Tectonic Features in a Coastal Setting at Wellington

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Abstract

The district here described includes and surrounds the city of Wellington. In addition to major relief related in origin to the transcurrent Wellington Fault and the large and deeply downwarped Port Nicholson (or Wellington Harbour) and shallower but equally extensive Porirua Harbour tectonic basins, a pattern of smaller tectonic blocks and related forms is now recognized in the relief of the district. The shapes and outlines of these blocks largely control the pattern of drainage, which must, therefore, be described as mainly consequent.

The tectonic pattern is made definite by partial preservation of a "key" land surface, which gives blocks and associated arches recognizable form. The development of this key surface, now referred to as the K Surface, is probably attributable to erosion that followed, rather than that which preceded, the Tertiary orogenic disturbance generally known as the Kaikoura Orogeny.

Early formed blocks and arched surfaces produced by the deformation of the K Surface are now considerably dissected; but intermittent earth movement, especially on or closely parallel to the line of the Wellington Fault, has continued until very recently, and must indeed be considered active still. All stages of this diastrophism must have been associated with the development of the south Wellington coast of transverse deformation, of which Port Nicholson and Palliser Bay are major features, and they are possibly secondary effects of transcurrent drift along the line of the Wellington Fault.

CONTENTS

INTRODUCTION

GENERAL ACCOUNT OF THE MORPHOLOGY
- Cycles and Drainage
  - The Port Nicholson Basin
  - Benched Spurs in the Port Nicholson Basin
  - The Wellington Coast of Transverse Deformation.
  - The Porirua Harbour Basin.
  - The Hutt Valley
  - The Pukerua Corridor
  - The Wellington Fault

THE TERMINAL PENEPLAIN OR K SURFACE

FORM AND TECTONICS IN RELATION TO THE K SURFACE
- A Landscape of Tilted Blocks
- Coastal as Well as Landscape Features Consequent on Deformation of the K Surface
  - The Waiariki Lineament
  - Dissected Domes Near the South Coast
  - The Consequent Karori Valley
  - Origin of the Fault-guided Waiariki Stream

PROLONGED BUT DISCONTINUOUS DIASTROPHISM
- Trends of Faulting
- North-east and NNE-trending Lineament Furrows

DATE OF ORIGIN OF THE TECTONIC RELIEF

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REFERENCES

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THE key to the interpretation of the Wellington landscape is recognition of the importance of an erosion surface that truncates some of its highest parts with the appearance of a terminal or summit peneplain, together with further recognition that this terminal surface, though in places it has been destroyed by re-dissection, is widely present also at lower altitudes because it has been warped and dislocated. With the help of this key it becomes possible to recognize an important early stage of deformation and the prevalence of a tectonic relief due to this, which has hitherto been largely overlooked. Thus the predominant features in large parts of the landscape are a rather heterogeneous jumble of forms produced by a somewhat disorderly diastrophism that began probably in early or middle Pleistocene times. Related to this in some way, while apparently distinct from marine terrace-making upheavals that also followed, is a later diastrophism, the products of which are some larger tectonic forms that have been long recognized as such. There are signs of yet another, though as yet milder, spasm of continuing activity.

A study such as this would grow to an inordinate length if an attempt were made to substantiate the above statements by describing the smaller units of relief throughout the whole area; but it is possible thus to examine the western part of the Wellington Peninsula, this being selected as displaying examples of various kinds of landform developed. (Wellington Peninsula is a name commonly applied by geographers and geologists to all the land west of Port Nicholson.) A brief survey will be presented first, however, of present knowledge of the morphology of the whole district based on earlier descriptions by the writer supplemented by more recent field study and scrutiny of vertical photographs and incorporating recent observations by Stevens and others. The area that will be described (Fig. 1) is covered by the topographic map 1:63360, sheets N160, N164, and N161 (western part). This map, though useful for location and for altitudes, affords less help than might be expected. Because of the small scale, it naturally fails to show with any approach to accuracy the details of an extremely fine-textured erosional relief; and partly for the same reason, though in part also because of an assumption on the part of the cartographer that the stream pattern must be dendritic, which obscures evidence of control by faults, the mapping of stream courses is very sketchy, especially on sheet N160. It is not only in New Zealand, however, that the topographic maps fail to help with geomorphological research. In France André Meynier complains of "la carte trop souvent médiocre" (Norois, 7, 1955, p. 436).
GENERAL ACCOUNT OF THE MORPHOLOGY

Sous la pression des faits [le naturaliste] doit être prêt, à chaque instant, à se renier et à lancer en avant de nouvelles théories pionnières.

P. BROT, 1955, p. 163.

Cycles and Drainage

In his account of the Wellington landscape Bell (1910) suggested, though without citation of supporting evidence, that a number of the features in this district with NNE elongation were determined by faults; but in descriptions by the present writer (Cotton, 1912a = 1955, pp. 1–8; 1912b = 1955, pp. 9–37) it was pointed out that this elongation coincided roughly with the general direction of strike in the deformed greywacke rocks of the terrain; and a theory was, therefore, proposed that such features were of subsequent erosional origin. Later the opinion gained ground that fault zones with similar strike—whether these originated in the period of major deformation of the greywacke strata or at some later time—had guided subsequent erosion (Broadgate, 1916; Gage, 1940; Hall, 1946). Such theories of subsequent origin, always consistently opposed by Adkin (1919, p. 291), are now discredited, at any rate in their widest application; and a hypothesis of tectonic origin of many features, including most of those with NNE elongation, is here adopted, which has already been suggested from time to time (Cotton, 1938, p. 6; 1953a, p. 6; 1955, pp. 4, 14, 15; Cotton and Te Punga, 1955, pp. 1008, 1017). Notwithstanding that the theory of subsequent valley erosion has been overworked, it is well established that there are in the terrain large lenses of little-jointed and therefore not deeply weathered greywacke that are resistant both to stream erosion and to slow degradation; on their outcrops are some high summits (Cotton, 1912b; 1955, p. 10) and the best preserved relics of a terminal peneplain (Cotton and Te Punga, 1955, pp. 1008, 1017).

In addition to the well-known Wellington Fault (Cotton, 1912b; 1955, pp. 18, 19), which cuts diagonally across the whole district (Fig. 1), the existence of other considerable faults was mentioned by McKay (1892) and by Bell (1910) and was more definitely indicated by Quennell (1938), and also by Adkin (1949, Fig. 1; 1954, p. 505) especially for the area north of Porirua Harbour, which the latter author includes in his "Wellington Peninsula geomorphic province". Stevens has, moreover, recently reported an elaborate network of faults that are expressed in forms of the land surface in the Hutt Valley area (Stevens, 1955, pp. 100–28; 1957a).

The discovery of some faults and the obvious probability of the presence of many others throughout the district (p. 777), faults that dislocate not only the underlying rocks but also the land surface, have thrown grave doubts on the validity of the theory of extensive development of subsequent relief. Failing this solution of the problem, the appearance of near coincidence of the elongation of both positive and negative landforms with the strike of strata in the greywackes and of the old folds must be explained as a result of control of more modern fault trends in some way by the pre-existing structure, notwithstanding the post-orogenic cratonization of the old rocks.

The obsolescent theory of dominance of subsequent forms of relief is bound up with one of polycyclic development. It has been thought that a number of cycles are recognizable. Quennell (1938) has more than suspected extensive partial planation at various successively lower levels by subaerial processes; but the cyclic theory as originally proposed (Cotton, 1912b = 1955, pp. 9–37) demanded development as far as senescence in only one cycle—a first, or "Kaukau" cycle. Forms attributable to later cycles were merely berms inset in the depressions that were either, as has been supposed, erosionally excavated by subsequent rivers or, as now seems probable at least in the majority of cases, tectonically lowered (relatively) so that they are now below the level of other parts of the terminal, or Kaukau, "peneplain", or K Surface (Photo 4), as it is convenient to call it (p. 775). Forms due to some such later polycyclic erosion in parts of the district, notably in the widely open
Makara Valley and in the Porirua Harbour basin, are developed only locally, so that correlation of those in one area with those in another is uncertain, as also are any attempts to correlate apparently cyclic river terraces with marine terraces—except with those on coasts in their immediate vicinity. The possibility of the correlation of berms throughout the district with the lower and broader of two marine terraces at Tongue Point (Photo 9) was implied, however, in the designation “Tongue Point cycle” (Cotton, 1912b) that remained in general use for many years (cf. Gage, 1940) for valley floors, berms, and terraces in various parts of the district. Such forms, however, are now relegated to less positively defined “intermediate cycles” (Cotton, 1955, p. 16) referable to episodes between a (Kaukau) period of penepalination and the present and to base-levels that are intermediate but may now vary in altitude from place to place because of irregular warping.

One of the most striking features of Wellington morphology is the great sea-filled basin of Port Nicholson (Fig. 1; Photos 1–3), bounded as it is by an imposing and unmistakable fault scarp along its NW side (Photos 1, 3), but with all other outlines such as to indicate extensive drowning (Photo 1) of a maturely dissected land surface so disposed around it as to suggest broad synclinal downwarping (Cotton, 1912b; 1921a = 1955, pp. 226–48; 1942, p. 54). The result of this deformation has been the insertion in the coastline of a great lake-like embayment of almost unique character that lies between relatively upheaved stretches of the south coast of Wellington. Along parts of this coast flights of marine terraces testify to tectonic emergence, though most of the uplift had taken place prior to the basining of Port Nicholson (Cotton, 1921a; King, 1930). Some emergence of the coasts bordered by terraces may, however, have been due to, or contemporaneous with, the warping, or “folding”, that has basined and partly drowned the adjacent coast (in and around Port Nicholson), there carrying marine terraces down below the present sea-level (Cotton, 1951b, Fig. 2; 1952b, Fig. 4).

As a result of such warping a single marine terrace would originate that would be of the same age as the adjoining embayment made by local drowning. Actually, however, there are usually two terraces or more—at one place immediately east of Port Nicholson there are many (Photo 2)—and the more continuous at least of these are so nearly parallel to one another (Cotton, 1921a; King, 1930) that though all are tilted down endwise towards the axis of the basin the upheavals forming and raising all the higher terraces had obviously taken place before the transverse warping. Very little warping took place, that is to say, during the long terrace-making period of intermittent upheaval prior to the cutting by marine erosion of the platform that has become the lowest terrace of the tilted flight.

The drowning of Port Nicholson referred to here has been independent of glacio-eustatic fluctuations of ocean level, and it seems certain that it must have preceded some of the largest of these, for soliflual debris dating from the last and possibly some earlier periglacial episodes has been traced to depths below present sea-level in the Hutt Valley arm of the basin (Stevens, 1957b, p. 294). Actual details of the shoreline pattern are, on the other hand, referable to drowning due to the postglacial (i.e., Flandrian) positive movement of sea-level.

Though down-tilting of the land surrounding the basin is to some extent centripetal—i.e., a true basining—the whole feature, including Port Nicholson and its NE extension (filled with alluvium) up the Hutt Valley, is more synclinal in form; and the Wellington Peninsula to the west and the Rimutaka Range to the east are anticlinal. It is of some importance, however, to distinguish the broad warping thus indicated from more acute though localized deformation anterior to it—or largely anterior—that has produced the tectonic ridges already mentioned. It is highly probable that much of the land submerged under and some of that immediately surrounding Port Nicholson, together with that north of it in the Porirua Harbour basin, was already comparatively low-lying prior to the occurrence of the paroxysm
of deformation that deeply drowned Port Nicholson; and presumably such land assumed that attitude in the earlier deformation in which much ridge-and-valley relief in other parts of the district was initiated. It is such relief, profoundly modified and so subdued by erosion that its tectonic origin is obscure, especially where it is now partly submerged, that is seen on the sides of drowned valleys and on embayed ridges (including a former island now land-tied) between the central, deeper part of Port Nicholson and the ocean (Photo 1).

**Benched Spurs in the Port Nicholson Basin**

Benches on spurs are described by Stevens (1957a) at roughly accordant, rather high levels (at about 30, 45, and 75 m) at scattered places around Port Nicholson (and also within it—at Somes Island), which he tentatively regards as traces of shorelines. The benches may mark eustatic levels, a possibility envisaged by Stevens; but it seems probable, in view of the past and present mobility of this part of the district, that the shoreline relics, if they are such, were raised by upheavals of the land, upheavals which might be nearly uniform over a considerable area, like that of 1855 and a similar one reported by Stevens (1956a) as occurring a little earlier.

A pattern of benchings due to upheavals may be complicated by the effects of eustatic lowerings of interglacial sea-levels from age to age during the late Pleistocene, just as the vertical intervals in a eustatic flight of terraces would be exaggerated by recurring vertical movement of the land whether continuous or intermittent. If it were intermittent, which seems the more likely to correspond with reality, the exaggeration of vertical intervals would be irregular and unpredictable. Because of longer time available, however, benching would be most marked when considerable time intervals between upheavals happened to coincide with interglacial ages. The Porirua Harbour basin (pp. 767–8) having been to all appearance much more stable—perhaps not affected at all by vertical movement—in the later Pleistocene, it is possible that benches there, such as are reported by Te Punga (1954) and by Leamy (1956), mark eustatic highs of ocean level; but in the Port Nicholson basin correlation with eustatic shoreline levels in other parts of the world seems less likely.

If the Port Nicholson benched spurs be indeed regarded as the work of marine erosion, one is obliged to seek an explanation why traces are not recognizable of more continuous shoreline features preserved as "parallel roads". If such have existed in the past they must have been obliterated by periglacial solifluxion on the harbourside slopes.

Correlative features that may be looked for in minor valleys include beaches and deeper-water deposits of marine silt and shells in the drowned-valley bays between benched spurs, with also built terraces consisting in part of alluvium bordering valleys leading into the bays. If there are any such they are either developed so imperfectly that they have as yet escaped observation or they also have been destroyed and/or buried by solifluxion and/or accumulation of solifluous debris.

Though the outer coast is strongly terraced by marine erosion, no benches have been found on it that can be correlated with the shorelines presumably indicated by the benched spurs within Port Nicholson. These ought to be distinctive if they have survived, for, remaining approximately horizontal, they must obliquely intersect at least the lowest of the well-known down-stepping flight of endwise-tilted marine terraces (Fig. 2; *cf.* Cotton, 1955, Fig. 3, p. 235). If ever present, they must therefore have since been cut away by coastal erosion, just as terraces of every kind and age have been eliminated from some stretches of neighbouring coasts. Even allowing for such destruction in many places it is difficult to understand the absence of even a few relics of horizontal terraces intersecting the Baring Head tilted terrace where it survives at a low level, descending to about 30 m altitude at its NW end (Cotton, 1921a; 1955, p. 234) (Fig. 2, B, T₁).

The recently emerged coastal plain covered with raised beaches of cobbles and boulders at the mouths of the Wainui-o-mata and Orongorongo rivers (Photo 2)
is an example of a new horizontal terrace in the making—i.e., not yet cliffed at the margin. The writer (Cotton, 1921a; 1955, p. 247) has commented on the difficulty of correlating this very young feature (and its continuation, now cut back in places to a low terrace, along the west side of Palliser Bay) with anything in Port Nicholson or on the coast farther west.

If it be assumed that the high benches on Port Nicholson spurs reported by Stevens mark shorelines and, further, that these are raised rather than, or as well as, eustatic, it would seem that the movement of intermittent broad upheaval that has affected the range to the east and to a smaller extent the peninsula to the west (so that the basin itself could hardly escape it) for perhaps hundreds of thousands of years (in the period of formation of the marine terraces that have since been tilted) was not terminated but merely interrupted by the great down-warping that gave the basin its present characteristics. Its latest manifestations are found not only in the very recently emerged coastal plain already mentioned on the outer coast, but also, both within and without Port Nicholson, in the small uniform emergences of historic and late prehistoric times (Stevens, 1956a). Perhaps the immediate cause of the persistent and more general upheaval, which may be compression, is distinct from that which earlier caused the block deformation of the K Surface and later the local basing of Port Nicholson (p. 772).

Taking a very long view (over thousands of years) it seems inevitable, if there is anything in this theory of persistent upheaval, that, notwithstanding the writer's earlier optimistic short-range forecast (1921b; 1955, pp. 223–4), Wellington's fine harbour is doomed eventually to be shallowed to a serious extent if not drained quite dry—that is to say, unless the melting of ice sheets now in progress continues and raises the level of the ocean sufficiently to neutralize the effect of upheaval of the land. To look at this threat in another way, indeed, the Wellington of the distant future, though it may suffer from many earthquakes (cf. Lensen, Stevens, and Wellman, 1956), stands a chance of being one of the few coastal towns not drowned out of existence. Such long-range speculation depends, however, on the assumption that the ocean level will continue to rise; but it may, on the other hand, sink, for refrigeration of the whole earth may set in, robbing the ocean of water to pile up glacier ice. (Emiliani, 1955, predicts another glacial age in about 10,000 years.)
As much time must be allowed for the upheavals postulated as occurring since Port Nicholson has been in existence and also for the obliteration of the various hypothetical features correlative with spur benches, a problem is thus posed as to the date of the main downwarping. It can be granted that that basing, though it took place in the later phase of Wellington diastrophism, since it was of later date than the coastal terracing, which went on subsequently to the first strong deformation, was not postglacial as the writer suggested some years ago (Cotton, 1951b; 1952b). Though no more than another suggestion can be made as to the actual date of downwarping, the question will come up again later (p. 773).

**The Wellington Coast of Transverse Deformation**

The tectonic history of the Wellington district is bound up with that of the whole southern end of the North Island. To the east lies the great synclinal southern end of the Wairarapa Valley, of generally similar origin to the Port Nicholson basin and still in a state of active tectonic development as late as 1855 (Lyell, 1868, Vol. 2, p. 82) and even later. The Wairarapa Valley is open at the south end to the ocean between the Rimutaka and Haurangi ranges, both actively anticlinal, forming Palliser Bay, an analogue of Port Nicholson though larger and not constricted seaward as Port Nicholson is. Anticlinal upwarping has thus made broad promontories and the sea has entered and embayed synclines, so that the coast is a standard example of a “coast of transverse deformation” (Cotton, 1942; 1951b; 1952b).

**The Porirua Harbour Basin**

Because of the presence of Porirua Harbour indenting the NW coast of Wellington between stretches of bold coast that appear to be upheaved, the question may arise whether this coast also must be classed as one of transverse deformation. The writer’s hypothesis that deformation of the land on a large scale took place in postglacial times being now abandoned, such classification seems inappropriate. It is necessary also to discard an explanation (based on the same hypothesis) which was applied to some stretches of coast that fail to show effects of drowning attributable to the postglacial rise of ocean level. One of these is south of Porirua Harbour, at the mouth of Makara River. It was confidently suggested that here, and probably at some other places, the rise of ocean level was neutralized by a contemporaneous local uprise of the land. Such a theory is obviously untenable in this case, and is, indeed, quite unnecessary. The true explanation of the “undrowned” Makara river mouth must be much simpler; it seems to be that, whatever erosion was in progress farther seaward in the extended course of the Makara Stream on a temporarily emergent coastal plain during the Würmian age of lowered base-level, either the age was so short or, more probably, the ratio of graded stream gradient to coastal-plain slope was such, that intrenchment failed to extend headward into the Makara valley. This must, indeed, have been the state of affairs at many, if not most, small river mouths (Cotton, 1951c, Fig. 4).

The partial drowning that has taken place at Porirua Harbour of a landscape of rather small relief, allowing the sea to penetrate a considerable distance inland, can be the result merely of the postglacial shift of ocean level. There has, therefore, been no suggestion of postglacial downwarping to account for any feature in that vicinity, and a neutral axis through the Porirua Harbour basin has had indeed to be postulated. Not only is there no evidence of postglacial warping, that is to say, but the area seems to have been stable during the diastrophism, not postglacial but older and of uncertain date, that finally basined Port Nicholson. The warping that produced the very broad Porirua Harbour basin was thus of considerably greater antiquity; it was quite probably more or less contemporaneous with an earlier ridge-and-valley-making diastrophism that uptilted blocks in other parts of the
district, perhaps the first paroxysm to break up and warp the K Surface. This surface, not very much modified by post-Kaukau erosion, is warped down into the basin from nearly all sides. It may be seen, for example, in the centre of Photo 5; farther seaward it appears to arch over the land between Porirua Harbour and Cook Strait (at the maximum altitude of 100 m); and it seems then to dip down to and below sea-level, only to appear again, however, on Mana Island (Photo 6), 3 km seaward, at an average altitude of 125 m. The branching Porirua Harbour embayments (Photo 5) are minor corrugations of the surface, which have not been to any great extent enlarged by erosional valley development.

Adkin (1951) regards the Porirua Harbour basin as a branch of the Port Nicholson basin and implies that the two were formed at the same time. This must be in part correct, but it must not be taken to mean that there was any strong deformation in the Porirua Harbour area as late as the last, and apparently the main, downwarping of Port Nicholson. Rather it appears that an ancestral but shallow Port Nicholson basin was formed along with the Porirua Harbour basin in the first, or at least an early, phase of the deformation of the K Surface. Adkin (1951, Fig. 4, p. 171) figures as the "Port Nicholson–Porirua sunkland" a depressed strip bordered by "monoclinical flexures," which includes the western parts only of the Port Nicholson and Porirua Harbour basins and might be equally well defined as a tectonic corridor connecting them (Fig. 1; Photo 3). Beyond the Porirua Harbour basin a corridor continues the "sunkland" NE-ward as far as the shore of Cook Strait at Pukerua Bay—a gap that will be referred to (infra) as the Pukerua corridor.

In the account given by Adkin (1951, p. 172) of the "sunkland," it is implied that differences between the Port Nicholson and Porirua Harbour basins, supposing them to have been formed at the same time, are due to the position of the Wellington Fault, which has let down the Port Nicholson area to a lower level. Consistently with the idea of subsidence implied in the use of the description "sunkland," Adkin regards all the associated faults, the Wellington Fault included, as "normal" (p. 772).

The Hutt Valley

The primitive shallow basin must have extended, or branched, also in a NE direction up the Hutt Valley (Cotton, 1948, Fig. 255), on the NW flank of which upraised block features are still conspicuous (Stevens, 1957a, Fig. 21); and a consequent Hutt River seems to have been in existence, fed by tributaries and developing a sequential valley, a valley that has been tectonically deepened again later into a more pronounced fault angle as activity of the Wellington Fault has continued (cf. Cotton, 1952a, Fig. 176).

Though the K Surface slopes down from various directions into the Porirua Harbour basin, this basin is flanked also in some places by fault-bounded blocks, and a complex of these forms a broad ridge that separates the basin from the Hutt Valley (Photo 4; see also Cotton and Te Punga, 1955, Fig. 3; Stevens, 1957a, Fig. 13). The Haywards–Pauatahanui pass between the basin and valley is a tectonic corridor through this divide. Immediately NE of the corridor are some high blocks, and beyond these (northward) still higher blocks form foothills of the Tararua Range (Photo 3, distant skyline).

The Pukerua Corridor

North of the Porirua Harbour basin there is a complex of upland blocks, but west of these a broad and low tectonic gap or corridor (here called the Pukerua corridor) connects the basin with the coast of Cook Strait at Pukerua Bay (Photo 7). Northwestward from the blocks mentioned above the K Surface descends, though somewhat unevenly, towards the axis of the corridor; and on its NW side the corridor is separated from Cook Strait by a narrow block which may be referred to as the
Pukerua ridge (Fig. 4, inset map). This ridge, which is strongly cliffed on the seaward side and has on the top, at about 225 m, an imperfectly preserved remnant of the K Surface, presents towards the corridor a straight but dissected scarp that very probably originated long ago as a fault scarp (Fig. 3).

Fig 3 — Suggested stages in the development of the SE slope of the Pukerua ridge, explained as stages in the degradational history of a tectonic scarp that was produced in an episode of deformation by faulting. The succession shown is hypothetical and tentative, pedimentation might begin earlier—i.e., might not be delayed until after normal processes have degraded the scarp to late maturity.

In front of this scarp is a submaturely dissected ramp, or belt of flat interfluves, at about 100 m, sloping from the base of the scarp SE-ward into the corridor (Photo 6); it might be taken for a lowlying strip of K Surface, but seems more probably to have originated as a pediment. Not only does it lie with such an inclination and general attitude in relation to the scarp behind it as to suggest this diagnosis very strongly, but also it is overspread with a veneer of somewhat angular fanglomeratic gravel. The present-day scarp may have been developed by backwearing of a fault scarp originally bounding the Pukerua ridge, and it is possible that such scarp retreat took place as a result of pedimentation in a hot and semi-arid climatic episode, perhaps of no great length. The pedimentation hypothesis gains some support from the sharp southward swing of streams debouching near the south end of the scarp (Fig. 4), which seem, when betrunken by marine erosion, to have intrenched themselves in courses they were following down southern lateral radii of rock fans.¹ The pediment-like feature and its fanglomeratic cover are fringed by and in part buried under thick aeolian sands which must have been blown up into and through the Pukerua corridor from a coastal lowland farther north, with little doubt at a time when the sea had withdrawn to a low level and a cold-desert or periglacial climate prevailed. (These sands were misinterpreted by Hall, 1947, as marine sediments.) Finer loess-like aeolian silts (since weathered to clay) that are probably from the same source, but farther carried, bury parts of the K Surface, or of surfaces of small

¹ An alternative though not convincing explanation that has been suggested for the southward-swinging streams is that they have been diverted by transcurrent faulting.
Fig. 4.—A hypothetical stage of development showing the first fixation of southwardly swinging streams from the scarp of the Pukerua ridge explained as an effect due to marine-cliff encroachment on a pediment made up of rock fans. Vertical incision produced by erosion stimulated by shortening of the course causes the fixation of streams in previously shifting courses that have casually turned southward down lateral radii of the fans.

relief derived from the K Surface, especially in the Porirua Harbour basin. If a pediment developed along the base of the Pukerua scarp in part of the long Mindel-Riss (Yarmouth) interglacial age, as may be suggested though only quite tentatively, then the aeolian cover above it may be attributed to a later glacial age or ages.

The Wellington Fault

The most prominent features of Wellington relief are developed in relation to the great fault that stretches from SW to NE across the Wellington Peninsula (Fig. 1 and Photo 3). Throughout much of its length this is expressed at the surface by a well-preserved fault scarp that descends below sea-level and bounds the Port Nicholson basin and its NE extension the Hutt Valley, with a length of about 30 km. It has been named the Wellington Fault (Gotton, 1912b = 1955, pp. 26–30; 1914 = 1955, pp. 91–96).

That this is a major plane, or zone, of dislocation is proved by a very thorough shattering, even comminution, of the rocks, as seen in many road cuttings and other

Fig. 5.—South-west part of the Wellington Fault trace. A: locality of shutter ridges that prove recent transcurrent movement. B: development of shutter ridges. (From the N.Z. Geographer.)
PHOTO 1.—The Port Nicholson tectonic basin and Wellington Fault scarp, viewed from south.

PHOTO 2.—Marine terraces at Baring Head, tilted down towards the axis of the Port Nicholson basin. The highest terrace (on the ridge between the nearer and farther river valleys—Orongorongo and Wainui-o-mata) is at an altitude of about 350 m. On the distant skyline tectonic blocks NW of the basin are seen in profile. In the foreground, east of Baring Head, is a recently emerged strip of coastal plain carrying raised beaches.

Facing page 770.
Photo 3.—The Wellington Fault furrow and scarp (cf. Figs. 1, 5), Port Nicholson, and (rear centre) the corridor, or "sunkland," branching northward into the Porirua Harbour basin. A trailing pattern of streams tributary to Silver Stream (in the lineament furrow) is seen in the left foreground and supports a theory of prolonged transcurrent drift and distributed faulting.

Lineaments parallel to the main fault are seen also, notching the spurs between these.

Photo 4.—View looking east across K Surface remnants (altitude 400 and 440 m) on the divide between the Porirua Harbour basin and the Hutt Valley. Beyond these is the Upper Hutt Valley, where the K Surface is warped down.
Photo 5.—View eastward over the down-warped Porirua Harbour basin. Beyond it are tectonic blocks. The latest drowning is due to the Flandrian transgression. The K Surface is seen on the ridge in the foreground.

Photo 6.—View looking S.W. over the Pukerua corridor and "pediment", Pukerua tectonic ridge, and Mana Island.

Photo 7.—View looking north across the Porirua Harbour basin, showing the Pukerua corridor branching northward from it.
**Photo 8.** View looking north across the western part of the Wellington Peninsula (*cf.* Fig. 7). Rectilinear Waiariki valley at right; dissected dome of upheaval at left; fault-angle valleys at left rear; large level remnant of K Surface at right rear.

**Photo 9.** View looking west along the south coast of Wellington Peninsula, showing a synclinal sag, in the axis of which is the Karori valley, between distant and foreground highs. The Tongue Point marine terrace, at left, is just beyond the mouth of Karori Stream.
Photo 10.—View looking south down the winding lower reaches of the Karori valley (cf. Fig. 7) from a point above the low Makara-Karori migrating divide. On summits at the right are small relics of the K Surface, which were reported by Gage (1940, p. 403).
Photo 11.—Eastern part of the Wellington Peninsula, showing Wellington Fault furrow (WF) and Owhiro rectilinear furrow (O). S: shutter ridges.
excavations, in a broad belt along the fault line. Discovery of well-marked shutter ridges (Cotton, 1951a) near the SW end of the surface trace of the fault (Fig. 5; Photo 11) has established activity at a date more recent than the very modern erosional development of a minor relief of spurs and gullies, which it dislocates. This late activity has been dextral transcurrent movement, and probably similar movement has been going on, though slip is intermittent, for a very long time. This may be distributed throughout a zone, as is strongly suggested by parallel lineaments and the "trailing" pattern of streams tributary to Silver Stream (which here occupies the fault furrow) on its SE side (Fig. 5A and Photo 3; cf. Cotton, 1950, Fig. 24). More or less continuous scarplets, however, along the surface trace of the fault (in the Silver Stream Valley), which are seen in vertical photographs (Photo 11), indicate also renewed faulting with upheaval along parts of the NW side—i.e., continued up-growth of a fault scarp. These features are described in some detail in a paper by Lensen (1957) now in the press.

In the upper Hutt Valley there are indications of the recent continuance of lateral movement either on the Wellington Fault itself (Lensen, 1957) or on a closely parallel line which Adkin (1951, Fig. 4) calls the Kaitoke Fault.

Strong confirmation of a long history of transcurrent drift is afforded also by a discovery made by Stevens (1955, pp. 100-28) on the upland NW of and descending to the fault and its actual scarp along the side of the Hutt Valley. Here a strain pattern affecting a wide zone that borders the line of transcurrent movement has been traced by mapping the orientations of numerous small faults indicated by minor valleys and spur features, some of them probably consequent on faulting, though Stevens has diagnosed others as fault-line erosional forms (Fig. 6).

Though transcurrent drift may well be dominant, and is presumably deep-seated, the main effects of the Wellington Fault that are apparent in the morphology of the district result from the vertical (dip-slip) component of movement, which,
though the throw is variable, produces upthrow on the NW side. It may be suspected, moreover, that other faults of smaller aggregate displacement in the surrounding district, together with the movements of tectonic blocks bounded by these faults and also the warping that are expressed at the surface as domes and basins, have been produced by bucklings that are secondary effects of secular transcurrent drift along the line of the Wellington Fault. These may be compared with similar bucklings perhaps attributable to transcurrent movement on the Alpine Fault in southern Westland (Cotton, 1956a). As such faults must from their nature extend to a very great depth, it might be correct to regard such undulations as the superficial expression of *plis de fond*.

This theory is applicable perhaps to the large Port Nicholson and Porirua Harbour basins also, and it may afford a more acceptable explanation of the downwarping of Port Nicholson than either gravity subsidence accompanied by normal faulting on the line of the Wellington Fault, as assumed by Adkin (1951), or downfolding in compression, perhaps as a posthumous effect of the Kaikoura Orogeny, as first suggested by Broadgate (1916, p. 76). Though the fault involved here is probably not a fundamental geosuture, the movement along it is comparable to that postulated by Cloos (1948), and his experiments on the production of crustal deformation of the Rocky Mountain and Basin Range types by torsion developing over geosutures seem relevant to this problem.  

It is easiest, in general, to explain transcurrent movement on a very large scale by postulating that the deep-seated plane of faulting is vertical (*cf.* Hill and Dibblee, 1953, p. 445), though at the surface it may seem to be inclined as a result of secondary faulting, normal perhaps at some places and reverse at others. Great faults, however, of the same system to which this one seems to belong (McKay, 1892), mainly in the South Island—faults which also show some transcurrent movement (Wellman, 1953)—are high-angle thrusts (see Cotton, 1947, Fig. 1, p. 80).

The morphology of the scarp of the Wellington Fault where it borders Port Nicholson has been described long ago (Cotton, 1912a; 1912b), considerable emphasis being then placed on its appearance of youth. Attention was drawn in particular to hanging ravine mouths, which have been claimed, probably correctly, as proof of a recent revival of faulting on a minor scale, and to a (possibly overstressed) resemblance of the lines of cliff between the dissecting valleys and ravines to the classic facets of the Wasatch fault scarp, in Utah. Perhaps too much theory has been built up on the analogy, seeing that in this case the cliffs can neither be surviving segments of the fault surface nor of slopes derived from the fault surface.

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1 Li Sze-Kuang (J. S. Lee) remarks, in *Scientia Sinica*, 4 (1955), p 593: "Once a weakness of some consequence, for instance a large transcurrent fault, is created in a tract of land from whatever source, gravity will be ever ready to intervene. The chances then are vertical movement may take place along, and take advantage of, the fractures created in connection with movements other than the vertical faulting itself. . . . A local movement must be determined by a more general movement . . . ."

2 Since the above was written, an abstract has come to hand of a paper on "Wrench Fault Tectonics," by J. D. Moody and M. J. Hill, *Geol. Soc. Am. Bull.*, 66 (1955), pp. 1598–9. These authors conclude that: "Major wrench [transcurrent] faults which penetrate the earth's crust and which result in wholesale segmentation of the crust into polygonal blocks [cf. Cloos] may constitute the primary type of yielding in the crust." Though the Wellington Fault is unlikely to be a line of such primary yielding, being only one of a sheaf of similar faults which diverge from the Alpine Fault in a vergation (Wellman, 1955, p. 249), and thus perhaps secondary, it may yet be possible for local buckling. It seems probable that the Alpine Fault, on the other hand, is a true geosuture, so that transcurrent drift along that line is quite possibly the cause of major deformation—i.e., of the Kaikoura Orogeny. Hill and Dibblee (1953, p. 455) have hinted at a similar theory to account for the origin of the Coast Ranges of California, thus taking them "out of the defeatist category of a 'heterogeneous mobile belt'". *Postscript:* See also Cotton, 1956b.
by subaerial degradation (Cotton, 1950, p. 737). They have been retrograded somewhat by marine erosion (Hall, 1946; Stevens, 1955, pp. 92, 97); but the extent of cliff retreat (mistakenly assumed to be the cause of an embayment of considerable amplitude) has been overestimated by both these authors. Such retrogradation as has taken place seems insufficient to account wholly for the hanging ravines on the scarp, though it does explain why these do not all open at the same altitude. It is almost impossible to believe, indeed, that retrogradation resulting from exposure only to waves arising on the landlocked waters of Port Nicholson could take place rapidly enough so to outpace subaerial dissection as to betrunck streams and produce such conspicuously hanging ravines as these, while on other shores of Port Nicholson no comparable effects of marine erosion are seen.

The numerous hanging ravines seem rather to prove a somewhat recent recurrence of vertical displacement along this part of the fault line, which could well have been contemporaneous with the transcurrent movement and development of scarplets known to have occurred at other places on the same line of faulting. It seems quite possible that the most recent vertical movements (rejuvenating the scarp) have been merely the effects of minor buckling that has accompanied the recent transcurrent slip. Fault rejuvenation is particularly conspicuous on the inland continuation of the scarp SW-ward into the city of Wellington. Here, below the mouths of ravines that dissect its upper part, the scarp is a continuous wall, and it is highly improbable that this wall has been exposed very recently by erosion as a fault-line scarp, though this is practically the only alternative to renewed faulting, for retrogradation either marine or fluvial can scarcely have taken place there.

Though marine retrogradation of the scarp has necessarily been a slow process, it obviously has not, as Hall (1946, p. 428) claims, continued through the whole of post-Pliocene time, for this implies not only a tempo of marine erosion far too slow to be compatible with truncation of the ravines that are now hanging (in so far as these are thus explicable) but also an inadmissible fixity of ocean level throughout the Pleistocene. The duration of post-Flandrian time may perhaps be insufficient to account for the observed retreat, but some of this may date from a high stand of ocean level in an interglacial or interstadial age.

Fresh landslide scars near the NE end of the scarp bordering Port Nicholson (Cotton, 1941, Fig. 186) may testify to the youth of the whole feature and a late date of faulting, but only if they are to be interpreted as due to slumping during or very shortly after the formation of the scarp. As evidence in favour of that view engulfment of the landslide debris below sea-level might be cited, it being as though the slumping had occurred while the scarp was so new that it still had deep water in front of it.\footnote{This was the orally expressed opinion of the late Professor W. M. Davis when he observed these scars in 1914.} The scars, however, intersect—are newer than—some erosional features due to dissection, which makes it appear that the scarp had been long in existence before these landslides occurred. It is conceivable that the cause of slumping was a re-steepening by marine erosion that took place when sea-level was high, probably prior to the last glacial maximum; for the slumping could be dated towards the end of that glacial age, during which, sea-level being very low, the Hutt River might swing over and remove whatever sediments had previously accumulated along the base of the scarp at that place, thus making room for the landslide debris below the present sea-level. The under-water contours (mapped by Stevens, 1955) seem to indicate its presence at no great depth.

Subaerial development of the scarp to submaturity and a certain amount of erosional widening close to the mouths of the valleys (really ungraded gorges) of two of the streams debouching across it from the hinterland (the Kaiwharawhara and Ngauranga) furnish probably sufficient evidence of antiquity to discredit the writer’s former theory, which will be discussed further below, that dated the major
faulting and down-warping of Port Nicholson in postglacial time. One must suppose that these streams, which are large and very vigorous, have again deepened and even widening their valley-mouths since the comparatively recent renewal of vertical movement that has been described above. Even that, therefore, cannot be regarded as an event of yesterday; it may have taken place thousands of years ago.

The last major diastrophic paroxysm occurred subsequently to the rather long-continued stillstand proof of which is found in the great breadth of the lowest terrace on the outer coast; for the terrace is strongly warped as a result of the basining that has made Port Nicholson, so that it is now found at altitudes varying from 30 m to 200 m. The episode in which the terrace was cut, though not yet precisely dated, cannot be thought of as terminated by emergence of very late date. Its margin has been cliffed back perhaps one or two kilometres in rather resistant rocks, and this demands a considerable allowance of interglacial as well as postglacial time. When the writer advanced a suggestion contrary to this (Cotton, 1951b; 1952b, p. 61) he was grossly overestimating the duration of postglacial time. How far back in the latter part of the Pleistocene the great subsidence and the last significant scarp-making movement on the Wellington Fault took place has yet to be discovered. As a rough estimate Stevens (1957a, p. 323) has suggested middle to late Pleistocene as the date of origin of the Port Nicholson basin and Hutt Valley. It is clear that this event preceded the last glacial age at least, for not only has considerable blurring taken place of tectonic features that may well be of that date, but also drowned slopes on the SE side of the basin and valley are plastered with periglacial solifluxion debris (Stevens, 1956b, p. 224). Dating might perhaps be attempted by estimating how long it would take to shallow Port Nicholson to its present shallow depth (25 m and less, though there are no shallow banks of mud or sand). Much sediment is carried into it by the Hutt River, and, as Stevens (1956b, p. 229) shows, the Hutt River delta, in which the coarsest of the waste is retained, has grown rapidly to its present size in Flandrian and post-Flandrian times. The application of such a method becomes difficult, however, when eustatic fluctuations of ocean level must be allowed for.

The scarp of the Wellington Fault continues, as already mentioned, SW beyond Port Nicholson for 2 km along the base of hills facing Wellington (Photo 3; Cotton, 1952a, Figs. 178, 179) with almost wall-like form, though it is divided into facets above a basal portion that seems to have been rejuvenated recently by renewed faulting (p. 773). Far NE-ward also, where it borders the Hutt Valley, the scarp is only youthful dissected. It is trimmed back in places also by river erosion, but the presence of bedrock at shallow depth in front of the scarp (Stevens, 1957b, Fig. 15) may be due more to step faulting than to retrogradation. The wall-like form as compared with the dissected condition of scarps on apparently older faults seems to afford strong additional evidence in favour of recognizing two (i.e., at least two) quite separate major phases of diastrophism. The sharpness of contour of those scarps of a first generation has been softened not merely by solifluxion but also by an earlier subaerial degradation, and some of them apparently (as in the case of the scarp of the Pukerua ridge already described) have been freshened again, it would appear by erosional backwearing under climatic conditions different from those of to-day.

The Terminal Peneplain or K Surface

In the case of the better defined of the “blocks” of the Wellington Peninsula and adjoining districts the tectonic form is given shape and character by the survival on top of the block, or on its flank, of a terminal surface. This is either a peneplain (or other plain, or plane, of erosion) that was developed in the Kaukau cycle or it is derived from such a surface, having undergone changes that do not, however, wholly mask its original simplicity of form, as they do not involve deep dissection.
Some blocks so topped, flanked, or backed are "fronted" by dissected scarps that seem to mark the lines of faults, though it would be rash at the present stage of their investigation to exclude an alternative hypothesis of climatically controlled erosional backwearing from less steep tectonic scarps or slopes. Other, generally more broadly developed, tectonic landforms are of the nature of domes and basins that are recognizable to some extent by observation of change of altitude of the surface of the land from place to place—i.e., a very rough accordance of summit levels with an irregularly corrugated tectonic pattern. (For examples see p. 780.) In many places, however, the initial forms of such a pattern are indicated much more definitely by the more or less incomplete preservation of the regional "terminal" surface, inherited, or relict, from an earlier cycle, which is to be seen on the tops or flanks of the tectonic units of the corrugated surface. This surface thus affords a key to the initial tectonic form of the landscape.

Whether the surface was produced originally by peneplanation (downwearing of the land), by pediplanation (backwearing of scarps), or even by some other process such as marine erosion scarcely matters for the present purpose, which is to make use of it as a "key" surface. It truncates a complex of thick early Mesozoic and perhaps also Permian marine strata with submarine volcanic intercalations, commonly referred to as the greywackes, which are cratonized, having been already compactly folded and in most places intensely deformed in a period long anterior to the events that led up to development of the present-day land surface. This erosional surface, either approximately plane immediately before it became deformed by earth movements or affected only by a very shallow dissection that followed earlier planation (Cotton, in Cotton and Te Punga, 1955, p. 1014), has already been referred to (p. 763) as the "K Surface".

It might be so called because of its "key" character, as explained above; but the initial K also recalls, and for this purpose replaces, the rather un euphonious name "Kaukau," which has been applied to the "surface" by Gage (1940, p 403) and has since been used by active investigators (e.g., Stevens, 1957a, pp. 315–7) as well as orally by casual observers who have latterly recognized its key significance for the elucidation of primitive tectonic form.

The surface was long ago described (Cotton, 1912b; 1955, p. 15) as one that attained "maturity" in a Kaukau cycle (or first cycle as far as traces in the landscape are concerned). Adkin (1951) has called it also a "subdued matureland". It is better described, however, as "postmature" (Cotton, 1955, pp. 4, 15) or even senescent or perhaps even senile in the cycle of normal peneplanation, if it originated in such a cycle, though this cannot be asserted (Cotton, in Cotton and Te Punga, 1955, pp. 1028–30); or it is possibly such a surface that has been modified by slow degradation with development of shallow infantile dissection.

Formerly the writer (Cotton, 1912b) relied on supposed evidence of considerable relief on the surface, an appearance as of monadnocks rising 100–200 m above a plain that survived in a few remnants now standing at about 300 m altitude. Though these higher areas are for the most part maturely dissected, the monadnock theory may now be discarded and a theory that they have resulted from differential upheaval of parts of the K Surface, followed by re-dissection, can be substituted for it with confidence.

A few flat summits, remaining approximately horizontal, that stand at about 300 m were almost the only parts of a terminal peneplain that had been identified as such until recently. Other more or less flat summits are now known, however, at lower levels. These may reasonably be interpreted as parts of a single surface that has been deformed; though this is not the only suggestion that has been made. Quennell (1938) has formulated a theory that a number of down-stepping partial peneplains have been formed in successive cycles; and Adkin (1951, p. 170) has supported this view to some extent by referring to "partial erosion cycles . . .
developing each at the expense of the graded surface of the preceding cycle." The latter author has, however, appealed also to marine erosion at progressively lower levels to account for planed surfaces at relatively low altitudes. One such is Table Top, a conspicuously flat summit area, at 260–275 m altitude, just south of Porirua Harbour (Fig. 1; figured in Cotton, 1952a, Fig. 137); and another is the flat top, only slightly tilted southward, of the marginally clipped Mana Island (Photo 6), the greatest altitude of which is 130 m. These have been placed in the same category as the indisputably marine terrace at Tongue Point, which is shown in Photo 9 (Adkin, 1951).

The summit of Kaukau Peak (Fig. 1) has been considered to be a monadnock, but it has given its name to the cycle as a whole and to the "surface" developed in it. Its altitude is 442 m, and it is 50 m higher than a more extensive flat remnant 3 km SW of it and up to 150 m higher than others that are more distant. On the Kaukau summit "an area of about 50 acres [2km²] . . . presents the appearance of mature topography" (Cotton, 1912b; 1955, pp. 14–15). Such an appearance of maturity might be developed, however, by secondary processes on a remnant as small as this as the heads of flank-dissecting ravines encroached on a horizontal surface; for, whatever the correct explanation of this may be, the profiles of the headwater reaches of streams are commonly convex. This summit, formerly more nearly plane, may, in other words, be now experiencing "slow degradation" (Birot, 1949, pp. 90, 118) by infantile valleys. Of criteria for the distinction of such from mature valleys "the most significant is the convex longitudinal profile of the former" (Birot, 1955, p. 25). Another explanation, possibly correct, that has been offered for such "infantile valleys" is that they are "dells" of cryergic (periglacial) origin (Cotton, in Cotton and Te Punga, 1955, p. 1028).

Whether or not Kaukau Peak was a low monadnock, some other (larger) surviving remnants of the K Surface, where they have escaped tilting, are much more nearly plane; and, in a general way, the larger these are the more perfectly has their flatness been preserved. This may be taken as an indication that the surface as a whole had very small relief. Such summit features have been discussed by Birot (1955, p. 25), who remarks that where they occur "the region has been approximately planed at least once in its history."

The fact of at least one period of reduction to very low relief is of the greatest importance in this case; for such denudation has provided one and one only surface, a plane of reference or key surface, for evaluation of the deformation in later times of the Wellington landscape—the sole criterion of this in parts remote from the sea. Views from the air and examination of oblique aerial photographs (cf. Photo 4) allow of an improved appreciation of the meaning of very extensively surviving but imperfectly preserved relics of the K Surface as they are seen from the ground, commonly in profile, and have revealed a previously unsuspected pattern of warping and block deformation. This is so not only immediately around the city of Wellington but also more widely throughout the greywacke mountains to the east and NE. ('Tectonic features of the nature of irregular tilted blocks are recognizable in Photo 1: distant hills, especially at the right; Photos 2, 3, and 5: distant skylines; Photo 8: at extreme left.)

Notwithstanding the evidence of block deformation thus provided, however, the contour of the K Surface fails to explain a number of long and strictly rectilinear valleys and also equally straight furrows successive segments of which are occupied by reaches of different streams. The trends and forms of these have been revealed by vertical photographs, which for this purpose are more convincing than the available topographic maps. Many of these furrows are too narrow to be seen at all in distant views, and one hesitates, without discussion of every other possibility, to describe them in the category of tectonic forms, despite support from the fact that in or near the axes of some of them there are scarplets and other fault cicatrices which show
that they are on lines of recent if not actually active faulting. Some discussion of these furrows will be found on pp. 783–6

FORM AND TECTONICS IN RELATION TO THE K SURFACE

A Landscape of Tilted Blocks

In the western part of the Wellington Peninsula (Figs. 7, 8; Photo 8) it may be confidently inferred from the form of the land surface that movements of faulting and strong tilting have there produced a number of small blocks.¹ Some blocks with east-

¹ Not only does this explanation of the relief contradict the theory that subsequent erosional ridges form the relief, but any theory of fault-block relief in this area is contrary to the view of Adkin (1951, p. 171) that the portion of the peninsula west of the Wellington Fault consists of a single “Wellington Peninsula block”. A theory implying the presence of tectonic ridges separated by consequent valleys is, however, consistent to some extent with Adkin’s contention that major meridionally-trending features here, as well as in the Tararua Ranges farther NE, are in all cases consequent, nowhere of subsequent origin. The theory on which Adkin has relied to explain such longitudinal relief features is, however, not one of faulting; he postulates a minor corrugation of a tectonically arched K Surface (assumed also to be diversified by monadnocks), but in his attempt to establish this he has had to depend on the mapped pattern of river courses (Adkin, 1949, p. 268). In the Tararua Range the equivalent of the K Surface is reported by him as surviving only as extremely small relics on peaks 1200 m to 1500 m high.
facing scarps, assumed to be fault scarps, are seen at top-left in Photo 8. These have moderately steeply inclined westward slopes, on which the K Surface survives though somewhat re-dissected.

The hypothetical faults thus indicated are parallel to one another, trending NNE, and account here, as fault-angle valleys, for three lineaments formerly classed as subsequent. These are: (1) the valley, corridor, or relatively low-lying strip that isolates the Terawhiti ridge (Fig. 7) and is followed by the Black Gully tributary of the Oteranga Stream, flowing SSW, which is separated at its head by a low divide from a stream discharging NNE into Ohau Bay; (2) the West Branch; and (3) the East Branch of the upper Oteranga (also known as Shepherds Gully), though the description “gully” is inappropriate for this wide-open tectonic feature, which is one of the broadest valleys in this part of the peninsula.

Between these valleys the divides appear to be submaturely to maturely dissected fault blocks tilted steeply to the west. Of these, the Terawhiti ridge and the long spur west of the Oteranga West Branch are strongly asymmetrical, their eastward slopes having the appearance of dissected fault scarps, while there can be little doubt that broader slopes descending westward are modified relics of the K Surface. This surface is recognizable at an altitude of 458 m on the top of the Terawhiti ridge, as may be seen in a published aerial oblique photograph (Cotton, 1952a, Fig. 80b), which shows also much of the area mapped in Fig. 7 and the embayed NW coast. The K Surface is not so obvious on the spur between the West Branch and East Branch, as these are separated only by a narrow block which is rather maturely dissected; but it appears again north of the head of the East Branch, where it descends gently NW-ward on long spurs that are the interfluvies separating streams (one of them named Sheep Gully) consequent on the general slope of the K Surface, which is here tilted down towards Te Ikaamara Bay and Cook Strait. North-east of this, north and south branches of the Opau Stream are aligned with the Oteranga East Branch, being apparently also fault-angle consequents.

East of the Oteranga East Branch, the valley of which (the so-called Shepherds Gully) is so asymmetrical that it seems quite obviously a fault angle, a long re-dissected slope ascends eastward from the valley axis. This slope is smooth in the sense that, though it is dissected in a fine-textured pattern, such sculpture is shallow and all summits on the slope are accordant with the (slightly modified) K Surface. This arches over eastward (with altitude, at Quartz Hill, 298 m) and descends again, though there maturely dissected, into the Makara Valley. On the crown of the

![Figure 8](image-url)

**Fig. 8.**—Surface profiles of the western part of Wellington Peninsula interpreted according to the theory of development of relief by deformation of the K Surface. A: profile (WE) across the north part of the area mapped in Fig. 7. B: profile (WE) across the south part of the area mapped in Fig. 7. Block diagram: rejuvenation of a fault-angle valley. (Small vertical exaggeration.)
arch so formed an area of about 2.5 km² is approximately level and almost undissected (Fig. 7; Fig. 8, profile A). This is one of the best preserved "peniplain remnants" in the whole region (figured in a published aerial photograph, Cotton, 1954, Photo 3, centre). It is one of a few similar survivals of the K Surface which, because they have remained level and therefore relatively undissected, have been formerly accepted as evidence (a) that the land, and with it the K Surface, has been upraised with little or no deformation (Cotton, 1912b); and (b) because of considerable differences in altitude between such remnants) that this district has experienced successive partial planations (Quennell, 1938).

Features in the southern part of the area mapped in Fig. 7 (and seen in the foreground in Photo 8) are for the most part different in character from the tilted surfaces and the associated fault angles already described; an attempt will be made below (p. 780) to find an acceptable explanation for them. The remarks which follow immediately have a bearing on the coastal outline shown in Fig. 7 (see also Cotton, 1952a, Fig. 80b).

Coastal as Well as Landscape Features Consequent on Deformation of the K Surface

The general form of the K Surface after its deformation, as it may be inferred from examination of the existing landscape, suggests descending slopes that reach to the coasts, especially on the NW side of the Wellington Peninsula, farther NE in the Porirua Harbour vicinity, and also on the SW coast west of the Wairariki Stream. Thus serious consideration must be given to a new hypothesis that the outline as well as the diversified surface form of this land mass is consequent on the deformation of the K Surface. Acceptance of this necessitates abandonment, at least in part, of the local application of the fault-coast theory advocated by the writer (Cotton, 1912b; 1916) and adopted by Gage (1940). It involves radical revision of explanations formerly given of some detailed forms of both the coast and the land surface in so far as these depend on an assumption that the Wellington Peninsula is but a fragment of a large land mass greatly reduced in size by marginal foundering that took place after a ridge-and-valley relief had come into existence. Even the eastern branch of the Karori Stream that taps the drainage from the Wellington Fault furrow—a long-cherished example of a roundabout course of supposedly secondary development (Cotton, 1916, p. 43)—appears to be consequent, looping as it does around the more easterly of the two tectonic domes overlooking the south coast (Fig. 7, summit 425 m).

Various peculiarities of the drainage pattern that were attributed to captures (Cotton, 1912b; Gage, 1940, p. 406) when the relief was thought to be entirely erosional and largely subsequent may now be otherwise explained. There need be no more mystery here about extremely roundabout and sharply zigzag river courses than there is in those other regions, such as Central Otago, where it has been recognized that the main lines of drainage are consequent in the fault angles and other initial furrows and hollows of a strongly deformed land surface (Cotton, 1917; 1948, p. 379; 1952a, p. 160; 1955, p. 142).

Bays also, especially those on the NW side of the peninsula, together with Oteranga Bay on the SW side, which have been attributed to differential marine erosion taking place subsequently to a simplification of the outlines by faulting (Cotton, 1912b; 1951b, p. 103; 1952b, p 55) can alternatively, and very probably correctly, be explained as re-entrants in the initial outline of a land mass after a paroxysm of faulting and strong warping (Fig. 7, Oteranga, Ohau, and Te Ikaamahu Bays). The theory of differential marine erosion of the bays of these coasts no longer receives support from the presence of land valleys with mutually parallel orientation (and thus by inference strike-guided along weak beds or zones) that open into the bays, for, as has already been shown, such valleys with NNE trend now appear to be of tectonic origin, at least in many cases. The bays appear to be tectonic also.
The Waiariki Lineament

Besides the valleys already mentioned in the western part of the Wellington Peninsula (Fig. 7) two others of the long-recognized NNE-trending system of parallel features are the Waiariki and Karori valleys. That of the Waiariki Stream is perfectly straight for four-fifths of its length (Fig. 7; Photo 8, right foreground). Unlike valleys on the line of the Wellington Fault, that of the Waiariki has not been proved by the discovery of scarplets in its axis to follow a fault line. Its rectilinear course for several kilometres, however, leaves little doubt of this, especially when its straightness is contrasted with the devious courses of its own largest tributary and of the other valleys in its vicinity.

The fact that the valley is of V section, with a narrow floor, need not be taken as an indication of its development from a recently active fault, for this form is due to rejuvenation following upheaval of the land. The valley as a whole does not seem to have come into existence independently of or more recently than those round about. The question whether this valley is of consequent (fault-angle) origin or has been excavated by subsequent (fault-line) erosion will be taken up on pp. 781–2.

Dissected Domes Near the South Coast

The Waiariki Valley is on the flank of one of the two highest and most deeply dissected parts of the Wellington Peninsula (Photo 9), two parts of it, that is to say, which must have been upwarped as broad, but not necessarily simple, domical forms (Fig. 8, profile B), which are now maturely dissected. The over-all hill forms (dissecting valleys and ravines being ignored) must preserve in a general way the contour of an initial surface that was produced by a bold arching of the K Surface (p. 775); but there are here no extensive flat-topped residuals; and few, if any, relatively smooth slopes have escaped dissection. Perhaps the absence of such, especially on the western dome (Photo 8), means that the form produced by doming was somewhat irregular—i.e., corrugated, with no flat or even flatish parts either horizontal or inclined. Such initial irregularity would determine also a close spacing of stream courses that would contribute to early development of mature dissection. On the western dome (culminating now at 532 m) radial, symmetrically arranged consequent streams are still easily recognizable (Fig. 7); and 2 km east of the valley of the Karori Stream another similar dome, though somewhat elongated E-W and with a flatter and presumably less dissected summit, culminates at 425 m (Fig 7). It seems unlikely, in view of the well-planed condition of the K Surface not far north of this, and in the absence of evidence that the rocks hereabouts are more resistant to erosion than elsewhere, that these highs instead of being tectonic forms are of the nature of monadnocks rising above the elsewhere level K Surface. Gage (1940, p. 403) has, however, adopted the monadnock explanation, in agreement with the writer's early suggestion (Cotton, 1912b) since withdrawn (Cotton, 1955, p. 15).

The Consequent Karori

The position of the Karori valley—or rather of the Makara–Karori depression, or line of valleys, which passes in a NNE direction from sea to sea across the Wellington Peninsula (Figs. 1, 7, 8)—is in the broad tectonic furrow of the land surface, or synclinal corridor, that lies at its south end between the two tectonic domes mentioned above and farther north between a high residual of the K Surface (so labelled in Fig. 7) and the Otari flat-topped residual (Fig. 1) (figured in Cotton and Te Punga, 1955, Pl. 36; also Cotton, 1955, Pl. 3: 1); and this suggests its inclusion among features consequent on the deformation of the K Surface. The existence of this low, the Makara–Karori through depression, supposedly of consequent origin, was one of the chief props of the theory of erosional adjustment to structure; but as the corridor seems to be primarily synclinal and the river courses in it therefore consequent, it no longer affords the theory the same support.
A certain minor crookedness of the Karori (Fig. 7; Photo 10) was attributed by Gage (1940, p. 408) to "its being made up of a number of sections of different streams connected by a succession of captures." Under the head "adjustment to structure" Gage (1940, p. 407) remarked also: "Short, gory transgressive reaches are characteristically joined by lengths of wider valley . . . more or less parallel with the general strike direction." It is reasonable to attribute some at least of such adjustment, as Gilbert (1877, p. 136; cf. Cotton, 1952a, Fig. 93) did in other regions, to the "monoclinal shifting" (i.e., homoclinal shifting) process during deep incision of streams that had assumed courses oblique to the structure but consequent on slopes or in furrows of the deformed K Surface. Such short strike reaches have not thus in most cases resulted from headward erosion as true consequents. "The tendency of hard strata to rid themselves of waterways and of soft strata to accumulate them is a prime element of the process which carves hills from the hard and valleys from the soft" (Gilbert, 1877, pp. 136–7).

Expansion of the middle and upper reaches of the Makara valley by lateral erosion at successively lower local base-levels to the form of a broad basin was long ago recognized as conditioned by the presence of an extensive area of fault-crushed rocks (Broadgate, 1916, Fig. 1, p. 77). The lowland thus developed actually extends southward over the present-day divide into the upper reach of the Karori (Gage, 1940), so that the divide is now an air gap (Fig. 7; see also Cotton, 1948, Fig. 78). Recognition of enlargement by lateral erosion on this belt need not, however, encourage belief in a theory that the valley originated as a result of headward erosion along such a belt in any cycle. It is at least conceivable that a warping of the K Surface unrelated to the origin or to the presence of the crushed zone caused a new consequent river of considerable size, which became the Makara, to flow by chance over its outcrop, thus, after the rapid incision of this valley in the soft material, providing an opportunity for lateral erosion also to widen it rapidly. Such a hypothesis may be formulated without prejudice to the question whether this crushed zone may have been followed by a since-lost subsequent valley in a more ancient cycle, or cycles.

Gage (1940, p. 407) noted a certain discordance between the trend of the Makara valley and the strike of the rocks. This might be explained now by the theory of post-deformational consequent origin suggested above; but Gage regarded it as a result of lateral wandering of the Makara River away from a strike course in the senescent stage of an ancient (Kaukau) cycle, with loss of some of a formerly established adjustment to structure. In view of the slowness of deformation that may be inferred from apparently antecedent gorges across an upheaved block north of Porirua Harbour, which will be described later (p. 786), it is unsafe to maintain that no considerable length of an ancient Makara River (developed possibly as a subsequent stream in a former cycle) could have been inherited into the post-deformational stream pattern; but the theory of consequent origin outlined above affords at least a very plausible explanation of the whole Makara–Karori line of valleys.

Origin of the Valley of the Fault-guided Waiariki Stream

The Waiariki valley, which as already shown (p. 780) is attributable, because of its remarkable straightness with NNE trend, to localization on the line of a fault, is partly in, though at the west side of, the syncline in the K Surface into the floor of which the apparently consequent course of the Karori Stream is incised deeply. The head of the Waiariki turns a little towards the west (Fig. 7), and may be consequent on the slope of a minor dissected dome of the K Surface (culminating at 486 m—see Fig. 7). This accounts, however, for only a fraction of the length of the valley; the long, rectilinear lower course must be explained in some way in relation to a NNE-trending fault.
Being narrow and of symmetrical V section, it cannot without further investigation be grouped with the branches of the Oteranga as probably of simple fault-angle consequent origin. Ridge summits at either side equidistant from the valley axis are at sub-equal altitudes of 270 m and 250 m (Fig. 7). Its approximate symmetry suggests for the valley an erosional fault-line origin; but, in addition to this hypothesis (a), another (b) claiming that it is really of fault-angle consequent origin must be kept in mind and confronted with evidence from the morphology of the valley itself. (It seems unnecessary to devote space to discussion of the applicability of other "fault-valley" hypotheses—but see Cotton, 1950, p. 749.)

The Waiairiki valley has not been widely opened out by erosion, but has remained rather sharply V-shaped despite the fact that it has obviously been long in existence. As Gage (1940, p. 402) remarks of the adjacent valley of the very much larger Karori Stream, this valley near its mouth (not an axial trench within it, due to rejuvenation, but the valley as a whole) is "strikingly youthful . . . its steep, unbroken valley-sides being devoid of high-level terraces". This youthful character, in both valleys, is due in part, however, to rejuvenations that have affected them as the land rose so as to leave marine terraces bordering the adjacent coast—the higher of two raised shorelines observed here being at 147 m altitude. Though the valley-sides are not themselves bordered by high terraces, they are broken by shoulders of rejuvenation.

As to how long it has taken to excavate the Waiairiki valley—thousands or hundreds of thousands of years—it is impossible to guess on the basis of such evidence as is obvious and has been yet described; but the fault that has determined the course of the stream appears to belong to the NNE system of lineaments prominent in the western part of the peninsula. If it be true (hypothesis a) that this valley is of purely erosional origin, then the fault guiding it was very probably formed at the same time as the NNE faults postulated to account for the Oteranga fault angles—i.e., in the first deformation that affected the K Surface—but, if so, the sub-equality of altitudes of ridges on either side indicates that it is a fault of very small displacement. It must then be a minor break that could scarcely have caused sufficient shattering of rocks to account for subsequent headward erosion of a valley along its line. It is possible, on the other hand, that this is an older (i.e., pre-Kaukau) fault, one of a system in existence before, though probably in some cases pre-determining the lines of, post-Kaukau displacements (Fig. 8, profile B). In that case it might be a major fault associated with much shattering of rocks. (Such a fault zone was assumed to exist in this position by Broadgate, 1916, Fig 1, p. 77.)

Turning now to the alternative hypothesis (b) that the Waiairiki valley is primarily a fault angle, it must be noted in favour of this that strictly only an inner valley, cut in episodes of rejuvenation, is of symmetrical V section. Steep and uniform high slopes are continuous for considerable parts of the length of the valley on the west side of it, upper parts of these being quite possibly segments of a fault scarp (Fig. 8, profile B, alternative b; also block diagram at left), but on the east side slopes of similar steepness are only facets of rejuvenation on the ends of spurs (Photo 8). The east side may, in fact, be tentatively interpreted as a steeply down-tilted strip of the K Surface which was ravined by shallow dissection prior to the rejuvenation that has faceted the spur-ends. Elimination of the effects of coastal rejuvenation—i.e., restoration of the form of the valley before it was rejuvenated (Fig. 8, rear of block diagram)—brings out a resemblance to the hypothetical fault angles, less rejuvenated by erosion, that contain the upper branches of the Oteranga. The hypothesis (b) thus presents fewer difficulties than (a). It does not call for the presence of a shatter zone, and it has the advantage of allowing the fault in the valley axis to be classified in the same category with the other (postulated) parallel faults not far away, all of which may reasonably be supposed to have been active at the same time. It does not, moreover, necessitate a special theory of headward
(subsequent) erosion to account for one valley in a district in which most lines of drainage appear to be consequent.

**Prolonged but Discontinuous Diastrophism**

Definite trends appear in the systems of faults in the Wellington Peninsula and adjacent districts in which the K Surface and tectonic forms due to the breaking up and warping of it are recognizable. Diastrophism has, no doubt, gone on intermittently ever since the interruption of the Kaukau cycle—and it will, in all probability, continue in the future. While, however, the impress of earth movements attributable to an early stage of this diastrophism seems more marked in some parts of the district and of late-stage deformation in others, it would be rash to attempt as yet to distinguish the *sequelae* of a succession of spasms of movement except in a very broad way. It seems probable, however, that some day the palimpsest presented by this landscape will be deciphered more clearly; when abundant deposits of debris derived by dissection and degradation from scarps formed at various times and eroded under various conditions of climate have been more fully investigated it may be possible to discover a legible story and to separate stages of diastrophism.

The most convincing evidence at present available of a very considerable lapse of time intervening between the first phase of the development of the existing tectonic relief and the eventual spasm of strong deformation that made the still rather youthful scarp of the Wellington Fault and basined Port Nicholson is afforded by the marine terraces bordering parts of the coast: for these were cut at successively lower levels by marine abrasion attacking as it rose a land with a relief due to deformation in the earlier diastrophism of the formerly low-lying K Surface. This implies lapse of time during which, though there was intermittent upheaval (indicated by the terraces) little deformation took place; whereas later, when Port Nicholson and its extension the Hutt Valley were warped and faulted down, these terraces were warped and tilted endwise (Cotton, 1921a; 1955, p. 234).

Evidence of the two widely separated paroxysms is found also in the erosional detail of the landscape drowned in the seaward part of the Port Nicholson basin mainly by downwarping (together, of course, with recent eustatic positive movement of ocean level). If, as seems inescapable, the ridges thus deeply drowned are themselves derived by erosion from forms of tectonic relief, then the earth movements that produced the early tectonic relief must have been followed by a long period of erosion before these features were drowned by the later earth movement.

**Trends of Faulting**

Two definite fault trends are prominent—the NNE trend, already delineated in the western part of the Wellington Peninsula (p. 778), and a NE trend that is seen in lineaments, fault scarps, fault-guided (possibly fault-line) valleys, and even recently formed fault cicatrices, or scarplets, in the extensive area to the east and NE. It would be rash, however, to assume that these were of different ages and referable to successive deformations. Though movement on some NE lines is still (intermittently) in progress, such lines of faulting have been also among the earliest to develop, bounding some of the oldest upstanding blocks. The major transcurrent Wellington Fault, which cuts right through the district with NE trend, is undoubtedly an ancient lineament, its origin probably dating at least as far back as the Pliocene (Kaikoura) orogeny; yet the shutter ridges and scarplets already referred to (p. 771) are indications of recently renewed movement on this line.

**North-East and NNE-trending Lineament Furrows**

Among the most mysterious features in the whole of the central New Zealand region are some long rectilinear furrows across the landscape that are difficult of explanation other than as erosional valleys developed by headward subsequent erosion
along fault lines. Such an explanation is possibly, even probably, incorrect, however; its adoption in certain cases has been only a temporary expedient, and it may be retained in other cases only provisionally and as an alternative hypothesis. Rectilinear furrows (aligned NE) intersect the Tararua Range—Prichard Furrow (Cotton, 1953b, p. 218)—and the western part of the Kaikoura Ranges district—the Lauderdale Furrow, in the axis of which there is a fault cicatrice that extends for a long distance (Cotton, 1950, p. 745). Both the Prichard and Lauderdale furrows, though they are of V-shaped section and each is occupied in different parts by different streams, so that they cannot be described correctly as valleys, are such well marked features, and are so long, that they are followed by air pilots as flying routes.

The best known of these features, on a rather smaller scale, in the vicinity of Wellington is on the SW portion of the surface trace of the Wellington Fault (Cotton, 1914; 1951a). The NNE-trending upper valley of the Owhiro Stream, though only 3 km long, is equally rectilinear, contrasting in this respect very strongly with other stream valleys of similar dimensions in this part of the district (Photo 11). The trends and general characteristics of such lineament furrows are clearly seen on vertical photographs, but some are not so easily recognizable on the available topographic maps. Some of them—notably that on the SW extension of the Wellington Fault (Photos 3, 11)—have fault cicatrices in, or close to and parallel to, their axes.

Though in the case of the Wellington Fault lineament the writer (Cotton, 1950, p. 751) has proposed to abandon the erosional fault-line-valley theory of origin, it is tempting to revive this as an alternative explanation of parts at least of two very long and remarkable V-section furrows (rectilinear, with NNE trend) in the hilly area NE of Porirua Harbour. This trend, be it noted, is oblique to that (NE) of the adjacent Cook Strait coast and of some elongated valleys and ridges, presumably tectonic, situated SW and north of the Porirua Harbour basin. These two

![Fig. 9.—The rectilinear Horokiwi and Kahao furrows, north of Porirua Harbour. (In part after Adkin, with corrections from vertical photographs)](image)

furrows may be called Horokiwi and Kahao. (The Horokiwi Furrow is continuous at its north end with the "Mt Wainui Fault," which as Adkin, 1954, Fig. 2, shows, is indicated by a high fault scarp, but the furrow does not "swing around" the slope of Mt Wainui; instead of Kahao, as on the topographic map, Adkin adopts the spelling "Kakaho".) The furrows lead at their south ends into the Horokiwi (East Branch) and Kahao stream valleys (Fig. 9). (The Kahao valley, with its bordering, i.e. not axial, fault cicatrice has been figured, in Cotton, 1953a, Fig. 1, p. 5.)

In both furrows streams in successive segments drain in opposite directions, and as this occurs several times in the Kahao Furrow the suggestion seems almost obvious that each segment has been excavated independently by a small headward-nibbling stream that has discovered a weak fault zone. Against this view, however, must be
set, for one thing, the narrowness and straightness of the furrows, especially of the Kahao. The Horokiwi Furrow also is much more nearly straight than it is shown on Adkin's map (1954, Fig. 2). Straightness, especially of the Kahao Furrow, is vouched for by available vertical photographs (mosaic Wn74/B39, Paraparaumu–Porirua No. 2) but not by the topographic map (N160), owing to the cartographer's softening of sharp bends and his ideal concept of dendritic drainage pattern. Fig. 9 shows the courses of the furrows as they really are. They are too narrow-floored (i.e., V-shaped in section), while at the same time straight, to have been developed by headward erosion as subsequent valleys along zones of fault-crushed rock if these have been, as usual, rather broad.

Another more weighty objection to the fault-line erosional explanation is that the fault line, where its presence is proved by evidence of recent movement dislocating the surface of the ground, is not in the axis of the eroded Kahao valley, but is, though strictly on the southerly continuation of the straight line of the Kahao Furrow, along the side of the valley of the Kahao Stream (Cotton, 1953a, Fig. 1), where it notches spurs and offsets both spurs and tributary ravines (Fig. 9), according to measurements by Adkin (1954, Figs. 2, 3), to the extent of 120 m to 300 m. A similar parallel, not axial, relation to a valley is seen in a scarplet along the side of the Īwhariu valley, in the northern part of Wellington Peninsula (figured in Cotton, 1948, Fig. 309, p. 406).

Coincidence of a zone of ancient faulting and crushing (such as is required by an erosional fault-line hypothesis) with the line of recent renewal of movement can scarcely be fortuitous; but it is legitimate to assume that dislocation developing recently as a result of accumulation of stress has followed a line of least resistance provided by an old fault.

The resemblance, when viewed vertically from above, between the furrows where they are typically developed and the line of fault-cicatrice notches across spurs along the east side of the lower Kahao valley suggests that the furrows are indeed true fault valleys, though perhaps of a kind the development of which demands a new theory. In view of the difficulties presented by other hypotheses, it is permissible to formulate, and indeed to favour, a theory that not only here but also in some other parts of the Wellington district rectilinear consequent courses in quite shallow fault angles (such as is shown at rear in Fig. 10) were taken by streams in a very early phase of the deformation of the K Surface in places that did not assume strong relief as a result of this faulting and perhaps were not at first upheaved to any

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**Fig. 10.—Suggested block structure (generalized and simplified) between the Puterua corridor and the Horokiwi valley. The diagram shows also a hypothetical early stage of the erosion of apparently antecedent western and north-western branches of the Kahao valley system. Inset map, Kahao Stream and its western branches, from vertical photographs.**

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great height. Such courses, or parts of them, must be thought of as persisting to the present day, the streams in them having since become more deeply incised generally as a result of local uplift, so that the valleys are now rather deep, with V section (Fig. 10, front).

In the case of the Kahao Furrow it might be inferred on the basis of this theory that the uprise of the country SE of the Pukerua corridor was gradual; and indeed striking confirmation of this is afforded by western branches of the Kahao Stream, for which no explanation suggests itself unless they are antecedent. This piece of country must have arisen as a (probably compound) block bounded on the SE side by a fault scarp descending to the tectonic depression which is now the lower Horokiwi valley, while there are sufficient traces of the K Surface still recognizable to indicate that it had a long back slope descending NW-ward into the Pukerua corridor (as shown schematically in Fig. 10). North-western tributaries of the Kahao Stream have their sources on what appear to be low-lying parts of the K Surface, flowing thence SE-ward against the back slope of the block and soon entering and traversing gorges 150–200 m deep (Fig. 10). Such courses must be antecedent, being inherited perhaps from the Kaukau cycle; and it seems that there may be a considerable admixture of antecedent with consequent reaches in the drainage pattern of the whole Wellington district.

DATE OF ORIGIN OF THE TECTONIC RELIEF

It seems almost compulsory because of the immaturity of erosional development—i.e., the partial preservation of the tectonic forms of even some rather small blocks—since the breaking up of the K Surface by earth movements to date the first paroxysm of post-Kaukau diastrophism at Wellington very much later than the main Kaikoura Orogeny in the Kaikoura Ranges. In order to develop this argument it is perhaps necessary, however, to resort to guesswork and speculate as to probable elapsed time. Though the Kaikoura Orogeny as it affected the central and southern parts of New Zealand may have occurred as late as mid-Pliocene, the advanced erosional development of the initially tectonic landscape in the Kaikoura Ranges and in the Aorere and Takaka valleys of northern Nelson—and perhaps also in Central Otago, where favourable conditions have contributed to the good preservation of tectonic forms (Cotton, 1917 = 1955, pp. 139–83, especially p. 149)—seems to require the lapse of millions of years. On the other hand, a similar “guesswork estimate” of the time required to smooth down the initially rough-hewn forms of a smaller-scale tectonic relief at Wellington in the current cycle might put it down as definitely less than half-a-million years. Before the diastrophic paroxysm occurred that produced the latter relief there might, therefore, be sufficient post-Kaikoura time for planation.

Adkin (1951) has claimed, on the other hand, that “the whole [K Surface] forms part of the emergent portion of the pre-Miocene peneplain” (which means the fossil surface under the “quartzose coal-measures” of Suggate, 1950), and in the absence of surviving covering strata over the greywacke basement of the Wellington district it would be rash to assert that that “peneplain” had not remained emergent and subject to secular planation until it developed into the K Surface. Stevens (1957a, p. 315) adopts without question the suggestion of “late Tertiary” age. At Paraparaumu, however, in a district into which the deformed K Surface of Wellington can be traced and where it is conspicuous, there is an outlier of Tertiary marine strata (Macpherson, 1949) many millions of years older than the Kaikoura Orogeny, but involved in faulting very probably of that date rather than referable to some “precursor” movements that might be hypothetically invoked, and bevelled, along with the underlying greywackes, by a K Surface of later date, therefore, than that block faulting and presumably later than the Kaikoura Orogeny. It is scarcely possible, moreover, that the environs of Wellington escaped Kaikoura deformation
and the development along with it of fairly strong relief; and it may be suggested that it was such relief that was destroyed as the K Surface was developed.

Much of the altitude of the adjacent mountains in the North Island was attained much later than this, however, as is shown by youthful development of their minor landforms and by the attitude on their flanks of a deformed surface apparently correlitive with the K Surface at Wellington, as well as by their relation to the marine Wanganui Series (infra.). A generalization of this (K) surface over the mountains has been made from topographic data and mapped (Wellman, 1949). In Wellman's opinion it is of post-Kaikoura age and is continuous with what is here called the K Surface at Wellington (1949, p. 125).

If true penéplanation developed the K Surface, which, as various authors (Gage, 1940, p. 403; Wellman, 1949; Stevens 1957a, p. 315) record, has the rock beneath it deeply weathered, such development and the accompanying weathering have required much time. Gage (1940) was of the opinion that such time was subsequent to a "crisis of the Kaikoura Orogeny" that caused submergence of Cook Strait. The writer (Cotton, 1938) had already claimed that it was "at least admissible" that the greywacke of the Wellington Peninsula and its vicinity, after having been stripped of any former cover and having any Tertiary or older penéplain, bare or fossil, destroyed by dissection, was reduced to small relief in post-Kaikoura times. The consideration that development of the K Surface has required a long anorogenic interval seems—on the theory of its post-Kaikoura age—to separate widely from the Kaikoura Orogeny the movements that dislocated the K Surface and produced diversified relief; and thus the existence of the surface may be used as an argument against the view that the Kaikoura movements have not yet come to a positive end but that they have continued through the Pleistocene and even into Recent time in this and in some other parts of New Zealand.

If a date can be assigned to the episode of backwearing that seems to have produced the ramp fringing the foot of the scarp of the Pukerua ridge (p. 769; Photos 6, 7), some light may be thrown on the age of the K Surface planation or, at any rate, the date of its interruption. If the feature is a true pediment it was probably developed in a hot and semi-arid climatic episode. Its age might be Villafranchian (Pliocene–Pleistocene) like that of the rañas (fanglomerates) of Portugal (Ribeiro and Feio, 1950) and of Spain (assigned to "upper Pliocene" by Hernández-Pacheco, 1950), together with the very extensive rampas (pediments) underlying them, which are broadly dated in the Pliocene by Birot and Solé Sabarís (1954, passim) but were, according to Llopis Lladó (1955, p. 26) "developed in times not far distant from our own". A Villafranchian age for this local pedimentation would date the deformation of the K Surface still earlier and would seem to demand a considerable allocation of Pliocene time for the Kaukau planation. Possibly, however, this local pediment, which is only a miniature feature as compared with the extensive rampas of Spain, was formed later, in a warm interglacial age, in which case the first deformation of the K Surface may have taken place in the earlier half of Pleistocene time.

The whole question of age is complicated by the fact that the main differential upheaval of the mountains of the southern part of the North Island took place in the Pleistocene, as shown by its relation to the younger stages of the Wanganui Series, so dated. Further, a surface comparable to the K Surface has been reported (orally, by Dr M. T. Te Punga) as passing under the marine Pleistocene on the Ruahine Range.

Whether or not this upheaval of the North Island ranges is to be described as of Kaikoura or post-Kaikoura date is only a matter of nomenclature, and depends

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1 It seems possible that the raña-like Gore Piedmont gravels and associated pediments in Southland (Wood, 1956) were also formed in a hot, dry Villafranchian age.
on how long the Kaikoura Orogeny is assumed to have continued. It would perhaps be well to restrict the designation Kaikoura Orogeny, specifically the time of upheaval of the Kaikoura Mountains, which afterwards apparently suffered dissection in a long anorogenic interval (Cotton, 1947, p. 81), so as to exclude the later episode of strong differential movement in which the Tararua–Ruahine Range was considerably upheaved. A phase of this latter diastrophism may have been contemporaneous with the break-up and deformation of the K Surface at Wellington.

In conclusion it is perhaps advisable to remind the reader that none of the dates proposed for events here chronicled can be other than tentative. The bench spurs that may be traces of high shorelines around Port Nicholson and the suggestion that these are eustatic and have suffered no warping force on our attention an alternative hypothesis as to the age of the K Surface and the dates both of its first and of its later deformation. This alternative is that the K Surface developed, as Adkin’s suggestion as to its age implies, prior to, and was deformed in, the Kaikoura Orogeny as strictly defined—i.e., in the Pliocene—a suggestion that leaves ample time for later events at Wellington. The Paraparaumu Tertiary outlier must then, of course, have been let down into the cratonized graywackes in some pre-Kaikoura episode of faulting, possibly contemporaneous with the origin of the “post-Miocene” conglomerate (Great Marlborough Conglomerate of Thomson) in the Kaikoura Ranges.

In case of even tentative adoption of a theory of an early, middle, or even late Pliocene age for the K Surface the tracing of the surface or of its correlatives northward will be an important subject for investigation. What is its relation to the similar surface fossilized by the marine Pleistocene on the Ruahine Range?

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