 km in the southwest from Taitapu to Lake Ellesmere. In regard to the mapped northwestern flank, they refer to very steep platform margins that can be described as "plunging" (e.g., at Ferrymead adjacent to the estuary of the Avon and Heathcote Rivers, one well c. 50 m from outcrop reached volcanic rock 93 m below the surface, whereas another well c. 300 m from outcrop reached volcanic rock c. 215 m below the surface).

If one accepts the observations detailed here, it is likely that the mapped rock platforms are contemporaneous. Rock platform formation must have been before 350 000 yr ago, since sediments 120 m below Christchurch (Shirley Formation) are inferred to be c. 310–350 000 yr old (Brown & Wilson 1988) and overlie the northern rock platform in the McCormacks Bay – Redcliffs area (see NCCB 1986, fig. 4.9, 5.3).

The question of how this deeply buried rock platform formed is unresolved. Although the metre to 100 m scale shore platforms along the ocean-facing southeastern coast of Banks Peninsula from East Head to Peraki Bay may be an analogue for the platforms described by Lawrie (1992, 1993), they are very poor analogues for the kilometre-scale rock platform described by Brown & Weeber (1994). Although the relationship between shore platform width and wave energy is often contradictory and complex, it is generally accepted that wave energy rapidly dissipates across shore platforms (Trenhaile 1987). Consequently, shore platforms that are discussed as being wide (c. 400 m) are usually associated with weak formations and large tidal ranges—properties and conditions not characteristic of Banks Peninsula. The mapped rock platform is clearly not characteristic of the present-day stable sea level (last 6500 yr) and, by analogy, is probably not characteristic of past interglacial high sea level stands.

Kilometre-wide (submarine) rock platforms backed by plunging cliffs are characteristic of offshore volcanic islands (e.g., Auckland Islands, Campbell Island, Lord Howe Island, Rocas Aijos; Summerhayes 1967; Cotton 1967; Kruse & Schmieder 1996). Cliffs are described as plunging if their base is well below the present-day wave base. Banks Peninsula is also characterised by plunging cliffs where exposed to the open sea (Cotton 1949, 1951, 1967), along the rock platform margins mapped by Brown & Weeber, and probably along the most western margin of Banks Peninsula, where a relict sea stack at Halswell suggests cöastal erosional processes have been active in the past (Lawrie 1992, p. 82). Banks Peninsula may be encircled by plunging cliffs.

The development of wide, submerged rock platforms backed by plunging cliffs is generally considered to be associated with lower sea level stands (Cotton 1967; Trenhaile 1987). Computer simulations by Trenhaile (1987) showed that such platforms and plunging cliffs are best developed during low sea level stands and especially during postglacial rising sea levels (up to 10 km with 0.5 and 2°

gradients). Trenhaile (1989) suggested inheritance plays a role in hard-rock platform development over multiple glacial–interglacial cycles.

More specifically, bathymetry along the eastern margin of Banks Peninsula between Le Bons Bay and Akaroa Harbour (Herzer & Carter 1983) has morphology similar to that mapped by Brown & Weeber (1994) in the northwest. Along this eastern margin, plunging cliffs intersect a gently sloping (c. 1.5°) platform, possibly a rock platform covered with a veneer of sediment (Fig. 4). The platform extends for c. 4 km due east to a water depth of 70 m, after which the seabed is relatively flat (c. 0.05°) through to the outer shelf edge (Herzer & Carter 1983). Since this assumed rock platform is at a similar depth below m.s.l. as the rock platform mapped in the northwest and southwest by Brown & Weeber (1994), it may be contiguous below the cover of recent deposition along the northern and southern margins of Banks Peninsula (Herzer 1981; Barnes 1994).

From the above discussion, I suggest that the rock platform mapped by Brown & Weeber (1994), and its assumed contiguous extension, was developed during multiple eustatic falling sea levels characteristic of glacial times or possibly during early postglacial sea-level rise(s), and before the sandy-gravels that form the Canterbury Plains fully prograded out to connect Banks island to the mainland.

Given that the rock platform is between –50 and –100 m, it is reasonable to assume that its development occurred when eustatic falls were limited to –50 and –100 m. More speculatively, and assuming a relatively stable Banks Peninsula, the rock platform may mark coastal erosion around a Banks "island" before 600 000 yr ago when $\delta^{18}O$ isotope data suggest eustatic falls were limited to <100 m (Ruddiman et al. 1989; Shackleton et al. 1990; Abbot & Carter 1994; Head & Nelson 1994). In comparison, during late Quaternary lowstands, Banks Peninsula was subjected to less coastal erosion because the then characteristic sea-level falls of c. 120–130 m or more meant the glacial shoreline was c. 60 km east of Banks Peninsula at the present shelf edge (Herzer 1981).

There is evidence that shows the offshore continental shelf to the north and south of Banks Peninsula has been subsiding throughout the Pliocene and Quaternary periods at estimated rates varying between –0.08 m/k.y. in the south (Field & Browne 1993; Wood et al. 1989) and –0.4 m/k.y. in the north (Herzer 1981; Barnes 1994). These rates are consistent with stratigraphic evidence from onshore water boreholes on the northern and southern margin of Banks Peninsula. I conclude, therefore, that the subsidence history and driving mechanism of north Canterbury Plains is more complex than hitherto considered.

## CONCLUSIONS

1. Coastal erosional features at Sumner reaffirm Lawrie's (1992, 1993) suggestion that Banks Peninsula has been relatively stable for at least 120 000 yr and not subject to differential subsidence.

2. The Banks Peninsula northwestern and southwestern 1–4 km wide rock platforms at c. –100 m, mapped by Brown & Weeber (1994), are probably contemporaneous platforms. The rock platforms formed as a result of coastal erosion effected by multiple eustatic sea-level changes, at lowstand levels, during glacial–interglacial cycles and probably before mid Pleistocene. By implication, Banks Peninsula was relatively stable since c. 850–600 000 years.

## ACKNOWLEDGMENTS

I thank R. Kirk and S. Weaver for discussion and critical review of an early draft. Colleagues Rod Burt, Steve Beresford, and Simon Ward are thanked for an enlightening discussion about the three-dimensional stratigraphy of Cave Rock. I am also grateful for surveying help from Michelle Wright, Cathy Knight, and Rob Spiers. The manuscript was improved through critical comments and editing by D. Lewis, D. Nobes, and finally further sharpened by comments from W. Bull, R. Kirk and an anonymous reviewer. The work reported here forms part of a Ph.D. funded by a University of Canterbury Graduate Scholarship.

## REFERENCES

Abbott, S. T.; Carter, R. M. 1994: The sequence architecture of mid-Pleistocene (c. 1.1–0.4 Ma) cyclothems from New Zealand: facies development during a period of orbital control on sea-level cyclicity. *In*: de Boer, P. L.; Smith, D. G. *ed.* Orbital forcing and cyclic sequences. *International Association of Sedimentologists special publication 19*. Oxford, Blackwell Scientific Publications.

Armon, J. W. 1970: Recent shoreline changes in the northern Canterbury Bight. Unpublished M.Sc. thesis, lodged in the Library, University of Canterbury, Christchurch, New Zealand.

Barnes, P. M. 1994: Structural styles and sedimentation at the southern termination of the Hikurangi subduction zone, offshore North Canterbury, New Zealand. Unpublished Ph.D. thesis, lodged in the Library, University of Canterbury, Christchurch, New Zealand.

Brown, L. J.; Weeber, J. H. 1992: Geology of the Christchurch urban area. Scale 1:25 000 (1 sheet and 104 pages). *Institute of Geological & Nuclear Sciences geological map 1*.

Brown, L. J.; Weeber, J. H. 1994: Hydrogeological implications of geology at the boundary of Banks Peninsula volcanic rock aquifers and Canterbury Plains fluvial gravel aquifers. *New Zealand journal of geology and geophysics 37*: 181–193.

Brown, L. J.; Wilson, D. D. 1988: Stratigraphy of late Quaternary deposits of the northern Canterbury Plains, New Zealand. *New Zealand journal of geology and geophysics 31*: 305–335.

Bull, W. B. 1984: Correlation of flights of global marine terraces. *In*: Morisawa, M.; Hack, J. *ed.* Tectonic geomorphology. Proceedings of the 15th Annual Geomorphology Symposium, State University of New York at Binghamton. Boston, George Allen and Unwin.

Chappell, J. 1983: A revised sea-level record for the last 300,000 years on Papua New Guinea. *Search 14*: 99–101.

Chappell, J.; Shackleton, N. J. 1986: Oxygen isotopes and sea level. *Nature (physical science) 324*: 137–140.

Cotton, C. A. 1949: Plunging cliffs, Lyttelton Harbour. *New Zealand geographer 5*: 130–136.

Cotton, C. A. 1951: Sea cliffs of Banks Peninsula and Wellington. *New Zealand geographer 7*: 103–120.

Cotton, C. A. 1967: Plunging cliffs and Pleistocene coastal cliffing in the Southern Hemisphere. *In*: Duculot, J. S.; Gembloux, S. A. *ed.* Mélanges de géographie physique, humaine, economique, appliquée offerts à M. Omar Tulippe.

Field, B. D.; Browne, G. H. 1993: A subsiding platform adjacent to a plate boundary transpression zone: Neogene of Canterbury, New Zealand. *In*: Ballance, P. F. *ed.* South Pacific sedimentary basins. Amsterdam, Elsevier.

Field, B. D.; Browne, G. H.; and others 1989: Cretaceous and Cenozoic sedimentary basins and geological evolution of the Canterbury region, South Island, New Zealand. *Basin studies 2*. Lower Hutt, New Zealand Geological Survey.

Findlay, R. H. 1984: The mouth of the Avon-Heathcote estuary. Christchurch, Christchurch City Council.

Griggs, G. B.; Trenhaile, A. S. 1994: Coastal cliffs and platforms. *In*: Carter, R. W. G.; Woodroffe, C. D. *ed*. Coastal evolution. Cambridge, Cambridge University Press.

Haast, J. von 1874: Researches and excavations carried on in and near the Moa-bone point cave, Sumner Road, in the year 1872. *Transactions and proceedings of the New Zealand Institute 7*: 54–98.

Head, P. S.; Nelson, C. S. 1994: A high-resolution oxygen isotope record for the past 6.4 million years at DSDP Site 593, Challenger Plateau, southern Tasman Sea. *In*: van der Lingen, G. J.; Swanson, K. M.; Muir, R. J. *ed*. Evolution of the Tasman Sea Basin. Rotterdam, A. A. Balkema.

Heath, R. A. 1979: Significance of storm surges on the New Zealand coast. *New Zealand journal of geology and geophysics 22*: 259–266.

Herzer, R. H. 1980: Ellesmere bathymetry. New Zealand Oceanographic Institute coastal chart series, scale 1:200 000.

Herzer, R. H. 1981: Late Quaternary stratigraphy and sedimentation of the Canterbury continental shelf, New Zealand. *New Zealand Oceanographic Institute memoir 89*.

Herzer, R. H.; Carter, L. 1983: Pegasus bathymetry. New Zealand Oceanographic Institute coastal chart series, scale 1:200 000.

Imbrie, J.; Hays, J.; Martinson, D.; McIntyre, A.; Mix, A.; Morley, J.; Pisias, N.; Prell, W.; Shackleton, N. J. 1984: The orbital theory of Pleistocene climate: support from a revised chronology of the marine $\delta^{18}O$ record. *In*: Berger, A.; Imbrie, J.; Kukla, G.; Saltzman, B. *ed*. Milankovitch and climate: understanding the response to astronomical forcing, part 1. Dordrecht, Reidel.

Jobberns, G. 1928: The raised beaches of the north-east coast of the South Island. *Transactions of New Zealand Institute 59*: 508–570.

Kirk, R. M. 1979: Significance of storm surges on the New Zealand coast. *New Zealand journal of geology and geophysics 22*: 765–767.

Kruse, W. A.; Schmieder, R. W. 1996: Bathymetry of Rocas Alijos. *In*: Schmieder, R. W. *ed*. Monographiae biologicae, vol. 75: Rocas Aijos. Dordrecht, Kluwer Academic Publishers.

Lawrie, A. L. 1992: Evidence for past higher sea levels on Banks Peninsula. Unpublished M.A. thesis, lodged in the Library, University of Canterbury, Christchurch, New Zealand.

Lawrie, A. L. 1993: Shore platforms at +6–8 m above sea level on Banks Peninsula and implications for tectonic stability. *New Zealand journal of geology and geophysics 36*: 409–415.

Macpherson, J. M. 1978: Environmental geology of the Avon-Heathcote estuary. Unpublished Ph.D thesis, lodged in the Library, University of Canterbury, Christchurch, New Zealand.

NCCB (North Canterbury Catchment Board and Regional Water Board) 1986: The Christchurch artesian aquifers. Christchurch, North Canterbury Catchment Board and Regional Water Board. 159 p.

Ruddiman, W. E.; Raymo, M. E.; Martinson, D. G.; Clement, B. M.; Backman, J. 1989: Pleistocene evolution: Northern Hemisphere ice sheets and North Atlantic Ocean. *Paleoceanography 4*: 353–412.

Sewell, R. J.; Weaver, S. D.; Reay, M. B. 1992: Geology of Banks Peninsula. Scale 1:100 000. *Institute of Geological & Nuclear Sciences geological map 3*.

Shackleton, N. J.; Berger, A.; Peltier, W. R. 1990: An alternative astronomical calibration of the lower Pleistocene time scale based on ODP site 677. *Transactions of the Royal Society of Edinburgh, earth sciences 81*: 251–261.

Speight, R. 1930: The Lake Ellesmere spit. *Transactions of The Royal Society of New Zealand 61*: 147–170.

Speight, R. 1943: The geology of Banks Peninsula—a revision. *Transactions of The Royal Society of New Zealand 73*: 13–26.

Suggate, P. R. 1968: Post-glacial sea-level rise in Christchurch metropolitan area, New Zealand. *Geologie en Mijnbouw 47*: 291–297.

Summerhayes, C. P. 1967: The marine geology of the Auckland Islands area. *Transactions of The Royal Society of New Zealand 4*: 235–244.

Thomson, K. 1964: A former shoreline of Banks Peninsula. Unpublished M.Sc. thesis, lodged in the Library, University of Canterbury, Christchurch, New Zealand.

Trenhaile, A. S. 1980: Shore platforms: a neglected coastal feature. *Progress in physical geography 4*: 1–23.

Trenhaile, A. S. 1983: The width of shore platforms; a theoretical approach. *Geografiska Annaler 65A*: 147–158.

Trenhaile, A. S. 1987: The geomorphology of rock coasts. Oxford, Clarendon Express.

Trenhaile, A. S. 1989: Sea level oscillations and the development of rock coasts. *In*: Lakhan, V. C.; Trenhaile, A. S. *ed*. Applications in coastal modeling. *Elsevier oceanography series 49*. Oxford, Elsevier.

Wellman, H. W. 1979: An uplift map for the South Island of New Zealand, and a model for uplift of the Southern Alps. *In*: Walcott, R. I.; Cresswell, M. M. *ed*. The origin of the Southern Alps. *The Royal Society of New Zealand bulletin 18*: 13–20.

Wood, R. A.; Andrews, P. B.; Herzer, R. H.; and others 1989: Cretaceous and Cenozoic geology of the Chatham Rise region, South Island, New Zealand. Lower Hutt, New Zealand Geological Survey.