NOTES ON THE CAINOZOIC HISTORY OF WESTERN TASMANIA— "MALANNA" GLACIATION

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(With 4 Text Figures)

ABSTRACT

The Cainozoic history of the Malanna area included faulting, deposition of sediments by streams or in lakes and swamps, two epochs of planation, and stream erosion. There is no physiographic, depositional or structural evidence for glaciation in this area, the type area of Lewis's Malanna Phase of the Pleistocene glaciation. This phase must be considered invalid on the evidence available in the type area and the term " Malanna Phase " should be abandoned.

INTRODUCTION

Gregory (1904, p. 51) first described the sediments near Malanna which were later considered to be morainal and adopted by Lewis as the type feature for his Malanna Glacial Phase of the Pleistocene glaciation. Gregory considered them to be glacial because of the presence of boulder clay containing boulders of very decomposed dolerite. Because of the depth of weathering of the boulders and " lack of indication of recent glaciation in this locality ", he provisionally assigned a Carboniferous (Permian of present day nomenclature) age to the glaciation. Later Loftus Hills showed these deposits to David, who was impressed by the shattering of the Permian rocks at Malanna and influenced by the flat-floored, steep-walled valley of the Eden Rivulet (now Badger River) and perhaps also by the morainal form of some of the hills near Firewood Siding and Koyule (see Fig. 2). David (1926) also considered the deposits near Malanna to be glacial and, because of the impressions he had gained of the physiographic effects of glaciation, he considered them to be Pleistocene. On the grounds of depth of decomposition of the dolerite boulders and amount of river erosion since the supposed glaciation he considered that the " Malanna Moraine is at least as old as Mindel, and possibly even as old as Günz ". The presence of dolerite boulders, the lack of known outcrops of dolerite in the neighbourhood and the supposed glaciation forced David to postulate transport of dolerite from Mount Sedgwick, twenty miles away, by an ice sheet, as Mount Sedgwick was, and still is, the nearest known dolerite-capped mountain showing glacial effects. In 1934 Lewis designated these deposits as the type evidence for his Malanna Phase.

Gill and Banks (1950) visited the area and made observations on the older rocks. In 1953 K. G. Brill, G. E. Hale and M. R. Banks visited the area and K. G. Brill made the important discovery that there was a large outcrop of dolerite less than one mile north of Firewood Siding, and less than half a mile from the nearest "morainal" deposit. Detailed sections were measured in some of the cuttings. In 1957 the present authors visited the area in an attempt to solve the outstanding problems connected with the glaciation but, after a few days further observation, concluded that there was no evidence at all for Pleistocene glaciation in this area and that all the features could be produced by Tertiary faulting and normal erosion.

Method of Measuring Heights

Heights quoted along the railway line and south of the Henty River are those for a series of survey pegs which were established by R. Braybrook, Hydro-Electric Commission surveyor, as part of an air-photo control survey. The heights of the survey pegs are related to mean sea level at Hobart. The four heights not on the railway line were measured in 1957 by an aircraft altimeter capable of reading to ten feet. The heights were found by reading on the survey pegs, then on the various physiographic features and then onto the same or another survey peg. Maximum time between successive readings on survey pegs was twenty minutes.

The authors wish to acknowledge helpful criticism of the manuscript by J. L. Davies, Geography Department, Professor S. W. Carey and Dr. E. Williams, Geology Department, University of Tasmania.

PHYSIOGRAPHY

The Malanna area is situated north of the mouth of the Henty River, a couple of miles inland from the western coast of Tasmania (see map, fig. 1).

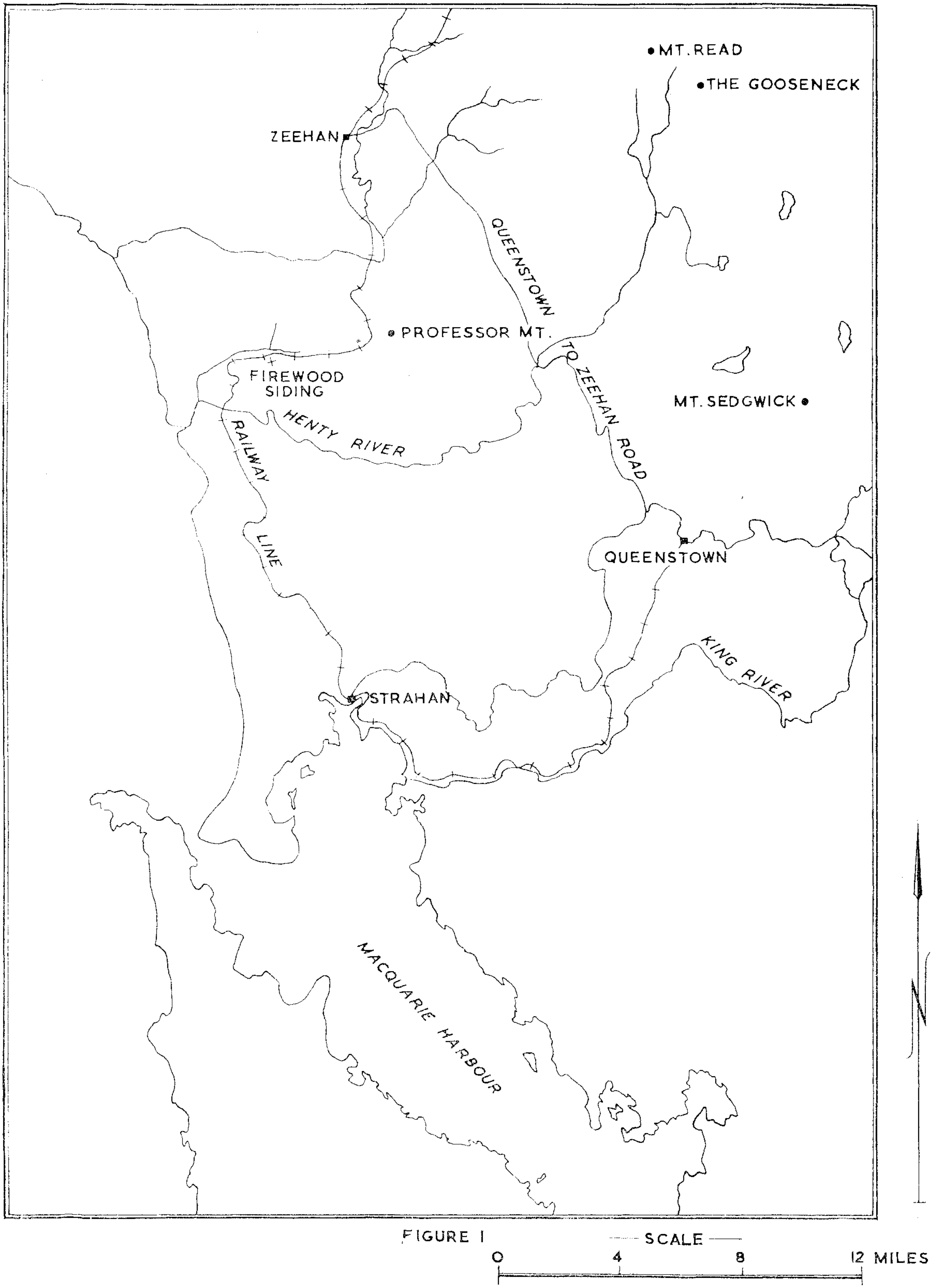

MT. READ
THE GOOSENECK
ZEEHAN
QUEENSTOWN TO ZEEHAN ROAD
PROFESSOR MT.
FIREWOOD SIDING
HENTY RIVER
RAILWAY LINE
MT. SEDGWICK
QUEENSTOWN
KING RIVER
STRAHAN
MACQUARIE HARBOUR
SCALE
0 4 8 12 MILES

FIGURE 1

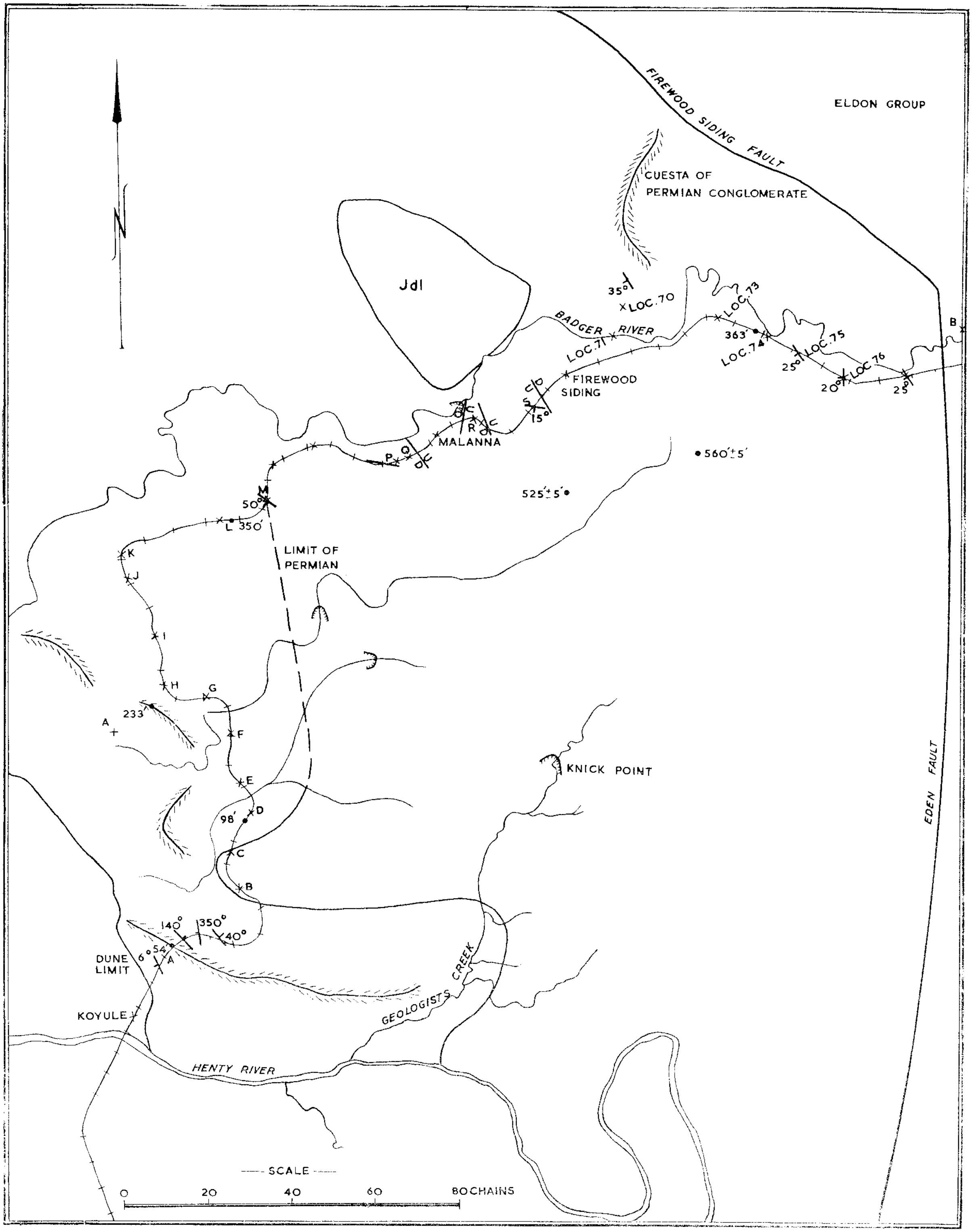
The main drainage of the area is by the Badger River to the north and the Henty River to the south. The Badger River rises about four miles to the east on the western slope of Mount Professor (see Gill and Banks, 1950, pl. III). From its source to about half a mile east of Firewood Siding the river flows in a swampy plain about half a mile wide which has a height of about 360 feet above sea level about a mile east of Firewood Siding. The plain lies between steep scarps on both sides and the river flows mainly near the western or northern boundary of the plain (see Gill and Banks, 1950, pls. I and III). There is one low, sharp ridge on the plain which parallels the western and northern wall and is about twelve chains from it. The main tributaries above Firewood Siding enter the Badger River from the east and south and are approximately at right angles to the scarp bounding the plain. In this part of its course the western and northern scarp is in Crotty Quartzite, the river plain in Gordon Limestone with a sandy band in it which is represented topographically by the small ridge on the plain, and the eastern and southern scarp a dip slope in Owen Conglomerate and Caroline Creek Sandstone. From its source to about half a mile east of Firewood Siding, the Badger River and its tributaries are strongly structurally controlled; the river follows the strike of the Gordon Limestone and the tributaries are perpendicular to the strike around the noses of a north-west-plunging anticline and syncline. Only minor streams join the Badger River from the scarp of Crotty Quartzite. The Badger River is separated at its source in the north by a low divide from a stream cutting down through the Crotty Quartzite and finally flowing into the Little Henty River. The divide is within the plain and is only a few feet high. After crossing the Eden Fault (see fig 2) half a mile east of Firewood Siding the Badger River enters a valley tract (cf Hills, 1946) in which it is cutting into Permian rocks. The main tributaries now enter from the north and are more or less parallel to the strike of the Permian rocks. About thirty chains west of Firewood Siding the river enters a mountain tract (of Hills, 1946) in which it is entrenched in the sandstones of the Cygnet Coal Measures. Further downstream the relief is lower but the stream still in mountain tract until about one and three quarters of a mile west-south-west of Firewood Siding it opens out into a valley tract before turning south and flowing between vegetated dunes to the east and intermittently moving dunes to the west.

Loftus Hills is credited by Lewis (1926, p. 88) with the discovery of a small glacial valley superimposed on a broader glacial one in the Eden Valley. David (1926, p. 91) implies that the Eden Valley (now Badger Valley) had suffered "very ancient glaciation", but in neither case was any detailed physiographic evidence offered. At first sight, the Badger Valley might appear glacial because of the steep side slopes, the flat floor and the gentle curve of the valley in plan. These features of the valley are the result of normal atmospheric and stream erosion in a topography of rocks of varying competence, the incompetent Gordon Limestone lying between the resistant formations, Owen Conglomerate and Crotty Quartzite. A local base level developed in Permian rocks, just east of Firewood Siding, has caused the erosion to that level of the Gordon Limestone in the Badger Valley. The entrenchment of the Badger River west of Firewood Siding may be due to rejuvenation, possibly associated with faulting or fall in sea level, with headward movement of the knick point (see fig. 2). The Badger River valley shows no physiographic evidence of glaciation.

The main stream draining the area is the Henty River, which rises about sixteen miles to the north-east on the slopes of Mount Read and the Gooseneck and flows through the Henty Surface as an entrenched, youthful stream to within a mile or two of the Malanna area. It is still in mountain tract to within a mile of the railway bridge, but below this shows some depositional features near present river level. The Henty River north of the Queenstown-Zeehan Road is glaciated and the terminal moraines of the glacier which occupied the Henty Valley occur a few hundred yards below the road bridge over the Henty River (Bradley, 1954, p. 196, and Yolande River Sheet). The exact level of the foot of these moraines is not known but it is probably not more than forty feet below the bridge which has a height of 282 feet above sea level (H.E.C. Bench Mark). Below these moraines the Henty River is in a typical mountain tract and there are no further signs of glaciation.

The area between the railway line and the Henty River is drained by west-flowing streams and by Geologists Creek. In all cases the headwaters are in wide, low valleys and swampy conditions are common. Further down their courses the streams pass into steep, narrow, mountainous valleys before entering short valley and plains tracts prior to joining the Badger or Henty Rivers.

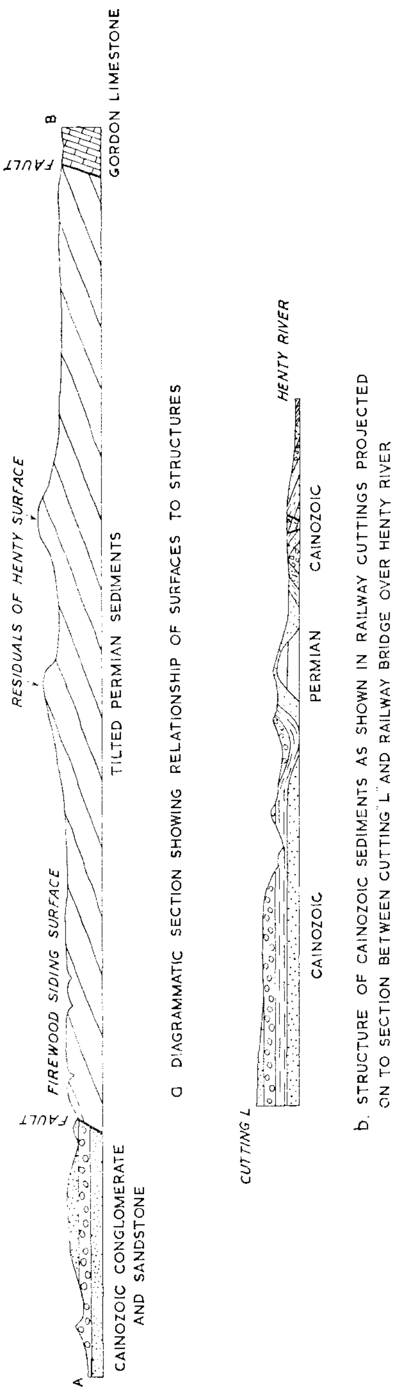
The surface topography of the area might, perhaps, be considered in terms of a number of erosional surfaces. The highest of these is the Henty Surface (of Gregory, 1903; not Bradley, 1954). This extends from the foot of the West Coast Range, where it has a height of from 1,100 to 1,200 feet above sea level, to the Malanna area. In the Malanna area a height was measured on a hill of Crotty Quartzite (Gill and Banks, 1950, pl. I, western photo, 1.5 cms. S.W. of centre point) which forms part of this Henty Surface. The height is 720 (± 10) feet above sea level, giving an average slope to the sea of about 60 feet per mile. Immediately south of Firewood Siding the heights of two hills in Permian sandstone and conglomerate were measured and found to be 525 (± 5) and 560 (± 5) feet (averaged figures) above sea level. The higher, easternmost one, is about two miles from the hill of Crotty Quartzite measured and the seaward slope is of the same order as that for the main part of the Henty Surface. North of Firewood Siding a sharp ridge of Permian and a hill of dolerite appear to reach a similar height to the hills south of Firewood Siding and to be accordant with flat-topped hills to the north, forming part of the Henty Surface. Thus the hills immediately south of Firewood Siding are considered to form part of the Henty Surface.



N
FIREWOOD SIDING FAULT
ELDON GROUP
CUESTA OF PERMIAN CONGLOMERATE
Jdl
LOC.70
LOC.71
LOC.73
LOC.74
LOC.75
LOC.76
BADGER RIVER
363'
FIREWOOD SIDING
MALANNA
560'±5'
525'±5'
LIMIT OF PERMIAN
L 350'
KNICK POINT
EDEN FAULT
233'
98'
DUNE LIMIT
KOYULE
GEOLOGISTS CREEK
HENTY RIVER
SCALE
0 20 40 60 80 CHAINS

FIGURE 2

Sections of Malanna Area Showing Physiography and Structure



a DIAGRAMMATIC SECTION SHOWING RELATIONSHIP OF SURFACES TO STRUCTURES

b. STRUCTURE OF CAINOZOIC SEDIMENTS AS SHOWN IN RAILWAY CUTTINGS PROJECTED ON TO SECTION BETWEEN CUTTING L AND RAILWAY BRIDGE OVER HENTY RIVER

FIGURE 3

Between these hills and the Henty River is a flattish area cut in dipping Owen Conglomerate and tilted Permian sediments. This rises abruptly along steep scarps to the north and falls abruptly to west and south along steep scarps. To the east it continues across Permian rocks and the Junee Group until it reaches a more resistant bed in the Owen Conglomerate which forms a steep dip slope about one and three quarters of a mile south-east of Firewood Siding. This surface is drained by wide, flat valleys. It is an erosional surface truncating the tilted rocks (see figs. 2 and 3). No heights have been measured on this surface, but from ground observations it would appear at its north-western end to be a few feet lower than the top of the Tertiary sediments (350 feet above sea-level). It rises somewhat to the east where it is a little higher than the height of the Badger River plain about a mile east of Firewood Siding, i.e., about 360 feet above sea-level. This surface at from about 350 feet to about 400 feet might be called the Firewood Siding Surface. Separating this surface from the present plain of the Badger River is an east-facing obsequent fault-line scarp of the Eden Fault about 40-50 feet in height. The plain east of this scarp is in Gordon Limestone that to the west in more resistant Permian mudstone and sandstone. Another flattish area occurs on the northern side of the Badger River north-west of Malanna. This also is eroded in tilted Permian sediments and is at about the same level as the Firewood Siding Surface.

The sharp ridge north of Firewood Siding is a compound one as a fault appears to pass across it near its southern end. Near the southern end it is made up of two connected cuestas, but a structural control for its northern end is not clear. The hills south of Firewood Siding forming part of the Henty Surface have steep southerly-facing scarps and gentler, although still steep, northern slopes. The southern scarp is a cut-off scarp of the creek shown on the map (fig. 2) now dissecting the Firewood Siding Surface. The northern slope is not a dip slope as shown by numerous dip readings in the Permian rocks in the railway cuttings.

On the hills east of Henty Siding, a siding about a mile south of the railway bridge over the Henty River, there are exposures of gravels containing large blocks of Permian sandstone and dolerite. These form part of a surface at about 300 feet above sea level. The hill west of cutting H has a height of 235 (± 5) feet above sea-level, and is more or less accordant with the hills immediately to north and south. The maximum height reached by the Tertiary sediments (in Cutting L, fig. 2) is 350 (±5) feet above sea-level.

Further west is a low sand-covered area, now vegetated, and beyond this an area of active dunes.

The two surfaces in the area, the Henty Surface and the Firewood Siding Surface, show no signs of glaciation in this area. The Firewood Siding Surface is shown on Gregory's map (1903, pl. XX) as part of his Western Peneplain. On neither surface are there any erratics locally, no ice polished, nor ice-scoured surfaces, and no sign of ice plucking. Although David noted roches moutonnées in the Eden Valley, he gave no details and the present authors are unable to find any. There are no signs of the passage of ice over any of the scarps and some of the ridges, e.g., that just south of Firewood Siding containing the measured hills, have steep irregular faces to the east (the alleged direction from which th ice sheet came) and a more gentle slope to the west. The sharp-crested ridge north of Firewood Siding is very steep sided and, in plan, convex to the west. It could, on superficial examination, be mistaken for a moraine, especially as it has blocks of rock scattered over its surface. However, detailed examination of this ridge shows it to be, at least partially, a cuesta in Upper Permian quartz sandstone and conglomerate and the scattered boulders to be entirely of these materials.

The Firewood Siding Surface is succeeded to the west and south by an area of lower hills (see fig. 3, *a*). Just south of the Badger River is a south-east-trending fairly-sharp-crested ridge cut by a south-westerly-flowing stream. In many places the crest of the ridge is demonstrably pebbly. Its height is 235 (± 5) feet above sea-level. South of the end of this ridge and separated from it by a deep valley is a sharp-peaked hill with a slight tendency to a south-south-westerly trend then a swing to the south-east. No outcrop occurs but boulders and pebbles are spread over the surface. This is separated by a creek valley and a swampy flat from a ridge which is cut by the railway line just north of Koyule and trends east-south-east. The surface of this ridge is gravel-covered, but the railway section reveals the presence of other types of sediments. It is clear that the ridge is not a depositional feature and, where cut by the railway line, it is anticlinal in structure. A superficial examination of these ridges may well suggest terminal moraines, more or less convex to the sea, later breached by streams. However, the section through the southern one clearly shows that it is not morainal and sections in railway cuttings just behind the others suggest the same. These considerations, together with a lack of glaciation in the hinterland, indicate that these ridges are not moraines. Thus, in the Malanna area, there is no physiographic evidence of glaciation.

CAINOZOIC DEPOSITS

The earliest record of Cainozoic deposits in this area is that of Montgomery (1890), who noted the presence of clays in the first creek valley west of the railway bridge and near the Henty Ferry and suggested their equivalence to the Macquarie Harbour Beds. In 1892 Johnston noted the presence of lignite in the same area and recorded a *Fagus* close to *F.* (now *Notofagus*) *cunninghami* and an *Acacia* close to *A. melanoxylon*. To him the close resemblance of these two forms suggested that the lignites were "of a more recent date than any other lignite formation hitherto described". Gregory (1904, p. 51) described some of the rocks in the railway cuttings. Boulder clays with boulders of Owen Conglomerate and decomposed dolerite up to two feet across were mentioned. Gregory described the boulders as lying at all angles and having a shape characteristic of ice-action, most of them having one or more flattened surfaces. David (1926, pp. 94-95) described the blocks in the northernmost railway cutting as up five feet in diameter and all rounded, although elsewhere on p. 95 he states that the shape of many is obviously glacial. In a footnote on page 102, David notes that the sequence is more complex than he had depicted. He states that the redistributed glacial beds at Henty Siding pass below sea level, are capped by lignitic shale and sandstone, and faulted.

It will be convenient to describe the deposits exposed in the railway cuttings between the railway bridge over the Henty River and Malanna in order from south to north.

Cutting A (see map)

At the southern end of the cutting a succession dipping 240° at 6° is exposed. At the base is a bed of gravel at least twelve feet thick and consisting mainly of rounded boulders of dolerite up to 30 inches long with some boulders of Permian sandstone, siltstone and conglomerate. Some of the boulders are sub-angular to angular. There is a suggestion of an upward decrease in grain size, although this is not marked. This is overlain by two feet of clayey sand and then one foot 10 inches of clayey pebbly sand with lignitic fragments used in radiocarbon dating. This latter bed of sand is cross-bedded, and contains some conglomerate bands in which there are pebbles of siltstone. In both of these sandy beds there are branching, cylindrical ferruginous concretions which are in some cases around lignitic fragments. The next bed is a conglomerate composed mainly of fragments of Permian siltstone with some lignite fragments. This is 1′ 8″ thick at its northern end but thickens to the south-west and becomes more conglomeratic in that direction. Some cross-bedding is present in the sandy matrix and the currents came from the north-east or north. This conglomeratic bed has an irregular lower surface and this forms a prominent overhang in the face of the cutting. The final bed in this succession is at least 15 feet thick and consists of gravels with sandy lenses showing cross-bedding indicating currents from north-east or north. Some clay lenses are also present. The main boulders are composed of Permian rocks and dolerite.

This succession is affected by two normal faults forming a small graben with a throw of a few feet. Further north in the cutting the succession is hidden for an interval by sand and vegetation. Beyond this gravels again occur. They are sandier than those in the southern end of the cut and contain rounded boulders of dolerite near the base, with boulders of Permian rocks and Owen Conglomerate becoming more common near the top. At the extreme northern end of the cutting these are overlain by a lignitic bed, then more gravels, sand, and finally a lignitic bed. The lower of these lignitic beds dips 50° at 40°. About half-way along the western wall of the cut sands and interbedded carbonaceous sand or peat abut disconformably against the gravels.

Cutting B

This cutting is mainly in Permian rocks which are described elsewhere (Banks and Ahmad ms). The Permian rocks are overlain by a bed of gravel two feet thick which, in one place near the southern end of the eastern bank of the cutting, occupies an old gully a few feet deep. The gravel is sandy and contains rounded to sub-rounded angular boulders of Owen Conglomerate, quartz, quartzite and Permian sandstone. This is overlain by about three feet of soil.

Cutting C

In this cutting Permian rocks are overlain by a couple of feet of gravel and then about three feet of soil.

Cutting D

The beds in this cutting dip 85° at 28°. At the base is a cross-bedded sandstone with some gravelly layers, which becomes lignitic and clayey towards the top. This is followed by sand and then, after a slight gap, sand with layers of peaty sand and boulders. Another cross-bedded sandstone follows. It is pale yellow-brown in colour and has rare boulders. The cross-bedding is due mainly to currents coming from the north-east. This sandstone passes up into the sandy clay, clay and then lignite. The top beds in the cutting are pebbly sands with three thin beds of boulders near the base and a bed of pebbles higher up. Cross-bedding dipping south-west is present. Boulders in these cuttings include those of Owen Conglomerate, Permian sandstone and weathered dolerite. These beds are overlain by a gravel is in Cuttings B and C.

Cutting E

At the southern end of this cutting there is a gravel with boulders up to four feet long which is rudely bedded and contains pockets of pebbles. There is a high proportion of boulders in the gravels, which range in size from a quarter of an inch up. The boulders are well rounded but the sphericity is frequently low. The boulders include those of dolerite, weather and fresh Permian rocks, including conglomerates and sandstone, quartzite, clay and Tertiary sandstone. The small dolerite boulders are completely weathered, the larger ones to a lesser extent. This part of the cutting is overlain by about three feet of soil.

To the north the gravels are overlapped by white cross-bedded, sandstones with interbedded clays and lignified wood, seeds and leaves with some pyrite nodules. Some of the larger fragments of lignified wood are still standing upright (i.e., are in growth position). The cross-bedding appears to be due to currents coming from the north-east. The succession in this part of the cutting dips 230° at 26° and is overlain unconformably by a surface gravel with boulders of Owen Conglomerate.

The succession was measured in some detail and is shown below:—

Top:

Gravel with boulders of Owen Conglomerate.
Unconformity.

18 feet: White, fine to medium grained sandstone with thin bedding.
1 foot: Coarse siliceous conglomerate with boulders of Permian sandstone.
4. feet: White, medium-grained, unbedded quartz sand.
1 foot: Coarse, siliceous conglomerate with boulders of Permian sandstone.
4 feet 6 inches: Grey clay with lignified plant remains near top and about one foot from top; top foot is fissile; some pyrite.
3 feet 6 inches: White, grey or white with red streaks, clay with cylindrical, spherical, branching and irregular limonitic nodules.
7 feet: Yellow to white, fine to medium grained sandstone, consisting of quartz with clay cement; friable; grains sub-angular to sub-rounded with a few pebbles.
5 feet: White, medium-grained sandstone with occasional bands of pebbles of Permian sandstone.
1 foot 6 inches: Conglomerate with rounded, elliptical pebbles and cobbles up to eight inches long, mainly of Permian sandstone.
1 foot: Medium-grained sandstone without pebbles.
9 feet: Sandstone with coarse bands of angular grains, with 9-inch pebble band with angular to rounded pebbles of several sizes of quartz, quartzite, Owen Conglomerate and Permian sandstone.
13 feet: Very pale, sticky clay.
4 feet: Gap in section.
6 feet 6 inches: Pale-brown, cross-bedded sandstone.
2 feet 6 inches: Clay, grey, with plant stems and some carbonaceous bands.
6 feet 6 inches: Pale-brown, cross-bedded, finely-bedded sandstone; quartzose, mostly fine-grained bed, some beds of medium to coarse grained sand; in the latter of which the grains are distinctly angular.
16 feet. Grey clay with plant stems and some carbonaceous bands.
26 feet. Sandstone, white to yellow, medium-grained, quartzite, thinly bedded.
5 inches: Conglomeratic, yellowish sandstone.
13 feet: White to pale-yellow sandstone with a few conglomeratic bands.
9 feet: Conglomerate sandstone with cross-bedding on small scale, dipping south-west; sub-rounded, sub-angular and some rounded pebbles and cobbles up to six inches long of Owen Conglomerate and Permian sandstone.

153 feet (approx.).

At the northern end of the cutting the south-westerly-dipping basal beds in the above succession are overlain unconformably by gravels with boulders of Owen Conglomerate.

Cutting F

At the southern end of this cut a fault throws cross-bedded sandstone to the south against beds of gravel and cross-bedded sand to the north. The cross-bedding dips north. The beds are almost horizontal and are from one foot to two feet thick. The boulders, which are up to three feet long are sub-angular to sub-rounded and rounded. They consist of Permian sandstone and siltstone, quartzite, quartz and dolerite. Many of the boulders are deeply weathered. The total thickness is about 30 feet. Further north again are sands containing a few large pebbles.

Cutting G

The main rock-type is a conglomerate lacking bedding and containing sub-angular to sub-rounded boulders up to several feet in diameter, with a few rounded ones. They consist mainly of Permian sandstone which is deeply leached and exfoliated. The matrix is sandy and there are some sandy bands, one of which is at least is in a washout.

Cutting H

Gravels are overlain by sands. The boulders are up to four feet long and are mainly Permian sandstone near the base but a few dolerite boulders occur near the top. The sands are cross-bedded with the dip of the cross-bedding to the south.

Cutting I

Sands at the base are overlain by lenses of gravel, followed by more sands and then gravel. The dip is at a low angle to the south. The top sands are cross-bedded with some of the cross-bedding traces in the cut dipping south-east, while most of them dip north-west.

Cutting J

Gravels with boulders more than three feet long are present.

Cutting K

The gravels in this cutting contain boulders up to five feet long. The boulders include those of Permian sandstone, and leached siltstone, with some quartz and quartzite. The gravels are interbedded with a fine-grained sand showing cross-bedding dipping north. A washout in the sands is filled with the conglomerate.

Cutting L

This is the last cutting in which Cainozoic deposits occur. They are gravels with many boulders up to a few feet long of Permian sandstone with a few boulders of dolerite.

The Cainozoic deposits exposed in the railway cuttings consist, then, of more or less unconsolidated rocks, with gravels, cross-bedded sands, clays and lignites being represented. The gravels are commonly bedded and the boulders in them are mainly sub-rounded. No striated pebbles were found, although they were looked for. The rock fragments consist mainly of Permian sandstone, siltstone or granule conglomerate, dolerite, Owen Conglomerate, quartz and quartzite and, more rarely, fragments of clay or clayey sand or lignite. Some of these boulders are now deeply weathered. It is notable that there is a general increase in grain size in the boulders from south to north, boulders up to five feet long occurring in Cuttings K and L, but all the gravels are not necessarily contemporaneous. It is also significant that the rock types present are all potentially of local derivation and could all come from within three miles to the east. The matrix of the gravels is predominantly sandy and they contain little clay.

Cross-bedding in the sands south of Cutting F dips mainly to the south-west, but north of this cutting the dip of the cross-bedding varies and tends to be northerly in several places. The presence of lignite indicates that some of the beds, at least, are paludal and no marine macrofossils were seen. There are numerous disconformities and some unconformities, suggesting folding or at least tilting before deposition of the later beds.

The radiocarbon dating indicates an age greater than 32,000 years for some of the lignites in Cutting A (Rubin, M, and Alexander, C, 1958, W444, p. 1483). This specimen was submitted on the mistaken idea that the conglomerates in this cutting were morainal and associated with the Malanna glaciation. A considerable age for most of the gravels is indicated also by the extent of weathering of the dolerite boulders. The deposits are clearly post-dolerite, the dolerite probably being Lower Jurassic. Some of the material from the lignitic beds in Cutting E was submitted to Dr. I. Cookson for palynological analysis. Seeds and seed cases on cones of *Banksia* cf. *marginata* were reported from the sample, so that a Cainozoic age seems likely and possibly an Upper Cainozoic age in view of the close resemblance of the seed cases to forms still living in the area. Final dating must await detailed palynological work but the beds might best be considered Upper Cainozoic and this would be in accord with Johnston's record (1892, pp. 12-13) of *Acacia* from this area.

The rocks in the cuttings thus provide no evidence of a glacial origin and there is no physiographic evidence for glaciation in the area. On these grounds alone the hypothesis of the existence of a Malanna Phase of the Pleistocene Glaciation in the Malanna area, must be considered invalid. Before providing an alternative explanation for the observed facts, a final point in David's argument must be dealt with, that of the " brecciated pavements ". To put the features so interpreted by David in their correct perspective the structure of the area must be considered.

STRUCTURAL GEOLOGY

The structure of the Lower and Middle Palaeozoic rocks to the east has been figured and briefly described by Gill and Banks (1950), is not relevant to the advancement of the argument, and will not be considered further. The Permian rocks near Firewood Siding are faulted against the older rocks. North of Firewood Siding is a fault, here called the Firewood Siding Fault, trending west-north-west and downthrowing to the south-south-west. This continues to about a mile east of Firewood Siding where a fault, the Eden Fault, trending north-north-east and downthrowing west, becomes the main structure. In general, the Permian rocks in the downthrown block dip to the south-west at angles varying from a couple of degrees to 50°, the latter occurring in Cutting M, that nearest the Tertiary beds, and suggesting a fault downthrowing to the south-west. The dips are all shown on the map (fig. 2).

In Cutting S there is a normal fault trending 330° (all bearings related to true north) and causing a distinct drag dip showing west side up. Joints trending 10° and 325° are common in this cutting. On some of the 325° joints are slickensides dipping west at a low angle and indicating west block north movement. Slickensides also occur on some of the bedding planes and show that the top moved west or north-west over the bottom.

Cutting R is that containing the rocks figured by David (1926, p. 102). At the eastern end of the cut the beds dip 115° at 30° and show joints trending 350° and dipping steeply west. Near the western end is a fault striking 340° and dipping west at about 45° and this is associated with much brecciation. In addition to these main faults, there are many minor normal faults dipping steeply west with a few normal faults dipping east and several minor thrusts dipping west. The beds affected are a formation of quartz sandstones and thinly-interbedded fine quartz sandstone and carbonaceous siltstones. The section figured by David is in the fine sandstone-siltstone alternation and

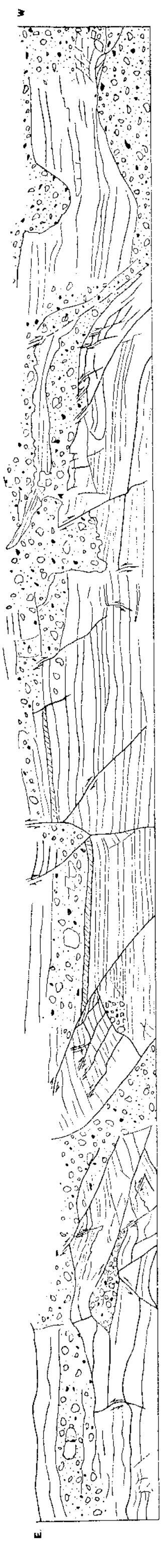


FIGURE 4 Diagrammatic Section of Cutting 'R', Malanna

these beds are consistently the ones showing the most brecciation and minor faulting. It is notable that in the main body of the cutting a bed of thickly-bedded quartz sandstone at the top of the cut is not affected by brecciation nearly as much as the underlying alternation of fine sandstone and siltstone. The structure along this section is shown as Figure 4.

Near the eastern end of Cutting Q is a normal, westerly-dipping fault striking 325°. In the body of the cutting the beds are horizontal. They are strongly jointed in places, the main joints trending north and showing horizontal slickensides indicating west side north movement. At the western end is a normal fault downthrowing to the east.

In Cutting P is a normal fault near the western end dipping 190° at 74°. In Cutting O the beds are almost horizontal, although in places they dip west and form a small monocline. They are disturbed by a small thrust dipping west and by joints mainly trending 340° but with some at 10°. The dip is west in Cutting N and there are minor faults. Joints are common, striking 120° and there are some parallel to the cutting which show horizontal slickensides. The Permian sandstone near the end of Cutting M dip 230° at 50° and this steep dip probably indicates a fault downthrowing south-west in the vicinity. Tertiary conglomerates in the next cutting west (L) appear to be horizontal. This may show that the fault is pre-conglomerate, but the cuttings are quite a few yards apart, so that the drag dip might lie due east of Cutting L.

The Permian rocks then show numerous normal faults, mainly trending north-westerly and forming small horsts and graben. With these are associated minor west-dipping thrust faults. The normal faults trend 330°, 340°, 325°, 10° and 280°. Joints trending 300°, 325°, 340°, 0° 10° and north-easterly occur. On the 325° set and the 0° set there is evidence of dextral movement and there is horizontal movement also on the north-easterly set. The faults are consistent with tension from S.W.-N.E. and some of the joints fit this pattern also. However, some joints do not seem to be related to this tension and a more detailed analysis is required. One case of bedding plane slip with movement down to the west or north-west was noted.

The major structures are quite inconsistent with faulting produced by an ice sheet moving from east to west. What thrusts are present dip west. The only evidence for ice thrust is the bedding plane slip but this could also occur with normal faulting of dipping beds.. Thus structures in the Permian rocks at Malanna used by David to support his hypothesis of glaciation in the area are inconsistent with this but consistent with normal faulting.

The Tertiary beds also show variations in the dip and some faulting (see fig. 3*b*). In the northern cuttings they are horizontal or nearly so. In Cutting E they dip 230° at 26° and in Cutting D they dip 85° at 28°, so that a syncline may be inferred, the axis trending roughly 340°, between these cuttings. In Cutting A the beds at the north end dip 50° at 40° and those in the south end dip 240° at 6°. An anticline, trending about 325°, would appear to be present. In Cutting F there is a fault with small displacement and in Cutting A two normal faults forming a graben. The northern one dips 260° at 45° and the southern one 50° at

50°. This graben would have a trend of about 335° and this is close to the main fault direction in the Permian rocks. Approximate coincidence of the fold axes with the fault directions suggests a genetic connection.

SOME ASPECTS OF THE GEOLOGICAL HISTORY

The Palaeozoic history of the Malanna area has been dealt with elsewhere (Gill and Banks, 1950, and Banks and Ahmad, ms). It is relevant to the present discussion only that the Lower and Middle Palaeozoic sediments were folded into plunging folds and then overlain unconformably by more or less flat-lying Permian sediments. Dolerite intrusions occurred in the Jurassic. At some later time the Firewood Siding and Eden Faults developed. The Henty Surface cuts across these faults and thus is later. This surface cuts across the Lower and Middle Palaeozoic rocks despite their differential resistance to erosion. It is, therefore, an erosional surface. Thin layers of gravel occur on it in places but there is no evidence that it is a stripped surface. It is certainly not a stripped pre-Permian surface as the Henty Surface extends inland to the foot of the West Coast Range where it has a height of 1,100 feet approximately. This range is probably a monadnock range as postulated by Bradley (1954, p. 195). The top of this range is probably part of the stripped pre-Permian surface (Bradley, 1954, p. 195), as shown by the Permian at Mount Sedgwick (Edwards, 1941), Mount Read and Mount Dundas, where the base of the Permian is at over 3,000 feet. The Henty Surface is now dissected by stream valleys up to 700 feet deep but some of the original surface remains, so that it is not likely to be as old as Early Tertiary. The surface was deeply dissected by rivers prior to the formation downstream from the Henty River road bridge of the terminal moraines. These moraines are dissected little except for the gorge cut through them by the Henty River and are thus probably not very old. Both the glacier responsible for these moraines and the glacier which occupied the Linda Valley are distributaries of the minor ice cap which occupied the West Coast Range between Mount Sedgwick and Mount Tyndall. The advance of the glacier occupying the Linda Valley has been dated as about 26,000 years, i.e., about equivalent to the beginning of the Wisconsin Glaciation, and the moraines below the Henty River road bridge might well be almost contemporaneous. They could probably safely be considered as Upper Pleistocene. Thus, the Henty Surface was formed well before the Upper Pleistocene.

The relationship of the sediments in the railway cuttings to the development of the Henty Surface cannot be established on evidence so far available in this area. They may have been deposited in lowlands in a pre-Henty surface of considerable relief. They may have been formed in a graben in this landscape delineated by the Firewood Siding and Eden Faults. The fault postulated between Cuttings L and M probably preceded the deposition of the gravels in Cutting L because of their horizontal disposition. At a later stage the Henty Surface would have been eroded in the Lower and Middle Palaeozoic, Permian and Cainozoic sediments. On the other hand the Cainozoic sediments may have been deposited as the Henty Surface was developing, streams stripping material off the higher country and depositing in the valleys until a surface, partly erosional and partly depositional, was formed. Yet again, the sediments may have resulted from uplift of the Henty Surface along a fault line between Cuttings L and M with formation of alluvial fans and fluviatile plains against the steep fault scarp. The sediments may have gradually filled up the fault lowland until they reached a profile of equilibrium related to the Firewood Siding Surface. No evidence is yet available to allow a choice between these alternatives.

The surface from which the Cainozoic sediments were derived must have had a considerable slope, at least in places, to account for the large particle size in the gravels. Boulders up to five feet in diameter in bedded deposits with a sandy matrix imply a considerable velocity and volume of water and thus a steep gradient. Variations in the competence of the depositional currents are shown by the occurrence of interbedded gravels, sands and clays. There is evidence of a systematic variation in current competence in the succession—gravel, sand, clay (with or without lignite)—which is developed completely or incompletely eight times in the sediments of Cutting E and three times each in Cutting D and Cutting A. The recurrent increase in competence represented by gravels, in many places associated with local disconformities, may be due to recurrent increases in rainfall following periods of lower rainfall, or to recurrent uplift due to faulting or lowering of base level. On several occasion peaty swamps were present. The cross-bedding in the sands suggests two sources, one to the north or north-east of Cutting L and the other somewhere between Cuttings E and F. Thus cross-bedding, dipping in a generally southerly or south-westerly direction occurs in most cuttings but cross-bedding dipping north or north-west occurs in Cuttings F, I and K. The presence of dolerite boulders in all cuttings suggests a northerly derivation, the dolerite mass near Firewood Siding probably being the source. The Owen Conglomerate boulders in the older deposits and superficial gravels in and south of Cutting E suggest a partial derivation of sediments in these cuttings from the east, the nearest Owen Conglomerate being about a mile and three quarters south-east of Firewood Siding. Some of these sediments are older than 32,000 years and some of them are older than the Firewood Siding Surface. In all cases it is probable that they are older than the last phase of the Pleistocene glaciation. Subsequent to deposition of the sediments in Cuttings A to E folding and faulting occurred. The trends of the folds and faults are almost parallel and this suggests genetic connection. They may well be due to slumping on a clay bed down a slope trending about 340° and dipping south-west. This roughly parallels many of the faults in the Permian rocks, and the slope may have been a fault scarp.

At some time after the development of the Henty Surface it was uplifted. Partial erosion of this surface produced the Firewood Siding Surface, cut in Lower Palaeozoic, Permian and Cainozoic sediments (at least those in Cutting L). The Henty River appears to have been a meander in this surface and after uplift was entrenched in it. At the time of development of the surface the Henty River locally had a height of about 400 feet relative to present sea level and must have been higher further upstream. As the terminal moraines on the Henty River have a height of only about 250 feet above sea-level at their downstream termination and there is no evidence of displacement or tilting of the Henty Surface between Malanna and the Henty River road bridge, the moraines must be later than the development of the Firewood Siding Surface. Thus this surface is pre-Upper Pleistocene. The surface falls from about 400 feet at the Eden Fault to 350 feet at Cutting L, a distance of about two miles, so that there is a fall of about 25 feet per mile. The base level controlling this surface is not known. " Beach terraces " at a level of about 400 feet above present sea-level are recorded by Twidale (1957, p. 12) from just north of the Pieman River, about sixteen miles north of the Malanna area, where they are incised into a higher plateau. No evidence is quoted for a marine origin for these " beach terraces ", nor near Malanna are any marine deposits known at this level. It is not, of course, clear that the " beach terraces " and the Firewood Siding Surface are in any way related but there is some parallel in the relationship of the two features to a higher surface and sea-level. The Firewood Siding Surface postdates both the sediments in the railway cuttings and the Henty Surface. Since development of the Firewood Siding Surface there has been rejuvenation and the knick-point on the Badger River has moved upstream about three quarters of a mile.

For fuller and more accurate reconstruction of the Cainozoic history and palaeogeographies, detailed sedimentation studies will have to be made and some method of correlation evolved which is applicable to the terrestrial sediments. This may well involve comparison of quantitative pollen analyses of the lignites. In addition, more information on rock distribution and detailed study of contour maps of this and neightbouring areas will be needed.

SUMMARY AND CONCLUSIONS

After development of the Firewood Siding and Eden Faults in a terrain of Palaeozoic sediments and dolerite, erosion produced the Henty Surface. Before, during, or after formation of this surface, a thickness of at least a few hundred feet of terrestrial gravels, sands, silts, and lignites was deposited. The grain size of some of the gravels indicates considerable gradient for the transporting streams. The succession, gravels, sand, silt or clay, is repeated completely or incompletely at least eight times.

Uplift of the Henty Surface was followed by erosion which finally produced the Firewood Siding Surface. This latter surface developed after deposition of some of the sediments. Further uplift resulted in erosion of the Firewood Siding Surface. After this uplift glaciation affected the West Coast Range and the Henty River valley as far downstream as the road bridge about eight miles east of the Malanna area at a height of about 250 feet above sea-level. This glaciation was probably equivalent to the Wisconsin in the Northern Hemisphere. The uplifted Henty and Firewood Siding Surfaces are locally being dissected by streams which, at least in the Lower and Middle Palaeozoic rocks, are strongly structurally controlled.

In the Malanna area there is no evidence of Pleistocene glaciation, whether by ice-sheet or otherwise, and the physiographic, sedimentational and structural evidence advanced by David (1926) in support of glaciation in this area was misinterpreted. More detailed studies indicate that all the facts known about the area suggest a Cainozoic history involving faulting, deposition of terrestrial sediments by streams, or in lakes and swamps and erosion by streams. It is concluded, therefore, that there is no longer any justification for retaining the term "Malanna Phase" for a Pleistocene glacial phase based on this area. Use of the term should be discontinued.

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LOCALITY INDEX

	Lat.	Long.
	41° 50′	145° 30′
Badger River	41° 59′	145° 14′
Firewood Siding	41° 59′	145° 16′
Geologists' Creek	42° 00′	145° 16′
The Gooseneck	41° 52′	145° 33′
Henty River	42° 02′	145° 18′
Henty Siding	42° 02′	145° 15′
Malanna	42° 01′	145° 13′
Mount Professor	41° 59′	145° 22′
Mount Read	41° 50′	145° 30′
Mount Sedgwick	42° 00′	145° 35′
Pieman River	41° 50′	144° 55′
West Coast Range	41° 44′	145° 33′
	42° 18′	145° 38′