Book Review: “New Zealand Landscape – behind the scene”

Author: Paul W Williams, Chapter Review by Deb Carden

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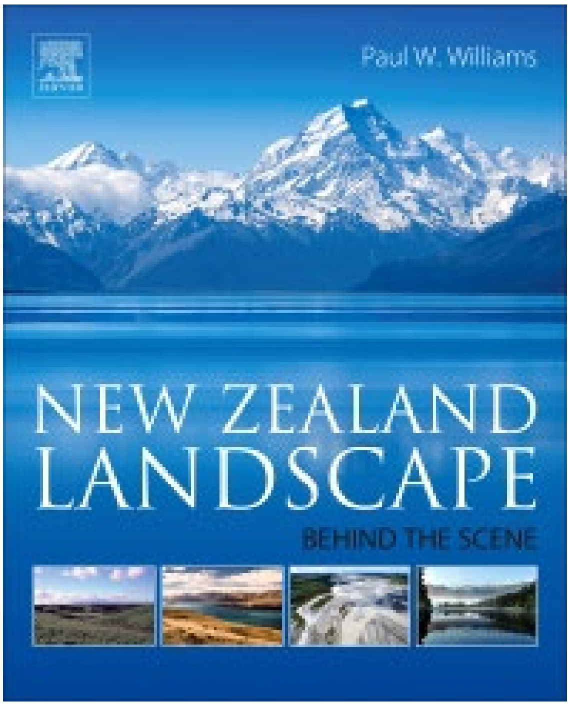

Review by Deb Carden

This is a really lovely book by an expert exploring in his field of earth science. Paul Williams is Emeritus Professor of the University of Auckland with research interests in geomorphology, hydrology and climate change. The book comprises nine chapters that comprehensively describe Aotearoa/New Zealand’s variety of physical landscape types.

The book commences with Aotearoa as a micro-continent breaking away Gondwana and then describes its landform development from that beginning to the present day. It tracks the evolution of this small landmass, investigating the origins of many landscape features. Volcanoes, mountains, ranges, glaciers, fjords, rivers and fluvial plains, caves and karst and the land-sea interfaces are studied. Paul’s writing style is user-friendly and accessible for students and researchers alike. Those new to the subject will find it eminently readable. It is Chapter Six that I agreed to review for ACKMA.

Chapter 6 – Abstract:

“Many small areas of karst are scattered throughout New Zealand. Most are developed in Cenozoic limestones, but the largest area of karst is in thick Palaeozoic marble. These karsts provide quantitative evidence of uplift rates and paleoclimatic history of the regions around them. The polygonal karst of the King Country in western North Island commenced development in the Mid-Quaternary and at times was buried beneath pyroclastic emplacements of ignimbrite. In northwest Nelson, alpine caves to over 1 km deep and over 70 km long have evolved over the last 2 million years or so. In Fiordland, some caves were overwhelmed by ice and contain dateable records of Quaternary glacial history.”

Figure 2 (6.1): Distribution of limestone and marble in Aotearoa/NZ, p 248

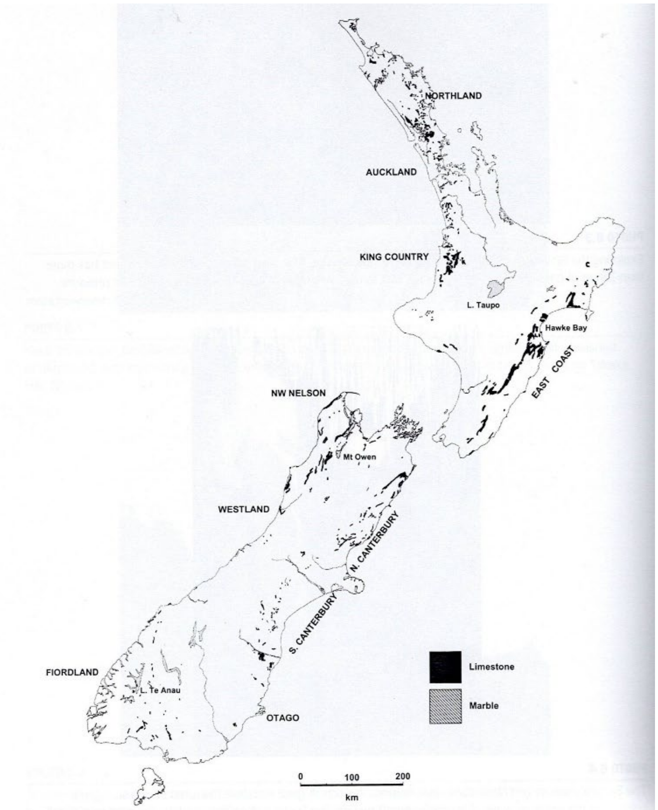

FIG. 6.1
Distribution of limestones and marble in New Zealand. Karst features are found on most of these outcrops, and also subsurface in limestones beneath insoluble covering rocks provided that they have groundwater circulation.

Chapter 6: Karst, Subterranean Rivers and Caves

Paul discusses the distribution of karst in New Zealand and photographs and maps illustrate his descriptions. He begins with the explanation of the origins of 'karst' and describes its formational processes. Karst is described in terms of its purity, density, porosity and solubility. He notes that the best karst is pure, densely compacted and well-jointed. It may have low primary porosity because of being well compressed, recrystallised and cemented within its pores but fissures such as joints, bedding planes and faulting allow water infiltration and movement.

He perceives that the best examples of quality karst are found in the crystalline Ordovician marbles and limestones of NW Nelson, which have negligible primary porosity and only about 2% insoluble residue. Varying in stratigraphic thickness of up to a kilometre or more in a discontinuous belt for 90 km with karst outcropping from Mts Owen and Arthur and Takaka Hill, NW Nelson, ending at Golden Bay at the top of the South Island.

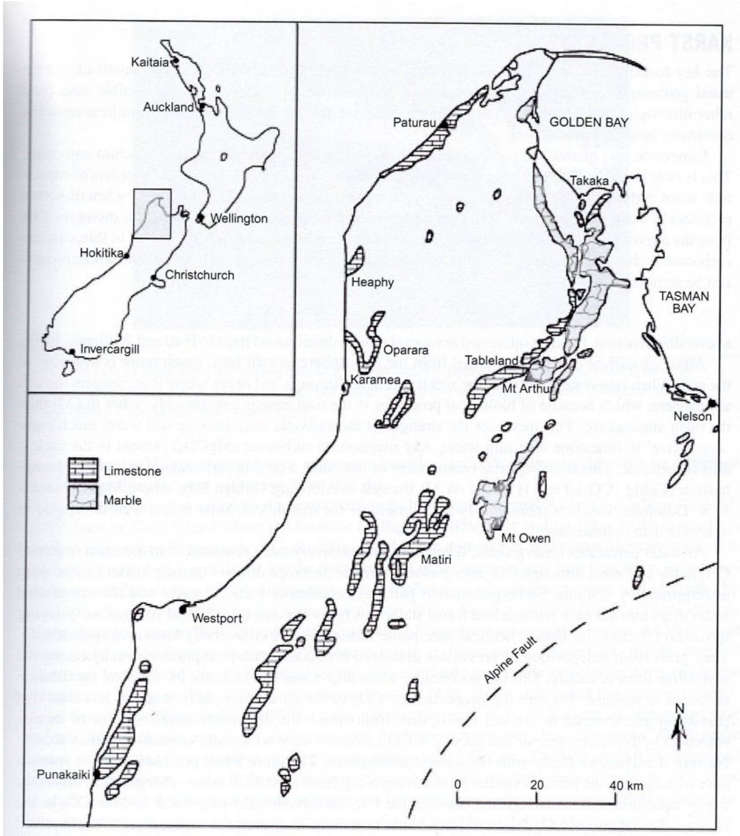

FIG. 6.2
Limestone and marble outcrops in NW South Island.

Figure 3 (6.2): NW Nelson Karst, p 251

Elsewhere in NW Nelson, in the South Island's West Coast and in the mid-west North Island King Country (Te Kuiti, Waitomo) karst has more finely textured topography due to the high frequency of joints. Another type of limestone is found in North Otago and South Canterbury, on the mid-South Island East Coast. This is a sandy-textured bryozoan Otatara Limestone almost devoid of karst features. It is quarried as Oamaru stone and used for buildings, fine examples of which are in Oamaru town and Christchurch city.

In his section on **karst processes** Paul takes the reader on a journey to understand the land-forming involved. He says while that all the usual geomorphic processes occur it is because limestone is so susceptible to dissolution by rainwater (more than most other lithologies), that chemical weathering is a dominating force in its landform shaping.

Paul's explanations of the physical processes and chemical compositions of speleogenesis is excellent reading for those at introductory level and anyone needing a refresher. He explains how limestone and marble, composed of the mineral calcite made from calcium carbonate, is weakly soluble in pure water, and he then explains what occurs when carbon dioxide is introduced into the mix. Dissolved from the air in rain, CO_2 produces a weak carbonic acid (H_2CO_3) that attacks karst, beginning the process of dissolution. Though CO_2 is sourced from the atmosphere much more is available in soil, being rich in the root zones of plants. Soil water is more highly aggressive to limestone than rainwater and as it percolates down from the acidic source it continues to make changes to the karstic stone. Percolation pathways eventually intersect with caves, drip into passages and speleothems (stalactites and stalagmites, many of wonderous shapes, sizes and types) are created.

From discussing the state and effects of water and development of 'pretties' Paul moves to **hydrogeology,** outlining the differences between allogenic and autogenic recharge. Water gets into karst in two ways. Either at the point water arrives from streams flowing from neighbouring impermeable rocks onto limestone outcrops (allogenic) or from the diffuse input of rainfall over the whole terrain (autogenic).

He talks of denudation-measuring at two sites, at Waitomo with Oligocene limestone and Takaka Hill with Ordovician marble. He describes the Waitomo site, composed entirely of limestone with a little interbedded calcareous sandstone, as receiving recharge only from rainfall, an autogenic situation with no additional allogenic contribution from adjacent land. Takaka Hill marble on the other hand, drained by the Riwaka South Branch, receives about 2185 mm annual rainfall and is worked by sinking allogenic streams that run onto the marble from neighbouring quartzite rocks.

He explains that where allogenic streams disappear abruptly at a sink point at the edge of limestone, a blind valley can be created. The stream will continue the dissolution underground but if it gets blocked at the sink point water can back up and temporary lakes occur, often known as 'Lake Sometimes.'

Paul discusses rates of dissolution and the results found from measuring and tracking water as it moves through a large catchment. Studies show 90% of dissolution occurs within 10 m of the surface, closest to the main sources of CO_2 in the soil zone, with most of its aggressiveness being expended where it first comes into contact with rock.

The subcutaneous layer beneath the soil where surface karst landforms develop, is known as epikarst. Water collects in surface hollows, etching into it to make flat-floored solution pans. Moisture trickles into joints that widen over time to become grikes. A geometric lattice of intersecting grikes becomes clints, the tops of which can become flat bedding-plane surfaces. These features are referred to as karren and extensive areas with flat top clints are referred to as karren fields or limestone pavements.

Paul's section on **subterranean drainage** comprehensively explains convergence and divergence of flow paths. After penetrating the surface, the percolating water eventually meets a permeability barrier where the limestone is still unaffected. Water accumulates here, forming a saturated zone, the top of which is the water-table or piezometric surface, the slope of which is the hydraulic gradient. Further below, where voids are full of water, is the saturated or phreatic zone. Water flowing rapidly enough from here to become turbulent, passes through in a matter of days. Rates of flow can be measured by dye tracing.

Paul explains that water-table levels fluctuate according to recharge from rainfall and the zone where this occurs is referred to as the epiphreatic zone. Above here is the vadose or unsaturated zone.

As time goes by the dissolution front moves down, water infiltrates more deeply, flushes sediment, the vadose deepens, caves deepen, the water table moves down, springs occur.

The section on **vadose processes and landform evolution** begins by explaining the depth to which karst can develop is controlled by two factors – the thickness of the host rock and the karst base-level of erosion and that most New Zealand karst is relatively shallow, e.g., 10 to 100 m thick. Exceptions are the coastal sites of Punakaiki on the west coast of the South Island, Kawhia Harbour in the west of the North Island and the Arthur marbles in Golden Bay, NW Nelson. Erosion at these sites has been to lower levels in the past but post-glacial sea level rise back-flooded the karst conduits and lowland valleys aggraded.

Paul goes on to discuss the development, differences and features of dolines or sink holes, bowl or funnel-shaped depressions that fill with thick, damp soil in which vegetation will grow, into which water travels to the base, CO_2 causing ongoing dissolution. Where dolines abut each other the landform takes an appearance of an egg-tray, in pentagon or hexagon shapes. This is known as polygonal karst and is visible at Waitomo where land clearing has occurred. Takaka Hill is pockmarked with solution dolines but there they are not so clearly defined. Ongoing dissolution can result in the bottom of the dolines collapsing and they then become steep sided, cylindrical in shape and can bring about the opening of a cave or cave passage to the sky. The Maori word 'tomo' (said as 'tormor') is favoured in Aotearoa to describe different types of collapse or solution pits.

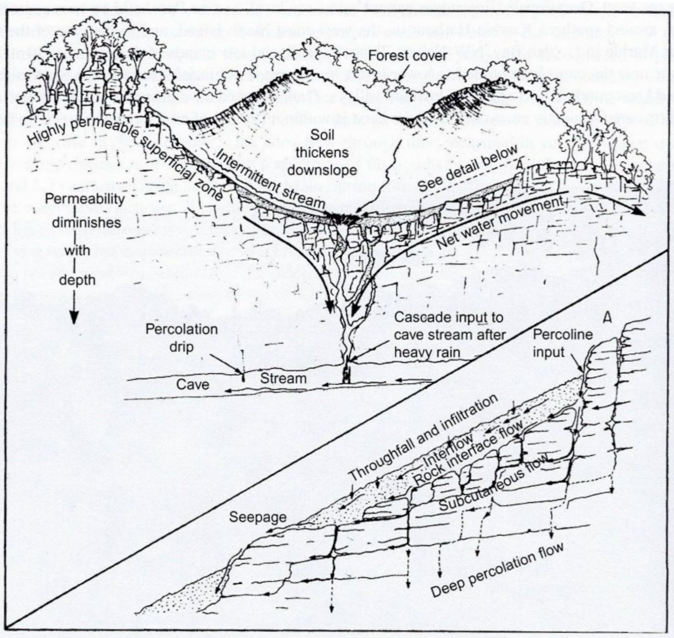

FIG. 6.4

Paths followed by water draining from an enclosed depression to an underlying cave.

From Williams, P. W. (1978). Interpretations of Australasian karsts. In J. L. Davies & M. A. J. Williams (Eds.), Landform evolution in Australasia (pp. 259–286). Canberra: Australian National University Press.

Figure 4 (6.4): Paths followed by drainage from an enclosed depression, p258

Glaciated Karst and Caves in Marble

The section about the marble karst of NW Nelson gives a detailed explanation of the complexity of this land formation, the most obvious attributes being acquired from glaciation. Mt Owen, covered by big icecaps during major glaciation events, is the culmination point of a plateau-like massif on the divide between the Motueka River to the north and Buller River to the south. A series of glacial cirques and U-shaped valleys radiate in all directions from the summit. During glaciation wet-based glaciers would have drained directly underground.

Figure 5 (6.15): Mt Owen summit area showing glaciated marble and post-glacial karren sculpture on rocky outcrops, p 263

PHOTO 6.15

Mt Owen summit area showing glaciated marble and postglacial karren sculpture on rocky outcrops.

Mt Owen contains Bulmer Cavern, Aotearoa's longest cave. Paul discusses the development of Bulmer Cavern as occurring in four stages, each associated with a period of stable water-table position. He describes the shape and configuration of its water table. In 2016 Owen's system had been surveyed for 72 km to a vertical depth of 755 m. Dye tracing indicated long sections with turbulent flow inside. Dye injected into Owen Chasm (1117 m) and Reverse Basin sink (1288 m), streams that submerge at the Hay Paddock a schist inlier, dye travelled within three days to the Blue Creek resurgence on the north side of the mountain at 579 m. The resurgence is at the head of Rolling River, a tributary of the Wangapeka in the Motueka basin.

The course is estimated as having a descent of 838 m and a direction of horizontal travel of 5.3 km. By 2017 cave divers had descended to 77 m in Blue Creek Spring, the dive indicating passages looping far below the water-table before rising and escaping at the spring.

Mt Arthur, 40 km north, has similar topography to Owen, with folding and faulting from the summit to below sea level. It contains the Stormy Pot-Nettlebed system, the deepest cave network in Aotearoa. In 2017, at the time of this publication, it was surveyed as 1174 m deep with a passage of 38 km. The projected profile indicated the water dropped from the summit almost vertically for 350 – 420 m, encountering a passage at 108 m, after which six more passage levels can be identified, plus several other intermediate stages. Indications are that a moderately efficient drainage system has developed in the mountain.

The assumption for both Owen and Arthur is the main control of passage-level is the water-table, with some situations of geological control where insoluble schist and siliceous horizons are interbedded in the marble. Both have had tectonic uplift stages and stream incision. Research and exploration continue.

Dating of speleothems deposited above the present water-table level of Nettlebed Cave provides information about water-table lowering rates and cave development. The data indicates that a vadose zone one kilometre deep, as found under Mt Arthur, took 2-3 million years to develop in the early Pleistocene when the Southern Alps were taking their present shape, but when any overlying Cenozoic sediments had already been eroded from the tops. Dry cave levels, above the present water-table by 60 m, then above that again by 50 m, allow estimates to be made of early water levels, presumably during inter-glacials. It is expected that Bulmer developments are similar, having been exposed to similar environmental controls.

Paul then describes the development of Takaka Hill karst in Abel Tasman National Park and Te Waikoropupu Springs in Takaka Valley, identifying an ancient history of uplift, streams and sinks. Beneath Takaka Hill the Greenlink-Middle Earth Cave system had been explored to a depth of 389 m and length of more than 32 km. The system resurges in the Riwaka Valley north branch spring and subterranean drainage on the western side feeds to the aquifer that sustains the gorgeous Te Waikoropupu Springs.

Karst in Fiordland

Fiordland terrain is rugged, access is difficult and exploration is limited though there are reports in the NZ Speleological Society Bulletin. Its karst is within Paleozoic high-grade metasedimentary rocks mapped in Deep Cove gneisses and Irene Complex. Thrust faulting and shearing contains isolated slivers of marble up to three kilometres long and a few hundred metres across. Deposits in caves beneath the walls of glacial troughs reveal the occurrence and depth of glacial ice inundation, shedding light on the area's glacial history. Deep Cove and Doubtful Sound karst is mentioned, with Doubtful's Xanadu Cave described briefly.

Aurora-Te Ana-au Cave, with about eight kilometres of passage descending 267 m on the western side of Lake Te Anau, is an important site. Draining from the Lake Orbel in the Murchison Mountains Tunnel Burn passes through Aurora Cave, into Te Ana-au Tourist Cave via a sump, resurging at 203 m beside Lake Te Anau. The cave was overrun several times by ice when the large Te Anau Glacier filled the valley during the Pleistocene, and the cave passages acted as a sediment trap. Datable speleothems between glaci-fluvial gravels have enabled a chronology of events to be determined.

Figure 6 (6.12 & 6.13): Top - Projected long profile of Aurora Te Ana-au Cave from about 450 m to lake level. Superimposed over the cave is the overlying surface profile of lateral moraine terrace steps. Bottom - Model of Aurora Cave as a glacial sediment trap, p 277

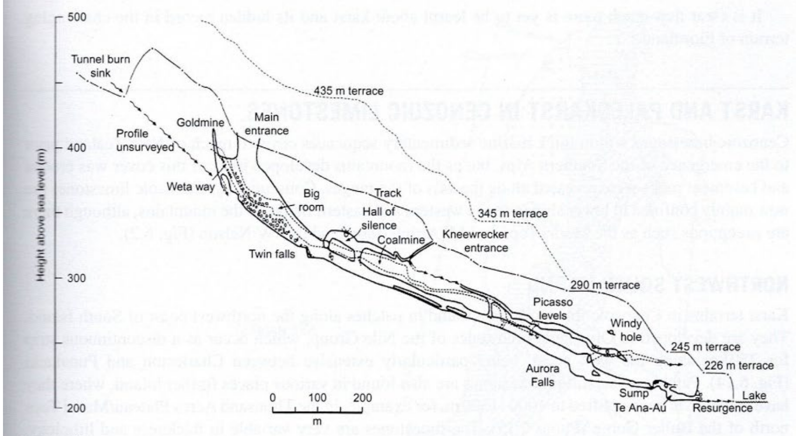

FIG. 6.12

Projected long profile of Aurora-Te Ana-au Cave from about 450 m to lake level. Superimposed over the cave is the overlying surface profile of lateral moraine terrace steps.

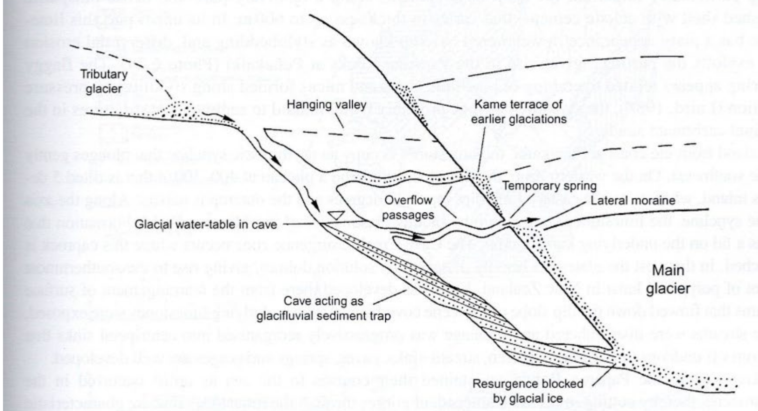

FIG. 6.13

Model of Aurora Cave as a glaci-fluvial sediment trap.

From Williams, P. W. (1996). A 230 ka record of glacial and interglacial events from Aorora Cave, Fiordland, New Zealand. NZ Journal of Geology and Geophysics, 39, 225–241.

Karst and Paleokarst in Cenozoic Limestones

Prior to the emergence of the Southern Alps thick sedimentary sequences covered much of Aotearoa. As mountains developed it eroded and bare rock was revealed. Nowadays the Cenozoic limestones are confined to the east and west flanks, except for the Mt Arthur Tableland in NW Nelson and the Thousand Acre Plateau/Matiri Tops north of the Buller Gorge which have uplifted to 1000-1500 m.

An extensive 250 km discontinuous strip of Cenozoic limestone along the West Coast between Punakaiki and Charleston comprises the Nile Group of Oligocene limestone divided into Waitakere, Tiropahi and Potikohua sequences. The latter is the most pure, dense biosparite (crushed shells with calcite cement) varying in thickness to 600 m.

In its upper part this limestone is platy – weathered outcrops are referred to as stylobedding with differential erosion exploiting the partings and resulting in the Punakaiki Pancake Rocks at Paparoa National Park. The flaggy layering looks related to etching of insoluble clays and micas formed along stylolites by pressure solution. Paul comments that the stylolite partings are probably related to sedimentary structures in the original carbonate sands.

Inland from the Punakaiki coast an asymmetric syncline dips gently southwest. The Paparoa Range rises to the east and the Waitakere (Nile), Fox and Pororari rivers course from the mountains to the sea through impressive antecedent gorges. The vertical incision ability matches that of land uplift due to tectonic forces. Subterranean tributaries flowing along the strike to emerge at the sides of the gorges have created significant stream caves - Metro/Te Ananui, Fox River Cave and Babylon/Te Orumata.

PHOTO 6.24

The Pancake Rocks at Punakaiki on the Westland coast are developed on a shore platform of probable Last Interglacial age uplifted to 34 m. It had a cover of beach gravels but, after uplift, dissolution beneath the gravels widened fissures and exploited partings that were eventually revealed as storm spray and subaerial processes removed the gravel covering.

Figure 7 (6.24) : The Pancake Rocks at Punakaiki on the Westland coast are developed on a shore platform of probable Last Interglacial age uplifted to 34 m. It had a cover of beach gravels but after uplift, dissolution beneath the gravels widened fissures and exploited partings that were eventually revealed as storm spray and subaerial processes removed the gravel covering, p 280

The Bullock Creek Gorge, coming from the heart of Paparoa National Park, contrasts with the other gorges consequent to a landslide that occurred 3-4 km upstream from the coast. Up to 60 m of alluvium backfilled the valley and the steepened gradient enforced a river capture, encouraging the subterranean transfer of Bullock Creek through the complex Xanadu aquifers to resurge at Cave Creek South and from thence into the Pororari. The resurgence is 75 m below the stream sinks with a series of springs emerging over 900 m at a vertical distance of ten metres. At the main spring a vertical shaft 2.5m in diameter has been dived to a depth of more than 30m. At least one phreatic loop is known. The discharge range of this system is extreme. Under flood conditions it discharges 30-40 m^3/second, the largest in Aotearoa. Low flows allow exploration of the area. The west plateau is heavily dissected by solution dolines, the southernmost extent of polygonal karst in the country. Dolines, karren, stream sinks, springs and gorges are well developed in this Park.

Karst of similar type is found further north between Karamea and the Heaphy, notably inland at the Oparara. Here contact between rock types is readily seen at the Oparara Arch, the largest natural bridge in the South Island, where the riverbed is granite and the Honeycomb Hill Cave roof is limestone, about 215 m above sea level. The cave is extensive, 13.7 km is surveyed. Numerous entrances and pitfall traps have yielded some of Aotearoa's largest Late Quaternary fossil fauna collection. Further north by the Gunner River, a tributary of the Heaphy River, is a karst area that contains the extensive 14.8 km Megamania Cave that requires scientific evaluation.

Paul notes more karst further north again, between Kahurangi Point and Cape Farewell, describing the Patarau caves, where, in spite of the Oligocene Takaka Limestone being only 25-50 m thick he notes there are numerous caves scientifically importance for their marine gravels and shells. He comments that this northwest corner of the South Island remained remarkably stable when inland and further south rapid uplift was occurring with the Southern Alps emergence.

Western North Island: King Country Karst

Outcrops of Cenozoic limestone are widespread in the North Island, mainly in the east and west of the main ranges, the King Country being the most well-known, comprising Oligocene - early Miocene karst in discontinuous patches over about 400 km. The limestone is up to 100 m thick, flaggy, pure and crystalline, well-jointed with broad simple folds, dipping less than 10-15 degrees. Since the Pliocene polygonal karst has developed with solution dolines attaining a density of 55 per km^2, a high density by any standards, due to high precipitation combined with high fissure frequency. Where native forest cover abounds over the karst the dissolution process is completely natural, affording insight into how a hydrological system functions normally.

Considerable investigation has occurred with regard the King County karst where surface topography gives little indication of the direction of underground flow. Dye tracing has revealed the subterranean drainage patterns, the direction of dip of underlying impervious beds, the detail of gradient to spring/s in neighbouring valleys and, in detail, the orientation of individual joints and fractures. Water reached the caves in many ways, by cascades into shafts, trickles into fissures, slow seepage into narrow joints.

Figure 8 (6.19): Limestone outcrops and karst locations in the North Island, p 287

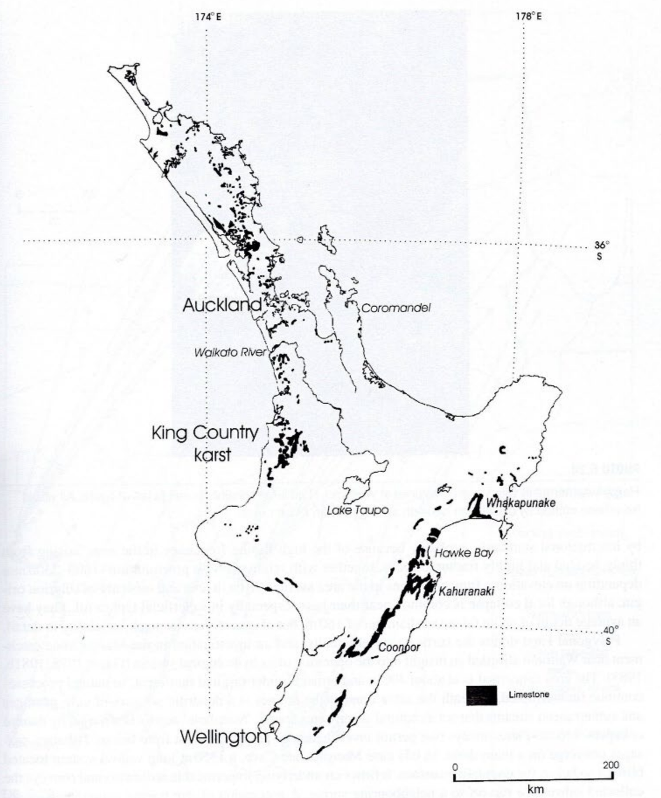

FIG. 6.19
Limestone outcrops and karst locations in North Island.
Modified from Williams, P. W. (1992). Karst in New Zealand. In M. J. Soons & M.J. Selby (Eds.), Landforms of New Zealand (2nd ed.; pp. 187–209). Auckland: Longman Paul.

<u>King Country Paleokarst.</u> Paul states that 'paleo' in this context refers to landforms that are completely decoupled from the process environment responsible for their formation. Volcanic eruptions in the early-to-mid Pleistocene from the Central Plateau smothered the central North Island repeatedly, burying and isolating the karst from its developmental hydrological system for several hundred thousand years. As the ignimbrite weathered the karst reappeared and normal processes developed again. Patches of ignimbrite are found now on hilltops about 200 m above valley floors.

The passage level of caves helps estimate the rate of incision of valleys and caves. Gardeners Gut Cave (12.2 km long), a left bank tributary of the Waitomo Stream, was developed on two main levels. Speleothems from near the active Gardner's Gut streamway are up to 12 thousand years old and the relationship of their age and height above the streamway indicates a rate of passage incision during the Holocene similar to the rate of the valley incision since the eruptions. Paul describes the relationship of the two natural bridges and the tourist caves, Ruakuri, Aranui and Glowworm Cave with regard their development.

East Coast: Hawke Bay to Wairarapa

The limestone here is generally young, in widespread patches from Hicks Bay near East Cape to Martinborough near Wairarapa and Wellington, occasionally reaching 100 m but more likely a few tens of metres thick. The main karst-forming rock are the Late Pliocene Te Onepu Limestone and Early Pliocene Whakapunake Limestone, comprising bioclastic cliff-forming units, 50 m or more in thickness. The units vary from each other in cementation and stratification, being young, barnacle-thick, coquina limestone. Importantly they demonstrate the extent to which karst can form at the margins of conditions that support the development in rocks which are sometimes poorly cemented and in situations where exposure is recent, e.g. less than one to two million years.

A massive outcrop of quite well cemented limestone is found on Whakapunake Mt (962 m) about 30 km northeast of Wairoa on the Hawke Bay coast. An escarpment runs 12 km southwards from the summit towards the Mangapoike River gorge. The river cascades in a series of rapids as it cuts through the escarpment to near the Te Reinga settlement. Te Reinga Cave (5.2 km long, vertical depth 140 m) comprises four segments and providing the main subterranean drain is the largest known cave system on the East Coast.

There is karst in southern Hawke Bay but more interesting karst is found further south in the Wairarapa region near Coonoor, southeast of Pahiatua being a 41 km long NE-SW oriented cuesta with a ridge of 600-800 m and a 200-300 m abrupt scarp facing southeast. It is a prime example of cast-hardening of young coarse-grained coquinas with interbedded lenses of calcareous sandstone. Being young they had little compaction prior to uplift so they are imperfectly cemented with porosity up to about 30%. Repeated wetting and drying cycles result in the surface of the outcrop being dissolved, and in reprecipitation occurring in pore spaces beneath. The pores gradually fill with calcite cement and fossil shells near the surface are replaced by a dense lime crust, quite commonly found in the Puketoi Range.

PHOTO 6.30

At Coonoor, in the Wairarapa, polygonal karst is developed in recently uplifted Pliocene limestones. It is a young entirely Quaternary landscape.

Karst here has formed in unusual lithological conditions which Paul considers an instructive example of karst development in its early stage of evolution. He says, "Point recharge form cover beds helps focus dissolutional attack and so enables caves to develop. Surface case hardening limits diffuse infiltration and so leads to surface runoff and the development of karren. All karst features in the area are young because of the frequency of uplift. Most of the dry valleys are less than one million years old. Upper level passages may have been initiated but active stream caves are likely to be less than 100,000 years old and some much less."

Figure 9 (6.30): At Coonoor in the Wairarapa polygonal karst is developed in recently uplifted Pliocene limestone. It is a young entirely Quaternary landscape, p 296

Baselevel Control in Karst

The chapter concludes with a discussion about the functioning of the Pearce Spring and Te Waikoropupu Springs.

Mt Arthur's Stormy pot-Nettlebed Cave drains to the Pearce Spring. Paul describes how the marble dips steeply at about 45 degrees ESE and plunges beneath overlying argillite and schist, these impervious rocks acting like a dam, impounding the karst water. Diving has shown that spring water ascends from depths in excess of 230 m, with continuing passages too deep to follow. The water flows in flooded passages well below the water table. The elevation of the dry season water table near to where the downstream exploration limit was reached, is 270 m. Before water can exit the cave at 265 m about half a kilometre away, the diving evidence shows that it must first descend to about 35 m above sea level. This indicates there is a deep phreatic loop in the system and where pressurised water is confined before breaking through joints or faults to reach the spring surface. The energy to achieve deep water circulation through the loop derives from the difference in hydraulic head between water level in the cave and the water level at the spring. From Nettlebed Cave to the Pearce Spring the difference at low flow times is just a few metres. This changes during heavy rain when the passages flood to tens of metres in depth. The Pearce Spring is the local baselevel control for the Stormy Pot-Nettlebed Cave system in Mt Arthur. Run-off passing through is clearly capable of eroding well below it.

The Takaka River/Te Waikoropupu Springs system in Golden Bay are another example of base level control in karst. This system is partly artesian being confined by a caprock of Cenozoic coal measures overlying the marble for 11 km at the downstream end of the aquifer. The location of the springs is determined by erosion, the caprock having thinned sufficiently to permit pressurised water to break through to the surface. Investigation has shown the main source of water emerging at Te Waikoropupu Springs is from the upper Takaka River about 17 km away. It loses water in its bed, much of that appearing in the Main Spring. About 13.3 m^3/second is discharged from a complex underground reservoir with a total volume of about 3 km^3. Though the Main Spring pool is 14 km above sea level and 2.6 km inland it has measurable tidal fluctuations and water tastes slightly salty. The local hydrographic charts show freshwater springs emerge offshore at 12-15 m deep, indicating that karst passages are likely to be running below sea level.

Figure 10 (6.31): Te Waikoropupu Springs near Takaka. This shows the artesian 'boil' in the Main Spring as water under pressure is released. The springs would not have functioned during glacial low-stands of the sea, p 297

PHOTO 6.31

Te Waikoropupu Springs near Takaka. This shows the artesian 'boil' in the Main Spring as water under pressure is released. The springs would not have functioned during glacial low-stands of the sea.

Field work shows that when karstified rock dips below sea level a baselevel control is exerted by the sea on the elevation at which karst water escapes. A balance is reached between the hydraulic head inland that drives the water to the coast and the impounding effect of the seawater. Where limestone does not extend below the sea level local baselevel control is exercised by the elevation of the karst spring, deep phreatic loops enabling dissolution to proceed below baselevel.

This unusual feature of karst is not known to occur in normal fluvial systems. The only other terrestrial geomorphic system where erosion can extend below baselevel is the glacier system. Glacial scour eroded valley floors well below sea level, e.g. Lake Te Anau in Fiordland.

Figure left: Ngarua Cave, Takaka Hill, photo by Neil Collinson, taken at the ACKMA Conference in 2022