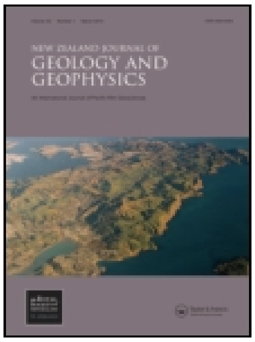

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Stratigraphy and sedimentology of the Coalgate area, Canterbury, New Zealand

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ABSTRACT

Stratigraphic and sedimentologic studies of the Cretaceo–Tertiary sequence overlying Torlesse rocks in the Coalgate area permit a review of the lithostratigraphy of the region. Much new information has come from borehole logs and cores. Coal measures conformably overlain by shallow marine strata and associated igneous rocks, including View Hill Basalt, are assigned to the **Eyre Group** (modified name) of upper Cretaceous and possibly Paleocene age. **Burnt Hill Group** (new name) is erected to accommodate some 200 m of Oligocene–Miocene non-calcareous marine, estuarine, and associated igneous rocks of central and northern Canterbury. Formations include: **Homebush Standstone** (new name for a massive estuarine deltaic deposit) (oldest unit); **Thongcaster Formation** of Duntroonian age (new name for a fossiliferous clayey fine sandstone); **Wairiri Volcaniclastite** (new name for a tuff-breccia deposit); **Chalk Quarry Sandstone** of Waiauan age (modified name); Chalk Hill Clay; **Sandpit Tuff** (name now formalised) consisting of sandy and silty tuffs and tuff breccias; **Bluff Basalt** (name now formalised) including breccia, flow and dike rocks; **Harper Hills Basalt** (name altered and restricted in usage); **Coalgate Bentonite** (rank of unit changed) (youngest unit). Burnt Hill Group is overlain by 55 m of sandstone and sandy mudstone of Greenwood Formation, of probable Waipipian age, and up to 40 m of viviantic sands, clays, and gravels of possible Castlecliffian and perhaps younger age which are included in **Aitkens Formation (new name)**. Much of the area is blanketed by Hawera Series outwash gravels which help to obscure the stratigraphic relationships of older formations in surface exposure.

KEYWORDS Tertiary, stratigraphy, Canterbury.

INTRODUCTION

The Coalgate area (Fig. 1) lies some 64 km west of Christchurch and may be divided physiographically into uplands, formed from Tertiary outliers surrounded by Pleistocene gravels of the Canterbury Plains, and gently rolling lowlands of the Glentunnel downs–Wairiri valley area. Harper Hills and Deans Range to the east form prominent basalt escarpments with a maximum height of 430 m on the south-east side of an old glaciated valley. The southern slopes of the Tertiary outliers are veneered with Pleistocene terrace gravels and loess giving a rolling topography in an early-mature stage of dissection on which no major streams are developed.

During a recent study of Coalgate Bentonite (Carlson & Rodgers 1974), the stratigraphy of the region was reassessed to clarify aspects of the depositional environment and alteration of the parental bentonite material. In the same work the mineralogy and petrography of sediments underlying and immediately overlying the bentonite were investigated to enable a distinction to be made between primary and derived components in the bentonite. The petrography and petrochemistry of the associated volcanic rocks has already been described (Carlson & Rodgers 1975). The following account is concerned with the lithostratigraphic and sedimentologic findings together with some notes on the structure..

Although many geologists visited the Malvern Hills area in the days of early geological work in New Zealand, little mention was made of the Harper Hills–Burnt Hill region. The principal work was by Haast (1871; 1872), who described the Cretaceous rocks. McKay (1887) reported on the Selwyn Rapids Beds and Woods (1917), Trechmann (1917), and Wilckens (1922) dealt with the Cretaceous paleontology. Hector (1871) and Haast (1872) briefly mentioned the "dolerites" of Harper Hills, and Haast (1872) also described the granular sands.

The most comprehensive survey was that of Speight (1928) who described in detail the Harper Hills Basalt, Bluff Basalt, and dikes of the Glentunnel downs. Speight (1927) also described the Burnt Hill sequence to which Marwick (1932) added the paleontology. Oborn & Suggate (1959) erected the Harper Hills Volcanics formation and mapped the onlapping Pleistocene terrace gravels. Gregg (1964) mapped the area for the 1:250 000 Geological Map of New Zealand. Previous work in connection with the bentonite was discussed by Carlson & Rodgers (1974; 1975).

The modal composition of the sediments was determined by the X-ray method of Nelson & Cochrane (1970) with the reservations of Carlson & Rodgers (1973). Clay mineralogic investigations followed the procedures given in Carlson & Rodgers (1974). Mechanical analyses of the sediments were made by conventional means; the object being merely to test conclusions concerning the depositional environment deduced from field observations. Full data are given in Carlson (1971).

Many data have been derived from boreholes sunk by Lime and Marble Co. Ltd. (prefixed W) and Canterbury Mineral Mines Ltd. (prefixed D). For economic

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reasons details of stratigraphy and structure revealed by these cannot be discussed, nor are any cross sections given.

Sample numbers cited in the text are those of the University of Auckland Geology Department petrology and paleontology collections. Fossil collections are allotted numbers within the New Zealand Fossil Record File (S75/f . . . or L35/f . . .); those prefixed GS refer to macrofossil collections held by the New Zealand Geological Survey. Grid references are based on the national metric grid NZMS 261 (1:50 000) Sheet L35.

REGIONAL GEOLOGY

The area mapped (Fig. 1) consists of upper Cretaceous and younger rocks unconformably overlying a basement of lower Mesozoic strata (Torlesse Supergroup) which is exposed immediately to the west. The Cretaceous rocks are of Mata age and constitute a south-westwards-thinning transgressive sequence with basal coal measures overlain by fossiliferous shallow marine sandstones. This sequence is intruded by olivine dolerite dikes correlated with the lower Paleocene View Hill Basalt (Gregg 1964).

Burnt Hill Group (new name) is assumed to be the next youngest unit, but contacts with older strata are obscured by Quaternary gravels. This unit is about 200 m thick and consists of quartz and glauconite sandstones, some containing Duntroonian and Waiauan marine faunas, an interbedded tuff sequence, and an upper volcanic portion. This group is believed to be of Oligocene–lower Pliocene age.

Within Harper Hills the volcanics are overlain with slight angular discordance by the marine Greenwood Formation consisting of about 55 m of sandstone and sandy mudstone of upper Pliocene–lower Pleistocene age. North-east of Stilson Point the Harper Hills Volcanics unit of Burnt Hill Group are overlain by vivianite-bearing blue or blue-green sandstone and sandy mudstone apparently deposited in channels scoured in the underlying bentonite and believed to be of lower Pleistocene age. These deposits, possibly in part coeval with Greenwood Formation, are included in the new **Aitkens Formation.**

Younger Quaternary deposits consist of glacial outwash gravels, till, and loess of the Hororata, Woodlands, and Burnham Formations (Porikan and Otiran age) and Holocene river gravels and swamp deposits.

STRATIGRAPHY

EYRE GROUP (modified name)

Macpherson (1947) erected the Eyre Sand Group for glauconitic and quartzose sandstones, mudstones, tuffs, and olivine basalt overlying the Torlesse Supergroup and underlying the Oligocene Oxford Chalk at Chalk Hill, northern Canterbury. Lower strata contain Mata Series molluscan faunas, although not in the type area, and upper beds include an orbitoid fauna now known to be of Mangaorapan age (Marwick *in* Fleming 1959). The full age range is not known but could be from Piripauan to Arnold Series; upper and lower contacts are unconformities.

Since its introduction, Macpherson's term has been largely ignored by New Zealand stratigraphers. Gregg (1964) reintroduced it apparently in a formational sense, as Eyre Sandstone, for "glauconitic sandstone, tuffaceous in part, with interbedded pillow lavas of View Hill Basalt". This usage is not accepted here because of the lithologic heterogeneity of the sequence (as pointed out by Macpherson 1947) and because it is considered terminologically simpler and therefore preferable to define discrete sedimentary formations separated by the igneous formation (View Hill Basalt). Furthermore, the presence of lavas, tuffs, and mudstones in the type sequence suggests that the lithologic term included in the name by Macpherson be dropped as misleading.

Upper Cretaceous and possible Paleocene rocks of the Coalgate area warrant correlation with Macpherson's unit as amended here.

As presently understood, Eyre Group includes coal measures, the conformably overlying shallow marine strata, and associated igneous rocks. To the north-east this would cover the upper Cretaceous coal measures, Ostrea Bed, Saurian Beds, and Waipara Greensand of Thomson (1920) in the Oxford–Glentui River, Mt Grey, and Middle Waipara to Motunau area (see also Speight 1928; Mason 1941; Wilson 1963; Gregg 1964) and could be extended to include the sequence from Okarahia Sandstone to Claverley Sandstone at Haumuri Bluff where, surprisingly, Warren & Speden (1978) did not employ a unit of group status. Fine-grained deeper-water beds of Dannevirke–Arnold age in this area, especially, for instance, Amuri Limestone (Thomson 1920; rejected as a formal formation by Wilson 1963, but used by Warren & Speden 1978), could be excluded from Eyre Group, but coarser beds of the same age to the north-west in the Mandamus–Pahau area (Mason 1949) should be included.

To the west, in the Broken River area, Gage (1970) erected the Broken River Coal Measures and Iron Creek Greensand as formations of upper Cretaceous–Eocene age lying unconformably between the Torlesse Supergroup and the Oligocene Porter Group. Gage regarded Iron Creek Greensand as the local equivalent of Waipara Greensand. Gage's formations were not assigned to a group, and in view of their similarity to Macpherson's (1947) units they can be included with confidence in Eyre Group. Gage (1970) also mapped these units further west in the Harper valley where Suggate & Wilson (1958) had previously recorded Eocene glauconitic and quartzose sandstones. These younger strata should also be included in Eyre Group.

South-south-west from Porter River, Lauder (1962) briefly discussed an upper Cretaceous sequence of about 21 m of coal measures overlain by 3 m of calcareous and carbonaceous mudstones and an oyster bed in contact with laccoliths of teschenite. The lower portion of the sequence can be included in the Broken River Coal Measures, but the marine sequence is fine grained

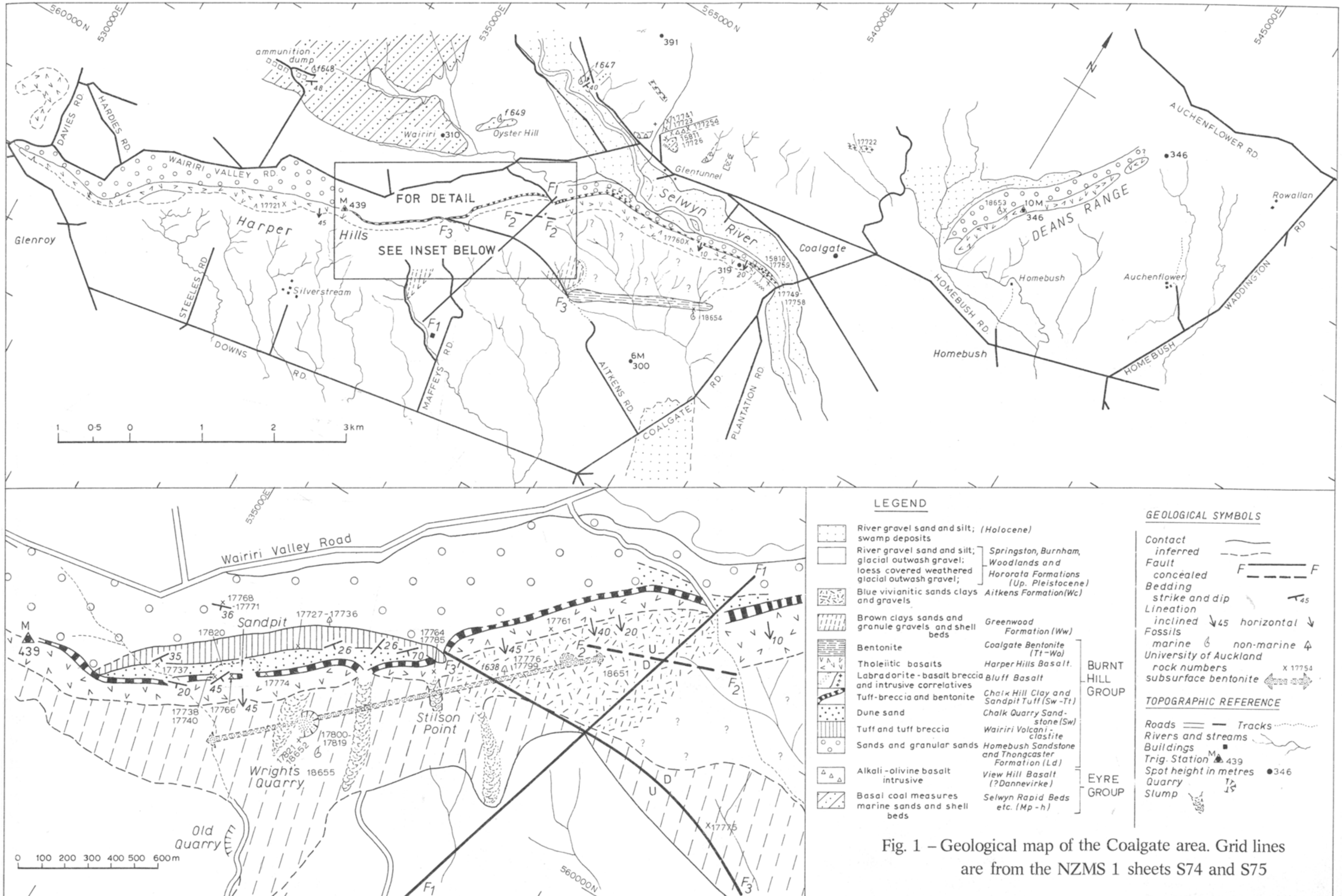

Fig. 1 – Geological map of the Coalgate area. Grid lines are from the NZMS 1 sheets S74 and S75

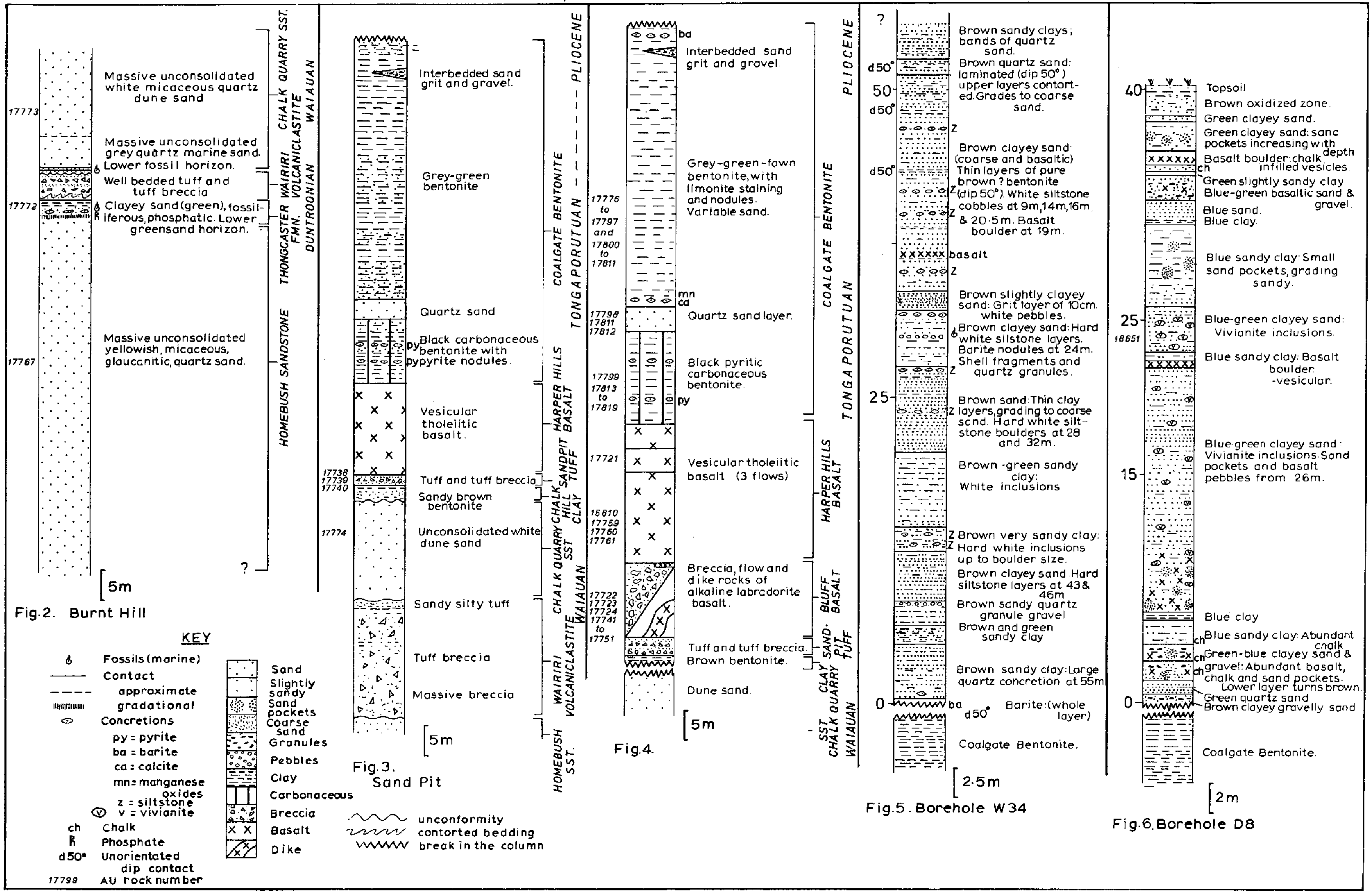

Fig.2. Burnt Hill

Fig.3. Sand Pit

Fig.4.

Fig.5. Borehole W34

Fig.6. Borehole D8

and non-glauconitic, and although an age-equivalent of part of Iron Creek Greensand it cannot be included in that formation.

South-west of the study area, rocks of Eyre Group pass laterally into the Colliers Coal Measures and Otaio Gorge Sandstone of Dannevirke and lower Arnold age in the Pareora–Geraldine district (Gair 1967).

In the Coalgate area, correlatives of some of the units discussed above have been described by Speight (1928) and earlier workers. These rocks were afforded only cursory attention during the present survey partly because of very poor exposure and also because the main aim of the work was to examine the bentonite deposits. Consequently, even though some fossiliferous horizons were newly discovered, and additional observations were made, erection herein of a full formal lithostratigraphic scheme is judged unwise.

BROKEN RIVER COAL MEASURES

Speight (1928) recorded about 1500 m of upper Cretaceous strata near Selwyn River, including basal coal measures consisting of a diverse sequence of conglomerates, sandstones, carbonaceous claystones, and coal underlying Mata Series marine strata. Exposures can still be seen in Selwyn River but they are less extensive than formerly. The unit also occurs in the Wairiri hills and is exposed at the ammunition dump. These strata are readily correlated with, and included in, Gage's (1970) Broken River Coal Measures.

SELWYN RAPIDS BED AND ASSOCIATED STRATA

Speight (1928) recorded a series of marine strata, including the fossiliferous "Oyster Beds" and "Selwyn Rapids Beds", overlying the Broken River Coal Measures. During the present survey the following units were noted (poor exposure prevents us being fully confident of the correct stratigraphic order):

(6) Grey and yellow quartz sands, current bedded in places and heavily iron stained (youngest unit). Thickness unknown.

(5) Calcareous sandstone. Thickness unknown.

(4) "Selwyn Rapids Beds". Hard grey fossiliferous sandstone. Within this unit is an 8-cm shellbed containing badly leached molluscan fossils. A total of 1·5 m is exposed, although Speight reported up to 9 m.

(3) "Oyster Beds". Hard grey cemented sandstone containing fossils that are dominantly *Crassostrea* cf. *dichotoma* (Bayle).

(2) Unconsolidated sands. Poorly exposed and of unknown thickness.

(1) Broken River Coal Measures (oldest unit).

Unit (2) is of uncertain origin. It may be non-marine and thus warrant inclusion in the Broken River Coal Measures, but until it is better known it is tentatively excluded. The overlying units are correlated most clearly with non-glauconitic marine Piripauan–Haumurian strata, to the north-east and west, for which as yet no formational name is available except in the Haumuri Bluff district (Okarahia Sandstone, Warren & Speden 1978). Although no greensands were seen during the present work, Speight (1928) recorded greensands and greyish and greenish sands with large calcareous concretions overlying the Selwyn Rapids Beds, so some correlation may also be made with Gage's (1970) Iron Creek Greensand and/or Warren & Speden's (1978) Claverley Sandstone.

These units are reportedly overlain by other upper Cretaceous sediments (Speight 1928), but none were encountered in this survey, and their previously recorded locality in Selwyn River is not now exposed.

Selwyn River affords the best exposure of upper Cretaceous sediments where they are also moderately fossiliferous. A shellbed occurring here is absent from other areas, but the surrounding fossiliferous sandstones, although thinner, extend as far inland as the ammunition dump. No clear exposures of overlying fossiliferous calcareous beds are known at present and only isolated boulders occur near Selwyn Rapids. Their extent is probably limited because further inland Selwyn Rapids Beds are overlain by the current-bedded sands (6).

The only good exposure of Speight's Oyster Beds is outside the present survey area (L35/355140) and it is by inference that the sole occurrence at Oyster Hill is placed lower in the sequence.

The loose sands underlying the Oyster Beds are not clearly exposed anywhere. Speight (1928) reported their occurrence at Selwyn Rapids as overlying coal measures, but exposures are now heavily overgrown. They, and the Oyster Beds, are absent to the west at the ammunition dump where Selwyn Rapids Beds rest directly on sulphurous coal measures.

The entire upper Cretaceous sequence lenses out towards the south-west.

Fauna and Age

A molluscan fauna of some 30 species has been recorded from these beds (see Speight 1928; Wellman 1959) and Wellman considered them to be Haumurian. Stevens (1965, p. 124) described the Haumurian belemnite *Dimetobelus hectori* and commented that "Selwyn River specimens . . . are not accurately located, but are probably from the Selwyn Rapids Beds, of Piripauan–Haumurian age"; none was discovered during the present work. Henderson (1930) recorded the presence of *Gunnarites denticulatus* and *Pseudophyllites* "prob-

FIGS 2–6—(*Opposite*)

FIG. 2—Stratigraphic column of Burnt Hill Group at Burnt Hill.

FIG. 3—Stratigraphic column of Burnt Hill Group at the Sand Pit.

FIG. 4—Generalised stratigraphic column of middle and upper portions of Burnt Hill Group.

FIG. 5—Stratigraphic column of Greenwood Formation in borehole W34 (L35/335092)

FIG. 6—Stratigraphic column of Aitkens Formation in borehole D8.

ably of Haumurian age". From the above one would conclude a Haumurian (and possibly Piripauan) age for the fossiliferous sequence; it is likely that the overlying strata include Teurian or even younger Paleocene rocks.

Additional fossiliferous localities were found during the survey:

S74/f645 (AU483, L35/355140), Bush Gully; light brown calcareous medium sandstone

S74/646 (AU484, L35/361141), Bush Gully; light brown very calcareous medium sandstone

S74/f648 (AU486, L35/311102), old ammunition dump, Wairiri valley; grey non-calcareous medium sandstone

All localities are in Selwyn Rapids Beds and produced a leached and crushed fauna of bivalves and gastropods, few of which have been specifically identified, and none provide assistance in closer age determination. The Oyster Beds were recollected on Oyster Hill (S74/f649, AU488, L35/332108), and in addition to some of the forms mentioned by Speight (1928, p. 26) *Dreissensia* cf. *lanceolata* (Sowerby) was identified. This form occurs in the type Piripauan and is "not known to be associated anywhere with Haumurian index species" (Warren & Speden 1978, p. 45), thus strengthening the likelihood of the marine Cretaceous here including Piripauan strata.

VIEW HILL BASALT

Speight (1927) first described the alkaline basalts and limburgites of the Oxford area as flows, sills, and notably pillow lavas. Gregg (1964) defined them as View Hill Basalt Formation with its type locality at Whites Creek where pillow lavas are overlain by Mangaorapan tuffaceous mudstones.

Olivine dolerite dikes are found in the Coalgate area (Carlson & Rodgers 1975) with no associated flows or pillow lavas. Intrusive contacts are not seen but undoubtedly exist, at least at the Glentunnel Pottery exposure, where basalt and a vertical sequence of Upper Cretaceous quartz sands are in close proximity; unfortunately the contact is heavily overgrown. Samples of basalt taken from near the assumed contact contain numerous quartzose xenoliths.

At Whites Creek, Oxford, View Hill Basalt is regarded as being of Paleocene age (Gregg 1964; Macpherson 1947). The distinctive alkali-olivine basalt lithologies of the Coalgate dikes imply correlation with View Hill Basalt rather than with the tholeiitic Harper Hills Volcanics. Furthermore, the distinct lack of extrusive upper Tertiary equivalents and the lack of lithologically similar basaltic material in Burnt Hill Ash (Upper Miocene) tend to substantiate the correlation. However, it is known that alkaline basaltic eruptions have occurred several times throughout the Tertiary in Canterbury and the local correlation with View Hill is considered tentative at best.

View Hill Basalt is a constituent unit of the Upper Cretaceous–Eocene Eyre Group (Macpherson 1947; Ritchie *et al.* 1969).

BURNT HILL GROUP (new name)

This new unit is erected to accommodate mid Tertiary non-calcareous marine and estuarine strata and associated rocks of central Canterbury. The group takes its name from the Tertiary outlier of Burnt Hill, the geology of which was described by Speight (1927). Speight differentiated nine units in the sequence at Burnt Hill and formational terminology introduced below closely parallels Speight's divisions (See Figs 2 and 3).

Carlson & Rodgers (1975) proposed Burnt Hill Formation to cover some of these same rocks and included in it various members. Neither the formation nor its members were adequately formalised and the present work seeks to correct this. At the same time the status of the units is raised in recognition of their use as mapping units which therefore constitute formations and because disconformable contacts occur in some instances.

Harper Hills Volcanics (Oborn & Suggate 1959) accommodates the top three of Speight's units. This formation is included with the underlying strata in Burnt Hill Group because of petrogenetic affinity with Wairiri Volcaniclastite in the lower part of the sequence (Carlson & Rodgers 1975).

Oborn & Suggate (1959) erected Harper Hills Volcanics for basic flows and pyroclastics in this area and tentatively correlated with them a teschenite sill in Rakaia Gorge. Gregg (1964) included bentonite deposits in the formation, and a fuller description, including correlation with igneous deposits at Burnt Hill, Oxford, Stravation Hill, and Chalk Hill (see Speight 1928; Macpherson 1947), was given by Ritchie *et al.* (1969). Carlson & Rodgers (1974; 1975) recognised five members within Harper Hills Volcanics, including the Chalk Hill Clay of Macpherson (1947). The new members were not formally defined. In the present work the bentonitic deposits above and below the lavas (Chalk Hill Clay and Coalgate Bentonite) and an associated tuff (Sandpit Tuff) are considered as separately mappable units of formational status. Petrogenetic differences allow separation of Bluff Basalt from Harper Hills Volcanics, which name is limited to the prominent tholeiithic flows forming the escarpments of Harper Hills and Burnt Hill.

The teschenites of Rakaia Gorge included by Oborn & Suggate (1959) in their Harper Hills Volcanics are here excluded on the grounds of their distinctly alkaline composition and possible Cretaceous age (Lauder 1962) and are correlated instead with View Hill Basalt (Speight 1928).

Upper and Lower Boundaries

Nowhere is the base of this unit exposed, but from drillhole evidence in the present area it may be assumed that the group unconformably overlies upper Cretaceous or older strata, including Mt Misery Volcanics, fragments of which occur within Wairiri Volcaniclastite (Carlson & Rodgers 1975) and the Paleocene View Hill Basalt. The unconformity resulted from marine transgression after a period of subaerial erosion and volcanic activity. No evidence was found for the existence of

Oxford Chalk below Chalk Quarry Sandstone in the Coalgate area and Macpherson (1947) has noted that the former unit is not known beyond Chalk Hill itself.

The upper contact of Burnt Hill Group with Greenwood Formation is also unseen, but unconformable relations are indicated by (1) slightly steeper dips in Greenwood Formation, (2) bentonite inclusions derived from Burnt Hill Group present in Greenwood Formation, implying an erosion interval, and (3) the facies change from non-marine (Coalgate Bentonite) to marine (Greenwood Formation).

Distribution

Burnt Hill Group includes rocks in front of the Canterbury foothills between the Ashley and Rakaia Rivers. Exposures are known at Burnt Hill, View Hill, and Chalk Hill in the Oxford district and Harper Hills and Deans Range, Coalgate. No certain correlatives of the group are known in the adjacent Mt Somers district.

Several good outcrops of the group occur in the Coalgate area and at all a disconformable contact is evident between the igneous units and underlying formations. At Deans Range exposures are poor except for at a recent road cutting near L35/404134. Here Homebush Sandstone is found directly underlying Harper Hills Basalt. Non-deposition of formations is also characteristic over much of Harper Hills and it is only at the Sand Pit locality that most of the sequence is presented. Exposures here are excellent due to wind erosion and the only bed missing is the lower marine horizon of Chalk Quarry Sandstone.

Age and Correlation

Macrofaunas from Burnt Hill have been interpreted as Awamoan (Marwick 1932), as Waiauan (Gregg 1964), and as Duntroonian (Keyes 1972). The full age range of the group is unknown but it could extend to, or even below, the base of the Oligocene and upwards to include rocks of lower Pliocene age.

To the north-east, Burnt Hill Group is contemporaneous with at least the upper portion of the fully marine calcareous Mount Brown Beds (Thomson 1920; Wilson 1963), Double Corner Shellbeds (Gregg 1959) of the Waipara district, and muddy and calcareous sandstones of the Mandamus–Pahau area (beds M7–9 of Mason 1949) of Mount Grey. In this general area both dominantly calcareous and dominantly non-calcareous lower to middle Miocene sequences occur, suggesting the interfingering of coeval lithofacies.

Porter Group (Gage 1970), in Castle Hill Basin to the north-west, also probably interfingers with Burnt Hill Group. Porter Group consists of fully marine dominantly calcareous lithologies and thus is separable from those of Burnt Hill Group, although contemporary.

To the south-west the sequence becomes dominantly non-marine (White Rock Coal Measures of Gair 1959) in the Fairlie–Geraldine–Timaru area. Coeval non-marine strata also occur to the west at the western end of Harper Range (Gair 1967).

Upper Southland Series rocks are absent from the Harper and Avoca River areas (Suggate & Wilson 1958), Ant Stream (Wilson 1956a, b), and Waimakariri (Gage 1956). There is probably some correlation with the upper part of section A (post-bryozoan limestone) of Gair (1962) in Esk Valley. Strata here are massive greensands and lithic tuffs with sharks' teeth and quartz granules not unlike the sequence at Burnt Hill. Unfortunately no ages are available and Gair did not suggest correlations away from Esk Valley.

The constituent formations of Burnt Hill Group found in the present study area are discussed below in ascending order.

HOMEBUSH SANDSTONE (new name)

This formation consists of massive unconsolidated, yellowish unfossiliferous quartz sands at least 60 m thick. The lower contact is obscured by alluvial gravels. The upper contact, gradational to Thongcaster Formation, is marked by greensand inclusions. Bedding is poor or absent throughout much of Harper Hills but is evident at Deans Range where the sands also contain lenses of unconsolidated conglomerate consisting of well-rounded pebbles of rhyolite, basalt, greywacke, and jasper up to 30 mm in size.

Lithofacies variations of this formation include granular sands exposed near the Sand Pit just below Wairiri Volcaniclastite. These are sands and gravels distinctive in containing well-rounded multicoloured quartz granules. They are poorly sorted, poorly bedded, contain minor pebble lenses, and are probably fluviatile equivalents of the yellow sands. Like the yellow sands, lower contacts are masked by Quaternary gravels, and the next oldest sediments appearing in the sequence are Cretaceous in age. Maximum thickness is 95 m.

This formation constitutes bed 1 of Speight (1928) and takes its name from Homebush Road which runs between the major outcrops of the unit in Harper Hills and Deans Range. The type locality is Burnt Hill where 60 m of the beds is exposed on the northern and western flanks. Speight (1928) reported in addition that a borehole sunk immediately to the north passed through some 80 m of similar sands.

Paleontology and Age

Only trace fossils have been found in Homebush Sandstone, apart from a badly weathered terebratulacean brachiopod seen on the northern slopes of Deans Range. It is possible that this fossil is reworked, but its occurrence midway between Burnt Hill (marine) and Harper Hills (estuarine) suggests that marine conditions extended to Deans Range.

No internal evidence for age of the formation has been found but as it conformably underlies Duntroonian strata it is likely to be of Whaingaroan–Duntroonian age.

Mineralogy

Sample 17770 is typical of the poorly sorted granular sands with well-rounded quartz (19%) and poorly sorted clear unstrained quartz grains of dominantly fine sand size (30%). Well-rounded sanidine granules and coarse sand grains comprise 7%. The dominant constituent (40%) is metamorphic quartz, with large grains sometimes occurring up to 4 mm in size. The grains are subrounded to well rounded, composite, non-schistose, and generally with straight to crenulate borders, but some individuals are stretched, well sutured, and have strongly undulose extinction; some contain abundant chlorite. Plagioclase (*c.* 14%) is biaxial positive, commonly shows pericline twinning, and, like most of the grains comprising the finer size fractions, is angular to subrounded. In 17768 rare biotite and muscovite were present together with some 10% glauconite. No volcanic fragments were seen and opaques are very rare.

Unlike the granular sands, 17767 (yellow sand) is a well sorted very fine sand. The mineralogy is very similar, but some relative abundances are different. Metamorphic quartz fragments are only 10%, even though total quartz content is 50%. Glauconite is very rare.

Clay Mineralogy

X-ray modal analysis of the $<2\mu$ fraction of 17770 gave 52% montmorillonite and 48% illite. Montmorillonite showed full expansion to 17Å with ethylene glycol. Total clay material in the sample is *c.* 3·4%.

In 17767 the whole clay fraction (7.0%) consists of montmorillonite. Possibly the lack of illitic components may correspond to a lack of glauconite.

Mechanical analyses

Homebush Sandstone ranges from poorly sorted (e.g., 17770) to moderately sorted fine sands that are only slightly silty (17768). Skewness varies from strongly fine skewed to near symmetrical (Sk_I 0·38–0·02) and the kurtosis ranges from platykurtic to very leptokurtic (K_G 0·87–1·54). The graphic mean varies from 1·34 ϕ for 17770 to 2·79 ϕ for 17768. These results are consistent with a field interpretation of the deposit having a fluvial origin. For example, compared with Vischer's (1969) curves, 17768 is typical of some modern river sands and 17770 shows a distinct similarity with fluvial deposits. However, 17771 has a rather unusual very convex curve which seems identical to deltaic distributory curves of Vischer for the Blue-Jacket–Bartlesville sandstone. Perhaps then the Homebush sands were deposited in a river estuary–tidal channel environment and are somewhat deltaic.

In contrast, the yellow sands from Burnt Hill (17767) are very well sorted (σ_I = 0·145) fine to very fine sands that are strongly fine skewed (Sk_I = 0·36) and very leptokurtic, with a graphic mean of 3·03 ϕ; a fluvial environment is most improbable.

THONGCASTER FORMATION (new name)

This unit is a massive brown fine sandstone. It is highly glauconitic, including a 0·6-m-thick basal greensand, markedly clay rich, and contains well-leached marine mollusca and shark teeth. It has been found only at Burnt Hill and takes its name from Thongcaster Road which runs along the northern side of Waimakariri River immediately south of Burnt Hill (Fig. 2).

The basal greensand contains phosphatic nodules and shark teeth, and while it can be seen to be gradational to the underlying Homebush Sandstone, a diastem may well have existed between the deposition of the two units. The unit is 2·5 m thick and is overlain conformably with sharp contact by Wairiri Volcaniclastite.

Thongcaster Formation consists of beds 2 and 3 in Speight's (1928) sequence for Burnt Hill.

Paleontology and Age

Molluscan fossils are poorly preserved, generally as casts, and difficult to identify; no microfauna has been recovered. The following macrofauna comes from collections S75/f499 (GS3534, E. O. Macpherson, Oct 1945), S75/f516 (no catalogue number given; D. R. Gregg, Sep 1962), S75/f518 (AU4516, Grant-Mackie & P. F. Ballance, May 1961) and S75/f532 (AU487, Carlson, Dec 1969):

Brachiopoda	*Waiparia*(?) *elliptica* (Thomson)
Mollusca	*Modiolus* sp. cf. *altijugatus* Marwick
	Dosinia (Kereia) sp. indet.
	Marama (Hina) sp. indet.
	Bartrumia tenuiplacata (Bartrum)
	Panopea worthingtoni Hutton
	Turritellidae indet.
	? *Austrofusus* sp. indet.
Cirripedia	? *Solidobalanus acutus* (Withers)
Chondrichthyes	*Carcharodon megalodon* (Agassiz)
	Carcharodon sp. indet.
	Isurus hastalis Agassiz
	I. desori Agassiz
	Myliobatis plicatilis Davis
Mammalia	Cetacea indet.

A Duntroonian age for these basal beds is indicated by the brachiopod (Keyes 1972) and this correlation is not contradicted in any way by the remainder of the fauna; the upper age limit of the formation is unknown, but in view of the Waiauan age for the basal part of Chalk Quarry Sandstone it is likely to be lower Miocene or younger.

Mineralogy

In 17772 the clastic grains comprise poorly sorted quartz (36%), feldspars (both potash, 5%, and plagioclase, 8%), and glauconite (20%) set in a weakly cementing clay matrix. One-third of the quartz grains are subrounded to well-rounded composite grains. Some plagioclase shows pericline twinning, opaques are rare, micas and volcanic fragments absent, and glauconite pellets are well rounded and up to 0·75 mm diameter.

Clay mineralogy

The $<2\mu$ fraction constitutes 42% and consists of montmorilonite (73%), illite (16%) and kaolin/chlorite (probably all chlorite) (11%). This clay component of the clastics may have arisen from alteration of ash falling at the depositional site—a possibility supported by the eruptive nature of the succeediing unit.

Mechanical Analysis

Sample 17772 is a poorly sorted (σ_I = 1·08) clayey fine sand that is fine skewed (Sk_I = 0·25) and very platykurtic (K_G = 0·60) with a graphic mean of 2·78ϕ.

WAIRIRI VOLCANICLASTITE (new name)

Speight (1928) recorded 3·5 m of interbedded coarser and finer ash beds overlying beds 2 and 3 (Thongcaster Formation) at Burnt Hill, and Carlson & Rodgers (1975) named it Burnt Hill Ash Member, describing especially the characteristics of coarse-grained facies at Harper Hills.

The unit requires a new name to avoid duplication for different levels of the hierarchy of lithostratigraphic terminology. Furthermore, whilst the term "ash" is a suitable description of the lithology at Burnt Hill, the main constituent is a massive volcanic breccia passing up into tuff-breccia (Carlson & Rodgers 1975) at Harper Hills where the unit is thickest, and the more all-encompassing term "volcaniclastite" is preferred.

The new formation takes its name from Wairiri Road and Stream which follow the north-western edge of Harper Hills where the unit achieves its most extensive outcrop and thickness. The type locality is designated at the Sand Pit and environs where the unit is 18·5 m thick and consists of massive breccia overlying Homebush Sandstone with undulatory contact and grading upwards through 1–2 m of tuff-breccia to 1·2 m of alternating sandy and silty tuff (Fig. 3). Here the upper contact is a sharp undulating surface below Chalk Quarry Sandstone. Carlson & Rodgers (1975) concluded that the eruptive centre for this deposit lay in Harper Hills, with the finer waterborne fraction spreading as far as Burnt Hill.

At Burnt Hill the formation consists of alternating beds of tuffaceous volcanic silts, sands, and tuff-breccias that contain basalt, glass, and palagonite, typical of hyaloclastic eruptions. The unit is only well bedded in the upper, finer phases which show locally developed contortions (Fig. 2). It is more resistant than adjacent strata and constitutes a well-defined marker horizon.

Here the formation is conformable between marine strata of Thongcaster Formation and Chalk Quarry Sandstone and is believed, therefore, to be marine in origin and its age must be in the range Pareora to lower Southland Series, but it could be as young as Waiauan, the age of the immediately overlying strata.

The most unusual feature of the deposit, in view of the presence of palagonite, glass, and ash, is the lack of clay minerals. Obviously conditions were not suitable for montmorillonite formation, in strong contrast to the freshwater bentonite beds that follow later in the sequence (Carlson & Rodgers 1974).

There are many tuffs, palagonite, and hyaloclastic deposits throughout the Canterbury area (e.g., Schofield 1951), but unlike Wairiri Volcaniclastite they are all of lower Tertiary (Eocene–Oligocene) age. They appear to have associaions with alkali basalts and pillow lavas such as View Hill Basalt, and one wonders whether the lower Tertiary volcanics that generally ceased eruption in the lower Oligocene (Schofield 1951) may have continued eruption in this area through the upper Oligocene–middle Miocene.

CHALK QUARRY SANDSTONE (modified name)

Macpherson (1947, p. 169) introduced the name Chalk Quarry Sand for "10 ft to 20 ft of loose grey angular sand the upper 8 in. to 2 ft of which is stained a striking rusty brown" and overlain by "2 ft to 5 ft of clear whitish quartz sand" at Chalk Hill. He gave the unit formational status "because of the striking change in sedimentation and the erosion intervals at the base and top"; it was reduced to a member of Carlson & Rodgers' (1975) Burnt Hill Formation, but now reverts to its earlier rank.

At the type locality the unit is best exposed, according to Macpherson (1947), at the chalk quarries, as a result of stripping operations. It overlies the lower Oligocene Oxford Chalk on an irregular surface of silicified chalk, the presence of which was taken by Macpherson as excellent evidence for an erosion interval. The upper boundary at Chalk Hill was believed to represent a break in sedimentation, although no evidence of discordance or erosion was seen, because of the sharp contrast in lithology between Chalk Quarry Sandstone and the overlying Chalk Hill Clay, because the former varies in thickness along its outcrop, and because Chalk Hill Clay overlaps on to other units to the east and also possibly to the west.

Macpherson found no fossils in this unit and could give no age estimate other than post-Oligocene (i.e., younger than the Whaingaroan Oxford Chalk).

The type area was not re-examined during the present survey, but generally similar grey and white quartz sands occur in comparable stratigraphic relations at Burnt Hill and Coalgate and are here included in Macpherson's formation.

In the present study area two distinct lithologies are recognised.

1. Grey, marine sands at Burnt Hill that are unconsolidated and generally massive apart from a basal 0·6-m-thick leached shellbed conformable on Wairiri Volcaniclastite. Total thickness here is at least 15·5 m. Compositionally the basal sand differs in no significant way from that of Thongcaster Formation. This formation accommodates beds 5 and 6 of Speight (1928).

2. Contrasting with this lithofacies at Chalk Hill and Harper Hills are unconsolidated, pure white, quartzose dune sands that are extensively leached and generally massive apart from local crossbedding; some horizons are cemented. They are moderately to well sorted fine sands, at least 15 m thick at the Sand Pit, thinning to 13 m inland. Contacts with lower units are not seen at Harper Hills; the upper contact with Chalk Hill Bentonite is an undulating erosion surface.

Palaeontology and Age

Fossils have been found only at Burnt Hill in the basal 60 cm of the formation. Large collections were made by Speight, and the molluscs were identified by Marwick (Speight 1928; Marwick 1932).

Marwick's list need not be reproduced here, but subsequent collecting and faunal revisions have produced additional records which are listed below:

Bryozoa	*Selenaria nitida* Mapleston *S.* sp. cf. *spiralis* Chapman *Cellaria immersa* Tenison-Woods Reteporidae indet.
Coelenterata	*"Flabellum" sphenodeum* Tenison-Woods
Echinodermata	Crinoidea indet. *Lambertona perplexa* Henderson *Taimanawa pulchella* Henderson & Fell
Mollusca	*Limopsis zitteli* Ihering *Turia waiauensis* Marwick *Sigapatella maccoyi* (Suter) *Zeacolpus willetti* Marwick *Zelandiella* sp. indet. ? *Falsicolus* sp. aff. *corrugatus* (Marshall) *Amalda (Spinaspira) stortha* (Olson) *Comitas* sp. *Neoguraleus (Fusiguraleus)* sp. Cancellariidae indet.
Cirripedia	*Solidobalanus* sp. cf. *acutus* (Withers).

These forms come from collection S75/f517 (AU4515, from L35/528099 Grant-Mackie & P. F. Ballance, May 1961) and S75/f530 (GS8696, D. Haw, Feb 1961) and from Speight's original collections. Dr P. A. Maxwell, N.Z. Geological Survey, is restudying the molluscan fauna and informs us (pers. comm. April 1977) that the forms recorded by Marwick (1932) as *Spissatela trailli* (Hutt), *Eumarcia curta* (Hutt), and *Typhis maccoyi* T-Woods are new species of these genera and that Marwick's *Penion latispinifer* is *P. crawfordi* (Hutt).

Marwick (1932) concluded that the molluscs indicate an "Awamoan" (i.e., Altonian) correlation, but this is considerably weakened by the above re-identifications. A Waiauan age for these beds is based on Finlay's (1947) record of the index foraminifera *Loxostomum truncatum* Finl. and supported by the presence of *Spissatella* n. sp. (as in the Waiauan *Hinnites* shellbed, Weka Pass), *Zeacolpus willetti*, and *Penion crawfordi* (P. A. Maxwell pers. comm.).

Mineralogy

The sand grains in both 17773 (Burnt Hill) and 17794 (Harper Hills) are of very fine sand size (approximately 0·1 mm), generally subrounded to well rounded. Frosted grains are abundant, but clear quartz is also present. Cemented aggregates comprise about 1% of the sample and may be the result of leaching and cementation by liberated silica. Quartz comprises between 53% and 61%, approximately half of which are composite (metamorphic) grains. Plagioclase varies between 12% and 18%, and potash feldspar totals 7%. Muscovite and minor biotite are occasionally present, but glauconite and opaques are very rare. No volcanic fragments were observed.

Clay Mineralogy

Clay minerals in the $<2\mu$ fraction of 17773 are montmorillonite 7·1%, illite 16·5%, and kaolin 76·4%. Kaolin also occurs in 17774 (23·2%), but the montmorillonite peak is very broad between 16·5Å and 17·0Å and this mineral may be interlayered with other clay components. In both samples examined illite is at the same level.

Possibly the high kaolin content of these sands, as compared to negligible values found in underlying units, may reflect leaching of the feldspars.

Mechanical Analyses

17774 is a moderately sorted fine sand ($\sigma_I = 0{\cdot}56$) that is fine skewed ($Sk_I = 0{\cdot}24$) and leptokurtic ($K_G = 1{\cdot}39$) while 17773 is a well-sorted ($\sigma_I = 0{\cdot}38$) fine sand that is notably negatively skewed ($Sk_I = 0{\cdot}02$) and platykuritic ($K_G = 0{\cdot}67$). Both samples have very similar graphic means of 2·7 ϕ respectively. These parameters are consistent with a dune origin (Friedman 1961; Vischer 1969) as might be expected from the good sorting, lack of rolling population, and a one-saltation population which forms 85%. However, leaching has probably modified the sediment, and the resulting clay has been recorded as excess "fines".

CHALK HILL CLAY

This unit was also erected by Macpherson (1947, p. 169) for a "grey-greenish plastic bentonitic clay" 3–6 m thick at Chalk Hill, extremely fine grained, and apparently containing considerably decomposed volcanic tuff. Carlson & Rodgers (1974; 1975) included it as the basal member of Harper Hills Volcanics, but it is here restored to formational status. At the type locality the unit is believed to lie disconformably upon Chalk Quarry Sandstone, overlapping on to the Oxford Chalk and older beds nearby, and is overlain with uncertain but possible disconformable contact by maroon clays and basalt (Macpherson 1947).

Chalk Hill Clay has not been identified at Burnt Hill or Deans Range, but at Harper Hills 0·6 m of brown-weathering bentonite, which dries out with the usual hexagonal shrinkage pattern, lies between Chalk Quarry Sandstone and Sandpit Tuff and is included in Macpherson's formation. The mineralogy and genesis of this deposit have been described by Carlson & Rodgers (1974). The only clay mineral present is of the montmorillonite group and forms 45% of the total sediment. Mechanical analyses were considered to be of little use as the clay is not of true detrital origin.

Neither at the type locality nor in Harper Hills has the formation yielded any fossils and its precise age is unknown.

SANDPIT TUFF (name formalised)

This unit was proposed by Carlson & Rodgers (1974; 1975) informally as a member of Harper Hills Volcanics. In formalising the name it seems best to run the geographic portion of the name into one word.

The formation has its type locality at the Sand Pit, Coalgate, and consists of alternating beds of brown and red, coarse and fine, sandy and silty tuffs and tuff-breccias. Leaf impressions and stems commonly occur but, in common with the whole unit, they are extensively leached. At the type locality the tuff is 1·7 m thick, which is also the average thickness for the study area; nowhere does it exceed 3 m. At the Sand Pit and at a few localities along strike this formation can be seen to overlie Chalk Hill Clay, but at other localities in Harper Hills it lies directly upon Chalk Quarry Sandstone with an undulating contact.

The deposit has been described by Carlson & Rodgers (1975). The clastic component is identical with the sedimentary detritus in underlying formations; the volcanic content, however, differs from Wairiri Volcaniclastite in that extensive leaching has produced montmorillonite as an alteration product. Carlson & Rodgers (1974; 1975) concluded that the tuffs had a freshwater origin.

From their stratigraphic position and constitution, Speight's (1928) bed 7 ("ash-bed, weathering red, 6 ft") at Burnt Hill and Macpherson's (1947) 6-m-thick maroon and red clay at Chalk Hill should be included in Sandpit Tuff. At Chalk Hill, Macpherson described the clays as being in part altered tuff and breccia and concluded that the deposit could be marine. In the absence of any evidence for such an origin, and taking into account the probable freshwater origin of the underlying Chalk Hill Clay, we prefer to postulate similar conditions of accumulation for the tuffs at Chalk Hill and Harper Hills.

The tuffs are too leached to produce a microflora, The macroflora has not been identified, and no direct age indications exist, but a Taranaki Series age is likely on stratigraphic grounds.

BLUFF BASALT (name formalised)

This name was introduced without definition by Carlson & Rodgers (1974) as a member of Harper Hills Volcanics and its general characteristics, petrography, and paragenesis discussed (Carlson & Rodgers 1975).

The unit takes its name from a promontory at the Selwyn Bridge, termed by Haast (1872) the Palagonite Bluff, and formed by resistant poorly bedded volcaniclastic breccia.

The formation consists of three genetically related facies (see also Carlson & Rodgers 1975):

1. Breccia: Crudely bedded eruptive breccia, dominantly composed of ash, lapilli, and blocks of labradorite basalt. Some accidental blocks of Wairiri Volcaniclastite and Sandpit Tuff are included. At its only occurrence (Selwyn Bridge) it is 12 m thick and thins rapidly to the south-west. At one exposure the breccia can be seen to overlie Sandpit Tuff.

2. Basalt flow: A 0·6-m fragmented labradorite basalt flow at Burnt Hill (bed 8 of Speight 1928) is considered stratigraphically equivalent to the breccia.

3. Hypabyssal intrusives: Two dikes occur in the Glentunnel downs area. Like 1 and 2 they are labradorite basalts, and the three lithologies are considered to be synchronous and comagmatic. Behind Glentunnel Pottery (S74/379632) the dike margin is fine grained, cut by parallel shears, and subvertical.

This formation is separated from the overlying Harper Hills Basalt because of important petrologic differences, the former being labradorite bearing and the latter tholeiitic; both are subaerial in origin.

HARPER HILLS BASALT (restricted name)

The restriction of Oborn & Suggate's (1959) Harper Hills Volcanics to the tholeiitic flow rocks constituting the most prominent portion of their larger more heterogeneous unit has already been discussed. This restriction justifies the above alteration of the name for the unit which is a widespread formation with good exposures. The type locality is Harper Hills where it has been extruded over Bluff Basalt or Sandpit Tuff and is overlain by Coalgate Bentonite. This unit comprises between one and three tholeiitic basalt flows. They are dark grey, fine grained, porphyritic, and vesicular with characteristic pipe vesicles and vesicle trains; their features, including petrography and paragenesis, have been discussed by Carlson & Rodgers (1975). The oldest flow is the most extensive and is uniformly 15 m thick. Later flows are not well defined and are of only local extent. Contacts with underlying units appear conformable.

Included in this formation are bed 9 at Burnt Hill, the lavas of Browns Rock 1700 m to the west and on the north bank of Waimakariri River, scoriaceous basalt at Oxford, and lava flows of Starvation Hill (all described by Speight 1928). From Speight's descriptions it is also clear that at least some of the basalts overlying Sandpit Tuff at View Hill should be included with Harper Hills Basalt, but it is not clear either from Speight's descriptions or from Macpherson's (1947) subsequent comments whether or not Bluff Basalt is also present here.

There is probably some correlation with tholeiitic basalts at Timaru and Geraldine (Gair & Rickwood 1965), which are remarkably similar to those at Coalgate, and have an age of $2{\cdot}47 \pm 0{\cdot}37$ m.y. (Matthews & Curtis 1966) (i.e., late Pliocene).

COALGATE BENTONITE (new formation)

This unit was named by Carlson & Rodgers (1974). It is here raised from member to formational status. Typically a grey-fawn-green-black plastic clay, it oxidises brown on exposure and dries with the shrinkage pattern of montmorillonite. Three units are recognised:

(3) The main seam, which averages 46 m thick, but lenses from 0 to 62 m in all directions.

(2) Quartz sand 3–4 m thick. Lower contacts are disconformable on Harper Hills Basalt and upper contacts are probably unconformable.

(1) A lower seam, averaging 15 m thick, which has a characteristic black colour from associated organic matter.

The seams are massive and interbedded with cross-bedded sands and grits.

The mineralogy of the bentonite is fully discussed by Carlson & Rodgers (1974). It is considered to be of freshwater origin and this accords well with the sedimentational pattern shown by the preceding sediments. Coalgate Bentonite covers most of Deans Range and Harper Hills, but is poorly exposed and was only proven by drilling. Extensive slumping of overlying beds on the plastic bentonite surface has masked most surface outcrops and the only reasonable exposure is at Wrights Quarry, the type locality. Nonetheless, this instability provides the broken ground that reliably indicates subsurface bentonite occurrences. Fortunately, numerous core samples from complete vertical sections were available for the present study.

Paleontology and Age

McIntyre (*in* Ritchie *et al.* 1969) reported the presence of upper Miocene pollen in a sample of Coalgate Bentonite from 20.7 m in a drillhole at Harper Hills and concluded that the deposit was not older than Southland Series or younger than Taranaki Series. With Waiauan marine strata (basal Chalk Quarry Sandstone) beneath the volcanic sequence one could infer a Taranaki Series age.

Palynologic analysis of two samples (S74/f638, S82/f518) of the carbonaceous lower portion of the bentonite showed that corrosion of pollen grains was evident and that redeposition may have occurred (D. C. Mildenhall pers. comm. 1970). The Waiauan–Tongaporutuan restricted *Triorites harrisii* Couper constitutes a sufficient proportion of both samples (36% of f638 and 11% of f518) for these palynomorphs to be unlikely to have been derived, and a Tongaporutuan age seems reasonable.

A younger age for S82/f518 is indicated however (D. C. Mildenhall pers. comm.) by the presence of *?Eugenia*, not elsewhere known before the Pliocene, and by the presence of Compositae pollen believed no older than lower Pleistocene (Castlecliffian). In this sample, *?Eugenia* and Compositae make up 19% of the identified grains.

A satisfactory explanation for the presence of the younger pollen is not readily presented. Whilst eruption of the parent ash of the bentonite could have continued into Pliocene times we think it most unlikely that activity went on into the lower Pleistocene. We therefore favour an age for Coalgate Bentonite of Tongaporutuan–lower Pliocene.

GREENWOOD FORMATION

The Kowai Series was proposed by Speight (1919) as a name for tilted gravels of the Kowai River area. He included basal marine beds within the formation although it is dominantly of non-marine origin. Thomson (1920) restricted the name to the non-marine sequence and Henderson (1930) altered it to Kowhai Gravels. Mason (1941) reverted to Speight's terminology, but Gregg (1959) followed Thomson's restriction and Speight's original spelling and erected Greenwood Formation for the underlying marine beds. This nomenclature is followed here and, as contacts are gradational and lithologies similar, "the dividing point is taken at where sediments containing shells and shell fragments pass up into sands and gravels bearing no trace of marine origin" (Gregg 1959, p. 522).

Only one good surface exposure was found (S74/356600) and it consisted of granular coarse sands, gravels, and minor pebble gravels and clays. Well-rounded multicoloured quartz granules and pebbles, very similar to those of Homebush Sandstone, are set in an unconsolidated matrix of fine sand that contains large fragments of redeposited bentonite. The sediments are very strongly crossbedded with individual units being of limited extent and discontinuous and overlapping down-dip much like deltaic deposits. Although no fossils were found in this outcrop a very similar sequence of sediments associated with minor shellbeds was found in Lime and Marble Company boreholes W34 and W33, and the whole sequence is included here in the marine Greenwood Formation. Lithologically the beds are similar to those described by Gregg (1959) from Lower Waipara, and a column erected for the Coalgate area is shown in Fig. 5.

Greenwood sediments were found only in the central area of Harper Hills in two boreholes and at one outcrop, but surface exposures are indicated over the whole central area by the occurrence of multicoloured quartz granules in disced furrows and firebreaks. Material obtained from borehole D8 (Ritchie *et al.* 1969) contains marine fossils in the bentonite overburden, and probably belongs to Greenwood Formation.

Age and Correlation

Fragments of echinoid spines and barnacle plates were found in the shellbeds of boreholes W34 and W33. Material from Canterbury Mineral Mines borehole D5 overlying Coalgate Bentonite contains Bryozoa and *Dentalium*.

Because the formation overlies Coalgate Bentonite and it is unconformably overlain by blue vivianite sands and Pleistocene gravels it cannot be younger than Castlecliffian. The age of Greenwood Formation at Waipara is regarded as Waipipian, possibly Nukumaruan (Gregg 1959), and this age is accepted for the Coalgate area.

Gregg (1959) correlated the type Greenwood Formation of Lower Waipara with the Mount Grey area (lowest part of Mason's Kowhai Series) and with Motunau or Greta beds in the Middle Waipara and Weka Pass (Thomson 1920). In these areas the equivalent units pass up gradationally into the non-marine lower Pleistocene Kowai Gravels. In the Coalgate area there is no evidence for the presence of this latter formation.

Mineralogy

Greenwood sands (17775) are very similar to Homebush Sandstone. Quartz is dominant (65%) of which 20% is composite grains occurring typically as well-rounded granules. Glauconite comprises about 10%. The plagioclase content is low (3%) and grains typically show pericline twinning. Potash feldspar totals 5%, and opaques are rare. Notable are the lack of greywacke fragments and the abundance of multicoloured quartz granules.

Mechanical Analysis

17775 is a slightly granular clayey coarse sand that is poorly sorted ($\sigma_I = 0\cdot73$), strongly fine skewed ($Sk_I = 0\cdot32$), and mesokurtic ($K_G = 1\cdot00$) with a graphic mean of $1\cdot33\ \phi$. These results are not inconsistent with an interpretation of these deposits as having a fluvial, perhaps marine-deltaic origin as indicated by their appearance in the field (cf. Passega 1957; Vischer 1969).

Clay Mineralogy

The only clay mineral identified in the $<2\mu$ fraction was montmorillonite, which in both hand specimen and X-ray diffractormeter pattern is very similar to Coalgate Bentonite. The $<2\mu$ fraction totals 20·5% of the bulk sample which agrees with the total clay value of 20% obtained from X-ray modal analysis. This clay is regarded as redeposited Coalgate Bentonite.

AITKENS FORMATION (new name)

This name is introduced for up to 40 m of vivianitic sands, clays, and gravels typically occurring in the north-eastern Harper Hills between Aitkens Road and the Sand Pit. It is seen here in only one surface exposure but is well known from drillholes.

Characteristically blue, sometimes blue-green or green in colour, the formation consists dominantly of quartz sands, but includes a whole spectrum of clays, clayey sands, sandy clays, and some gravel and boulder material. Commonly it contains white vivianite inclusions up to 5 mm in size that rapidly oxidise blue on exposure. A representative sequence obtained from borehole B8 is given in Fig. 6.

Aitkens Formation rests unconformably on Coalgate Bentonite and appears to be concentrated in channels scoured out of the bentonite surface. Wrights Quarry, the only surface outcrop, shows the contact dipping 60° NW with the bentonite dipping 38°SE.

Similar relationships are also interpreted for Greenwood Formation although no contacts were found. Whilst Aitkens Formation seems to be restricted in its outcrop chiefly to the area north-east of Stilson Point, the beds are likely to be more extensively distributed beneath upper Quaternary terrace gravels.

Away from Coalgate the only deposit of a similar type which may be correlated with Aitkens Formation is bed M11 on Pahau River, North Canterbury (Mason 1949). Here there are interstratified clays, sandy clays, and greywacke gravel containing bright blue vivianite granules up to 15 mm diameter. The beds are flat-lying in contrast to the tilted Kowai Gravels and Mason therefore judged them to be younger. He noted them to be lithologically quite distinct from adjacent younger terrace gravels and concluded that they had also had a different origin, postulating deposition in sluggishly flowing predecessors of the modern rivers at a time in the Pleistocene when the topography was more subdued. Mason also concluded that the deposit was probably widespread beneath the masking terrace gravels.

Age

No fossils have been found in Aitkens Formation, or at Pahuau River, Mason assumed M11 to be younger relationships between Aitkens and Greenwood Formations exists. As noted above, although no contact is exposed in Pahau River, Mason assumed M11 to be younger than Kowai Gravel because of apparent lack of tectonic disturbance; this would suggest a Castlecliffian or younger age.

At Harper Hills the oldest of the overlying terrace gravels is Hororata Formation (Gregg 1964), believed to be of Porikan age (earliest Hawera Series), whereas at Pahau River the sequence is disconformably overlain by Windwhistle and Burnham Formations of Otiran age (Mason 1949; Gregg 1964). Contemporaneity of accumulation at Pahau River and Harper Hills need not be postulated, and Aitkens Formation could be slightly older than M11.

PLEISTOCENE OUTWASH AND HOLOCENE DEPOSITS

Outwash gravels of Hawera age deposited by the present rivers during midde to late Pleistocene glacial periods form abandoned terraces and fans and overlap the older rocks. The oldest of these, Hororata Formation, has its type locality in Harper Hills (Oborn & Suggate 1959) and reaches an altitude of 370 m. Surfaces are increasingly dissected with age and older surfaces show a loess cover.

In postglacial times aggradation has produced river gravels and swamp deposits of minor extent within the study area.

These Hawera deposits were not closely studied during the present work and their distribution is shown adequately by Oborn & Suggate (1959) and Gregg (1964).

DISCUSSION

Conditions at the time of deposition of the oldest sediments of Burnt Hill Group were marine at Burnt Hill, but probably fluviatile to estuarine inland at Harper Hills. Shallow marine conditions prevailed in the Oligocene and middle Miocene at Burnt Hill with deposition of Thongcaster Formation and the basal shellbed of Chalk Quarry Sandstone. A brief interruption occurred with deposition of the hyaloclastic Wairiri Volcaniclastite. Although marine fossiliferous beds are absent further inland, a possible temporary marine incursion may have occurred with deposition of Wairiri Volcaniclastite at Harper Hills. Conditions then changed rapidly to a nearshore environment with deposition of dune sands and finally to freshwater conditions for the estuarine Sandpit Tuff and later sediments. Greenwood Formation (Pliocene) represents a resumption of marine conditions which were terminated in the lower Pleistocene.

Detrital minerals present in the sediments are dominantly quartz but include potash feldspar, plagioclase, glauconite, and occasionally biotite and muscovite. Some of the well-rounded quartz granules may have inherited much of their roundness from their primary environment as resorbed phenocrysts in Mount Misery rhyolite. This is supported by the dominance of plagioclase feldspar with pericline twins, and the occurrence of sanidine, both of which are characteristic of these rhyolites. The composite quartz grains could have been derived either from the nearby basement greywacke or from higher grade rocks of the Southern Alps. Biotite may also have come from the Mount Misery volcanics, but the origin of the muscovite is unknown. Muscovite in sediments of this area also puzzled Speight (1928). Most of the glauconite is reworked from Cretaceo–Tertiary greensands which abound in the Canterbury area and, in view of this, many of the other clastic grains probably have come from a previous erosional cycle.

The dominance of montmorillonite in sediments preceding bentonite formation implies either that volcanic activity occurred throughout most of the Tertiary or that the dominant clay available for reworking was montmorillonite. Both are equally possible, as the hyaloclastic deposits testify to the volcanic activity, whilst the abundant Cretaceous and Eocene bentonites in the area could account for a secondary origin (Gregg 1969). Kaolin is found only in dune sands and this implies that leaching has been prevalent in developing this clay from feldspar (cf. Carlson & Rodgers 1974).

STRUCTURAL NOTES

The structure of the Harper Hills–Burnt Hill area is rather simple and in the present survey only general observations were made.

Tertiary outliers form a number of south-easterly-dipping blocks on which the only complication has been post-Tertiary faulting. Exposures of the Tertiary sediments are few, and even where exposed the massive poorly bedded strata of many of the formations yield little structural information. Measurements made in the Tertiary sediments include:

Homebush Sandstone—indistinct bedding—160°/36°E
Wairiri Volcaniclastite at Burnt Hill—150°/10° E
Wairiri Volcaniclastite at Harpers Hills—102–156°/20–70°E (dips increase close to fault F_3—q.v.)
Sandpit Tuff—highly variable, but at the Sand Pit 116–155°/45–20°E
Coalgate Bentonite—average dip of 38°E.

These attitudes may be compared with those of the Cretaceous rocks which range from 150°/48°E at the ammunition dump to 130°/40°E further east at S74/379654. A broad flexure in these beds oriented roughly north–south was noted by Speight (1928).

Four minor faults were found during this survey (Fig. 1).

Fault F_1 trends 020° with unknown dip, and movement was probably largely transcurrent; it separates Harper Hills Basalt with a 45°SE dip on the west from basalt with a 10°SE dip to the east. As there is no significant vertical displacement of the basalt it is possible that strike-slip movement has bought basalt of different original dips into juxtaposition. The original dip of the basalt is likely to have lessened down-dip in view of the lake environment in which the parental material of Coalgate Bentonite was deposited (Carlson & Rodgers 1974). This difference of dip could account for the bentonite occurring some distance away from the basalt scarp at Aitkens Road whereas in the Wrights Quarry area, where the dip is greater, the bentonite occurs at the foot of the basalt scarp.

Fault F_2 trends 065°; dip is unknown, but evidence from boreholes suggests it must be near vertical. It appears to fade out to the west towards the basalt scarp which shows no disturbance. This fault is interpreted as a hinge fault associated with reversal movements of F_3. Faults F_2 and F_3 may be antithetic to F_1 whose north-east trend is typical of the Canterbury area (cf. Speight 1928; Wellman 1953; Gregg 1964).

Fault F_3 shows marked topographic expression. It trends 090 and is also of unknown dip. The basalt flow on its southern side shows both a sinistral, horizontal offset of 30 m and a vertical upthrow of 30 m. However, Wairiri Volcaniclastite in this southern block is dragged upwards near the fault and fails to occur within the full 150 m of sediments exposed below the basalt on the northern block.

These relationships cannot be satisfactorily explained by a single, simple movement. Initial movement whether vertical or reversed, followed accumulation of Wairiri Volcaniclastite. Erosion removed this unit from the upthrown northern block. After deposition of dune sands, basalt, and bentonite the fault rejuvenated both downthrowing the northern block and producing the sinistral horizontal displacement. The land surface to the north of F_3 is at a distinctly lower level than that to the south, and the sharp change in elevation occurs along the fault itself. This supports the idea of reversal of movement sometime in the late Quaternary.

The Burnt Hill fault strikes 135° and dips 14°SW. The north-eastern block is downthrown some 15 m and the fault is low angle reverse.

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