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GEOMORPHOLOGY OF THE BUCKLAND BASIN, TASMANIA

By

A. GOEDE,

Department of Geography, Australian National University.

(With 11 text figures.)

ABSTRACT

The Buckland Basin is an exhumed tectonic basin considerably modified by erosion. Its drainage pattern has been altered by river capture. A longitudinal profile of the Prosser shows that the basin is not graded to present day sea level. The theory of the effects of changes in base level is considered. Erosional terraces are described which may be due to Pleistocene glacio-eustatic oscillations in sea level.

The morphology of the floodplain is examined in detail. Types of river channels and the nature of the floodplain alluvium are discussed. Surface morphology of the aggradational Turvey Terrace indicates that the terrace was formed under climatic conditions very different from the present. Depressions on the terrace may be thaw sinks. Measurements of a fossil stream on it, the prior Tea Tree, indicate much larger bankfull discharges. Alluvial fans which may be related to the Turvey Terrace occur along the Eastern Boundary Scarp of the basin.

An attempt is made to interpret and date the alluvial deposits. Aggradation in the basin is probably due to climatic factors causing a change in the load-discharge ratio of the streams. Differences between floodplain and Turvey alluvium are shown. Floodplain alluviation is believed to be due to a mid-Recent period of increased aridity, while the Turvey alluviation is periglacial in origin.

INTRODUCTION

The Buckland Basin is located near the East Coast of Tasmania some forty miles north-east of Hobart. Measuring approximately five miles from west to east and almost the same distance from north to south, it is approximately triangular in plan. On the eastern side it is bounded by a steep scarp, interrupted only where the Prosser River leaves the basin. Steep undercut slopes form a distinct boundary to the north-west. To the south-west the edge of the basin is defined by a row of steep dolerite hills reaching their highest point at Mt. Gatehouse.

As a background to a consideration of the nature and origin of the basin itself, it is necessary to extend the discussion to the whole of the Buckland one inch to one mile topographic sheet. To the south and west the watershed of the drainage basin of the Prosser and its tributaries falls within the sheet whereas to the north the watershed falls outside it. No contoured maps are available for the area to the north.

THE CONTEXT

Climate, vegetation and soils.

The average yearly rainfall in the Buckland Basin and along the coast ranges from 20 to 30 inches (Nicolls and Aves, 1961). In the more elevated regions the rainfall is higher, probably between 30 and 40 inches. It is fairly evenly distributed throughout the year although there is a slight tendency towards a winter rainfall maximum.

The mean annual temperature is probably in the vicinity of 52° F. River valleys and basins experience severe frosts in winter. In Köppen's system the climate is classified as Cfb.

The vegetation is similar to that of the Sorell-Carlton-Copping area immediately to the south where it has been described by Loveday (1957). He found that the vegetation could be divided into three major groupings depending on rainfall. Savannah woodland is characteristic where rainfall is less than 25 inches. With rainfalls from 25 to 30 inches a dry sclerophyll forest develops, while areas with rainfalls exceeding 30 inches may be classified as wet sclerophyll. There is a continuous gradation between these vegetation classes.

The savannah woodlands are mostly cleared unless they are too steep or stony for cultivation. Dry sclerophyll forests are mostly in the natural state except where undergrowth has been cleared to allow rough grazing by sheep. Wet sclerophyll forests are found in the higher rainfall areas, in the Prosser's Sugar Loaf-Middle Peak area to the south-east and around Blue Tier to the north of Buckland as well as in moist sheltered valleys within the drier regions.

The soils of the Buckland Sheet have been described by Loveday and Dimmock (1957), who produced a reconnaissance soil map on a scale of 1 inch to the mile. The main soil divisions are based on differences in lithology. Podzolic soils on sandstone, feldspathic sandstone, mudstone and dolerite are described, and in addition there are small areas of brown and black soils on dolerite as well as krasnozems, black and red-brown soils on basalt. The only soils of large areal extent are the podzolic soils on dolerite (251 sq. miles) and sandstone (79 sq. miles). Soils of alluvial deposits (30 sq. miles) are mapped as a single unit. These soils vary considerably both in age and in mineral composition depending on the lithology of the terrain from which they have been derived. Since alluvial deposits are not differentiated, the soil map is of limited use to the fluvial geomorphologist. In the Buckland Basin there is a sharp contrast between alluvial soils derived from sandstone and dolerite. In the latter there are also important differences between the soils of the present floodplain, the Turvey Terrace and the fans. These differences will be discussed later.

Lithology

The oldest rocks outcropping in the area (Department of Mines, 1958) are flat-lying to gently dipping Permian marine mudstones of the Malbina Formation (formerly known as the " Woodbridge glacials "). They are exposed along the course of the Prosser River downstream from the Buckland Basin and also to the south of the Tea Tree Rivulet just before its confluence with the Prosser. The mudstones are overlain by a thick sheet of Jurassic dolerite. Due to their limited outcrop of approximately one square mile the Permian rocks are of little importance in the geomorphology of the Buckland Basin. Their susceptibility to fluvial erosion is similar to that of the Triassic sandstones.

Triassic rocks outcrop extensively in the region, occupying a roughly wedge-shaped area with the point of the wedge formed by the Buckland Basin. They have been mapped as two units: (1) The older Ross Sandstones and Knocklofty Sandstones and Shales. (2) The younger Feldspathic Sandstones and New Town Coal Measures. The use of these formation names is very questionable. In discussing the Triassic System in Tasmania, Hale (1962) has already pointed out the difficulties of correlating strata even over short distances. This is due to rapid horizontal variations in thickness and lithology, repetition of similar beds and the lack of marker beds and fossils. The Buckland region is a considerable distance from the Triassic type sections and the lithology of at least part of the succession is rather different. (1) The older " Ross Sandstones and Knocklofty Sandstones and Shales " consist in part of a succession of several hundred feet of cross-bedded sandstones rich in halite and epsomite. These salts are very susceptible to chemical weathering and, where slopes are steep, shallow caves are formed by atmospheric weathering in layers rich in these salts. The unit as mapped also includes sandstones with thin bands of shale. The latter contain poorly preserved plant fossils and outcrop in one place along the bank of the Prosser in the Buckland Basin (grid ref: 560540). (2) The younger " Feldspathic sandstones and New Town Coal Measures " outcrop in two small areas only: one along the Back River near " Stonehurst " and the other at Tiger Hill between the Bluff and Sand Rivers. The rocks consist of sandstones and shales containing bands of coal up to three feet thick. Both areas have been mined for coal on a small scale 50 to 100 years ago.

From the geomorphological point of view only the rocks discussed under (1) are of real importance. They underlie the Buckland and Runnymede Basins and occupy large areas to the north and north-east especially in the drainage basins of the Bluff and Sand Rivers. The Triassic sandstones are more liable to weathering and erosion than the Jurassic dolerite thus partly explaining their coincidence with basins. However, to the north and north-east of the Buckland Basin they outcrop in country of strong relief where the upper courses of the Bluff and Sand Rivers have cut deep gorges.

The Jurassic period is represented by thick sills of dolerite, which are intruded at various levels into the Permian and Triassic strata. Individual sills may be 1000 feet or more thick. They are often transgressive, hence cannot be used as stratigraphic markers. As well as sills there are dykes and necks of dolerite. This rock occupies by far the greatest area on the Buckland Sheet. The Buckland Basin is bounded by extensive areas of dolerite to the west, east and south. The most resistant rock, it outcrops in nearly all the higher country. This is so despite the fact that it is susceptible to both chemical and physical weathering. It is composed mainly of two minerals: augite and labradorite both of which are susceptible to chemical weathering. Physical weathering is promoted by the well jointed nature of the rock making it particularly vulnerable to frost wedging under periglacial conditions.

Tertiary freshwater sediments are also represented in the Buckland Basin although they are not shown on the geological sheet. The presence of Tertiary sediments was first suspected by Loveday and Dimmock (1958) who produced a reconnaissance soil map of the Buckland Sheet. They described an area of lateritic soils (1 sq. mile) in the Buckland Basin stating that these were " considered to have been developed on lake sediments similar to those of the Launceston Tertiary Basin, with which the soils have much in common ". An outcrop of these sediments was discovered by the writer who found light grey clays, underlying Quaternary terrace and floodplain deposits, in the bed of the Tea Tree Rivulet up to three feet above low water level (plate 3). This outcrop is intermittent for a distance of several hundred yards but the most extensive outcrop occurs at grid ref. 597516 just north of the boundary fence between Court Farm and Mr. Turvey's property. The clays contain abundant vitrinized fossil wood and lenses of paper coal up to 6 inches thick, interbedded with thin sandstone beds. Polished sections show that the clay is laminated. The laminations are wavy and one layer of clay between two sandstone bands showed strongly convoluted laminations. Deformation of the clay laminations is probably due to post-depositional compaction. The sediments are flat lying and are not jointed. In one outcrop root voids penetrate the top six inches indicating the presence of vegetation before the deposition of Quaternary alluvium. An auger hole (t) was put down in the bed of the Tea Tree Rivulet and went through 4′ 4″ of clay with three bands of sandy material before striking a log of vitrinized fossil wood.

The age of the clays is critical to the interpretation of the evolution of the Buckland Basin. Townrow (in press) has found a rich flora, including abundant conifer remains, and has already described the following new species from the locality: *Podocarpus strzleckianus*, *P. tasmanicus*, *P. setiger*, *P. goedei*, *P. acicularis*, and *Microstrobos sommervillae*. Other plant fossils identified are *Coronelia*

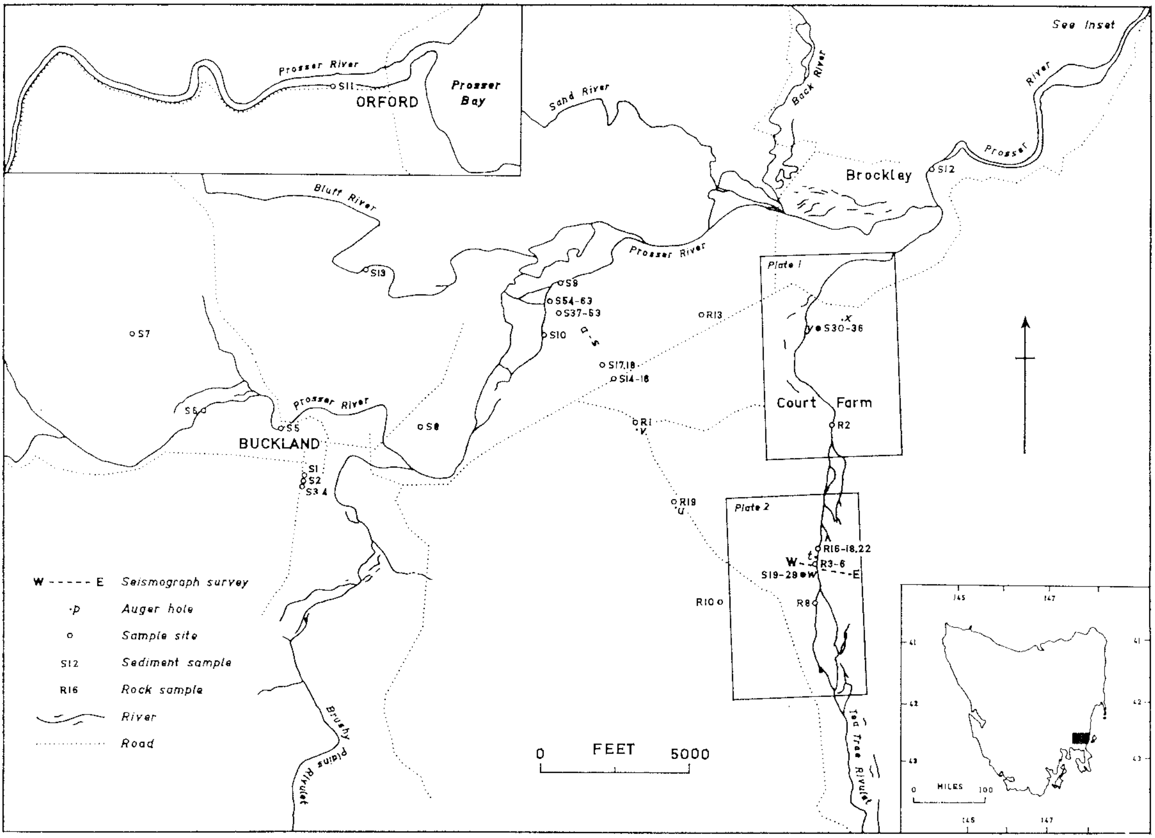

FIG. 1.—Index and sample map of the Buckland Basin.

molinae and a species of *Athrotaxis*. *Coronelia molinae* had previously been recorded only from the Eocene of Chile (Coronel, Buen Retiro) where it was described by Florin (1940) as a new genus and species. Some material was sent for pollen analysis to Dr. Duigan (University of Melbourne), who found that most of the pollen belonged to *Nothofagus*. Several species were present including *N. emarcida*, *N. cincta*, and either *N. goniata* or a closely allied form. *N. cincta* is recorded from Eocene to Lower Miocene and *N. goniata* from the Lower Tertiary. Other angiosperm pollen grains included those of Proteaceae and Casuarinaceae but myrtaceous pollen grains were not observed. There was also an appreciable amount of gymnosperm pollen probably belonging mainly to the Podocarpaceae but including *Trisaccites micropteris* and *Ephedra notensis*. Both of these have been recorded only from Lower Tertiary and earlier deposits. In Tasmania they have also been identified in the Launceston Tertiary Basin in sediments of Palaeocene—Lower Eocene age (Gill and Banks, 1962). The combined evidence of plant macrofossils and pollen analysis strongly suggests an early Tertiary age.

The extent of the Tertiary sediments is difficult to determine because of the lack of outcrop. A seismic traverse across the Tea Tree Valley (fig. 10) showed that, from the outcrop in the bed of the Tea Tree, Tertiary freshwater sediments underlie Quaternary fluvial deposits for at least 1300 feet to the east and 500 feet to the west. The soil evidence together with that from auger holes indicates that the area of lateritic soils described by Loveday and Dimmock is also underlain by Tertiary sediments. This area has been called the " Ironstone Surface " by the writer and will be more fully described later. Similar lateritic soils have also been found on a low swell separating the Turvey Terrace from the present floodplain a short distance south-east of Gatehouse's Marsh Bridge. The maximum extent of the Tertiary sediments is a triangular area of at least 2 square miles in the Tea Tree Valley. It is bounded on the east by the Eastern Boundary Fault which forms a prominent dolerite scarp. To the south-west it is bounded by a line of sandstone hills but to the north the boundary is less definite. It does not extend more than a few hundred yards north of the Tasman Highway and runs approximately parallel to it.

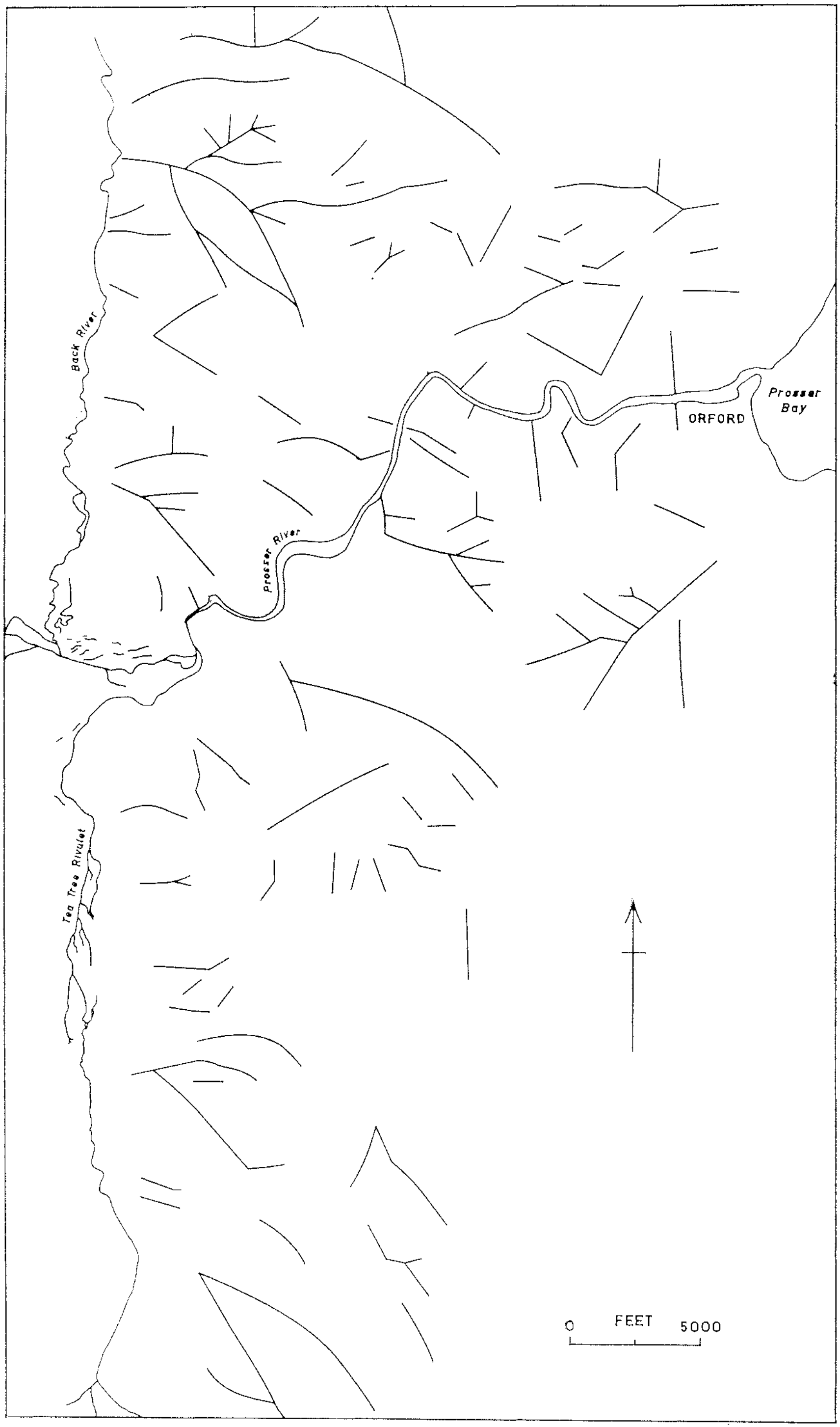

FIG 2.—Linears in the dissected area east of the Buckland Basin. The Eastern Boundary Fault is located parallel to and a short distance east of the Back and Tea Tree Rivers and is associated with strongly curved and splayed fractures.

Small flows and necks of Tertiary basalt outcrop two miles south of Buckland near Sally Peak and also in the Runnymede Basin, near Nugent and in the vicinity of Orielton and Pawleena.

Quaternary sediments occur along the coast and along the rivers especially in the Buckland Basin. The fluvial sediments of the basin will be discussed later.

Structure

The area has been faulted in the Tertiary in two dominant directions—

(1) A north-south direction with faults bounding the horst that runs parallel to the east coast. The westernmost fault has given rise to a prominent scarp, 8 miles long, which forms the eastern boundary of the Buckland Basin and is called here the Eastern Boundary Fault.

(2) A northwest-southeast direction with faults to the west of the Eastern Boundary Fault and appearing to terminate against it. They are tensional faults forming a complex graben.

Since the northwest-southwest trending faults appear to terminate against the Eastern Boundary Fault they are unlikely to be older than the latter. If both directions of faulting are of the same age the pattern can best be explained by regarding the north-south running faults as sinistral shear faults associated with tension faulting at an angle of approximately 40° to 50°. From aerial photographs all lineations in the dissected area to the east of the Buckland Basin were plotted on a map (fig. 2) and it would appear that the Eastern Boundary Fault of the Buckland Basin is associated with a number of strongly curved and splayed fractures. This association suggests that the fault is not a tensional one. It is most unlikely that the curved fractures are cooling joints since in the dolerite these tend to either straight or only gently curved. If the fault is a shear fault, the curved fractures are best explained as small thrusts. A third possibility is that the northwest-southeast faults are younger than the Eastern Boundary Fault. Both directions of faulting predate the formation of the Nugent Surface, an erosion surface standing at a height of 1100 to 1200 feet above sea level.

The relationship of the faults to the Tertiary sediments is important but not clear. The Tertiary sediments exposed in the bed of the Tea Tree are no more than 2000 feet away from the Eastern Boundary Fault. Had they been deposited before

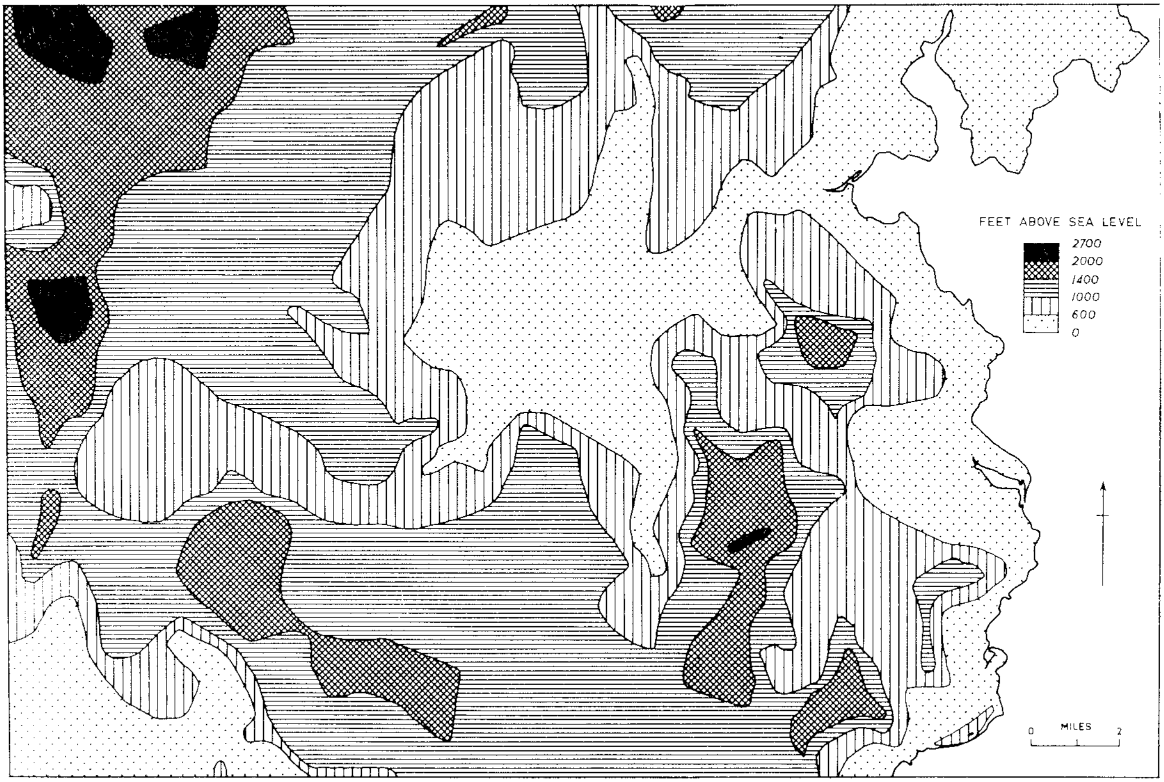

FIG. 3.—Generalized relief map of Buckland Sheet showing extent of the basin.

north-south faulting began one would have expected to find evidence that the beds were disturbed. Yet they are flat-lying and unjointed. It is therefore likely that they postdate the Eastern Boundary Fault. The relationship of the Tertiary sediments to the northwest-southeast trending faults is unknown. Whether or not the two directions of faulting are of the same age they provide a way in which the Buckland Basin could have formed as an enclosed tectonic basin. The Tertiary freshwater sediments which outcrop in the Tea Tree Valley could well represent the remnants of the infilling of such a basin. Their character suggests that they are lacustrine rather than fluvial sediments. If the Tertiary clays represent the infilling of the Buckland Basin during and after its formation, their early Tertiary age indicates approximately the date of at least one period of faulting. It is generally recognised that the early Tertiary was a period of major faulting in Tasmania. The character and extent of Tertiary faulting in eastern Tasmania is generally difficult to determine because of the prevalence of Jurassic dolerite and Triassic sandstones, neither of which provide suitable marker horizons.

EROSIONAL MORPHOLOGY

Relief

A generalized contour map (fig. 3), summit contour map and a summit frequency graph (fig. 4) were constructed from the Buckland topographic sheet. Since the generalized contours and summit contours give similar results only the generalized contour map is shown. Although summit concordance is lacking over much of the Buckland Sheet, it is marked over a considerable area to the west of Buckland and to a lesser extent around Nugent. This is reflected in the summit frequency graph showing a very marked peak at 1,100 to 1,200 feet. Much smaller peaks occur at 2,100 to 2,300 feet, 1,800 to 1,900 feet and 600 to 700 feet possibly indicating other erosion surfaces. The one at 1,100 to 1,200 feet is by far the most pronounced and is here called the Nugent Surface. It shows no evidence of having been faulted and since it is fairly widespread and in places very well preserved it is safe to say that no significant faulting has taken place since its formation. The surface is developed across both dolerite and Triassic sandstone but is best preserved on the more resistant dolerite, its extensive development on dolerite must have required a long period of time. However, the surface may at least in part be a structural one formed by the stripping of less resistant overlying sediments from the top of a dolerite sill. Since the area was affected by Tertiary faulting it seems likely that stripping was at best only a minor factor in its development. The surface is characterized by low, rounded hills and broad, flat-bottomed valleys which are frequently dry. As in the Buckland Basin, they may have been partly filled in by alluviation and the actual rock surface may not be as flat as it would appear.

Of the five surfaces postulated by Davies (1959) only his higher coastal surface seems to be present on the Buckland Sheet. Davies and the writer (fig. 4) have both produced summit frequency graphs showing a strong peak at 1,100 to 1,200 feet, which is slightly lower than the usual range of 1,200 to 1,500 feet given for the higher coastal surface. The lack of contoured maps for areas surrounding the Buckland Sheet makes it impossible to tell whether the 1,100 to 1,200 feet surface is continuous with similar surfaces at a slightly greater height in the Lower Midlands. To the west of Buckland it is separated from them by a continuous ridge extending from Black Charlie's Sugar-loaf to Mt. Hobbs and forming the watershed between the Prosser and Coal Rivers. The Nugent Surface could be a separate surface related to an earlier phase in the history of the Prosser and its tributaries.

Origin of the basin

In first analysis it would appear that the basin was erosional in origin, excavated in the easily weathered Triassic sandstones which occupy its floor, surrounded on three sides by more resistant dolerite. However, a completely erosional origin is now ruled out by the discovery of Tertiary clays in the Tea Tree Valley. The evidence suggests that the basin is basically tectonic in origin and that the faulting which led to its formation predates the development of the Nugent Surface. If the basin formed as an enclosed basin as postulated it must have been a lake of considerable extent at the close of the faulting. This lake was filled with sediment derived largely from dolerite terrain, probably during the early stages of the development of the Nugent Surface. At this time the Prosser may have flowed out between the Three Thumbs and Prosser's Sugar Loaf to enter the sea near Rheban (fig. 3) to be captured later by a smaller stream extending its drainage area inland from Prosser Bay.

A series of negative changes in baselevel then caused the Prosser to become incised in its new lower course while simultaneously causing it and its tributaries to cut rapidly into the unconsolidated lake sediments which had filled the Buckland Basin to an unknown height. The Tertiary clays are particularly susceptible to stream erosion and the probability of finding remnants of these beds at higher levels is remote. The clays outcropping in the bed of the Tea Tree Rivulet and also underlying the " Ironstone Surface ", appear to be remnants of a more extensive lake sedimentation. The pronounced dolerite scarp forming the eastern boundary of the Buckland Basin is regarded as a resurrected fault scarp due to the removal of Tertiary sediments from the basin.

Drainage

The present drainage pattern is an asymmetrically centripetal one with six streams converging on the Buckland Basin and draining an area of approximately 270 square miles. The Back River and the Tea Tree Rivulet run parallel to the Eastern Boundary Scarp. The Prosser, Bluff and Sand Rivers flow into the basin from a northwesterly direction and the Brushy Plains Rivulet enters it from the south-west.

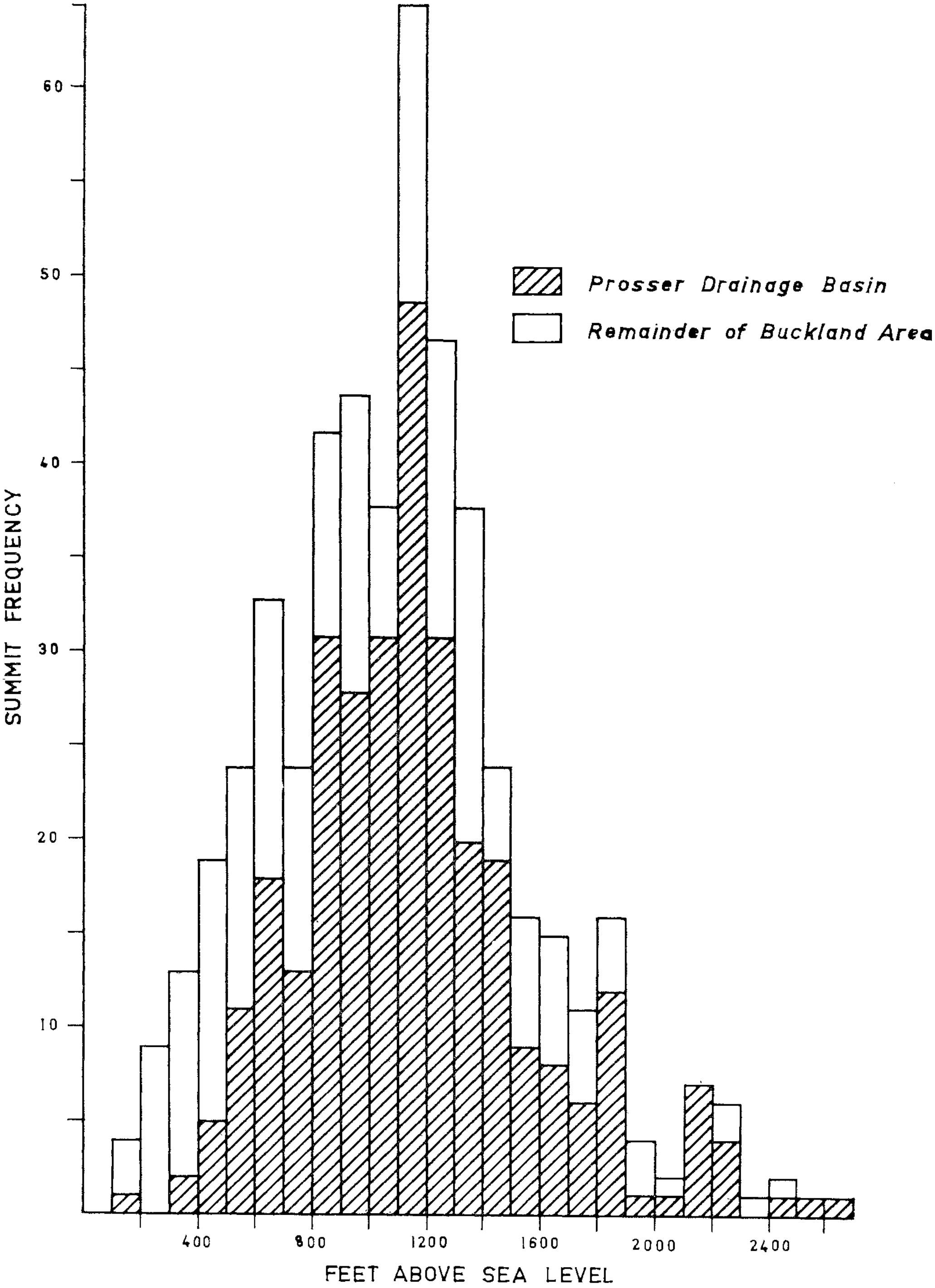

FIG. 4.—Summit frequency graph of Prosser drainage basin and Buckland Sheet.

There have been several river captures. The Sand River apparently once joined the Bluff River about five miles north of Buckland before being captured by a stream draining directly into the basin. The evidence for this is a distinct gap in the watershed between the Bluff and Sand Rivers, the floor of which is now approximately 200 feet above the present beds of the two streams. A classic example of river capture is found in the case of the Bluff. This river once flowed down a broad, dry valley—now followed by the Levendale Road—to join the Prosser just west of Buckland. It has since been captured by a small stream draining directly into the Buckland Basin thus creating a perfect elbow of capture. The river has now cut down about 50 feet below the windgap representing its old course. Immediately downstream the steep valley walls indicate strong incision after capture due to the sudden increase in erosive power at this point. Reversal of drainage has barely begun; there is a very short, shallow gully extending to the windgap which will eventually develop into a reversed stream. The upper part of the dry valley just below the windgap is rather swampy in nature.

The Prosser may once have flowed to the south of Buckland where it joined the Brushy Plains Rivulet before cutting its present course further north. The area through which the stream may have flowed is shown doubtfully as an old channel fill on the river terrace map (fig. 7) but no undoubted fluvial sediments have yet been found there. The area is fairly flat and stands at a height of 45 to 65 feet above the bed of the Prosser. Most of the soils appear to have been developed on colluvial material from the steep sandstone hills immediately to the south or on bedrock sandstone. Deep, strongly podsolized sands are found 300 yards south of the Tasman Highway bordering the road to Sally Peak. As these might be fluvial sediments four samples (S1-4) were collected for analysis. The method employed was that by Folk and Ward (1957). The mean size of the samples varied from .164 to .209 mm. (fine sand). They are moderately sorted, positively skewed and leptokurtic to very leptokurtic (excessively peaked). The percentage silt and clay present varied from 5.4 to 12.1%. The mean Wadell sphericity for 25 grains chosen at random from each sample ranged from .804 to .815. The sediment analyses permit but do not require a fluvial origin for the sand. Therefore it is distinctly possible but not proven that the Prosser once flowed south of Buckland.

Longitudinal profiles

It is probable that significant faulting has not taken place since the early Tertiary and certainly not after the development of the Nugent Surface. Hence irregularities (nickpoints) in the longitudinal profiles of the Prosser and its tributaries cannot be attributed to faulting. Such nickpoints are therefore due either to irregular changes in discharge, channel characteristics and load or to changes in baselevel, i.e. changes in the relative level of land and sea. One has to consider how the graded river in the sense of Mackin (1948) is affected by the lowering, rising or stability of baselevel. Mackin's definition of a graded stream is " one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and the prevailing channel characteristics, just the velocity required for transportation of all the load supplied from above ". He also states that " slope usually decreases in a down valley direction, but because discharge, channel characteristics and load do not vary systematically along the stream, the graded profile is not a simple mathematical curve ".

(1) Lowering of baselevel.

When the baselevel is lowered the mouth of the stream is normally displaced both vertically and horizontally. There are three cases—

(*a*) If the slope of the newly emerged land is steeper than the gradient required for the river, the velocity of flow in this section will be accelerated resulting in down-cutting and the steepening (nickpoint) will be propagated upstream. The initial slope of the nickpoint will depend on the slope of the emerged land surface.

(*b*) If the slope of the newly emerged land is the same as the gradient required for the river the graded profile will not be affected.

(*c*) If the slope of the newly emerged land is less than that required for the river the velocity of flow in the lowest part of the river will be reduced and aggradation will occur. The flattening will be transmitted upvalley causing a wave of deposition.

Thus lowering the baselevel does not necessarily lead to rejuvenation. It does so only if the slope of the emerging land is steeper than the gradient required by the river to maintain its graded profile. The importance of the slope of the emerging land in this respect has already been pointed out by Sparks (1960). The Davisian idea that lowering of baselevel always gives rise to rejuvenation has also been criticized by Simons (1962) who in discussing Penck's work stated that: " Davis assumed a simple relationship between rates of upheaval and rates of river erosion. It is obvious if we accept the principle of nickpoint retreat that there is no simple relationship between changes in baselevel and river downcutting. A change of baselevel can only give rise to a nickpoint if it causes a discontinuity in the graded river profile.".

(2) Rise of baselevel.

Following Mackin many workers have suggested that a rise of baselevel causes aggradation. Mackin (1948) stated that " a rise of baselevel is equivalent to the rising of a barrier across the path of a graded stream. Each unit of increase in the height of the barrier tends to flatten the declivity immediately upstream. The stream unable because of the decreased declivity to carry all the load through the flattened segment, deposits in the segment, thus increasing the declivity and transferring the flattening upvalley. Continuation of the process results in upstream propagation of a wave or, better, of an infinite number of small waves of

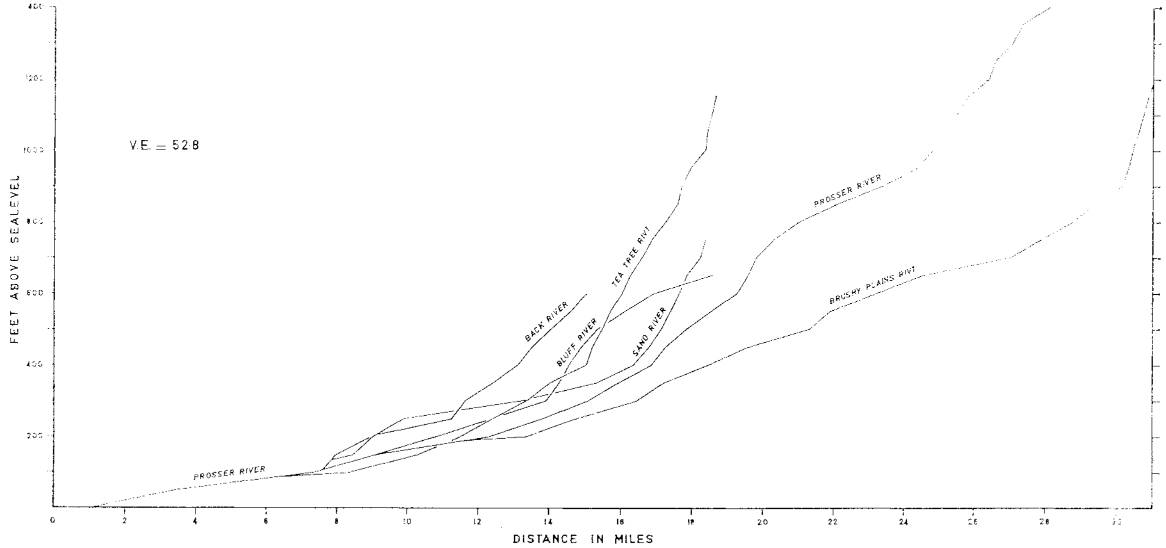

FIG. 5.—Longitudinal profiles of the Prosser and its tributaries.

deposition". Mackin supports his statement with examples of reservoir dams and debris barriers causing upstream aggradation in United States rivers. But from his own paper it is clear that it is not the dam itself which causes aggradation but the progressive regrading of the delta which begins to build out into the reservoir once it has been filled. It is not the rise in baselevel which causes aggradation but the building out of a delta when baselevel has ceased to rise. Applying this to streams in relation to sea level one can say that the rise in sea level since the last glaciation did not cause aggradation because it prevented river deltas from emerging. It is only since the postglacial rise in sea level was completed that river deltas began to build out. Contrary to Mackin the writer believes that a rising sea level does not cause aggradation but is the ideal condition for the rivers to maintain their graded profile.

(3) Stability of baselevel.

Under these conditions rivers are likely to build out deltas unless prevented from doing so by longshore or other ocean currents. The building out of a delta will cause aggradation upstream in a similar manner to that in reservoirs, but since the gradients of all larger rivers are usually low near their mouths the effects of such aggradation may be only slight.

The maintenance of a graded profile during a considerable period of time is required for the development of a rockcut surface, whether formed by pan- or pediplanation, especially where a stream flows over resistant bedrock. Hence a period of rising baselevel is more favourable to the development of rockcut surfaces than a stationary one. Such surfaces can however form with a stationary baselevel provided little or no aggradation takes place due to delta building at the mouth. When the development of rockcut surfaces is interrupted by a period of downcutting resulting from a lowering of baselevel and the consequent upstream migration of a nickpoint, the surfaces are transformed into rockcut terraces.

Profiles for the Prosser River and its tributaries were constructed from the Buckland Sheet contoured at 50 feet intervals. The inaccuracy of the contours, already discussed earlier, is a serious problem. The resulting longitudinal profiles (fig. 5) can only be discussed in the most general terms. The profiles of the rivers between contours are shown as straight line segments since a curved line would give a false sense of accuracy. The longitudinal profile of the Brushy Plains Rivulet approaches most closely the theoretical hydraulic curve being essentially concave upward. In the smaller rivers the profiles become more irregular. The Bluff and Sand Rivers and to a lesser extent the Prosser River show marked convexities. The most striking thing is that the longitudinal profile of the Brushy Plains Rivulet is well below that of the Prosser which is generally regarded as the main river. However, a comparison of the drainage areas shows that the Brushy Plains Rivulet drains an area of 70.35 square miles compared with 49.08 square miles for the Prosser above the confluence of the two streams. The designation rivulet is rather misleading since the Brushy Plains is easily the largest stream flowing into the Buckland Basin.

For further analysis of the basin a more accurate profile of the Prosser River was required. Since surveying the course of the river was impracticable, surveys were run down to the Prosser from bench marks and survey pegs along the Tasman Highway using a Dumpy level and staff. All heights were determined relative to the state datum which approximates to mean sea level. Heights at the Prosser Dam and up to a mile upstream were obtained from a contoured plan made available by the Rivers and Water Supply Commission. Altogether the height of the Prosser was established at seventeen points over a distance of less than fourteen miles. The height of the Tea Tree Rivulet was determined at two points: one of them at Gatehouse's Marsh Bridge. The profile of the Tea Tree upstream from the bridge was also surveyed for 6000 feet using a staff and Abney level. The results are set out in fig. 6, where the heights given refer to low water stream level. Distances along the Prosser and Tea Tree were measured on aerial photographs. The profile of the Prosser is a smooth curve from the upper end of the Buckland Basin down to Brockley Bridge. There are three nickpoints in the profile: the first at Brockley Bridge, the second half a mile above the weir and the third about a mile upstream from the Prosser Dam. The nickpoint at Brockley Bridge appears to have no cyclic significance since the rock-cut Buckland Terrace maintains the same height above the river above and below this point. The Bluff, Sand and Back Rivers join the Prosser immediately upstream and the steepening of the gradient may be due to adjustment to the heavy load of sand carried by these rivers. The nickpoint half a mile above the weir is probably cyclic. Terraces below it cannot be correlated on the basis of height with those in the Buckland Basin (fig. 7). The third nickpoint about a mile upstream from the Prosser Dam is a very marked one. It occurs at a height of about 70 feet and from this point downstream there is a steep gradient to the tidal reach of the river except for a break of slope just above the Prosser Dam giving the nickpoint a stepped appearance. It is also interpreted as a cyclic nickpoint, since there appears to be no other reason for the sudden steepening of the profile. There is no evidence of recent faulting along the coast which could have initiated the lower two nickpoints and it is suggested that they are due to intermittent lowering of baselevel, which may have been epeirogenic or eustatic or a combination of both. The nickpoints may well be glacioeustatic—due to the lowering of sea level during Pleistocene glacials.

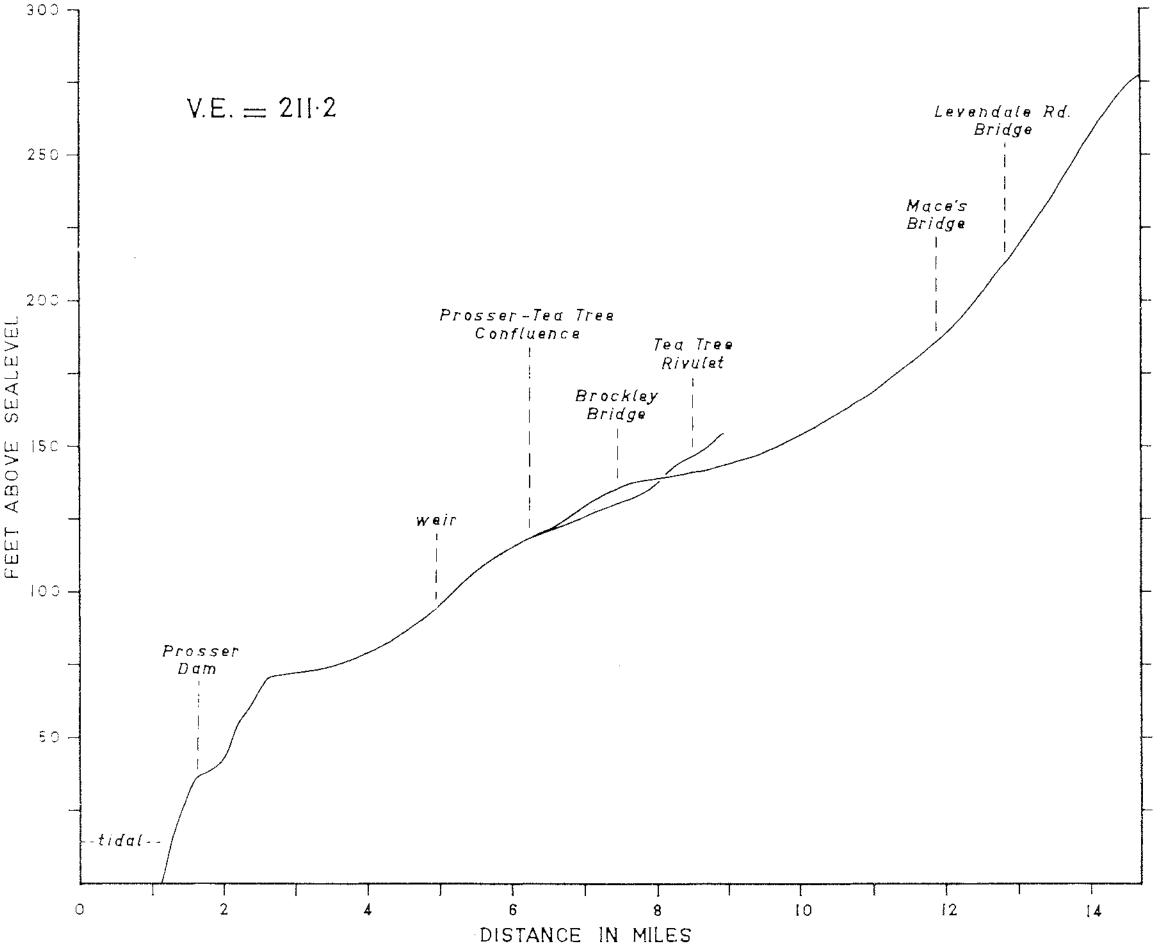

FIG. 6.—Longitudinal profile of the lower courses of the Prosser and the Tea Tree Rivulet.

An interesting feature of the profile of the Tea Tree Rivulet is that it passes below that of the Prosser just above the confluence although the former is a much smaller stream. The Tea Tree here flows through an area known as Gatehouse's Marsh and is actively aggrading its floodplain although vigorous downcutting occurs further upstream. Deposition in Gatehouse's Marsh may be due to a recent increase in load resulting from rapid gullying further upstream, aided by the damming back of the floodwaters of the Tea Tree by those of the Prosser. The floodplain of the Tea Tree is as much as 5 feet below that of the Prosser just above the confluence. The Gatehouse's Marsh situation may be analogous on a small scale with the Lowbidgee area on the Murrumbidgee River before it joins the Murray (Langford-Smith, 1960).

Erosional terraces

Two or possibly three erosional terrace levels can be recognised in the basin. They are: the Buckland Terrace at 30 to 40 feet, the Court Farm Terrace at 70 to 110 feet, and a possible higher level at 170 to 240 feet above river level (fig. 7). The height of the Buckland Terrace was established by transverse profiles surveyed by level and staff. Abney level and aneroid were also used. The heights of the Court Farm Terrace and a possible higher level have been established by aneroid only. All heights are given as heights above low water level of the nearest river. It was found that below the nickpoint half a mile upstream from the weir, terraces could not be correlated with those of the basin on the basis of height above river level. There is a rockcut terrace at 60 to 80 feet which may correspond to the Buckland Terrace and a lower terrace at 30 feet. Heights are indicated in fig. 7.

The Buckland Terrace is fairly extensive and remarkably flat. It is particularly well developed along the Prosser maintaining a constant height of 30 to 40 feet above the river throughout the length of the basin, and is cut in Triassic sandstones, Permian mudstones and Jurassic dolerite. On the dolerite it is much less extensive but particularly well preserved. No fluvial sediments have been found on the terrace. The soils appear to have been derived from the underlying rock. Podsols are well developed on sand- and mudstones and may have buckshot gravel in the profile but on dolerite they are thin and stony. Where the terrace is developed on Triassic sandstone it locally has on its surface shallow depressions due to wind deflation, two of which are quite large. One is found a short distance to the east of Buckland. It is approximately 900 feet long and up to 470 feet wide, elongated at right angles to the prevailing wind and backed by a low lunette. A sand sample taken from the windward side of the lunette (S8) was found to be moderately sorted with a mean size of .155 mm. The lunette is rather irregular in plan and has a vegetation of scattered eucalypts up to three feet in diameter with an undergrowth of cutting grass and bracken fern. The sand of which the lunette is composed has been leached. The depression has a mottled brown and dark grey clayey floor in contrast to the sandy soils surrounding it. On the western (windward) side it is rather irregular in outline, while the eastern side forms in part a smooth curve. It was formed by west-north-westerly winds which are still prevailing at the present time. The depression is located in line with the gap cut through the dolerite by the Prosser just north of Buckland. The other wind-blown depressions are found just west of the road to Brockley before it crosses the Prosser, the largest of these being 670 feet long by 370 feet wide. The eastern side is a curve concave to the wind, and there is no lunette. The other depressions are all much smaller and very shallow one showing a curve concave to the wind with arms trailing to windward making it crescent shaped in plan. None of them are backed by lunettes and all indicate prevailing westerly winds. It seems likely that the depressions were formed during a time more arid than the present as some have been ploughed without being activated. They may have formed by deflation of the sandy A-horizon of the soil during a more arid period or could even be the result of drier conditions combined with destruction of vegetation through burning off by the Tasmanian aborigines.

The Court Farm Terrace stands at 70 to 110 feet above river level. It is most extensive around Buckland and in general appears to have been stripped of any fluvial sediments it may have had.

North-west of Buckland is the dry valley through which the Bluff River used to flow before its capture and along its eastern side the terrace is found only 40 to 60 feet above the valley bottom. This is not unexpected since the Bluff River has cut down 50 feet since its capture while there has been little or no lowering of the bottom of the dry valley. Near the windgap through which the road to Levendale passes some deeply weathered gravels have been preserved on the terrace. Included in the Court Farm Terrace is the "Ironstone Surface" to the west of Court Farm, standing at an average height of 70 feet above river level but reaching 100 feet at Court Farm Hill. It is rather dissected and lumps of ironstone are scattered over its surface. The surface has been developed on Tertiary clays. Its soils were described by Loveday and Dimock (1958) as lateritic soils: "A typical profile has sandy surface and subsurface horizons with concretionary ferruginous gravel in the subsurface overlying a yellow-brown short clay, with red and grey mottling and ferruginous gravel. This continues to a considerable depth with a gradual lightening in colour to a light grey clay with occasional red and yellow mottling". Similar profiles were found by the writer in auger holes s, v and u (fig. 1). The following depths were reached before a hard layer was struck: 7 feet 5 inches in auger hole s, 6 feet 9 inches in v and 3 feet 7 inches in u. From the bottom of u chips of red ironstone were brought up suggesting that a layer of ironstone exists at a variable depth below the surface. Fragments of ironstone found on the surface may be up to a foot or more across but none of them show any sign of stream transport. The fragments are largest and most frequent on Court Farm Hill Individual specimens may show botryoidal, bedded or concentric structures. The material probably formed in situ as a ferruginous hardpan during a process of podsolization of an earlier formed soil. When the surface was degraded from its original

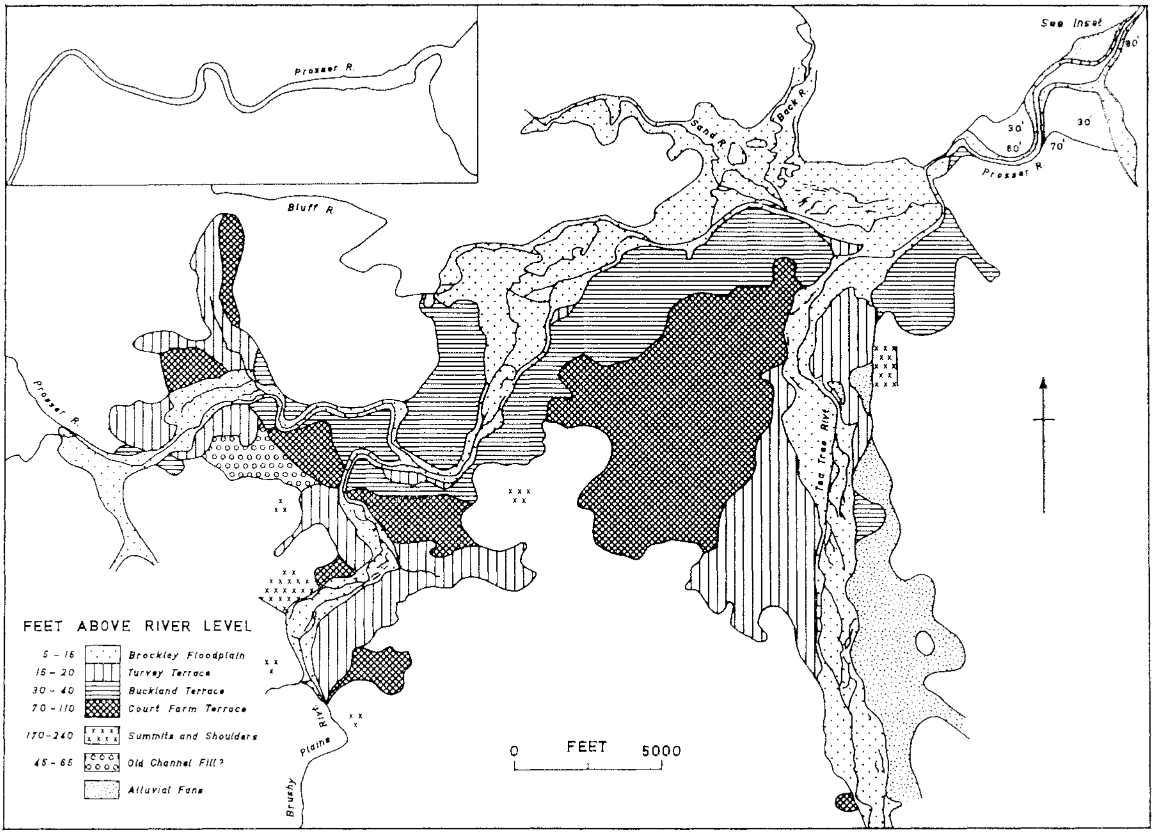

FIG. 7.—Distribution and extent of floodplain and river terraces in the Buckland Basin.

level by slope wash, the ferruginous hardpan was broken up and some of the larger fragments left behind. One specimen collected at Court Farm Hill had a distinct reddish colour and on X-ray diffraction analysis was found to contain hematite and quartz. Most of the ironstone however is limonite. The " Ironstone Surface " is at a slightly lower level than the Court Farm Terrace further west but has been included as part of the terrace because the ironstone provides clear evidence that the surface has been degraded.

There is some evidence of remnants of a higher terrace between 170 and 240 feet above river level. Summits and benches cut in both dolerite and sandstone are well developed along the Brushy Plains at an approximate height of 200 feet (fig. 7) and, along the Tea Tree east of Court Farm, a bench is cut in dolerite at a height of 200 to 240 feet. South of the Prosser one mile south-east of Buckland is a marked break of slope between 160 and 190 feet. They may all be remnants of a higher terrace but the evidence is not conclusive.

The erosional terraces are believed to have formed during long periods of stream profile stability separated by times of rapid downcutting resulting from the upstream migration of nickpoints. The origin of nickpoints has already been discussed.

ALLUVIAL MORPHOLOGY

Floodplain morphology

In the Buckland Basin the Prosser and its tributaries are associated with a floodplain which in places is more than half a mile wide. It has been named the Brockley Floodplain and its extent is shown in fig. 7. During heavy floods such as the one which occurred in April, 1960, the floodplain is converted into a temporary lake. When the water is low the flow is confined to a single channel but during floods more than one channel is occupied as some of the rivers are braided. Braiding is well developed at the confluence of the Prosser and Bluff Rivers and on the floodplain of the Brushy Plains Rivulet.

The character of the load transported by the rivers depends on the lithology of their drainage basins and there is a marked contrast between rivers draining dolerite terrain and those draining sandstone areas. Rivers draining dolerite carry a load of boulders, sand and clay, e.g. Prosser River, Brushy Plains Rivulet and Tea Tree Rivulet, whereas those draining sandstone carry mainly sand, e.g. Bluff and Sand Rivers. The Back River carries a mixture of the two types of load. The nature of the load is very important in understanding the composition of the alluvial deposits and the behaviour of streams under conditions of aggradation. Fragments of bog iron ore were found in the Tea Tree Rivulet. They occur in gravel bars and also in the floodplain gravels and may be up to several feet across. They differ in several ways from fragments found on the " Ironstone Surface " (page 11). In some fragments iron oxide coats the surface of branches or roots of trees which themselves have been replaced by fine-grained structureless silica. The limonite coating has been deposited as a large number of small beads projecting from the surface suggesting deposition around bacterial centres. Other fragments consist of iron oxide cemented sediment showing hollows once occupied by stems and leaves while some are made of chemically deposited iron oxide showing a cellular structure. Some iron oxide from the surface of one of the fossil branches or roots was crushed for X-ray diffraction analysis. Since the iron oxide gave no pattern it was probably limonite. The only mineral which gave a pattern was doubtfully identified as manganese oxalate. Manganese is a common constituent of bog iron ores. The source of the bog iron is unknown. It may have been derived from swamps occurring at a height of 1700 feet one mile north of Prosser's Sugar Loaf, drained in part by tributaries of the Tea Tree Rivulet. This area has not been visited.

Three types of channels in the floodplain can be distinguished. They are—

(1) **Meandering channels** not yet affected by downcutting and characterized by their small width and irregular meanders. Some of these channels still carry low water flow. Examples are the channels of the Tea Tree downstream from Gatehouse's Marsh Bridge and the Prosser near its confluence with the Bluff. Others have been abandoned in favour of channels of type (2). Channels no longer carrying any flow or where the flow is insignificant are often choked with vegetation. An example which has been abandoned since the photograph was taken, occurs in the upper Tea Tree Valley.

(2) **Channels formed by gullying.** They are a striking feature of the basin and are typically U shaped in cross section, being deeper than the meandering channels, with the alluvium standing up as vertical cliffs. Low water level may be anything from a few to 18 feet below the floodplain but averages 8 to 12 feet. There is usually little or no scrub vegetation along the banks. These channels are much wider than the meandering ones and are relatively straight. They are usually formed by headward erosion, a minor exception being a small gully formed by forward stoping on the floodplain of the Bluff River. The channels are widened by slumping of the banks as they are undermined by floods. Gullying starts in suitable localities along the stream and during floods headward extension may be rapid. The head of a gully may be bulbous in which case it is usually occupied by a shallow pool or it may be branching (plate 2). According to reliable local reports a gully in the floodplain of the Tea Tree (plate 2) was initiated 80 years ago. In 1946, when plate 2 was taken, it had reached a length of almost two thirds of a mile by headward extension. In the 1960 flood the Tea Tree broke through into this new straight course abandoning its older meandering one. Because the gullies are relatively straight they have steeper gradients than the older courses and also have, at least initially, efficient cross-sections. Gullying is often promoted by the fact that many of the older courses occupy the highest part of the floodplain. During floods the water spills over sideways across the floodplain and flows down the lowest point until it rejoins the river. It is here that gullying is usually initiated. Since the lowest point of the floodplain is often at a junction with a higher terrace, gullying frequently occurs at or close to the edge of the floodplain (plates 1 and 2). There is a limit to the width of the channels. As the width becomes excessive longitudinal banks of sand and occasionally gravel are formed along the channel sides. These banks prevent further undercutting and the cliffs of alluvium start to degrade. The name " internal levees " is tentatively suggested as a suitable one for these features. Three samples of levee sand from the Prosser (S 5, 9 and 12) and one from the Bluff (S 13) have been analyzed (fig. 1). One sample of sand (S 11) from the tidal reach of the Prosser was also analyzed. The sands are well to moderately sorted with nearly symmetrical skewness. The exception is S 11 which is poorly sorted and negatively skewed. The different character of this sample is due to tidal influence.

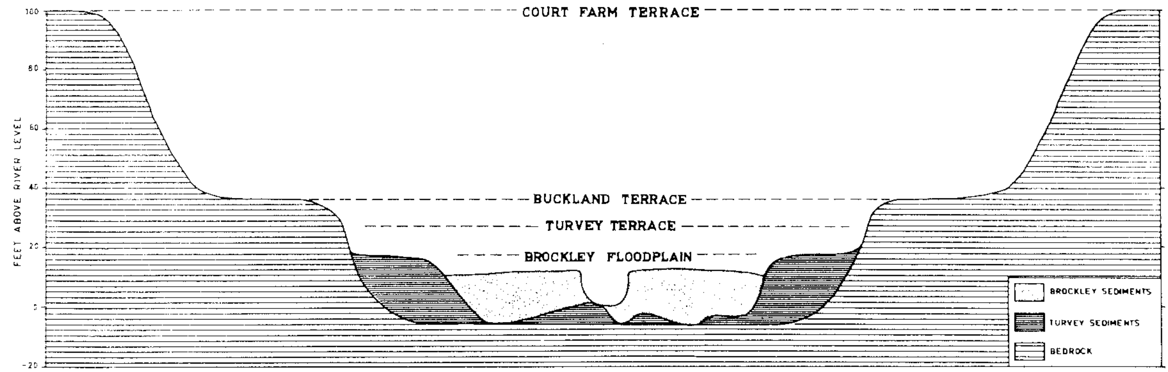

FIG. 8.—Generalized valley cross-section of Prosser River showing relationship of terraces and alluvial deposits.

(3) **Intermediate channels.** They are meandering channels which have been rejuvenated instead of abandoned as in the case of type (1) but, except for their meandering habit, they resemble the second class.

The last two types of channels are very reminiscent of the recently cut arroyos of the Colorado Plateau and adjacent parts of the dry Southwest of the United States (Bryan, 1925, Leighly, 1936). The bottom of none of the channels reaches down to the base of the floodplain (Brockley) sediments except in a few places. The Tea Tree has cut down to Tertiary clays near the boundary fence between Court Farm and Turvey's property, while Triassic sandstone outcrops in the bed of the Prosser River in at least three places.

Gravel bars are common in the beds of the streams except in the Bluff and Sand Rivers. They may form more or less straight across the bed or project into the stream from one bank at an angle such that the toe of the bar points downstream without reaching the opposite bank. In the latter case they are said to be skewed. Leopold and Wolman (1960) suggested that the occurrence of bars in a straight river should correspond morphologically to the point of inflection of a meandering channel and that the distance between successive bars was comparable to the wave length of meanders. They also stated that in some straight reaches gravel bars assumed the form of lobate wedges sloping alternately towards one bank and then the other. In the Buckland Basin bars in the beds of the streams show no regularity in either their spacing or the way in which they are skewed. In skewed bars the coarsest gravel is found in the middle of the stream becoming finer and the bar higher towards the bank from which it projects. The bars are usually separated by deep pools. In the upstream part of the Prosser before it enters the basin the pools often dry up in summer leaving an algal matte covering the boulders. This matte may prevent erosion during floods. The Tea Tree has cut through its floodplain deposits in places and has excavated deep pools in the Tertiary clays underneath while elsewhere the rivulet is cutting through floodplain clays. Here the stream has, during a period of low flows, excavated a one foot wide meandering channel in its bed with an interesting development of miniature meanders. At one place on the bank of the Sand River sand has been blown from the bed and has accumulated as a low dune with a steep lee slope slowly encroaching on the floodplain vegetation.

Overbank deposition on the floodplain is probably significant only in the Gatehouse's Marsh area discussed earlier. However, since 1963 was an extremely dry year the basin has not been seen under flood conditions, overbank flow occurring only once—in July. It was found that deposition on the floodplain of the Prosser was limited to small elongated mounds of sand deposited on the upstream side of gorse bushes which locally dot the floodplain. The greatest effect of the flood was to build up the " internal levees " described earlier. Afterwards the surface of the levees showed current ripples in places. The morphology of the floodplain suggests that at present scour rather than deposition takes place. The floodplains are marked by numerous lakelets always elongated in the direction of flow. They are particularly numerous and well developed on the floodplains of the Brushy Plains Rivulet and the Prosser below Brockley Bridge. Unlike oxbow lakes, they are usually straight or only slightly curved. Most of them are irregular in plan but on the floodplain of the Brushy Plains they are frequently wider at the downstream end tending to be tear-shaped. A few of the lakelets follow old stream courses and are rather sinuous. The lakelets are thought to be due to floodplain scour. Where gullies are formed by headward extension some may be incorporated in the advancing gully. Scour lakelets also occur in Gatehouse's Marsh (Plate 1) where at present deposition is dominant. Their outlines are less distinct and vegetational zoning is characteristic indicating that they are being filled in. Floodplain scour must have occurred in the not too distant past and it is possible that the recent change to deposition has taken place because of an increase in load due to rapid gullying further upstream.

Crevassing is shown by the Brushy Plains Rivulet just after its emergence from the hills. Here the fairly wide stream breaks up into a number of crevasses fanning out across the floodplain where large quantities of gravel are dumped. The place of the wide stream is taken by a much narrower stream the channel of which is discontinuous with the crevassed distal end of the larger stream. Crevassing appears to be the way in which the Brushy Plains disposes of a sudden excess of load. The reason is probably a rapid change in gradient combined with a sudden widening of the valley floor.

Where the floodplain (Brockley) sediments are exposed they have a characteristic section. Auger hole b in the floodplain of the Prosser (fig. 9) gave the following profile:

0—1′9″ dark brown loam, somewhat clayey from 9″ to 1′2″.
1′9″—5′10″ black clay rich in organic matter.
5′10″—8′1″ sticky yellow-brown clay.
8′1″—10′7″ mottled grey and brown sand.
10′7″ + gravels.

The black clay, rich in organic matter, is very characteristic of the Brockley sediments wherever dolerite has been the source rock. The yellow-brown clay is not always present. In the Tea Tree Valley this horizon is usually a brown clayey sand. Numerous good exposures of Brockley sediments can be seen exposed by recent gullying. There is usually but not always a variable thickness of gravels at the base and near the head of the Tea Tree Valley bands and lenses of gravel occur higher up in the succession. In this locality logs up to several feet in diameter are present. A sample for C 14 dating was taken from a log approximately one foot in diameter and seven feet below the surface. It gave a date of 4435 ± 110 years B.P. indicating a mid-Recent age for the deposition of the Brockley sediments. A well made aboriginal scraper was found in situ approximately 8 feet below the surface in the Brockley gravels on the bank of the Tea Tree approximately 1000 feet upstream from the Court Farm-Turvey boundary (R 8 on fig. 1) indicating mid-Recent aboriginal occupation of the Buckland Basin.

A problem in the study of the floodplain sediments is to what extent differences in section are due to sedimentation or to soil development. The surface layer of dark brown loam shows sedimentary layering in some places at least, indicating that some of the characters of the top horizon are not pedogenic. The floodplains of the Bluff and Sand Rivers consist of a thick deposit of sand showing a little podsol development with thin A and B horizons marked by slight changes in colour. The floodplains of the Back River and the Prosser below its junction with the Bluff and Sand contain a mixture of sediments derived from both dolerite and sandstone terrain.

In the Tea Tree Valley a refraction seismograph was used to determine the thickness of alluvium (cf Dury, 1962) on the floodplain as well as the alluvial Turvey Terrace, overlying Tertiary freshwater sediments. The locality chosen had the advantage that the survey could be started from a known section exposed in the banks of the Tea Tree Rivulet. The following seismic velocities were determined:—

Turvey alluvium—1,125 feet/second.
Brockley alluvium—1,200 feet/second.
Tertiary sediments—4,400 feet/second.

The large difference in seismic velocities between the Tertiary sediments and the alluvium made it relatively easy to determine the boundary between them. The results obtained from the survey are shown in figure 10.

The floodplain vegetation of the Prosser, Tea Tree and Brushy Plains was originally dominated by dense tea tree scrub. The floodplains of the Bluff and Sand Rivers were better drained and supported a more varied and open vegetation including eucalypts. The floodplains were largely cleared during the first half of the 19th century and it is certain that most, if not all, of the gullying has occurred since then.

Where the lowest point of the floodplain is away from the river and borders a higher terrace, underground percolation may occur. In the case of the Prosser floodplain it is indicated by the depression of the water table in auger hole c (fig. 9).

The river meanders cannot be analyzed quantitatively because of their irregular nature. There is a marked contrast between the ingrown meanders cut in bedrock in the upper reaches of the streams and below the Buckland Basin, and the alluvial meanders within it. The ingrown, rock-cut meanders have a very much larger meander length and amplitude than the alluvial ones. Although the rivers in the basin are confined to one channel during times of low flow they tend to use more than one channel during floods. In addition much of the flow tends to be dispersed over the floodplain causing any floodplain channel at bankful discharge to carry very much less water than a corresponding channel in an ingrown meander. Also many ingrown meanders have been partially inherited from an earlier cycle and may not be adjusted to present discharge.

Other alluvial landforms

In addition to the floodplain there is evidence of another period of alluviation in the form of an alluvial terrace—the Turvey Terrace, which occurs at heights of 15 to 20 feet above river level. It has been identified along the Tea Tree, Brushy Plains and Prosser Rivers but is best preserved in the Tea Tree Valley. Near the Court Farm-Turvey boundary the rivulet is cutting into the edge of the terrace and a complete section is exposed. The Turvey sediments in the section have a maximum thickness of sixteen feet and are underlain by Tertiary clays (fig. 10). Like those of the floodplain the Turvey sediments are characterized by a variable thickness of coarse gravels at the base. These Turvey gravels are more consolidated than the Brockley gravels making it possible to distinguish them in the field. Remnants also occur in the bed of the Prosser upstream from Buckland where they are overlain by Brockley gravels. In the bed of the Tea Tree Rivulet the Turvey gravels form a resistant bar across the stream with a small waterfall. The basal Turvey gravels are overlain by a sequence of silty sands. A good section is exposed only along the Tea Tree. The terrace has well developed soils containing a variable amount of ferruginous gravel. Three auger holes e, w and y (figs. 1 and 9) were put down to get an idea of the soil profile and to collect samples for mechanical analysis. The following section was obtained in auger hole e.

0′—1′2″ brown sand.
1′2″—2′7″ yellow brown sand.
2′7″—2′11″ light brown sand with numerous small pebbles.
2′11″—4′5″ mottled brown sand with some ferruginous concretions.
4′5″—5′6″ grey and brown mottled silt.
5′6″—15′2″ grey and brown mottled sand.
15′2″—17′1″ grey sand with sandstone fragments near base.
17′1″ sandstone.

Similar sections were obtained in auger holes w and y. The former penetrated 11′ 4″ of silty sands and was stopped by gravel while the latter reached a depth of 7′ 7″ before striking rock.

From all three auger holes samples were taken at one foot intervals for mechanical analysis. The sample numbers are shown on the index and sample map (fig. 1).

Grain size parameters were calculated using the method outlined by Folk and Ward (1957) whose parameters have been modified from those of Inman (1952) to provide a more detailed coverage of bimodal and strongly skewed size curves making the method particularly useful for fluvial sediments. Folk and Ward established mathematical relationships between mean size, sorting, skewness and kurtosis and showed that the relationship between them could be depicted in a four-variate graph. Insufficient analyses were done to check the validity of the mathematical relationships established between parameters. Of the Turvey sediment samples taken only those from auger hole e have been analyzed. There are seventeen samples (S 37-53). The variation in depth of all parameters, as well as silt and clay content, is shown in fig. 11. It was found that the mean size of the sediments varied from 3.08 to 1.77 Ø (.118 to .293 mm.). The standard deviation ranged from 1.035 to 2.345 Ø, indicating that the sediments are poorly to very poorly sorted. Skewness ranged widely from —.164 to .534Ø. One sample was negatively skewed and four were nearly symmetrical while the remaining twelve were positively to very positively skewed. Kurtosis ranged from 1.31 to 2.61 Ø, all samples being leptokurtic to very leptokurtic. The analyses show a direct linear relationship between mean size and skewness. Folk and Ward found that skewness and grainsize are closely related and that the relationship is sinusoidal. However, within the mean size range of the samples analyzed the relationship becomes approximately linear.

In interpreting the results one has to take into consideration the effects of post-depositional changes due to soil development. The increase in mean size from 3 to 6 feet in depth is due to the formation of iron oxide nodules in the soil profile. Their formation has also affected the standard deviation (sorting) and skewness. With the formation of the nodules sorting becomes poorer and the skewness tends to change from positive to negative. Soil processes must also have affected the distribution of the silt and clay content suggesting that the relatively high concentration between 4 and 11 feet is at least in part due to downward leaching of clays.

Where the Turvey Terrace has not been dissected its surface is undulating. In the Tea Tree Valley it is covered with circular to slightly elliptical depressions, a single depression has a trilobate plan in the photograph (plate 2). They are quite shallow, being never more than a few feet deep and tend to be swampy, though most of them have been artificially drained by trenches. The largest and best example has been deepened to serve as a waterhole for stock and is approximately 180 feet long and 110 feet wide. The smallest depression is no more than 30 feet across.

Their origin is not known with certainty. They are unlikely to be wind-deflated hollows as, quite unlike the wind-deflated depressions on the Buckland Terrace, they show no preferred orientation. They cannot be karst phenomena as the Turvey sediments in which they occur are underlain by Tertiary clays while their shape in plan rules out a fluvial origin. The most likely explanation is that they are thaw sinks formed under periglacial conditions. Similar features have been found in Alaska (Hopkins, 1949) and France (Pissart, 1958). Pissart described more than 4,500 enclosed depressions south of Paris and suggested that most of them had a periglacial origin. Because they lacked annular mounds he thought that they were not relicts of pingoes (Pissart, 1956), but thaw sinks of a different kind. The vast majority of his depressions are circular to oval in plan, quite shallow and comparable in size with those found in the Buckland Basin.

The depressions in the Tea Tree Valley are approximately 200 feet above sea level whereas Loveday and Dimmock (1958) estimate that the downward limit of solifluction deposits is about 1,500 feet. However, periglacial activity is not just a function of height. The Buckland Basin is an enclosed basin surrounded on all sides by higher country (fig. 3) and in winter severe frosts occur due to marked temperature inversions. During the Pleistocene ice ages, frost action in the basin could have been sufficiently severe for permafrost to occur. In a discussion of thermokarst features in Alaska, Péwé (1954) found that permafrost occurred on the floodplains and alluvial fans while absent or insignificant on surrounding hill slopes. This also suggests that temperature inversions are important in the location of permafrost.

In the Tea Tree Valley just south of the Tasman Highway the Turvey Terrace shows evidence of an old stream bed of much larger dimensions than the present rivulet (plate 1). This prior stream can be traced for approximately two thirds of a mile and is sufficiently well preserved to permit the measurement of the channel width as well as the wavelength and amplitude of the meanders. The measurements were made from plate 1 and are approximate since the scale of the photograph is not known with absolute accuracy. The meander wavelength (L) is 3,450 feet, the amplitude (A) 923 feet and the channel width (w) 187.5 feet. Leopold and Wolman (1960) established empirical relations between size parameters for meanders in alluvial valleys and found that meander length is usually 7 to 10 times channel width. In this case the ration L/w is 18.4:1, which is almost twice the usual ratio. Leopold and Maddock (1953) found that there is a statistical relationship between width and discharge which can be expressed as $w = aQ^b$ where w is water surface width, Q is discharge and a and b are numerical constants.

Dury (1960) used this relationship in his study of misfit streams to calculate ratios between present and former discharges and stated that "the generalised relationship $w \propto Q^b$ can be employed to calculate the ratio between the discharges required to shape the large channels and the discharges that are shaping the present channels. Let W be the width of the large channel, Q the corresponding bankfull (or near bankfull) discharge, w the present bed width, and q the present bankfull (or near bankfull) discharge. Then

$$W/w = aQ^b/aq^b = (Q/q)^b$$

$$Q/q = W/w^{1/b}$$".

The formula can be used to compare the bankfull discharge of the prior Tea Tree with that of the present stream provided we know the width of both channels. Dury stated further that the "results obtained in this way are affected by the degree of accuracy with which the width of the large channels can be measured, and by the value taken for the exponent b". He suggests that "an average value of 0.5 for b seems well substantiated by much hydrological research".

The width of the prior Tea Tree was measured from plate 1 at two places where the channel was clearly defined. It was found that the channel width was approximately 187 feet. The width of the present Tea Tree cannot be measured satisfactorily upstream from Gatehouse's Marsh Bridge because the river here is actively downcutting into its floodplain. As a result the width is extremely variable. Gatehouse's Marsh downstream from the bridge is more satisfactory because here the stream

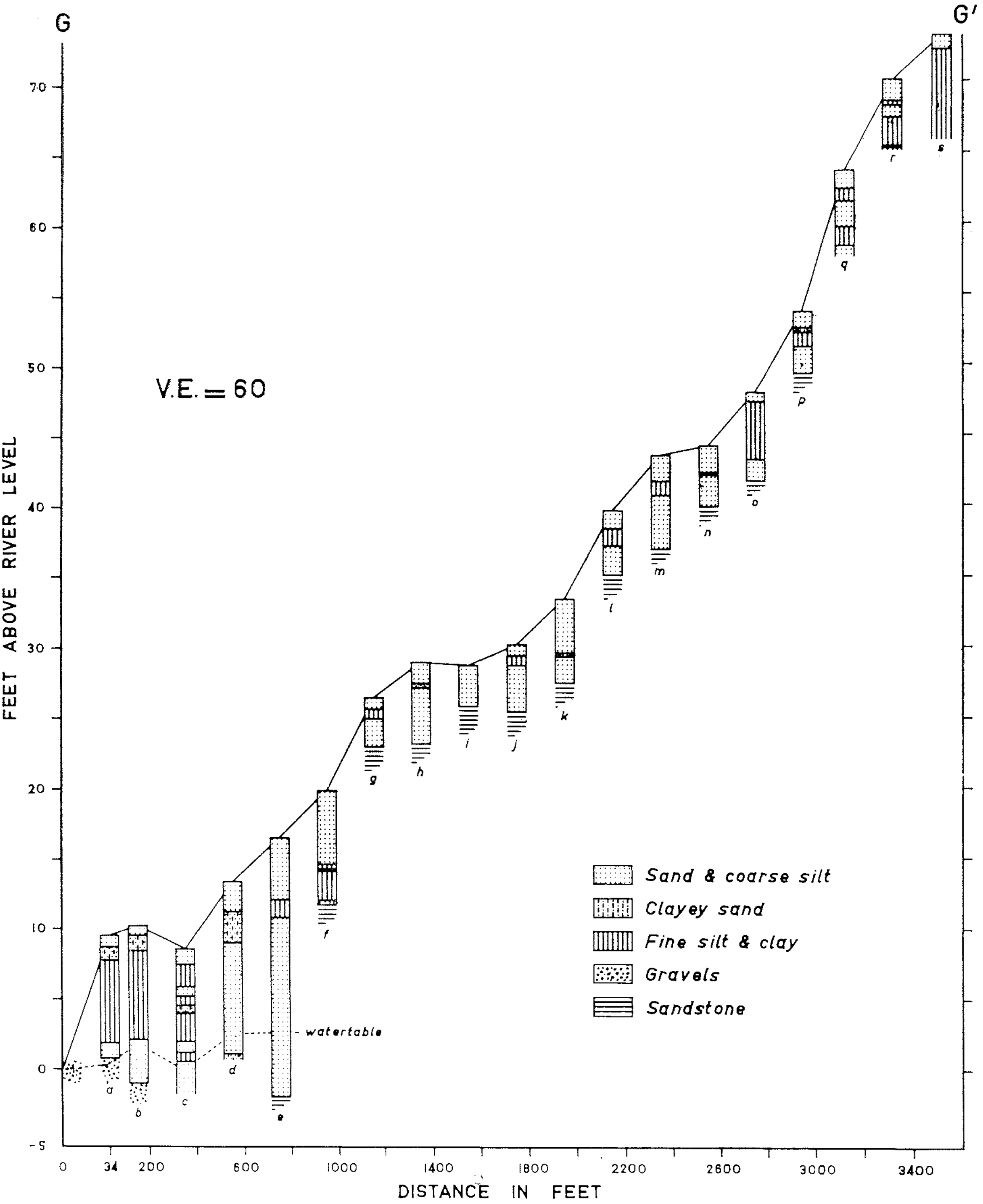

FIG. 9.—Series of auger holes at 200 foot intervals from the Ironstone Surface down to the Prosser River.

is not downcutting. The channel width was measured in several places and it was found that the maximum width did not exceed 25 feet. Taking the values W = 187 feet, w = 25 feet and b = 0.5 and substituting these in Dury's formula we get:

$$Q/q = (187/25)^2 = 56.$$

This would indicate that the bankfull discharge of the prior Tea Tree was fifty-six times greater than that of the present stream. The figure fifty-six should be regarded as very approximate but it does show that the prior Tea Tree was a very much larger stream. The reduction in discharge cannot be due to a reduction in the area drained by the Tea Tree as there is no evidence that its drainage area has recently been reduced by capture.

The problem is similar to that of the misfit streams investigated by Dury. The writer agrees with his views that " the disparity between present discharges and calculated former discharges is so great as to indicate a change in the regimen of runoff—a change that can scarcely not have been associated with a change in climate, including a change in the total annual precipitation ". It is difficult to imagine that the large changes in discharge are due to changes in precipitation alone and Dury has suggested three other possibilities—

(1) When the large channels were being cut, runoff was seasonally concentrated by snow melt.

(2) The yield of runoff per unit of precipitation was increased by reduced evapotranspiration.

(3) There has been a change in rainfall intensity.

Regarding (1) and (2) Dury stated that they " plainly refer to times of low temperatures ". Thus the very much larger discharge of the prior Tea Tree is best explained as a result of seasonally concentrated snow melt and reduced evapotranspiration. this may, or may not, have been accompanied by an increase in precipitation. The conditions suggested here would have existed in the Buckland Basin during the last ice age. The evidence from the prior Tea Tree is consistent with the suggestion of a periglacial origin for the depressions found further upstream on the Turvey Terrace.

Along the Eastern Boundary Scarp bordering the basin are a number of large low angle alluvial fans. They occur in the valleys of both the Back and Tea Tree Rivers but have been mapped only along the latter (fig. 7). Further south in the Tea Tree Valley they unite to form a continuous apron, with their apices from 60 to 150 feet above the level of the rivulet. Their surfaces are strewn with ferruginous (buckshot) gravel. Where the fans are dissected they are seen to be made up of layers of dolerite gravels sometimes separated by bands of clay. The matrix between the boulders is also rich in buckshot gravel. This gravel consists of magnetic iron oxide which is not derived from the dolerite but is concretionary in origin. It probably originates from the breaking up of older soils with ferruginous hardpans.

The last depositonal phase in the history of the fans was a very minor one and may have been due to a single flood. In some channels incised in the surfaces of the fans this phase is indicated by small fill terraces, while other channels were completely filled with gravels and have since partially re-excavated their courses exposing gravels of two distinctly different ages in their beds. The fans are truncated by the present floodplain and as well, one of them has been cut into by the prior Tea Tree. The evidence suggests that, apart from minor deposition confined almost entirely to the present channels, the fans predate the closing phase of the Turvey aggradation. They may be the same age as the Turvey Terrace but could well be older Pleistocene features with a complex history.

Discussion

There is evidence of two periods of alluviation in the basin. The older is represented by the Turvey alluvium and the younger by the sediments of the Brockley floodplain. The Brockley sediments are considered to be aggradational because the stream channels in general do not reach down to the base of the sediments. This is true even of channels which are actively cutting down. There is also a tendency towards braiding particularly in the case of the Prosser and Brushy Plains. The sediments are characterized by a typical sequence of horizontal layers. The floodplain was probably built up by deposition during floods accompanied by a certain amount of braiding. The Turvey Terrace is also thought to be aggradational. Although the alluvium is coarser and thicker it is also horizontal and shows the same sequence of coarse gravels at the base followed by finer grained sediments.

Aggradation may be due to tectonic, climatic or eustatic causes. Since there is no evidence of recent faulting or tilting, a tectonic origin can be excluded. Recent movements on the Eastern Boundary Fault can be ruled out by the fact that the rock-cut Buckland Terrace passes across it without change in height. Pleistocene lowerings of sea level, whether eustatic or epeirogenic, can be excluded as a cause of aggradation since the slope of the emerging land was sufficiently steep to produce nickpoints in the stream profile. Aggradation due to regrading of the river profile as a result of delta building can also be ruled out. Postglacial aggradation due to this cause is impossible since the drowned mouth of the Prosser has not yet filled up to above water level, while interglacial aggradation can be disregarded as both the Turvey and Brockley sediments postdate the last interglacial period (page 19). It is very likely that the two periods of aggradation are due to climatic causes.

A hypothesis of climatic terraces, which is often referred to as Huntington's Principle, was developed by Huntington (1914), who (quoted from Hadley, 1960) argued " that all terraces form in a similar manner as follows: The first cycle begins when the streams are deepening and widening their channels and are cutting into bedrock. Deposition is then brought about by a climatic change which encourages erosion. The process is reversed later and results in trenching of the alluvium. The vestiges of these alternating processes are terrace remnants ".

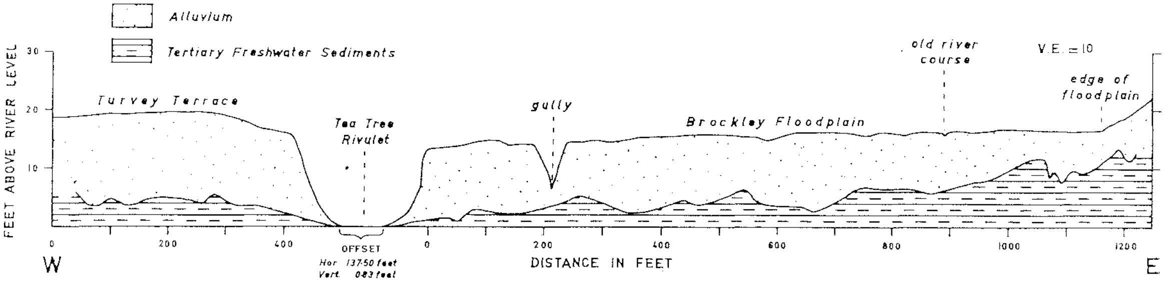

FIG. 10.—Seismic survey across the Tea Tree Valley showing depth of floodplain and Turvey alluvium.

Cotton (1945) restated Huntington's Principle and placed emphasis on the role of vegetation: " It may be urged with confidence that at least in certain cases an increase of precipitation will so encourage the growth of vegetation on catchment slopes in the headwater reaches of a river valley as to reduce their output of waste, and also that, even without such a reduction in the load to be carried by the river, higher precipitation will also increase the ratio of water to waste in the stream coming from the headwaters as to cause degradation down the valley; whereas a lessening of the ratio of water to waste in the stream, such as will be brought about by reduced precipitation probably aided by sufficient weakening of the vegetational protection of the soil in the catchment area to increase the absolute rate of supply of eroded debris, will cause overloading and result in aggradation of the valley ". Basically Huntington's Principle means that any process which increases significantly the load/discharge ratio will tend to produce aggradation. In this respect the coarsest fraction of the load is most critical.

Three types of climatic conditions have been thought to give rise to the following classes of climatic terraces (Zeuner, 1959):

(1) fluvioglacial terraces.
(2) periglacial terraces.
(3) terraces in regions of arid and semi-arid climates.

Aggradation in arid regions is not only the result of a decrease in rainfall but also depends on rainfall distribution and intensity, temperature, vegetation and the rate of weathering.

In the Buckland Basin aggradation may have resulted from either a period of greater aridity or one of periglacial activity. A fluvioglacial origin can be ruled out since there is no evidence that any part of the drainage basin of the Prosser was ever glaciated. Carbon 14 dating has shown that the Brockley sediments are mid-Recent in age so that they cannot be of periglacial origin. The Brockley alluviation was probably initiated by a mid-Recent arid period (altithermal?). However, the vigorous downcutting which is now in progress in the basin is not directly a result of a wetter climate. It is almost certainly due to clearing of the dense tea tree vegetation from the floodplains. Perhaps the clearing upset a precarious equilibrium between aggradation and downcutting.

Evidence has already been presented that the Turvey Terrace was probably formed during a glacial period. It is not likely to be older than the last glacial (Wisconsin) judging by its state of preservation and by the fact that it was deposited at a level close to that of the present river profile. A periglacial origin for the terrace seems most likely, since solifluction deposits are known to occur in the drainage basin of the Prosser down to 1500 feet and periglacial activity must have greatly increased the load supplied to the streams. Zeuner (1959) considered that periglacial terraces occurred in cold, dry regions but it follows from Huntington's Principle that periglacial action could significantly change the load/discharge ratio by solifluction thus increasing the load without the need for a drier climate.

If the two aggradational phases have different origins as suggested, some differences in character between the Brockley and Turvey sediments can be expected. Such can be discerned although, where studied, both are derived from dolerite terrain. The Brockley alluvium is rich in clay. Black clays are very characteristic of the upper part of the sequence while yellow-brown clays are not everywhere present but also have a distinctive character. Although a thin band of medium grey clay was found in auger hole e, clays are rare in the Turvey sediments. However, under the binocular microscope they were found to be rich in unweathered plagioclase. This and the contrast in clay content suggest that the alluvium of the floodplain suffered more chemical weathering before deposition than that of the Turvey Terrace.

A comparative study was made of the basal gravels of the Turvey and Brockley alluvium. The method used to determine sphericity and form of the pebbles is the one developed by Sneed and Folk (1958). A total of 150 dolerite pebbles was measured, 75 from the Brockley gravels and 75 from the Turvey gravels. Care was taken to select sites with pebbles of comparable size. Both samples were collected from narrow bands one foot high and eight feet long. The Brockley pebbles were collected near R3-6 on the sample map (fig. 1) from the base of the gravels just above the contact with the Tertiary clays. The Turvey pebbles were collected near the locality marked R16-18 and taken two feet above the base of the gravels because of water levels.

The pebbles were scrubbed clean and the long (L), intermediate (I) and short (S) axes measured using vernier calipers. The measure of sphericity used was the maximum projection sphericity introduced by Sneed and Folk (1958) which has several advantages over the more widely used Wadell sphericity. Form was determined by calculating the ratios S/L and L-I/L-S, plotting the values on a triangular form diagram and using the form classification proposed by Sneed and Folk. Roundness was estimated by means of the visual comparison chart of Powers (1953). Small differences in sphericity, form and roundness were observed but they were not statistically significant.

In comparing the surface characters of the pebbles it was noticed that pitting due to chemical weathering appeared to be deeper and more frequent in the Brockley than in the Turvey pebbles. The pitting is due to the weathering out of pyroxene crystals in preference to plagioclase. In order to find out if the degree of pitting was significantly different in the two sets of pebbles a standard of comparison was made up. It consisted of four Brockley pebbles showing a range from smooth to severely pitted. All pebbles were compared with this standard and put in the class of the standard pebble which they most closely resembled. The following results were obtained:—

	Brockley Pebbles	Turvey Pebbles
Smooth	17	32
Lightly pitted	29	28
Moderately pitted	20	11
Strongly pitted	9	4
Total	75	75

A chi^2 test gave a value of 9.2 with three degrees of freedom so the difference is statistically significant. It suggests that the Brockley pebbles were subject to more chemical weathering before deposition than the Turvey pebbles. If weathering had occurred after deposition the Turvey gravels would have been more weathered since they are older.

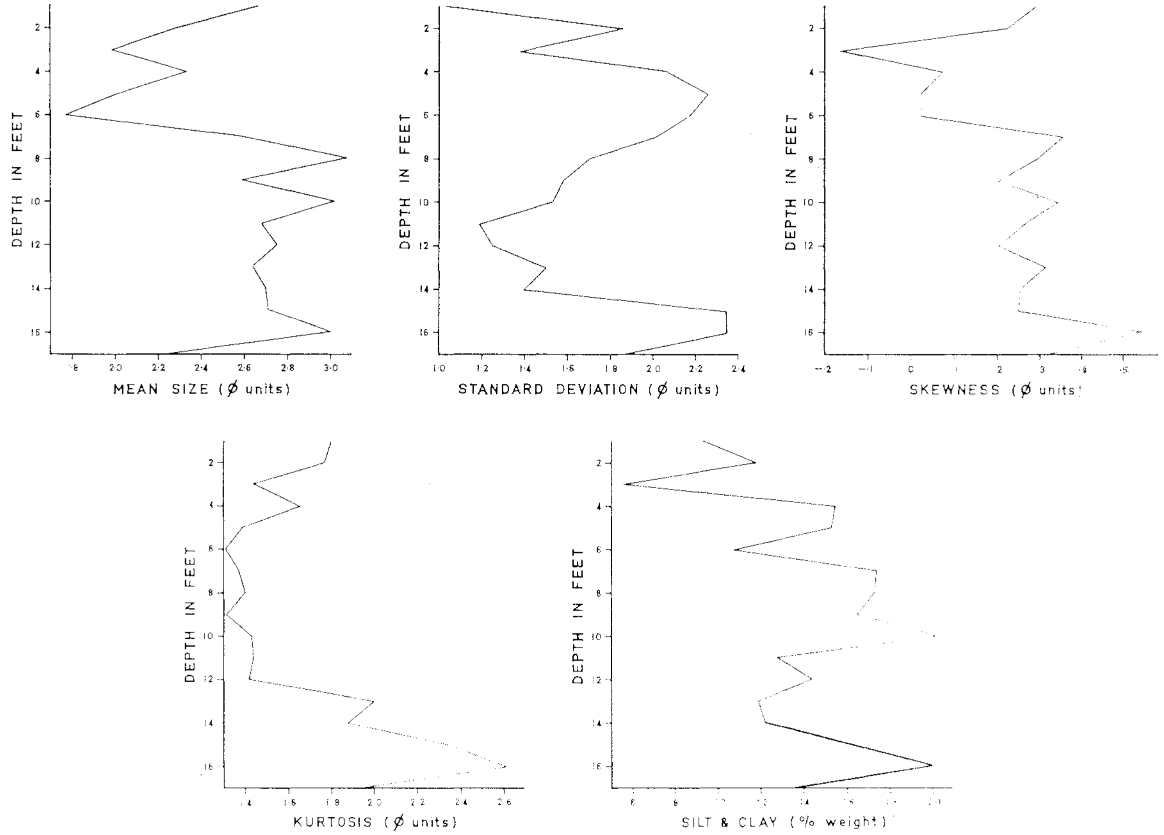

Fig. 11.—Sedimentary analyses of samples of Turvey alluvium taken at one foot intervals from auger hole e.

CONCLUSION

The Buckland Basin probably originated as an enclosed tectonic basin as a result of early Tertiary faulting. Two dominant directions of faulting are present but it is not known if both are of the same age. Early Tertiary freshwater sediments in the Tea Tree Valley are thought to represent remnants of the infilling of the basin.

Faulting predates the development of the Nugent Surface the formation of which required a long period of stability due to a stable or rising baselevel. It may have been initiated during the Oligocene-Miocene marine transgression. The Prosser at this time may have flowed out between the Three Thumbs and Prosser's Sugar Loaf to enter the sea near Rheban, to be captured later by a small stream extending its drainage area inland from Prosser Bay.

As baselevel was lowered the Prosser became incised in its new lower course, at the same time cutting rapidly into the unconsolidated lake sediments which had filled the basin. The Eastern Boundary Fault was gradually exposed as a resurrected fault scarp. The summit level at 600 to 700 feet to the west and north of the basin marks another period of stability, perhaps in the Pliocene. This level predates a small basalt flow south of Buckland which goes down to less than 500 feet and may be Pliocene or early Pleistocene in age.

Oscillations in the relative levels of land and sea during the Pleistocene caused alternating periods of down-cutting and stability in the Prosser and its tributaries giving rise to erosional terraces. Three or four periods of stability are recognized in the basin. One doubtful period is suggested by the presence of summits and shoulders from 170 to 240 feet above river level while three others are indicated by the Court Farm and Buckland terraces and the erosional surface underlying the present floodplain. The first two periods were sufficiently long to enable the rivers to cut terraces in dolerite as well as in the softer rocks whereas the last one lasted long enough for a surface to be cut in the Tertiary clays and Triassic sandstones but not in the more resistant dolerite. This is well seen near Buckland where the Prosser and Brushy Plains have cut only a narrow channel into the Buckland Terrace. The development of the sub-floodplain surface has been retarded by periods of aggradation.

There is a considerable time lag between the formation of nickpoints and their effect on the Buckland Basin. The last two nickpoints formed have not yet affected the basin but must eventually do so even if no further lowering of baselevel occurs.

The basin has been affected by two periods of alluviation represented by the Turvey and Brockley sediments respectively. The surface morphology of the Turvey Terrace suggests a periglacial origin. Chemical weathering of the Turvey dolerite pebbles is less than that of the younger Brockley pebbles. As well, the comparative absence of clay and the presence of unweathered feldspar in the Turvey sediments suggest deposition after a long period of predominantly mechanical weathering. Therefore a late Wisconsin age for them seems most likely.

Carbon 14 dating has shown that the Brockley sediments are mid-Recent in age. The high clay content and more pronounced chemical weathering of dolerite pebbles suggest a warmer climate for some time prior to and during their deposition. Aggradation is believed to have been initiated by a mid-Recent period more arid than the present which may also be responsible for the wind-deflated hollows on the Buckland Terrace. However, the present rapid dissection of the floodplain is primarily due to clearing of dense tea tree vegetation perhaps upsetting an already precarious equilibrium between aggradation and downcutting.

Alluvial fans along the eastern boundary of the basin may be related to an early phase of the Turvey aggradation or could be older Pleistocene features.

The almost complete removal of fluvial sediments from the older erosional terraces suggests a past period of much greater mass movement on gentle slopes. This applies particularly to the Buckland Terrace, only 30 to 40 feet above river level and remarkably flat. The older terraces may have been stripped of their fluvial sediments under the periglacial conditions existing at the time of the Turvey aggradation.

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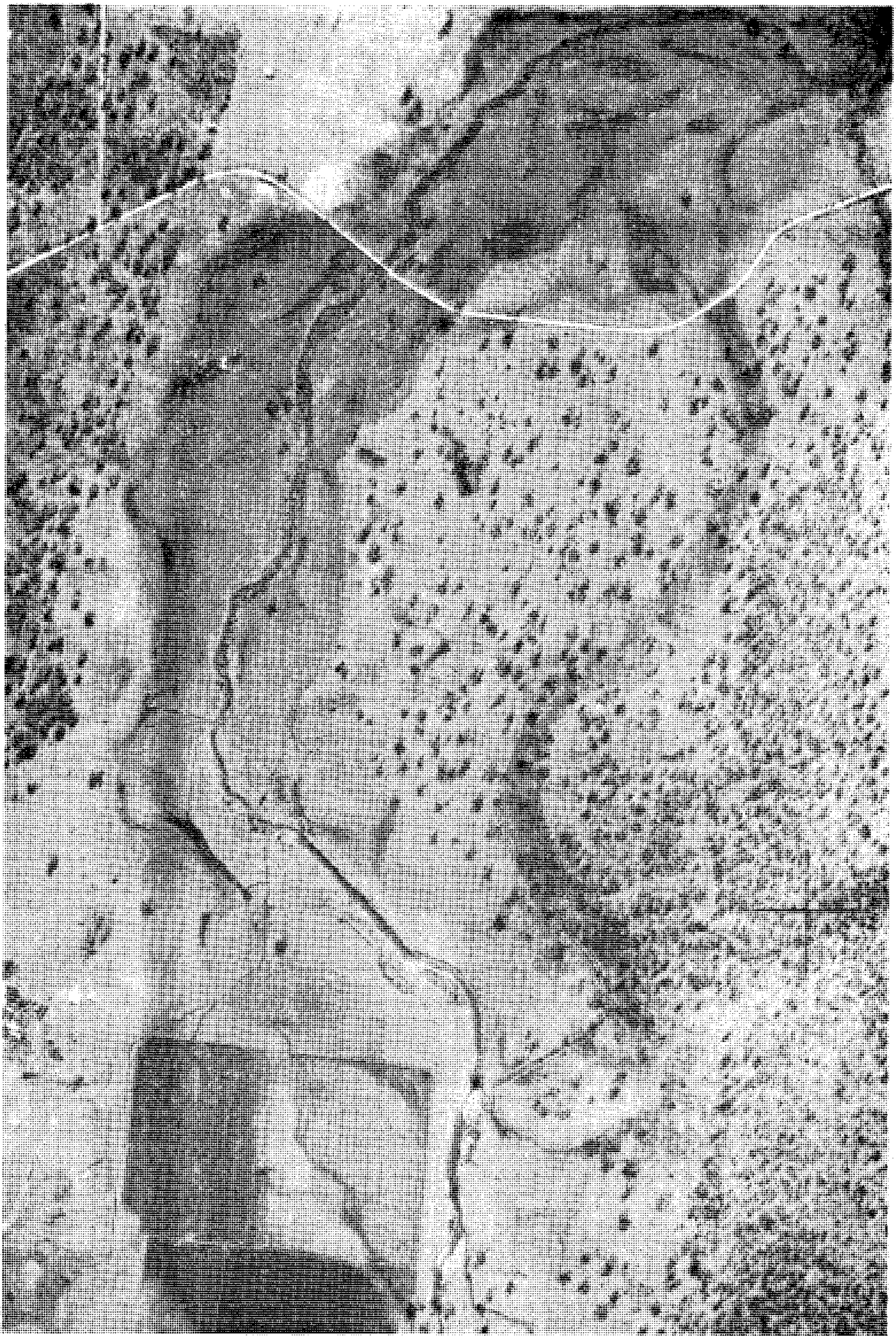

PLATE 1.—Aerial photograph of lower Tea Tree Valley. Prior Tea Tree is seen on Turvey Terrace at right hand side of photograph. Gatehouse's Marsh occupies top right hand corner. North is at the top of the page.

Photograph: Lands and Surveys Department. Scale: 1 inch to 750 feet.

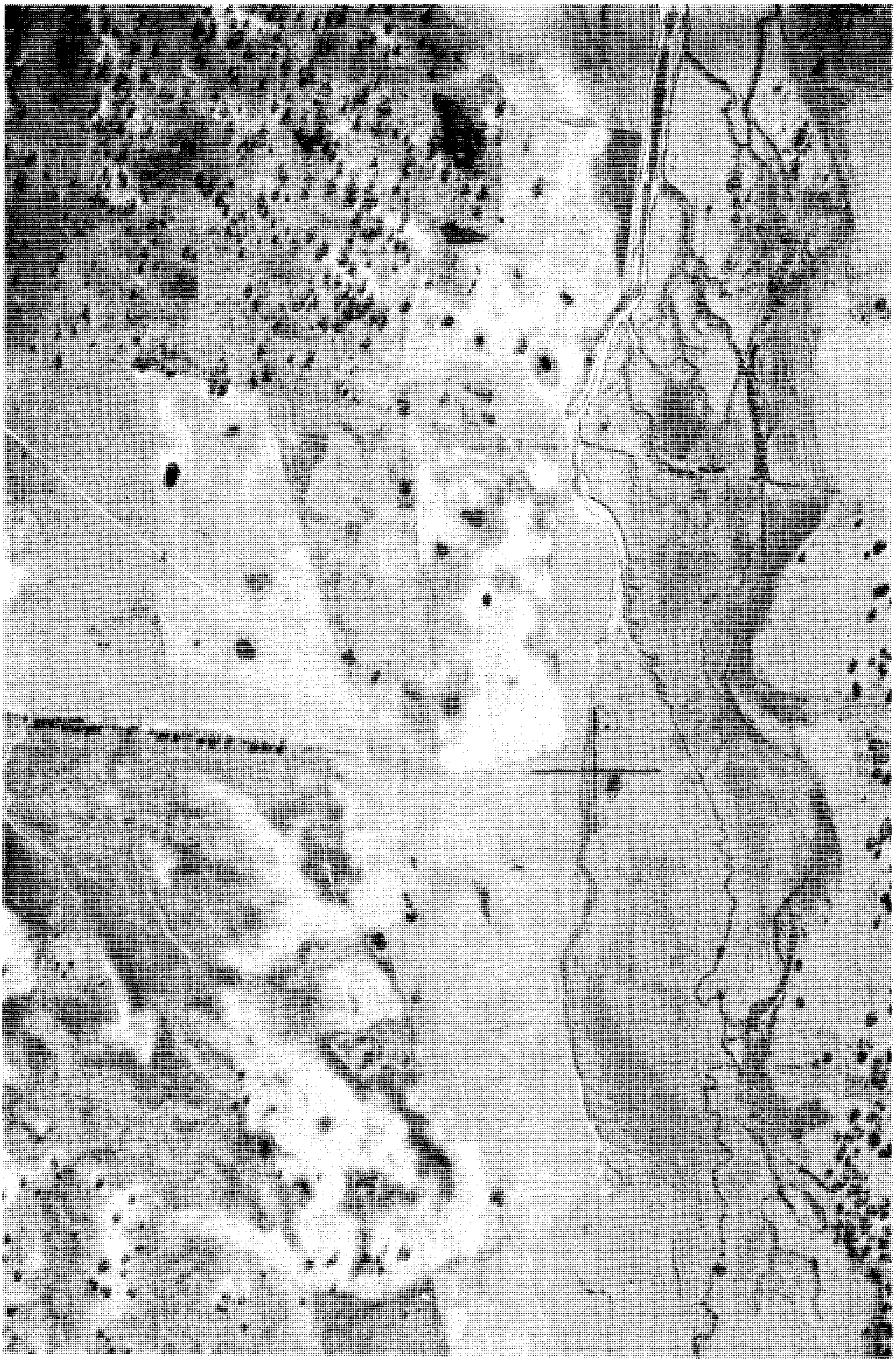

PLATE 2.—Aerial photograph of part of Tea Tree Valley showing extensive gullying of floodplain and branching nature of gully heads. Two thirds of photograph shows Turvey Terrace with circular and elliptical depressions which may be thaw sinks formed under periglacial conditions. North is at the top of the page. Scale: 1 inch to 750 feet.

Photograph: Lands and Surveys Department.