

The Post-Tertiary History of New Zealand.

By J. HENDERSON, M.A., D.Sc., B.Sc. in Eng. (Metallurgy).

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THROUGHOUT the geological literature of New Zealand are numerous references to changes in the height of the land in respect to sea-level within Recent and post-Tertiary times. At many points on the coast features definitely associated with the sea or its edge are inland and above the strand; at other and perhaps adjacent points there is equally definite evidence of considerable depression. The object of this paper is to bring together, and as far as possible to correlate, the known pertinent facts, and to endeavour to outline the sequence of the oscillations. The evidence suggests that New Zealand has changed its level in respect to the sea as a unit, either on account of the retreat of the ocean or by uplift of the whole archipelago. There may have been some local tiltings and differential warpings, but these appear to have been unimportant if compared with the widespread epeirogenic oscillations that have affected the Islands.

In New Zealand the Tertiary closed with a long-continued series of movements by which groups of earth-blocks were uplifted to form mountain-ranges, while adjacent blocks were relatively depressed in trough-like basins. The mountains have since been much carved by ice and water, and the great tectonic valleys in part filled in by the rivers and the sea, but the broad outlines of New Zealand as it now is were created at this period. The land was at one time 1,000 ft. or more higher than it now is, but later was depressed till the old strand-line was submerged to 1,000 ft. or more below its present level. The deposits formed prior to and during this depression are here considered of early Pleistocene, and those of the succeeding elevation of younger Pleistocene age. The former deposits are represented by volcanic accumulations and by beds of glacial, fluvial, estuarine, and littoral origin. The younger Pleistocene beds are chiefly high-level terraces bordering river-valleys, and littoral deposits forming coastal platforms or veneering wave-cut benches. The general elevatory movement was continued till the land was several hundred feet higher than at present. It was succeeded by depression that raised the strand-line about 120 ft. above that of to-day. The last considerable movement has been one of uplift to the present position. The deposits of the last-mentioned depression and subsequent elevation form the bulk of the Recent deposits of New Zealand.

This paper deals chiefly with the evidences of uplift and subsidence that have been observed in coastal districts. No account is given of the plains and river-valleys of New Zealand, though these have been profoundly modified and in part created by the movements. The effects of glaciation are not discussed, nor do the deposits of early and middle Pleistocene age receive more than mention.

GENERAL CONSIDERATIONS.

After long-continued standstill there will be formed around any sea-girt land a gently-sloping submarine shelf, which consists of a wave-cut platform, of such a platform veneered with loose deposits, or of loose deposits

entirely. The new shore-line produced by elevation will soon be modified. In some localities it will be cut back by the waves, in others it will be prograded, and between the points of maximum sea-advance and maximum sea-retreat will be innumerable gradations.

The under-water slope of a prograded shore is likely to be continued above sea-level by slope, fan, or deltaic deposits with little or no change of grade. After elevation, unless there is considerable difference in the nature of the terrestrial and marine deposits, the old strand-line will probably soon be obliterated. The summit and basal edges of sea-cliffs cut by the waves during a period of comparative rest are much more decided lines of demarcation. The summit edges, except on coasts where the controlling conditions are far more uniform than in New Zealand, are not likely to be horizontal even if the uplift is horizontal. The base of an old sea-cliff—that is, the inner edge of a coastal terrace—will probably furnish much more reliable information as to the nature and amount of movement of the strand-line; but, as explained by Darwin in the second chapter of his *Geological Observations on South America*, it by no means follows that the inner edge of a coastal bench on a horizontally uplifted shore is horizontal. "With respect to the basal or lower edges of the escarpments, from picturing in one's mind ancient bays *entirely* surrounded at successive periods by cliff-formed shores, one's first impression is that they at least necessarily must be horizontal, if the elevation has been horizontal. But here is a fallacy: for after the sea has, during a cessation of the elevation, worn cliffs all round the shores of a bay, when the movement recommences, and especially if it recommences slowly, it might well happen that, at the exposed mouth of the bay, the waves might continue for some time wearing into the land, whilst in the protected and upper parts successive beach-lines might be accumulating in a sloping surface or terrace at the foot of the cliffs which had been lately reached: hence, supposing the whole line of escarpment to be finally uplifted above the reach of the sea, its basal line or foot near the mouth will run at a lower level than in the upper or protected parts of the bay; consequently this basal line will not be horizontal." This explanation has evidently a wider application than Darwin gave it. The base of any sea-cliff that, during gradual horizontal uplift, is unequally cut back by the waves, either by reason of unequal hardness of the rock or unequal protection from wave-attack afforded by promontories or coastal drift, will not be horizontal. And the New Zealand coast is formed of rocks so differing in hardness within short distances, and is so irregular in outline, that caution is necessary in interpreting the evidence afforded by the inner edge of a coastal terrace. Moreover, the base of a sea-cliff after uplift is peculiarly liable to be obscured by talus, alluvial, and dune deposits. Notwithstanding these defects the inner edges of raised shore-platforms furnish the most reliable information regarding land-uplift, and, provided observations are sufficiently widespread to eliminate local peculiarities, the evidence may be confidently accepted.

Darwin in the work already quoted discussed the nature of the uplift between the periods of comparative rest or slight depression when the sea-cliffs were formed. He concluded from the uniformity in size of the pebbles over the whole surface of platforms miles in width, and from the fact that the shells strewing the benches were all of littoral species, that the uplift had been by small sudden starts such as those accompanying recent earthquakes, or, more probably, by such starts conjointly with a gradual upward movement, and had not been due to great and sudden upheavals. In New Zealand the irregular coast-line causes the beach deposits to vary greatly

in short distances, and shells are rarely found on the coastal terraces. But the series of low raised beaches at Miramar (61, p. 316), Gisborne (52, p. 23, and 80, p. 533), and Tolaga Bay (52, p. 23), together with the fairly uniform distribution of *blacksand* on the raised beaches of the west coast of the South Island, suggest the uplift in New Zealand took place in a manner similar to that of South America.

If the elevation of the land is fairly uniform, though interrupted by periods of rest or slight depression, there will be places, on a coast so diversified as that of New Zealand, where the emerging wave-formed shelf will be (1) prograded, (2) unaltered, (3) partially destroyed, and (4) wholly destroyed. In the first case the surface of the coastal terrace will be fairly uniform, with a grade flatter than that of the foreshore; in the second case the grade will be the same throughout; in the third case the raised platform will be cut into a series of steps which may occur as decided breaks, or be so small that the whole surface may approximate a sloping plane with a grade steeper than that of the under-water surface; in the fourth case the attack of the waves may be strong enough to advance the strand landward past the old shore-line. All these types of shore may be represented on a short stretch of coast, each type grading into that adjacent to it. Again, because one part of the coast was prograded at one particular contour it does not follow that it was prograded at another contour, for elevation may bring to the surface of the sea promontories and islands of hard rock which may protect and cause to be prograded parts of the coast that at other contours were retrograded. Again, a slight depression may cause a stream to change its course owing to alluviation, and its discharge by another outlet may alter locally the distribution of the coastal drift. Hence, though the whole coast may have been uniformly subjected to a series of oscillations, the full history of the oscillations may not be decipherable in any one area, and different chapters of the history must be read in different districts.

EVIDENCE OF ELEVATION.

North Auckland Peninsula.

The evidences of elevation will first be considered, and, in order that the facts may be conveniently presented, the coast of each Island is divided into four portions. S. Percy Smith (72, pp. 403-10: see also 33, p. 157; 35, p. 11; 40, p. 4; and 43, p. 30) noted the occurrence of raised beaches about 15 ft. above sea-level at many points on the east and west coasts of the North Auckland Peninsula. McKay (25, p. 77) observed beaches and mud-flats at a similar height in the extreme north of North Zealand, and Hochstetter (111, p. 266) and Hutton (63, p. 161) remarked on the slight elevation that has taken place at Manukau North Head. Smith (72, p. 409), without mentioning precise localities, has stated that a bench about 100 ft. above sea-level occurs at several points near Auckland and Kaipara. At Onerahi, in Whangarei Inlet, there is a platform about 60 ft. high, and the Town of Whangarei, at the head of the harbour, is built in part on a 10-15 ft. raised beach and in part on a terrace about 50 ft. high that rises inland along the continuing valley.

Other base levels of erosion have not been definitely recognized in North Auckland, but several facts of physiography noted by various writers have significance if considered in this connection. Thus McKay (25, p. 71) wrote: "Whangape Harbour is bounded on the south and west by heights . . . which, from an elevation of 1,000 ft. to 1,500 ft., slope

gradually to half that height on the coast-line." And again: "Towards the east [of Parengarenga Harbour] there is a tendency to form tablelands 400 ft. to 600 ft. above sea-level." Bell and Clarke (87, p. 614) suggest that a tableland about 1,000 ft. high that occupies a relatively considerable area in the extreme north of New Zealand is the remnant of a peneplain. Lignitic bands occur in the cliffs of Pleistocene sands that back the low raised beaches along the west coast between Kaipara Harbour and Maunganui Bluff (79, p. 565). These are evidence of elevation, but of what amount is unknown.

Auckland to East Cape.

Smith (72, pp. 403 and 407) has also traced the 15 ft. raised beach at various points in the Hauraki Gulf and Bay of Plenty. Hutton (6, p. 23) was the first to note this strand-line at Thames. According to Cussen (78, p. 404), an old beach 17 ft. above sea-level occurs at Maukoro, in the Hauraki Plain, about eighteen miles from the sea. Other raised beaches up to 100 ft. high have been recorded at several points between Auckland and East Cape. Beaches 25 ft. high occur near Thames (45, p. 29) and Tauranga (114, p. 212); at Cabbage Bay, 80 ft. (28, p. 70); north of Cabbage Bay, up to 70 ft. (42, p. 61); at Waihi Beach and Orokawa, near Waihi, up to 50 ft. (48, p. 30); and at Te Kaha Point, 50-60 ft. (17, p. 199). At Opotiki is a tableland 100 ft. above the sea, and according to Smith remnants of beaches from 80 ft. to 100 ft. high occur at intervals from East Cape to Tauranga and along the east side of Hauraki Peninsula (72, pp. 406-8).

Another group of raised beaches is represented by the terrace at the back of the Town of Thames, 150-175 ft. (28, p. 38), at the mouth of Kauaeranga River, and for several miles along the east side of Hauraki Plain. Beach-remnants 200 ft. high occur between Hastings (Tapu) and Kiritā Bay (28, p. 70). The ridges of the lowlands west and south of Tauranga Harbour, which are formed of soft Pleistocene deposits, rise regularly inland to about 250 ft.

West of Tauranga, and farther south-east in the Te Puke district, these beds slope gently upward to a plateau which rises regularly to more than 1,000 ft. Towards the sea this surface is deeply incised by the streams and dissected by their numerous branches. Many years ago Hutton noted the gently-undulating high-level plateau near Thames, which he considered to have been formed when the land was about 1,600 ft. lower than at present (6, p. 23). At Hicks Bay fossiliferous sands and muds form wide terraces which extend inland for seven or eight miles and rise from 350 ft. to 650 ft. above the sea. Between Te Araroa and East Cape are gravel-veneered wave-cut benches from 870 ft. to 1,000 ft. high.

East Cape to Wellington.

The slight uplift, the effects of which farther north have been mentioned, also raised the coast from East Cape to Wellington. Marine terraces up to 20 ft. above the sea occur at Tuparoa and at Waipiro, Tokomaru, and Tolaga bays (52, p. 23). They have been recorded at various places in the Gisborne district (7, p. xvi, and 8, p. 120), at Mahia (17, p. 198), Wairoa, Herbertville (34, p. 103), and Palliser Bay (11, p. 85). Crawford observed a series of beaches near Wellington respectively 4 ft., 9 ft., and 15 ft. (61, p. 316) above the sea, and wave-formed caves at Miramar lifted 15 ft. (65, p. 396). Benches somewhat higher, but belonging

to the same group of marine terraces, occur at many points along the northern part of this portion of the coast. They are 50-90 ft. high near the mouth of the Waiaapu River, 40-50 ft. at Tokomaru Bay, 90 ft. near Tolaga Bay (52, p. 24), 40 ft. at Makarori Point, and 60-70 ft. near Wairoa. There is a wave-cut bench rising to about 50 ft. near Cape Turnagain, and another at Cape Turakirae up to 95 ft. (90, p. 209). A marine terrace at Mukamuka is 50 ft. above sea-level, and one at Lake Onoko 70 ft. (30, p. 29).

A prominent beach from 240 ft. to 260 ft. above sea-level occurs at Tapuwae Rocks, ten miles north-east of Gisborne (52, p. 23), and terraces at similar heights, though much dissected by streams, near Tolaga Bay, at Tawhiti Hill, and near Port Awanui. Marine terraces belonging to this group also occur near Gisborne, on Mahia Peninsula (17, p. 199), east of Wairoa, and at several points about Palliser Bay (11, p. 85). A gravel-strewn terrace from 200 ft. to 300 ft. above the river extends for ten miles up-stream from the mouth of the Mohaka (69, p. 574).

In this portion of the coast the higher groups of marine terraces are well represented, near Wellington. A rock platform, the inland edge of which is from 450 ft. to 500 ft. (104, pp. 136-37) above the sea extends from Baring Head to Orongorongo. Wave-cut benches at this height have not been definitely observed in the soft Tertiary strata that front the sea along the greater portion of the east coast of the North Island, but in the Herbertville and Gisborne districts (52, p. 25) dissected plateau-like uplands rising gradually from about 600 ft. were probably formed when the sea was some 500 ft. or 600 ft. higher. Inland along the Waiaapu and Waipaoa Valleys (44, p. 32) are extensive terraces from 400 ft. to 600 ft. above the beds of these maturely graded rivers.

Terraces and gravels in these valleys at a still higher level suggest that at one time the land was even lower. In the Waiaapu Valley there is an extensive terrace 900 ft. and more above the adjacent stream-bed, and the even crests and flat tops of the ridges of the uplands between the Waiaapu and the coast indicate erosion from an extensive high-level plateau 1,000 ft. or more above sea-level. The top of Cape Kidnappers is a sloping flat, possibly wave-cut, 700 ft. high. Near Wellington a wave-cut bench 950 ft. high occurs at Orongorongo (104, p. 137), and other terraces of unknown but probably of similar height are to be seen on the eastern shore of Palliser Bay (61, p. 316).

Wellington to Auckland (West Coast).

Raised beaches from 10 ft. to 20 ft. above sea-level occur at numerous points along the west coast of the North Island between Wellington and Auckland. Crawford (65, p. 396) has described those near Wellington, and Adkin those at Porirua Inlet (106, pp. 148-53). They also occur near Foxton, Wanganui, Hawera, New Plymouth, Waitara, Mokau (54, p. 13), Kawhia, Raglan, and Manukau (107, pp. 101-2). The railway near Paekakariki is on a gently-shelving slope formed during the last period of uplift. In north Taranaki a sloping surface rises regularly inland from sea-cliffs in places less than 30 ft. high. North of Urenui this plain is reduced to a narrow strip, which continues along the shore as far as Awakino. This gravel-covered bench was first noted by Hector (1, pp. 3-4). It is backed throughout by an ancient sea-cliff, and except where covered with dunes is rarely more than 120 ft. high (54, p. 13). Small remnants of terraces up to 100 ft. above the sea occur at many points between Awakino and Raglan Harbour. Between Raglan and Waikato mouth there are a

few remnants of marine terraces belonging to this period, and the mud-flats of Manukau Harbour continue above water as gentle slopes that rise to 70 ft. or 80 ft.

The 200–300 ft. group of coastal terraces is well represented near Wellington by the Tongue Point platform, which is 240 ft. above the sea (92, p. 255). The low hills west of Evans and Lyall Bays are probably carved from a shelf of this period. Dissected littoral deposits occur near Pukerua Station (267 ft.), north of Plimmerton; and, according to Adkin, raised beaches from 200 ft. to 240 ft. above the sea occur near Levin (89, p. 507). From Marton to Mangaweka the Wellington–Auckland Railway is built on an ancient flood-plain of the Rangitikei River, which stream is now entrenched from 200 ft. to 250 ft. below. In north Taranaki and west Auckland marine terraces of this cycle have been observed at several points. Small remnants 200–260 ft. high occur some miles north of Awakino (54, p. 13); the flat-topped isthmus of the peninsula between Kawhia and Aotea inlets, which is 200 ft. above sea-level, consists of soft sands similar to the banks now forming in the inlets; and thirteen miles north of Raglan a bench 190–230 ft. high, about 4 chains wide, and backed by an ancient sea-cliff, extends for half a mile along the coast.

At Tongue Point there is a terrace-remnant about 450 ft. above the sea (92, p. 256); the flat-topped Mana Island slopes gently up to 440 ft.; and the gravels at Johnsonville and those at Brooklyn and Kelburn probably accumulated when the land was some 400–600 ft. lower. According to Cotton there is a base level of erosion in the Wellington district 800–900 ft. above the present one (92, p. 248). Adkin mentions a 530 ft. beach near Levin, and states that this beach rises to 770 ft. inland from Palmerston North (101, p. 108). McKay (24, p. 2) noted flat-topped spurs formed of soft sandstone, and from 500 ft. to 800 ft. high, south of Shannon. Marshall states that gravels cap hills 500 ft. high near Wanganui (118, p. 47), and Morgan is of opinion that the land in this area was formerly at least 500 ft. lower than at present (103, p. 63). A little north of Urenui a well-dissected gravel-covered terrace rises from 450 ft. to 800 ft. Wave-cut benches from 450 ft. to 650 ft. above the sea extend for miles along the coast north of Awakino (54, p. 13). The Marakopa district has certainly been uplifted 500–700 ft., and an undoubted beach about 615 ft. above sea-level occurs at a point seven miles north of Marakopa (60, p. 183). Mount Karioi, southwest of Raglan, has a sloping plain 450–550 ft. on three sides. Between Raglan and Waikato the sea-cliffs are formed of or capped with dissected littoral deposits, at many points showing broad sloping surfaces 400–600 ft. above tide-mark. Mount Pirongia is flanked on the west by a gently-sloping plateau from 1,200 ft. to 1,400 ft. above the sea, and sands typical of the littoral deposits of this district cap hills up to 1,000 ft. high a few miles south of the mouth of the Waikato.

Cape Farewell to Kaikoura.

In the northern portion of the South Island raised beaches up to 100 ft. high occur at many points. A gently-sloping surface rises from the western shore of Golden Bay to a height of 60 ft. or 80 ft. along the base of the hills (55, p. 14). Collingwood, Takaka, Motueka, Richmond, Nelson, and Blenheim are built on the slightly uplifted deltas of various rivers. According to McKay, Pelorus and Queen Charlotte Sounds were once connected by way of Mahakipawa Arm, which ends in a flat 25–30 ft. above the sea (12, p. 97); the terrace on which Havelock, at the head of Pelorus Sound, is built, and the flats at Cullensville, suggest elevation to the extent

of 40 ft. (21, p. 40). Cotton has remarked on the narrow strand-plain along the east coast of Marlborough (94, p. 293), and Morgan on sea-worn caves 10 ft. to 12 ft. high at Kaikoura (37, p. 20). Here also are wave-cut benches 60 ft. and 100 ft. above the sea. The flats at Kekerangu, according to Cotton, suggest an elevation of about 120 ft. (94, p. 290; see also 16, p. 125).

The 200-300 ft. group of terraces are also represented in this part of New Zealand. A raised beach about 250 ft. high extends across Kaikoura Peninsula; and Cape Campbell is a flat-topped promontory about 200 ft. above the sea (36, p. 19). According to McKay, gold-bearing gravels occur in the Mahakipawa Valley 200-400 ft. above stream-level (21, pp. 41-42), and there are gravel terraces of similar height in the Pelorus and Wakamarina Valleys, a few miles from the head of Pelorus Sound. Marine terraces of this period extend for miles along the south shore of Golden Bay, and rise in gentle slopes to heights of 180-270 ft. along the foot of the hills.

In this locality also are remnants of terraces 400-500 ft. high, and near the tops of the hills are deposits of well-rounded granite boulders and pebbles, 1,000-1,200 ft. above the sea, that could only have been carried to their present position by shore drift. On the southern side of the Riwaka Valley, facing the sea, is an elevated shelf of about the same height. Near the shores of Blind Bay there is no record of the presence of high-level benches. In the Sounds districts, a few miles up the Wakamarina Valley, there are fluviatile gravels about 700 ft. above stream-level (56, p. 12). Downs 600-700 ft. high, formed of gravels, occur south of the Wairau Plain near Blenheim (23, p. 179). The high-level terraces of the Awatere Valley (800 ft. and more above the stream) (94, p. 288), and the ancient delta of the Clarence, 500-600 ft. high (94, p. 291, and 16, p. 125), probably reached their present position by uplift. Near Kaikoura are wave-cut benches 450 ft. or more above the sea (37, p. 20), and the so-called Kaikoura Plain, formed by the coalescing of several shingle-fans, rises on the flanks of the Kaikoura Range to more than 600 ft.

Kaikoura to Dunedin.

The low strand-plain of Marlborough occurs at many points for some miles south of Kaikoura. Near the mouth of Conway River are beaches 40-50 ft. (38, p. 24), and at Gore Bay 12 ft. and 80 ft. above the sea (58, p. 174, and 59, p. 26). Speight records recent uplift near the mouth of Waipara River as having produced a plain sloping gently upward to a cliff the top of which rises from 50 ft. to 150 ft. at Amberley (91, p. 222). This latter terrace is probably the same as that recognized by Hutton (9, p. 54-55) near Motunau, some miles to the north-east (80-150 ft.). Haast many years ago recorded the occurrence of raised beaches, up to 20 ft., between Kaiapoi and the sea, at Sumner, and on the south side of Banks Peninsula (110, pp. 49, 52). The delta of the Waitaki River extends for miles north and south along the coast as a low strand-plain of varying width, and at Oamaru rock-cut benches 12 ft. and 42 ft. high are veneered with pebbles, sand, and broken shells (51, p. 112, and 15, p. 65). The flats at the mouth of Shag River are uplifted estuarine beds, and south of this river are marine terraces about 100 ft. high (112, p. 78, and 18, p. 234). The isthmus of Otago Peninsula is formed of raised littoral deposits, and the flats round the shores of the many coastal indentations of this district are of a similar nature.

According to Hutton (9, p. 55) coastal terraces from 200 ft. to 300 ft. high occur between Kaikoura and Conway River. There is a rock-cut bench 300 ft. high south of the latter locality. Morgan (38, p. 24) has noted the presence of platforms about 200 ft. above the sea at Amuri, Conway, and Claverley. A gravel-veneered rock-bench from 220 ft. to 250 ft. high (58, p. 174) occurs at Port Robinson; and a terrace from 200 ft. to 300 ft. above the sea extends for about seven miles between Stoneyhurst and Motunau (13, p. 76). Near Oamaru the strand-plain is backed by old sea-cliffs from 150 ft. to 200 ft. high, from the top of which an extensive plain extends inland along the Waitaki Valley, rising from 230 ft. to over 650 ft. near Papakaio (100, p. 118). Park (51, p. 111) considers that this high-level plain was produced by an uplift of the land of about 200 ft. There are several marine terraces near Seacliff between 200 ft. and 300 ft. high, and Marshall (115, p. 386) mentions a well-defined bench at Sandymount, near Dunedin, 250 ft. above sea-level.

McKay (10, p. 177) observed a 500 ft. terrace at Amuri Bluff with shells on its surface; and Morgan (38, p. 24) records a 400 ft. bench near Claverley, and beach-shingle and sand up to 600 ft. According to Speight and Wild (99, p. 80) a platform 500 ft. high occurs between the Blyth River and Napenape Cliff. The plateau-like uplands above Port Robinson, north of the Hurunui River, were probably once an extension of this latter terrace. Beach-remnants 450 ft. above the sea occur at Lyttelton Heads (85, p. 32), but between this point and Dunedin the only definite record that the sea was once higher is furnished by the plateau, 1,100–1,200 ft. above the sea, on the eastern side of the Malvern Hills (9, p. 57). At Highcliffe, near Dunedin, Hutton long ago noted several rock-benches up to 900 ft. above sea-level (112, p. 78).

Dunedin to Jackson's Bay.

A 10 ft. beach occurs at the mouth of Kaikorai Stream, a little south of Dunedin, and Grange (105, p. 161) considers that the topography of this district suggests an uplift of about 100 ft. There are several low coastal terraces near the mouth of Taieri River. The extensive flats at Inch-Clutha are from 10 ft. to 20 ft. above tidal river-channels. North of Port Molyneux a sand-veneered wave-cut bench which rises gently from cliffs 30–60 ft. high to about 120 ft. at the inner margin of the platform continues along the coast for at least seven miles. Raised beaches up to 20 ft. above the sea have been worked for gold for some miles eastward from Waipapa Point. From Invercargill to Riverton the swampy silt-plains have obviously been recently raised above high-water mark. Petrie (71, pp. 323–24), writes of Stewart Island, "At no remote date a strait here [between Paterson Inlet and Mason Bay] ran across Stewart Island, separating the high land in the north . . . from the southern portion . . . a depression of 50 ft. or 60 ft. would suffice to restore this strait, and part Stewart Island once more into two." According to Hutton (112, p. 80) one of the Green Islets rises from a platform 40 ft. high, at which level is an arch evidently formed by sea erosion. Hector (109, p. 453) many years ago noticed sea-worn caves on Steep-to Island, Preservation Inlet, 10–20 ft. high. An old channel between Chalky and Preservation Inlets is now represented by a flat-bottomed gap 50 ft. above the sea in the separating mountainous peninsula (27, p. 33). At Gulches Head, in Preservation Inlet, there are, according to McKay (27, p. 45), gravels 130–140 ft. above tide-mark. Lake McKerrow, north of Milford Sound, which is separated from the sea by a low gravel spit, has terraces from 10 ft. to 60 ft. high (3, p. 43).

Near Dunedin the 200-300 ft. group of terraces is represented by the gently undulating surface above the cliffs fringing the coast south of the town. East of Kaitangata are beach-remnants 260-300 ft. high, and similar terraces formed of buff-coloured gravels and sands occur at Orepuki, where Park (53, p. 54) states they reach a height of 230 ft. Hutton (112, p. 79) wrote in 1875 that "the chain of small islands between Paterson's Inlet and Ruapuke are quite flat-topped, the result evidently of marine denudation. They are between 140 ft. and 200 ft. high." According to Park (20, p. 130) there is a coastal terrace between Barn Bay and Martin Bay from 100 ft. to 300 ft. above sea-level; and Hector (109, pp. 455, 467) noted terraces near Lake McKerrow, 270 ft. high, and the wooded tableland of Coal Island (200-300 ft.).

The higher group of terraces is not well represented on the east coast of Otago, or at least there is no reference to its presence except by Hutton (112, p. 171), who noted that gravels occur up to a height of 400 ft. on the sea face of the coast range opposite Otakaia. This range extends south to Kaitangata, where its even flat-topped crests appear to have been carved from a plain (600-700 ft. high) sloping gently seaward. A little west of Orepuki are terrace-remnants 400-450 ft. high. In Stewart Island, McKay described the south end of the Tin Range as a broken tableland from 500 ft. to 700 ft. high (22, p. 83), and wrote that the land between Big River and Puysegur Point was a terraced bench from five to ten miles wide rising from 200 ft. to 1,200 ft. (27, p. 32). Marshall states that raised beaches occur in this part of New Zealand up to 1,000 ft. high (119, p. 200). McKay (27, p. 37) noted the presence in this locality of gravel terraces 800 ft. high, and considered that the sea was once 750 ft. higher than now. Hutton (112, p. 80) in 1875 mentioned a series of wave-cut benches up to 800 ft. at the entrance of Doubtful Sound, and stated his belief that Otago had been elevated both on the east and west coasts 500 ft. or more (112, p. 83). Hector (3, p. 43) noted the gently sloping plateau at Cascade Point, that in seven miles rises from 300 ft. to 700 ft.

Jackson Bay to Cape Farewell.

Blacksand beaches up to 60 ft. above the sea have been worked for gold at innumerable points on the narrow strand-plain that extends along the coast for most of the distance between Jackson Bay and Cape Farewell. The towns of Okarito, Hokitika, Greymouth, and Westport, as well as the railways from Ross to Greymouth and from Westport to Mokitini, are built on this plain. Between Greymouth and Westport the strand-plain occurs at many points. Haast (108, p. 112), observed raised beaches 12 ft. above the sea between the Wanganui and Karamea Rivers, and Cox (14, p. 73) similar beaches 5-20 ft. high between Big River and Westhaven Inlet. Higher terraces belonging to this group are represented by the gravel-bench north of Hokitika (120 ft. on the seaward edge) and the wave-cut platforms at Perpendicular Point (about 90 ft.) and Seal Island (60 ft.) north of Greymouth (50, p. 43).

According to Hector (3, p. 47) the coast south of Paringa River is formed of flat-topped cliffs from 150 ft. to 200 ft. high, of which the upper 50 ft. is gravel. Hackett (5, p. 9) observed similar cliffs in the Okarito district, where they are from 200 ft. to 300 ft. high, formed chiefly of morainic material; north of Okarito is a gravel cliff 100 ft. high (5, p. 10). Auriferous beach leads occur in North Westland in successive terraces up to 220 ft. or more above the sea (2, p. 30; 46, p. 33; 66, p. 296). At Point Elizabeth, north of Greymouth, Darkie's Terrace is over 200 ft. (26, p. 22;

46, p. 44), and still farther north the Barrytown lead and Welshman's Terrace is about 220 ft. above tide-mark (50, p. 43). Bartrum (95, p. 259) has described sloping plains between Charleston and Westport that rise to about 250 ft. at the foot of an old sea-cliff. Near Westport there are beach leads between 200 ft. and 300 ft., and at Gentle Annie Point marine gravels occur about 200 ft. above the sea (49, p. 94). Still farther north, in the Paturau district, there are raised beaches up to 200 ft. high (32, p. 25).

The only reference suggesting that the land in South Westland was once more than 200 ft. or 300 ft. lower than at present is by Hackett (5, p. 10), who observed that the plateau between the Omoeroa and Waiho Rivers, two or three miles from the sea, is about 700 ft. high. Between Greymouth and Westport there is abundant evidence of uplift. North of Point Elizabeth, near Nine-mile Bluff, an extensive marine terrace occurs at a height of over 400 ft. Gold-bearing beach-gravels have been worked at between 500 ft. and 750 ft., near the mouth of Punakaiki River (50, p. 43). Some of the high-level blacksand leads of the Charleston district occur 500 ft. and more above sea-level, and there is, according to Bartrum, a wave-cut bench at 759 ft. (95, p. 258; see also 67, p. 445). Marine terraces belonging to this group are also present in the Westport district (49, p. 94), and platforms 1,000 ft. or more face the coast near Kahurangi Point.

Summary of Evidences of Elevation.

The coastal terraces of New Zealand may evidently be grouped into several sets. Two sets, one comprising raised beaches up to 120 ft. above the sea and the other the terraces from 200 ft. to 300 ft. high, are well marked, and probably were formed during times of comparative slower elevation, rest, or depression occurring in the general elevatory movements of the younger Pleistocene and Recent periods. There is also a prominent set of benches between the 400 ft. and 600 ft. contours. Terraces at a higher elevation are widely scattered and fragmentary or greatly denuded.

As Hector (64, p. 269) observed many years ago, raised beaches up to 25 ft. above sea-level occur at innumerable points round the coast of New Zealand. There are also widely distributed remnants of platforms up to 120 ft., and in sheltered embayments are sloping wave-built terraces rising from sea-level, the landward edges of which, for reasons already given, vary considerably in height. Infilled estuaries show these surfaces (entrenched by streams owing to the latest elevations) most clearly; but in these the distinction between fluvial and littoral deposits is difficult to make, and the height of the strand, when the period of standstill or depression ended, cannot be determined. On exposed portions of the coast, where, however, owing to the cutting-back of the land by the waves, the complete bench is nowhere preserved, the old strand-line is most definitely marked. The best example of this terrace known to the writer is at Colac Bay, whence it extends westward to the Waiau River. Another bench cut during the 120 ft. standstill in hard early Tertiary rocks, extends for at least seven miles along the coast north of the Molyneux River. In the North Island a narrow strip of a platform cut in beds of Middle Tertiary age extends south from Awakino River for twenty-five miles to Urenui, where it merges in the Taranaki Plain. In these localities the old strand-line of what may be termed the Awakino cycle is about 120 ft. above sea-level. The general occurrence at about this height of remnants of wave-formed terraces round the coast of New Zealand, as described in preceding pages, suggests that the Islands were uniformly uplifted to this height.

Again, the presence of steep hillsides, believed to have been derived from old sea-cliffs, along the landward edge of the remnants of this platform, together with the occurrence of a decided break at or some little height above the 120 ft. contour in the more subdued topography of the lowlands occupying sheltered embayments, infilled estuaries, and localities where delta-plains are being extended seaward, suggest that a decided pause in elevation of the land, or even depression, is represented. Haast (110, p. 43) noted this break in connection with the Canterbury Plains, and Cotton in connection with the Manawatu lowlands; both, however, explain it as being probably due to differences in the supply of waste brought to the sea by rivers.

The 200-300 ft. group of benches, except in North Auckland, is well represented at many points round the New Zealand coast. Where wave-attack has been the rule only remnants occur, but in sheltered localities the sloping surfaces are more extensive. As far as the writer knows, sea-cliffs everywhere back the wave-cut platforms, but where the terrace is chiefly wave-built no definite break in the land profile has been observed. The bench is particularly well preserved at Tongue Point, near Wellington; at Tapuwae Rocks, ten miles north-east of Gisborne; and near Crayfish Point, thirteen miles north of Raglan. In the South Island it is well shown on Golden Bay, between Collingwood and Takaka, between Westport and Charleston, at many points in North Westland, and, according to McKay, between Stoneyhurst and Motunau. The terraces belonging to this group are decidedly dissected by streams, and their inner edges are concealed in most localities by later debris, but seemingly the stillstand or slight depression of the land they mark occurred at about the 260 ft. contour. The coastal terraces of this period may be considered to belong to the Tongue Point cycle, a term first used by Cotton (92, p. 250) in connection with the physiography of the Wellington district.

The terraces higher than those of the Awakino and Tongue Point cycles may be divided into two groups—namely, those between 350 ft. and 600 ft. and those still higher. The lower group is represented by remnants decidedly better preserved than the benches of the higher group; but these in turn are much more dissected than those of the Awakino and Tongue Point cycles, although both the higher groups of platforms, on the evidence of extensive dissected upland surfaces, represent decidedly longer periods of comparative standstill.

Terraces of the 350-600 ft. group occur at various points all round the coast of New Zealand, but, so far as known to the writer, are best represented north of Raglan and again at Hicks Bay (formed of Pleistocene sand), north of Awakino (carved from Tertiary rocks), between Palliser Bay and Wellington Harbour (carved from greywacke), near Charleston, at Cascade Point in South Westland, and at the mouth of the Clarence River, where they represent the uplifted delta of that stream. There seems to have been a considerable pause between 400 ft. and 450 ft., for wide terraces at that height are preserved at most of the localities mentioned; but no considerable topographic break occurs from the 350 ft. to the 600 ft. contour. Between Charleston and Westport the inner edge of this terrace at many points abuts against steep hillsides, presumably old sea-cliffs. This suggests that a definite pause occurred in the elevatory movements at about the 600 ft. contour. The name "Charleston cycle" is suggested for the cycle to which the 400-600 ft. group of terraces belongs.

Marine terraces and other land-features formed when New Zealand was more deeply depressed than 600 ft. below present sea-level are represented

by widely scattered remnants. Definite benches are best preserved near Te Araroa, at Orongorongo, near Collingwood, and in the south-west corner of Otago. The cycle to which they belong has been termed by Cotton the "Kaukau cycle" (92, p. 249).

The above facts support the suggestion that New Zealand has moved in respect to sea-level during later Pleistocene and Recent times as a whole. Any differential movements between adjacent earth-blocks that may have taken place during these periods must have been small, if compared to the plateau-forming movements by which New Zealand has been uplifted as a unit.

EVIDENCES OF DEPRESSION.

The numerous embayments and branching indentations on both sides of North Auckland Peninsula definitely prove the depression of this part of New Zealand. A bore on the flats at the northern end of Kaipara Harbour penetrated 212 ft. of river silts and estuarine beds (83, p. 458) without reaching solid rock, but beyond this record there seems to be no evidence as to the amount of the depression. Ramifying inlets occur also along the west coast as far south as Kawhia. Hochstetter (111, p. 273) long ago pointed out that the Waikato has completely filled in a similar inlet. This at one time extended inland as far as Huntly, over thirty miles from the sea. Here a band of marine shells in unconsolidated estuarine beds 67 ft. below sea-level (39, p. 31) was passed through by a bore. A slight depression would create an extensive inlet about Waikato mouth; on the other hand, a slight elevation would convert the greater part of the harbours from Manukau to Kawhia into dry land. Although the straight cliffed coast between Raglan and Waikato Heads has been cut back by the sea, all, save the smallest streams, are tidal at their mouths, and flow through swampy flats produced by the recent slight uplift of their infilled estuaries.

Some of the valleys drowned to form the Aotea and Kawhia inlets have been cut in a marine terrace up to 220 ft. high, and have since been partly filled with sands and muds to the present 105 ft. contour. Evidently, after the 200–300 ft. coastal bench had been formed the land was considerably elevated, and the valleys thereby produced partly filled in during a later depression when the land was 100 ft. or more lower than at present. The coast between Kawhia and Waitara is similar to that between Raglan and Waikato Heads; and the rivers, which are tidal at their mouths, enter the sea through infilled estuaries. The Mokau, the largest river, is tidal for twenty-four miles, and near its mouth there are extensive mud-flats bare at low water. Its estuary, therefore, is not yet completely filled (54, p. 13).

Submerged forests with peat and lignitic beds are exposed on the coast of Taranaki a mile and a half east and two miles west of the Waitara (47, p. 26), and near the mouths of the Patea and Waitotara Rivers (19, p. 59; 62, p. 158; 98, p. 416). The carbonaceous material is overlain by clays, sands, and gravels, usually stained with iron oxide from the oxidation of ironsand derived from the volcanic rocks of Taranaki. According to Park (19, p. 60) the lignitic beds nowhere are found more than a mile or two from the present coast. They probably represent the vegetation of the old land-surface smothered by littoral deposits during the depression that ceased when the 120 ft. coastal terrace was formed.

Wanganui is built for the most part on the raised estuarine flats of the river. At the town, bores have shown that the infilling beds extend at least 172 ft. (77, p. 348), and near Aramoho, three miles up-stream, about 100 ft. below sea-level (82, p. 452). At Longburn (81, p. 552), near Palmerston North, beds of sand and shingle occur to a depth of nearly 300 ft. below

sea-level. Porirua and Wellington Harbours prove the depression of the southern end of the Island. According to Cotton, the depression on the eastern side of Wellington Harbour is about 200 ft. (104, p. 140). Palliser Bay, like Wellington Harbour, occupies part of a tectonic depression, and once extended some miles up the Wairarapa Valley, as is proved by the raised shell beaches that occur round the shores of the lake (11, p. 86). That the land has been higher in this locality is suggested by the wide low-lying plains and the sprawling spurs that project into them.

The streams flowing to the eastern coast of Wellington are all small. The Akitio and Wainui (34, p. 103), and probably others also, near the sea, flow slightly entrenched in raised estuarine deposits. Hill has shown that the extensive Heretaunga Plain is an old extension of Hawke Bay filled with detritus brought down by the Tukituki, Ngaruroro, and Tutaekuri Rivers (74, p. 288; 76, p. 431). The silts, sands, and gravels of the plain reach 369 ft. below sea-level at Havelock (84, p. 444). The lower valleys of the Wairoa, Waipaoa, Uawa, and Waiapu Rivers are all obviously infilled estuaries (52, p. 22). The loose deposits in the Waipaoa Valley at Makauri, on the flats four miles from the sea, extend to 200 ft. below sea-level (86, p. 434).

In the Bay of Plenty the harbours of Ohiwa, Tauranga, and those on the eastern side of Hauraki Peninsula amply prove depression. At Tauranga, valleys cut in a 200-300 ft. bench have later been depressed and partly filled. The submerged forest at Opotiki (50 ft.), and the swamps at Coromandel (150 ft.) (29, p. 12), and near Thames (30 ft.) (116, p. 244), probably belong to a late period of oscillation. Hauraki Gulf, like Palliser Bay, is the drowned portion of a structural depression. The numerous peat-beds passed through by bores on the lowlands south of the inlet prove a depression of this portion of New Zealand of at least 400 ft. (117, p. 6). At Horotiu, in a tectonic trough adjacent to the Hauraki depression, peaty beds occur at a depth of 550 ft. below sea-level (96, p. 614).

The coast round Golden and Tasman Bays has obviously been depressed. On the shores of the former Parapara, Onekaka, and Onehau inlets are partly filled drowned valleys carved in a raised terrace of the 200-300 ft. standstill. Croixelles Harbour and the sounds are definite proof of the depression of the Marlborough Peninsula. The pattern of the valleys now forming the inlets indicates that they were excavated along a system of parallel faults. Thus the valley-floors of relatively small streams became maturely graded in relatively short periods, so that, when depression occurred, the sea penetrated unusually long distances. The Pelorus River has filled in several miles of its old narrow estuary, and has produced decided shoaling for eight miles below the present head of the sound. But the drainage area of Queen Charlotte Sound is so small that only a trifling amount of infilling can have occurred. Cotton (93, p. 216) has discussed the amount of depression of this area, and considers it to have been from 250 ft. to 500 ft. The neighbouring lower valley of the Wairau River is an infilled estuary. This low-lying area is primarily of tectonic origin, but the choking with debris of minor valleys excavated in Pleistocene gravels south of Blenheim suggests recent depression unconnected with the earlier structural movements.

From Wairau River to Motunau there is convincing evidence of uplift, but the only definite recorded evidence that the land was once lower than now is furnished by the submerged forests at Grassmere (68, p. 97) and near the mouth of Conway River (4, p. 40). The embayments, however, in the rock-platform surrounding Kaikoura Peninsula and the lower valley of Kahutara Stream suggest depression. Farther south the drowned valleys

of Banks Peninsula and the peat-beds 600 ft. below sea-level, penetrated by bores in the Christchurch area (85, p. 29; 88, p. 427; 97, p. 385), definitely prove depression. Some of these bores, before reaching the peat and shingle deposits of terrestrial origin, passed through sandy beds containing shells to a depth of about 80 ft. (88, p. 428). This suggests a depression of at least 80 ft. after the land had been built up above the sea. In the Chertsey oil-bore gravel occurs to a depth of 1,500 ft., and oxidized sands (88, p. 423) and clays to 1,800 ft. below sea-level (41, p. 12). According to Speight, a submerged forest occurs near the mouth of Pareora River, and valleys near Timaru have been depressed below sea-level. All the larger streams entering the sea between Oamaru and Dunedin have infilled estuaries at their mouths. The drowned valleys of Otago Harbour and the numerous inlets of this neighbourhood furnish undoubted evidence of depression. The sea once penetrated through the lower Taieri Gorge into an inlet which is now occupied by the Taieri Plain, and of which Waiholo Lake is a portion not yet filled to sea-level. Similarly, Lakes Kaitangata and Tuakitoto are infilled portions of an arm of a drowned valley. Between Nugget and Waipapa Points are numerous inlets and estuaries, of which Newhaven and Waikawa are the chief. The depression of Stewart Island is obvious, and on the north side of Foxeaux Strait are Bluff, New River, and Aparima inlets. Waiau River has cut a valley, three miles wide at present sea-level, through the deposits laid down during the 200–300 ft. standstill. This it has since filled with gravel, the terraces bordering its flood-plain being up to 30 ft. high.

The West Coast fiords are drowned glacial valleys which are all decidedly shallower at or near their mouths than farther inland. The entrance of Sutherland Sound is almost completely blocked with sand and gravel, and tidal waters enter only the lower end of Lake McKerrow, which is also a depressed glacial valley, with a floor, at its upper end, 450 ft. below sea-level (3, p. 44). With the exception of Preservation Inlet, which nowhere appears to be more than about 300 ft. deep, the floors of the fiords are from 800 ft. to more than 1,700 ft. below the surface of the sea. That the glaciers overdeepened their valleys to this extent is unlikely, and the bulk of the excavation was probably done when the land was about 1,500 ft. above its present level. The submarine bars have been explained as moraines deposited as the ice retreated, but they may have accumulated as coastal drift during ancient periods of standstill, or they may be formed of both deposits. There is no mention in the literature of moraine at the sea ends of Lake McKerrow and Sutherland Sound, which are thought to have been choked during the present period of inconsiderable movement.

The immense amount of gravel carried to the sea by the Westland rivers and distributed northward along the shore by the coastal drift has filled in the estuaries that at one time no doubt existed along the shore. Ross Flat occupies an embayment, and beneath it gravels, apparently of fluvial origin, have been penetrated by a shaft to a depth of 265 ft. below sea-level (31, p. 24), and worked for gold to 191 ft. Blacksand beach leads occurring below sea-level have been sluiced and elevated or dredged at several points in the Okarito, Hokitika, Greymouth, Barrytown, and Westport districts, and bores near the mouth of Waimangaroa River penetrated gravel and sand to a depth of 80 ft. without reaching solid rock (49, p. 187). Haast (108, p. 112), noted a submerged forest a few miles west of Westport. Small coves in granitic rocks near Charleston appear to be drowned valleys, as Westhaven Inlet, at the northern end of the Island, is undoubtedly.

At Kawhia, Tauranga, Golden Bay, and Waiau Mouth valleys, now in part drowned or infilled, were excavated, when the land was at a higher level than now, in the deposits and coastal terraces formed during the 200-300 ft. standstill. At Kawhia the valleys are filled with sands and silts to a height of over 100 ft., so that there has been a later depression of that amount. This was almost certainly the same depression and pause during which the 120 ft. coastal terraces were formed. At the other localities mentioned no precise observations as to the amount of infilling have been made.

The buried forests and old land-surfaces at Thames, Coromandel, Opotiki, and Gisborne, and those of the Hamilton (70, p. 36; 73, p. 459; 75, p. 410), Taranaki, and Christchurch districts, probably belong to this period of oscillation. The submerged forests of other parts of New Zealand, most of which occur at sea-level on the coast, may have been formed during slight movements of still more recent date. This especially applies to the scrub-covered land-surfaces occurring a little below high-tide mark in Mānukau, Raglan, Aotea, and Kawhia inlets.

The inlets last mentioned, together with those of Kaipara and Tauranga, are formed by the drowning of valleys in part carved in Pleistocene deposits; Tauranga is entirely in these beds. They correspond in size among themselves, and also to other inlets round the coast of New Zealand formed by the drowning of stream-valleys. This suggests that all these features were produced by the same movement of depression, which occurred between the Tongue Point and Awakino erosion cycles. There are, however, no data by which the depths of these drowned valleys can be compared, since all, except the Marlborough Sounds, are largely infilled. Cotton concluded that these last-mentioned inlets had been produced by a subsidence of the land of between 250 ft. and 500 ft., and such bores as penetrated the beds deposited in the drowned valleys do not contradict this conclusion.

The layers of vegetable material and the other terrestrial beds that are penetrated by the deeper bores at Christchurch and Chertsey probably belong to the Middle Pleistocene period. Progradation of this portion of New Zealand was continuous throughout Pleistocene times. At Chertsey gravels and sands more or less oxidized extend to 1,500 ft. below sea-level, at which depth they pass into sands and clays probably of marine origin. It should be noted that the bottoms of several of the fiords of western Otago are at a similar depth below sea-level. In the North Island the greatest known depth at which surface deposits occur is in a bore at Horotiu, in the Hamilton district, where peat-beds occur 550 ft. below sea-level. This bore when abandoned was still in unconsolidated deposits which had accumulated in a tectonic depression. At Thames, in an adjacent structural trough, loose sands and silts are known to occur to a depth of 1,100 ft., but those beds do not furnish proof that the land in this area was ever elevated to this extent.

POST-TERTIARY VOLCANIC ROCKS.

The post-Tertiary volcanic rocks of New Zealand are confined to the North Island. They consist of the three following groups: (1) Basaltic rocks that occur at many points near the west coast from Kawhia to Auckland and in North Auckland Peninsula; (2) rhyolitic flows, breccias, and tuffs that cover large areas in the Taupo-Rotorua zone, and occur near Waihi and probably other parts of Hauraki Peninsula; and (3) the andesitic cones of Egmont, Ruapehu, and adjacent mountains, Edgecumbe, White Island, and probably other volcanoes.

Basaltic Rocks.

The basaltic rocks range in age from the oldest Pleistocene to Recent times. The first eruptions appear to have been closely associated with the great fault-movements that separate the Tertiary from the Quaternary. The large cones of Pirongia and Karioi occur at crossing-points of important fracture-systems. The former fills part of the trough the drowned western end of which forms Kawhia Harbour. The building of these mountains and the cones associated with them was certainly completed after movement along the great fracture-zones of this part of New Zealand had ceased; the volcanic rocks of this group rest for the most part on land surfaces; and the youngest Tertiary rocks of the district (the late Pliocene Kaawa beds) contain no trace of basaltic material. On the other hand, the high-level shelf (1,200–1,400 ft.) on the west flank of Pirongia shows that the mountain existed at the maximum depression separating the early from the younger Pleistocene. For these reasons Pirongia, Karioi, Kākepuku, Te Kawa, and various lava-flows and dykes between Raglan Harbour and Waikato Heads are considered to be of early Pleistocene age.

Some of the basaltic rocks of this district are certainly of later date. Scoria-cones with associated lava-flows occur in valleys that were excavated during the last considerable elevation. They are connected through the volcanic rocks of the Tuakau with the basaltic cones and lavas of Auckland. But the eruptions at Auckland were later, since the cones still have well-preserved craters and the scoria is unweathered, whereas the cones south of the Waikato show no trace of craters and consist of deeply-weathered rock.

The basaltic rocks of North Auckland, which chemically and mineralogically resemble those of Pirongia and Tuakau, are divided by Clarke into two closely-connected groups. They probably range through the Pleistocene to Recent times.

Rhyolitic Rocks.

Large amounts of rhyolitic material were erupted during late Pliocene times, but probably the bulk of the acid rocks in the Taupo-Rotorua zone is of Pleistocene age. Although flow rocks are abundant near the centres of vulcanism, fragmental material is much more widespread, and occurs in greater mass. Thick layers of rhyolitic tuff and breccia of sub-aerial deposition cover large areas in the centre of the North Island and completely smother the underlying rocks. On surrounding districts extending to the east and west coasts finer material, in many parts weathered to a characteristic sandy loam, caps the hills and upland surfaces. Sub-aqueous tuff and breccia are interbedded with subaerial, and, in low-lying country towards the edge of the area of thickest deposition, almost entirely replaces it. Beds of this description occur in vast amount in the Waikato and Hauraki depressions, near Tauranga, and eastward in the Bay of Plenty, and in less amount in the Waipaoa and Wairoa Valleys. In the Waikato district the subaqueous rhyolitic tuffs contain water-worn fragments of basalt, and wrap round and overlap the bases of several of the basaltic cones. Clearly the earliest basalts are older than this rhyolitic material.

Andesitic Rocks.

The great volcanoes of the centre of the North Island, Ruapehu and Tongariro, together with the small adjacent cones, are formed of andesitic material, and overlie the rhyolitic rocks mentioned above. In the Waihi district massive andesitic dykes penetrate the later rhyolitic fragmental rocks (48A, p 75).

The active volcanoes, Ngauruhoe, White Island, and Tarawera, all discharge andesitic material. The ash produced by the explosive eruption of the last-mentioned was chiefly derived from the rhyolitic rocks through which the line of vents was formed, and was, consequently, acidic in composition. Probably the large amount of rhyolitic sand brought down during Recent times by the Waikato and other rivers flowing from the Taupo region was similarly produced from older acidic rocks by the explosions of andesitic volcanoes. The loose pumiceous sands and gravels about Lake Taupo, and the unweathered rhyolitic ash found over the country eastward, were probably blown out at the same time.

The andesitic cone of Mount Egmont rises from a volcanic pile of decidedly older rocks of similar composition. Its relation to the rhyolitic rocks is nowhere shown. But on physisographic grounds it is clearly of Recent origin; and, since its rocks are of similar composition to those of the central volcanoes, this mountain is considered to be of about the same age. The Taranaki Plain surrounding Mount Egmont is covered with tuff derived from it. In the Mokau district, about fifty miles north-east of the peak, the 120 ft. coastal terrace, which is in direct continuity with the Taranaki Plain, is formed of or veneered with similar material more or less sorted by wave-action. On the other hand, the higher coastal terraces of this district are covered with siliceous sands containing pebbles of greywacke, but no trace of andesitic material. The coastal drift is northward, and had Egmont been active while the higher marine shelves were being cut the detritus on them could scarcely have failed to contain some trace of volcanic material. Probably, then, the last eruption of the Taranaki volcanic centre, which presumably produced the peak of Egmont, was associated with the Recent land oscillations that produced the 120 ft. coastal terraces.

CONCLUSION.

The deposits of Pleistocene and Recent age are, in New Zealand, of greater economic importance than those of all other ages. The plains, river-valleys, and lowlands generally were formed or profoundly modified, and the soils that cover them were produced during these periods. During the same time, too, practically all the detrital gold won from the gravels of the South Island was liberated from a hard matrix and concentrated into workable deposits. New Zealand boasts of its abundant water-power, which is derived from streams that have not yet, owing to the recency of land uplift, cut their valleys to grade. And in this connection the vast mass of rhyolitic material which, ejected by Pleistocene volcanoes in the centre of the North Island, acts as a porous sponge and regulates the flow of rivers is of special interest. On the other hand, land-depression has provided harbours and valuable artesian basins in many parts of the Dominion.

LITERATURE.

The official geological reports dealing with New Zealand occur scattered through various publications. A central Geological Survey was established in 1865, and the reports of the officers were issued with more or less regularity up to 1894 independently of other publications. After that date they appeared as parliamentary papers, and were bound with the volume of reports, records, &c., issued yearly by the Mines Department. The Geological Survey was reorganized in 1905, since which year, in addition to the annual report printed as a parliamentary paper, bulletins dealing

with areas examined in detail have been published as prepared. The *New Zealand Journal of Science and Technology*, founded in 1918, provides a more accessible and popular record for official reports than parliamentary papers, and many special reports prepared by officers of the Geological Survey are published therein. The *Transactions and Proceedings of the New Zealand Institute* contain much information on the geology and physisography of New Zealand, as also do other publications of which the titles are given below in full.

In the appended list the titles of papers have, for the most part, been abbreviated.

Reports of Geological Explorations.

(By the New Zealand Geological Survey.)

1. HECTOR, J., 1868. Taranaki District. No. 4 (during 1866-67).
2. — 1868. Westland Goldfields. *Ibid.*
3. — 1868. West Coast Harbours. *Ibid.*
4. BUCHANAN, J., 1868. Kaikoura District. *Ibid.*
5. HACKET, T. R., 1869. Okarito District. No. 5 (during 1868-69).
6. HUTTON, F. W., 1869. Thames Goldfields. *Ibid.*
7. HECTOR, J., 1877. East Cape District. No. 8 (during 1873-74).
8. MCKAY, A., 1877. East Cape District. *Ibid.*
9. HUTTON, F. W., 1877. North-east Portion of the South Island. *Ibid.*
10. MCKAY, A., 1877. Kaikoura Peninsula and Amuri Bluff. No. 9 (during 1874-76).
11. — 1879. South Part of East Wairarapa. No. 12 (during 1878-79).
12. — 1879. Kaituna Valley and Queen Charlotte Sound. *Ibid.*
13. — 1883. Motunau District. No. 15 (during 1882).
14. COX, S. H., 1883. Collingwood - Big River District. *Ibid.*
15. MCKAY, A., 1884. North-eastern Otago. No. 16 (during 1883-84).
16. — 1886. Eastern Marlborough. No. 17 (during 1885).
17. — 1887. East Auckland and Northern Part of Hawke's Bay. No. 18 (during 1886-87).
18. — 1887. Moeraki Peninsula and Kakanui. *Ibid.*
19. PARK, J., 1887. West Wellington and Part of Taranaki. *Ibid.*
20. — 1887. District between the Dart and Big Bay. *Ibid.*
21. MCKAY, A., 1890. Mahakipawa Goldfield. No. 20 (during 1888-89).
22. — 1890. Stewart Island. *Ibid.*
23. — 1890. Marlborough and Amuri District. *Ibid.*
24. — 1894. Shannon District. No. 22 (during 1892-93).
25. — 1894. Hokianga and Mongonui Counties. *Ibid.*

Parliamentary Papers.

(Published in the annual volume issued by the Mines Department.)

26. MCKAY, A., 1895. South-west Part of Nelson and Northern Part of Westland. C.-13. (Also published in pamphlet form, 1897.)
27. — 1896. Wilson River and Preservation Inlet Goldfield. C.-11.
28. — 1897. Cape Colville Peninsula. C.-9.
29. MACLAREN, J. M., 1900. Coromandel Goldfield. C.-9.
30. MCKAY, W. A., 1901. Pencarrow Head to Ruamahanga River. C.-10.
31. REED, F., 1916. Alluvial Mining in New Zealand. C.-2.

Annual Reports of the New Zealand Geological Survey.

32. WEBB, E. H. J., 1908. Paturau District. No. 2. C.-9.
33. HENDERSON, J., 1914. Warkworth District. No. 8. C.-2.
34. — 1915. Weber District. No. 9. C.-2.
35. MORGAN, P. G., 1916. Kaipara District. No. 10. C.-2b.
36. — 1916. Cape Campbell District. *Ibid.*
37. — 1916. Kaikoura District. *Ibid.*
38. — 1916. Amuri-Conway District. *Ibid.*
39. HENDERSON, J., 1916. Huntly District. *Ibid.*
40. FERRAR, H. T., 1920. Whangarei Subdivision. No. 14. C.-2c.
41. HENDERSON, J., 1922. Chertsey Oil-bore. No. 16. C.-2c.

Bulletins of New Zealand Geological Survey.

42. FRASER, C., and ADAMS, J. H., 1907. Coromandel Subdivision. No. 4.
43. BELL, J. M., and CLARKE, E. DE C., 1909. Whangaroa Subdivision. No. 8.
44. ADAMS, J. H., 1910. Whatautu Subdivision. No. 9.
45. FRASER, C., 1910. Thames Subdivision. No. 10.
46. MORGAN, P. G., 1911. Greymouth Subdivision. No. 13.
47. CLARKE, E. DE C., 1912. New Plymouth Subdivision. No. 14.
48. BELL, J. M., and FRASER, C., 1912. Waihi-Tairua Subdivision. No. 15.
- 48A. HENDERSON, J., and BARTRUM, J. A., 1913. Aroha Subdivision. No. 16.
49. MORGAN, P. G., and BARTRUM, J. A., 1915. Buller-Mokihinui Subdivision. No. 17.
50. HENDERSON, J., 1917. Reefton Subdivision. No. 18.
51. PARK, J., 1918. Oamaru Subdivision. No. 20.
52. HENDERSON, J., and ONGLEY, M., 1920. Gisborne Subdivision. No. 21.
53. PARK, J., 1921. Western Southland. No. 23.
54. HENDERSON, J., and ONGLEY, M., 1923. Mokaui Subdivision. No. 24.
55. ONGLEY, M., and MACPHERSON, E. O., 1923. Collingwood Subdivision. No. 25.

New Zealand Journal of Science and Technology.

56. HENDERSON, J., 1918. Wakamarina Valley. Vol. 1.
57. ——— 1918. Waikato Valley. Vol. 1.
58. ——— 1918. Cheviot District. Vol. 1.
59. ——— 1921. Cheviot District. Vol. 4.
60. HENDERSON, J., and GRANGE, L. I., 1922. Marakopa District. Vol. 5.

Transactions and Proceedings of the New Zealand Institute.

61. CRAWFORD, J. C., 1869. Geology of North Island. Vol. 1.
62. PHARAZYN, R., 1870. Kai Iwi-Waitotara Coast-line. Vol. 2.
63. HUTTON, F. W., 1870. Manukau Harbour. *Ibid.*
64. HECTOR, J., 1871. Editorial Note. Vol. 3.
65. CRAWFORD, J. C., 1873. Miramar Peninsula. Vol. 5.
66. DOBSON, A. D., 1874. Notes on the Glacial Period. Vol. 6.
67. ——— 1875. On the Date of the Glacial Period. Vol. 7.
68. ROBSON, C. H., 1876. Moa-remains at Cape Campbell. Vol. 8.
69. SMITH, S. P., 1877. Northern Portion of Hawke's Bay. Vol. 9.
70. STEWART, J., 1878. Waikato District. Vol. 10.
71. PETRIE, D., 1881. Visit to Stewart Island. Vol. 13.
72. SMITH, S. P., 1881. Coast-line in the Northern Part of the North Island. *Ibid.*
73. HUNTER, A., 1884. Waikato District. Vol. 16.
74. HILL, H., 1888. Artesian Basin of Hawke's Bay. Vol. 20.
75. CUSSEN, L., 1889. Waikato River Basins. Vol. 21.
76. HILL, H., 1890. Napier-Ruapehu District. Vol. 22.
77. ——— 1893. Artesian Wells, Wanganui. Vol. 25.
78. CUSSEN, L., 1894. Piako and Waikato River Basins. Vol. 26.
79. MAXWELL, C. F., 1897. Changes in Coast-line of the North Island. Vol. 29.
80. HUTCHINSON, F., 1898. Maori Middens at Wainui Beach, Poverty Bay. Vol. 30.
81. MARCHBANKS, J., 1899. Artesian Wells at Longburn, Palmerston North. Vol. 31.
82. STEWART, J. T., 1902. Artesian Well at Aramoho, Wanganui. Vol. 34.
83. MULGAN, E. K., 1904. The Northern Wairoa. Vol. 36.
84. HILL, H., 1905. Artesian Basin of Heretaunga Plain, Hawke's Bay. Vol. 37.
85. SPEIGHT, R., 1908. Terrace Development of Canterbury Rivers. Vol. 40.
86. HILL, H., 1909. Artesian Wells in Poverty Bay. Vol. 41.
87. BELL, J. M., and CLARKE, E. DE C., 1910. Northernmost New Zealand. Vol. 42.
88. SPEIGHT, R., 1911. Christchurch Artesian Area. Vol. 43.
89. ADKIN, G. L., 1911. History of Ohau River, Manawatu. *Ibid.*
90. ASTON, B. C., 1912. Raised Beaches at Cape Turakirae. Vol. 44.
91. SPEIGHT, R., 1922. Lower Waipara Gorge. *Ibid.*
92. COTTON, C. A., 1912. Wellington Physiography. *Ibid.*
93. ——— 1913. Tuamarina Valley. Vol. 45.
94. ——— 1914. Uplifted East Coast of Marlborough. Vol. 46.
95. BARTRUM, J. A., 1914. Westport-Charleston High-level Terraces. *Ibid.*
96. HETHERINGTON, J. R., 1915. Boring at Horotiu, Waikato. Vol. 47.
97. SPEIGHT, R., 1917. Banks Peninsula. Vol. 49.
98. THOMSON, J. A., 1917. The Hawera Series. *Ibid.*
99. SPEIGHT, R., and WILD, L. J., 1918. Weka Pass Stone and Amuri Limestone. Vol. 50.
100. UTTLEY, G. H., 1918. Oamaru-Papakaio District. *Ibid.*

101. ADKIN, G. L., 1919. Horowhenua Coastal Plain. Vol. 51.
102. ——— 1920. Taranua Drainage. Vol. 52.
103. MORGAN, P. G., 1921. Patea District. Vol. 53.
104. COTTON, C. A., 1921. Warped Land-surface, Port Nicholson. *Ibid.*
105. GRANGE, L. I., 1921. Green Island Coalfield. *Ibid.*
106. ADKIN, G. L., 1921. Porirua Harbour. *Ibid.*
107. GILBERT, M. J., 1921. Waikato Heads District. *Ibid.*

Miscellaneous Publications.

108. VON HAAST, J., 1861. *Report of a Topographical and Geological Exploration of the Western Districts of the Nelson Province, New Zealand.*
109. HECTOR, J., 1863. Geological Expedition to the West Coast of Otago, New Zealand, *Otago Provincial Gazette*, vol. 6.
110. VON HAAST, J., 1864. *Report on the Formation of the Canterbury Plains.*
111. VON HOCHSTETTER, F., 1867. *New Zealand.*
112. HUTTON, F. W., and ULRICH, G. H. F., 1875. *Report on the Geology and Goldfields of Otago.*
113. VON HAAST, J., 1879. *Geology of the Provinces of Canterbury and Westland, New Zealand.*
114. HUTTON, F. W., 1885. Sketch of the Geology of New Zealand, *Quart. Jour. Geol. Soc.*, vol. 41.
115. MARSHALL, P., 1906. The Geology of Dunedin, New Zealand, *Quart. Jour. Geol. Soc.*, vol. 62.
116. PARK, J., 1910. *The Geology of New Zealand.*
117. THOMPSON, J. B., 1910. Drainage Operations in Hauraki Plains. C-8 (Parliamentary Paper).
118. MARSHALL, P., 1912. *New Zealand and Adjacent Islands.*
119. ——— 1912. *Geology of New Zealand.*

Evidences of Pleistocene Glaciation at Abbotsford, near Dunedin.

By Professor JAMES PARK, F.G.S., F.N.Z.Inst., Dean of the Faculty of Mining at Otago University.

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In an excellent thesis* on "The General and Economic Geology of Green Island Coalfield," Mr. L. I. Grange, M.Sc., A.O.S.M., briefly discusses the origin of certain clayey boulder-beds at Abbotsford, a few miles south of Dunedin. Referring to the published views of different observers, including my own,† he says, "The presence at Abbotsford of well-rounded boulders consisting of dolerite, basalt, trachydolerite, and rarely phonolite rocks at the base, all of local origin, is very damaging to the idea of classing the deposit as a boulder-clay. Had the beds a glacial origin boulders of schist would naturally occur, since that rock outcrops at no great distance from the clay."

The aforesaid boulder-clay formation occupies the floor and slopes of the Abbotsford basin. From about 100 ft. above the sea it rises gently northward to a height of 475 ft. Generally it ranges from a few feet to 40 ft. thick, and rests unconformably on the denuded surface of the Tertiary greensands, Burnside marl, and drab-coloured sandstone underlying the marl. The character of the deposit changes with astonishing rapidity from blue clay with boulders to a yellowish-brown clay and rock-rubble.

The base of the deposit is generally a stiff blue clay that contains widely scattered boulders. In places the clay is streaked or intercalated with

* *Trans. N.Z. Inst.*, vol. 53, pp. 157-74.

† The Great Ice Age of New Zealand, *Trans. N.Z. Inst.*, vol. 42, pp. 580-612.