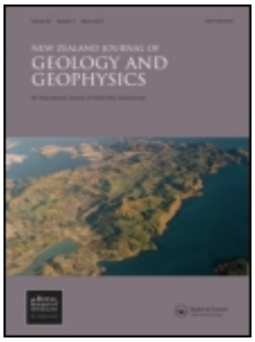


Taylor & Francis
Taylor & Francis Group

New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: https://www.tandfonline.com/loi/tnzg20

Stratigraphy and sedimentology of the tertiary rocks of the Mandamus - Dove River Area, North Canterbury, New Zealand

W. D. Sevon

STRATIGRAPHY AND SEDIMENTOLOGY OF THE TERTIARY ROCKS OF THE MANDAMUS - DOVE RIVER AREA, NORTH CANTERBURY, NEW ZEALAND

W. D. Sevon

Pennsylvania Geological Survey, Harrisburg, Pennsylvania, U.S.A.

(Received for publication 24 July 1968)

Abstract

A sedimentological study of the Tertiary sediments of the Mandamus - Dove River area in North Canterbury, New Zealand, indicates that fluvial conglomerates and coal were the first sediments deposited on a Cretaceous peneplain developed on greywackes of the Torlesse Group. Subsequent cross-bedded glauconitic sands were deposited by north-flowing longshore currents following marine transgression in the area. Rapid build-up of bedded tuffs produced by volcanic activity to the north-east diverted longshore current sedimentation from the area and permitted an environment suitable for the growth of an algal–crinoidal–bryozoan biostrome. Cessation of volcanic activity and continuing basin subsidence halted biostrome growth and allowed renewed deposition of detritus by marine currents.

Introduction

This paper is an investigation of the stratigraphy and sedimentology of a sequence of Tertiary rocks preserved in an isolated syncline lying between the junction of the Mandamus and Dove Rivers and Hurunui Peak (3 km to the east) in the Mandamus Survey District of North Canterbury, New Zealand. The focus of the study is the petrography of the Flaxdown Limestone, but data from all sedimentary rocks of the area are necessary to interpret the geological history of the sequence.

The field work was carried out during several field trips with University of Canterbury Stage II students between 1961 and 1965 and during a week in December 1964. Mapping was accomplished on aerial photographs using standard field procedures and the map (Fig. 1) was produced from the aerial photographs by use of a radial line plotter. Hand specimens, washed samples, and igneous rock thin sections were studied in January and February 1965 at the University of Canterbury, and sedimentary rock thin sections were studied during April 1968 at the Pennsylvania Geological Survey.

Previous Work

The early work in the area by Haast (1871), Hutton (1877), and Speight (1918) has been adequately reviewed by Mason (1949, pp. 405–6). Mason (1949) described the topography, structure, and stratigraphy of the Mandamus - Dove River area as well as the related Pahau River area about 9 km to the east. He delineated seven sedimentary units in this area, all of which overlie Mesozoic greywackes and igneous intrusives. In 1951 he described the intrusive rocks of the area and discussed their origin. More recently Andrews (1963) assigned formation and member names to three of the units included in this report. Gregg (1964) showed the pattern of rock distribution in the area, but gave almost no description of the rocks.

GEOLOGICAL SETTING

The Tertiary rocks discussed in this report occur in an outlier surrounded by topographically higher peaks of older greywacke and igneous rocks. Rocks in the outlier are preserved mainly in a small south-westward-plunging syncline, herein called the Tekoa syncline (after Tekoa homestead, Fig. 1), upheld by a cap of resistant limestone which forms the crest of an isolated trough-like hill standing a few hundred feet above the

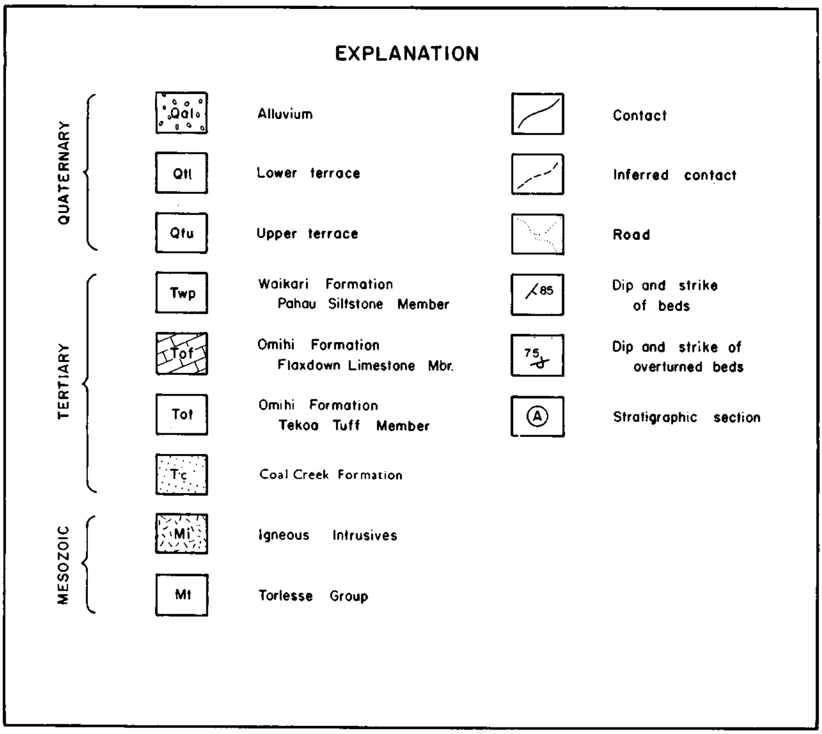


FIG. 1 (above and opposite)—Geological map of the Mandamus – Dove River area, North Canterbury, New Zealand. Map compiled from aerial photographs by radial line plotter. Grid lines are those of the national thousand-yard grid as shown on the 1 : 63,360 topographical map series (NZMS 1), sheet S61.

bed of the Mandamus River (Fig. 1). Mason (1949, p. 408) suggested that the syncline "probably formed the northern extension of an anticlinal structure represented by the Hurunui Peak ridge", and the present writer concurs.

Erosion has removed almost all of the Tertiary rocks except those protected by the limestone cap rock and those rocks not yet eroded by Coal Creek. The amount of Quaternary fluvial activity is indicated by the drainage development and the alluvial deposits shown in Fig. 1.

LABORATORY PROCEDURES

Eighty-three rock and sediment samples were collected for laboratory study. From these samples 52 thin sections were prepared, 26 samples were washed, and 9 samples were submitted to the New Zealand Geological Survey for age determinations. Some hand specimen descriptions were done in the laboratory to supplement field observations and all colour determinations were made in the laboratory using natural light and the Rock-Color Chart.

Twenty-six poorly consolidated samples were washed on a 0·062 mm sieve to remove the finer grained material. The retained fractions were dried and examined with a binocular microscope. Results of this study are incorporated in the described sections (Measured Sections A, B, C, D).

A qualitative examination was made of 36 of the 52 thin sections. Visual estimation of composition and grain size distribution was made for the greywacke thin sections. The igneous rock thin sections were used only for identification of the petrographic rock types. These data are incorporated in the described sections (Measured Sections A, B).

A point count analysis was performed on each of 16 thin sections prepared from unoriented limestone samples collected from a vertical sequence at Section D (Fig. 1) and the data are shown in Table 1. A mechanical stage was used to traverse each thin section using a 1 mm spacing between points along traverse and a 2 mm spacing between traverses. An average of 204 points (range: 148 to 292) were counted per slide. Composition and grain size were tabulated on the form shown in Fig. 2. The following standards were set and used during the point count analysis:

(1) Calcareous filling of interior parts of fossils (e.g., bryozoa) was counted as skeletal material;

(2) Clear, sparry calcite surrounding skeletal material, having definite external margins and internal optical continuity with the enclosed skeletal material, was counted as overgrowth material.

The percentage composition was calculated using all components counted, but the percentage of specific organic components (e.g., algae) was calculated using only the total skeletal materials.

Size of component parts was determined by measuring the maximum width of the shorter axis of elongate grains or the diameter of circular grains. Grain size distribution data are presented in Table 3.

SAMPLE NUMBER	Cryp	Microxyline		Macroxyline						
	xyl .005	F .031	C .062	VF .125	F .250	M .50	C 1.0	VC 2.0	GRAV	
NON SKELETAL										
QUARTZ										
STRAIGHT										
SLIGHT UND.										
STRONG UND.										
GLAUCONITE										
CARBONATE										
OOLITE										
INTRACLAST										
PELLET										
CLAY										
IRON										
MATRIX										
SPARITE										
VOID										
MICRITE										
FOSSIL INTER.										
OVERGROWTH										
SKELETAL	Whole	Frag	C	VF	F	M	C	VC	GRAV	
ALGAE										
BRACHIOPOD										
BRYOZOA										
CORAL										
CRINOID										
FORAMINIFERA										
GASTROPODA										
OSTRACODA										
PELECYPODA										

FIG. 2—Check sheet used for point count analysis of limestone thin sections.

ROCK UNITS

With one exception the nomenclature used in this report has been adapted from the reports of Mason (1949), Andrews (1963), and Gregg (1964). The name Coal Creek Formation is defined below for that unit designated as M3 by Mason (1949, p. 413).

Mesozoic

Torlesse Group

Rocks of the Torlesse Group are the oldest exposed in the study area. Two types of sequences occur in rocks of this group. The first type comprises 6- to 24-cm-thick beds of greywacke grading upward into argillite. The second type is massive greywacke beds up to 1 m thick separated by ½- to 20-cm-thick beds of argillite. Some massive beds have closely spaced parallel laminations in their upper part and some of the graded sequences have cross-bedding in the upper part of the greywacke bed. Colour varies from medium grey (N5) to olive grey (5 Y 4/1) to brownish grey (5 YR 4/1) with lighter shades of these colours produced by weathering. Outcrops of the Torlesse Group are not abundant. Therefore, continuity of the sequence types could not be determined.

A conglomerate comprising well rounded quartz, chert, and greywacke pebbles occurs north of Coal Creek (Fig. 1). The areal extent and thickness of the conglomerate is not certain. The conglomerate pebbles are mainly 2 to 20 mm in diameter with a few cobbles 6 to 10 cm in length. A coarser conglomerate is well exposed along the east bank of the Mandamus River and in the hill immediately north of Tekoa homestead. This conglomerate is composed of greywacke, red chert, trachyte, hornblende andesite, and basalt cobbles and boulders up to 70 cm in diameter (generally less than 25 cm).

Thin sections indicate that the greywackes generally contain angular detrital grains ranging from 0·01 to 0·3 mm in size floating in a clay matrix which constitutes up to 30% of the rock. The matrix is sericitised for the most part with some alteration to chlorite. The detrital components are generally 10% to 50% quartz, 5% to 20% plagioclase feldspar, and 10% to 50% sedimentary rock fragments.

Since no fossils were found in the greywackes, the Triassic age assignment of Gregg (1964) is accepted. The Torlesse Group has been intruded by numerous igneous rocks and is separated from the overlying Tertiary rocks by an angular unconformity.

Igneous Intrusives

A variety of igneous intrusives occur in the Mandamus – Dove River area and are discussed by Mason (1951). Although the present writer has identified only the intrusive rocks encountered during the field work, he feels that detailed mapping and petrology of these rocks will reveal a more complex history of intrusion than is reported by Mason.

The main body of igneous intrusive is a large mass of syenite which outcrops south-east of the Tertiary rocks. In some exposures this syenite is cut by dikes of melanocratic biotite hornblende microsyenite and biotite gabbro.

Numerous sills occur in the greywacke rocks and range from 0·3 m to several tens of metres thick. Identified sill rocks are: hornblende trachyte, melanocratic hornblende microsyenite, trachyte, and trachybasalt.

In a few outcrops the geometry of the intruded rock could not be determined. The rocks in these instances are: andesite, trachyandesite, trachyte, and basalt.

None of these intrusives is known to penetrate the Tertiary rocks overlying the Torlesse Group.

Tertiary

Coal Creek Formation

The name Coal Creek Formation is here given to that unit designated as M3 by Mason (1949, p. 413). The type locality is in Coal Creek and the lower part of the unit is described in Measured Sections A and B below.

MEASURED SECTION A. Stratigraphic Section of the Basal Part of the Coal Creek Formation Exposed in Coal Creek (A, Fig. 1)

Unit	Description	Thickness (metres)
10	Mudstone, light olive-grey (5 Y 6/1) to olive-grey (5 Y 4/1), massive, slightly calcareous, semi-conchoidal fracture, grades upward within a few metres into sandstone similar to unit 9; sample S61/635 taken 20 m above base yielded Dh age; contains angular quartz grains (0·125–0·25 mm diameter), glauconite (0·125–0·25 mm diameter), and foraminifera.	20·0 +
9	Sandstone, greenish-grey (5 GY 6/1) to dark greenish-grey (5 GY 4/1), moderately indurated, gradational upper contact; contains about 60% dark greenish-grey (5 G 4/1) to greenish-black (5 GY 2/1) glauconite grains (0·25–1·0 mm diameter) and 40% angular quartz grains (0·05–0·062 mm diameter).	20·0
8	Clay, between medium bluish-grey (5 B 5/1) and moderate blue (5 B 5/6), weathers to greenish-black (5 G 2/1), massive, hard, greasy weathered texture, sharp upper contact; sample S61/640 yielded a Dm–L age; contains some quartz and glauconite grains (0·25–0·50 mm diameter).	0·68
7	Conglomerate, well-rounded boulders, subangular cobbles, pebbles, and sand (1 boulder 1 m diameter, several ½ m diameter, abundance in range 15–20 cm diameter), sharp upper contact; following lithologies recognised (via thin section): quartz microsyenite, quartz trachyandesite, microsyenite, quartz trachyte, andesite, sandstone, and greywacke.	2·0
6	Coal, irregular seam, low rank sub-bituminous; scattered pyrite nodules up to 8 cm diameter, some of the underlying material intermixed in lower part, sulphur efflorescence on weathered surface, sharp upper contact.	0·6
5	Claystone, dusky yellowish-brown (10 YR 2/2), abundant black carbonaceous fragments, massive, moderately well indurated; silty with occasional quartz grains up to 5 mm diameter.	0·75

4	Conglomerate, rounded pebbles 5–10 cm diameter in sand, silt and clay matrix, pebbles highly weathered igneous and greywacke rocks, pebbles and matrix nearly a single coherent mass with a purplish weathered colour, pebbles more rounded than those in underlying unit, gradational upper contact.	1·0
3	Conglomerate, subangular to rounded pebbles 5–30 cm diameter (majority 5–10 cm diameter) in matrix of sand, silt, and clay, colour generally light grey, gradational upper contact; pebbles are highly weathered greywackes which are distinct from matrix and have an iron oxide coating.	1·5
2	Mudstone, dark greenish-grey (5 GY 4/1 to 5 G 4/1), massive, hard, contains sand, silt and clay, considerable iron stain along fractures, breaks into blocks, thickness ranges from 10 cm at stream level to 70 cm a few metres upslope, sharp upper contact; contains highly etched and pitted quartz grains (0·1–0·5 mm diameter) and some muscovite flakes.	0·7
	Total	47·23

UNCONFORMITY

Torlesse Group

1 Greywacke, near brownish-grey (5 YR 4/1), massive, well indurated, uniformly distributed white grains up to 1 mm diameter, no discernible bedding, highly fractured, no weathering at sharp irregular upper contact; unsorted mixture of angular grains up to 1 mm diameter, of equal amounts of quartz, feldspar, and sedimentary rock fragments in a clay matrix (10% ± of rock), some rock fragments highly distorted, variable weathering of feldspar grains.

MEASURED SECTION B. Stratigraphic Section of the Basal Part of the Coal Creek Formation Exposed in Coal Creek (B, Fig. 1)

Unit	Description	Thickness (metres)
5	Clay, between medium bluish-grey (5 B 5/1) and moderate blue (5 B 5/6), weathers to greenish-black (5 G 2/1), massive, hard when fresh, greasy weathered texture, upper contact lost in cover; about 1% angular quartz grains (0·125–0·25 mm diameter), flakes of white $CaCO_3$, and irregularly shaped dark yellowish-green (10 GY 4/4) glauconite grains (0·5–0·75 mm diameter).	0·25
4	Tuff, irregular mass of fine-grained material with bubbly and flow-like structures, and white $CaCO_3$ lenses, various colours such as dusky yellow-green (5 GY 5/2), moderate red (5 R 4/6), olive-black (5 Y 2/1), and brownish black (5 YR 2/1), mixed with angular tuff pebbles 5–10 cm diameter, sharp upper contact; contains a few angular quartz grains (0·02–0·1 mm diameter) and fractured glauconite grains (1 mm diameter).	0·15
3	Mudstone, greyish olive-green (5 GY 3/2), weathers to pale brown (5 YR 5/2), moderately hard, glauconite grains set in clay matrix, variable amounts of glauconite indicate bedding laminations, sharp upper contact; samples S61/633 and S61/634 yielded a Dm–Dh age; contains irregularly shaped glauconite grains (0·125–1·0 mm diameter), a few rounded and polished quartz grains (0·25 mm diameter), and foraminifera.	0·35
2	Tuff, as unit 4, sharp upper contact.	0·25
	Total	1·0

UNCONFORMITY

Torlesse Group

1 Greywacke, between medium bluish-grey (5 B 5/1) and dark greenish-grey (5 G 4/1), hard, well indurated, massive ½–1-m-thick beds of greywacke separated by a few thin (4–20 cm) interbedded black argillites, no weathering at upper contact; thin section shows 20%–40% rock fragments, equal amounts of quartz and feldspar, 10%–20% clay matrix, grains up to 0·5 mm diameter averaging 0·1–0·25 mm.

The middle and upper parts of the unit are best seen along the Mandamus River north-east of Coal Creek and are described in Measured Section C. Good exposures of the middle part of the formation occur along Coal Creek, but stratigraphic continuity is lacking.

The Coal Creek Formation comprises all of the moderately indurated sediments lying above the Torlesse Group greywackes and below the overlying Tekoa Tuffs. The unit is predominantly glauconitic sandstone and is about 122 m thick at its most complete exposure along the east bank of the Mandamus River opposite Tekoa homestead (C, Fig. 1). Measured Sections A and B are descriptions of the basal part of the unit exposed in Coal Creek. Except for the above-mentioned outcrops and a few exposures along Coal Creek, the formation is generally poorly exposed.

Unit 7 in Measured Section A contains pebbles of igneous rocks similar to those found locally intruded into the underlying greywackes. Unit 8 in Measured Section A and unit 5 in Measured Section B are lithologically similar and may represent the lowest laterally persistent bed within the formation.

Above the sequence described in Measured Section A, the Coal Creek Formation is predominantly cross-bedded and burrowed glauconitic sandstone. The cross-bedding generally has acute angles at the base and top of foresets and is distinctly marked by glauconite (Fig. 3). Some exposures show several superposed beds (½ to 1 m thick) each containing similarly oriented steep cross-beds. Each cross-bedded unit is separated by a thin (1–2 cm-thick) bed of glauconitic sandstone. Measurements of eight cross-beds in the outcrop area gave an average direction of dip of 11° (range between 342° and 67°) and an average dip of 24° (range of 12° to 35°).

A form of graded bedding occurs frequently in beds 2 to 3 cm thick (Fig. 4). Each bed has a sharp base and a high percentage of glauconite in the lower part of the bed. An upward decrease to almost zero of the percentage of glauconite within the bed results in a mineralogical and colour grading. Such graded beds occur parallel to bedding and in cross-bed foresets. Burrow structures are also common in the sandstone (Fig. 5). Calcite cementation within the sandstone is variable and laterally discontinuous cemented beds (up to 1 m thick) occur sporadically throughout the formation.

Angular grains of quartz generally ranging from 0·125 to 0·50 mm in diameter constitute most of the Coal Creek Formation although some subrounded to well rounded grains larger than 0·25 mm in diameter occur.

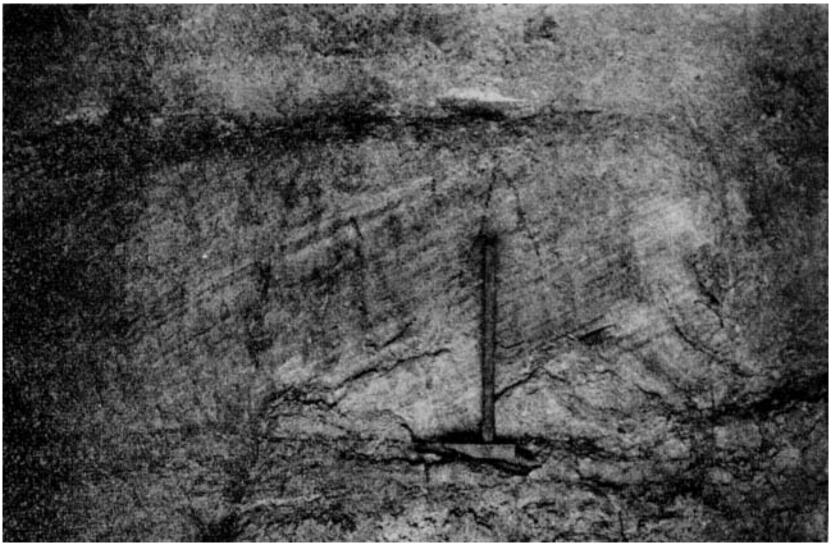


FIG. 3—Cross-bedded glauconitic sandstone of Coal Creek Formation exposed along Coal Creek. (Hammer is 60 cm long.)

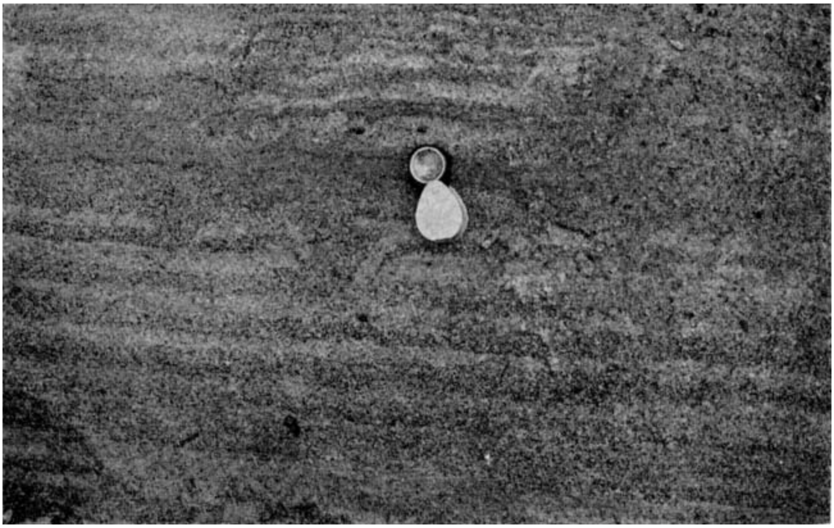


FIG. 4—Graded glauconite beds in Coal Creek Formation exposed along Coal Creek.

FIG. 5—Burrow structures in Coal Creek Formation exposed along Coal Creek.

Some beds contain well rounded and discoidal quartz pebbles 2 to 4 mm in diameter, *Ostrea* shell fragments, and occasional shark teeth. The glauconite grains are greenish black (5 GY 2/1), very irregular in shape, and range in size from 0·125 to 0·50 mm in diameter.

Sample S61/641 was taken on the south side of Coal Creek above Measured Section A (Fig. 1) and is probably from the lateral equivalent of unit 5 in Measured Section A. This sample yielded a pollen flora of Haumurian (Late Cretaceous) age. Foraminifera in four samples taken at stratigraphically higher positions in the Coal Creek Formation indicate a probable Mangaorapan–Heretaungan (Eocene) age. The stratigraphic positions of these samples are presented in Measured Sections A and B.

The upper contact of the formation is well exposed only at the location of Measured Section C (C, Fig. 1) where there is a sharp contact with the overlying Tekoa Tuffs.

Omihi Formation

Tekoa Tuffs Member. The Tekoa Tuffs Member of the Omihi Formation (Andrews, 1963, pp. 242–4) is best exposed at its type locality on the east bank of the Mandamus River opposite Tekoa homestead (C, Fig. 1; Fig. 6) and is well exposed at Measured Section D (Fig. 1). Descriptions of these sections follow.

MEASURED SECTION C. Stratigraphic Section of the Tekoa Tuffs at the Type Locality of the Member (Andrews, 1963, p. 242) on the East Bank of the Mandamus River Opposite the Tekoa Homestead (C, Fig. 1)

Unit	Description	Thickness (metres)
12	Interbedded tuff and limestone; tuff, moderate brown (5 YR 4/4), particles 1 mm to 1 cm diameter surrounded by white $CaCO_3$, tuff particles fine upward; limestone occurs as lenses, nodules, and discontinuous beds of hard, yellowish-grey (5 Y 8/1) limestone up to 10 cm thick, sharp contacts of tuff and limestone, sharp upper contact of tuff.	2·0
11	Tuff, moderate yellowish-brown (10 YR 5/4) to moderate brown (5 YR 4/4), particles of tuff up to 1 cm diameter enclosed by thin matrix of $CaCO_3$, massive, weathers to reddish-brown, gradational upper contact.	5·0
10	Tuff, pale greenish-yellow (10 Y 8/2) to moderate greenish-yellow (10 Y 7/4), massive, calcareous, fine-grained, current laminations, weathers to flaky and powdery mass, contains angular quartz grains (0·25 mm diameter), gradational upper contact.	1·8
9	Tuff, moderate olive-brown (5 Y 4/4) to moderate red (5 R 5/4) to yellowish-grey (5 Y 7/2), tuff particles 0·25–4·0 mm diameter in matrix of white $CaCO_3$, massive with colour banding as result of variable $CaCO_3$ content, gradational upper contact is irregular and some mixing with overlying unit may occur.	0·25
8	Tuff, upper 30 cm is banded material similar to unit 9; remainder is 1–10-cm-thick bands of (1) tuff, greyish-olive (10 Y 4/2), hard, brittle, fine grained, some quartz grains (0·25 mm diameter), some glauconite grains, and (2) tuff, as unit 10; gradational upper contact.	1·8
7	Tuff, as unit 9, gradational upper contact.	2·5
6	Tuff, greyish-olive (10 Y 4/2), hard, brittle, fine grained, some quartz and glauconite grains (0·25 mm diameter), interbedded upper contact.	1·2
5	Tuff, as unit 10, sharp upper contact.	0·5
4	Tuff, mixture of materials as units 9 and 10, gradational upper contact.	0·15
3	Tuff, as unit 10, gradational upper contact.	1·8
2	Tuff, yellowish-grey (5 Y 7/2) to dusky yellow (5 Y 6/4), massive, fine grained, white $CaCO_3$ gives salt and pepper appearance, numerous $CaCO_3$ veins in upper quarter, sharp upper contact.	13.0
	Total	30·0 +
	Coal Creek Formation	
1	Sandstone, fine- to medium-grained, light olive-grey (5 Y 6/1), uppermost part variably cemented with $CaCO_3$ and generally forms small ledge, numerous rounded and flattened quartz pebbles 1–4 mm diameter, some shark teeth and abundant *Ostrea* shell fragments up to 10 cm long and 2 cm thick, uppermost 25 cm has abundant flattened pebbles up to 2 cm diameter and some tuffaceous material, some glauconite grains, sharp upper contact; sandstone exposed for several tens of metres below base of tuff.	

MEASURED SECTION D. Stratigraphic Section of the Tekoa Tuffs and Flaxdown Limestone at North-east End of the Tekoa Syncline (D, Fig. 1)

Unit	Description	Thickness (metres)
	Flaxdown Limestone	
4	Limestone, light grey (N7) tending toward light brownish-grey (5 YR 6/1), hard, massive, crystalline, with abundant dusky yellow (5 Y 6/4) to dusky yellow-green (5 GY 5/2) to light brownish-grey (5 YR 6/1) pieces of tuff which are up to 4 mm in diameter, rounded and uniformly distributed; stylolitic seams with concentrations of tuff occur frequently in lower part; basal 2 m is interbedded tuff and limestone; samples used for thin section petrography taken from this section starting about 3 m above base.	15·0 +
	Tekoa Tuffs	
3	Tuff, moderate brown (5 YR 4/4 or 5 YR 3/4), coarse (1–10 cm diameter), dark grey (N3) to greenish black (5 GY 2/1) volcanic particles enclosed in fine-grained matrix, numerous brachiopod shells; contains abundant irregularly shaped $CaCO_3$ fragments, crystals of augite, a few rounded and polished quartz grains (0·5 mm diameter) and a few glauconite grains, foraminifera, and shell fragments; sharp upper contact; sample S61/636 from top of unit yielded L series (?) age.	0·4
2	Tuff, banded, fine grained, brittle, moderate brown (5 YR 4/4), 2–20-mm-thick beds interbedded with: pale brown (5 YR 5/2) to moderate brown (5 YR 4/4) bands, 10–15 cm thick, coarser than interbedded materials, colour depends upon amount of $CaCO_3$ present, gradational upper contact.	7·5
1	Tuff, massive, uniform, occasional bed is well defined, between dark yellowish-brown (10 YR 4/2) and greyish-brown (5 YR 3/2), gradational upper contact, lower contact lost in cover and unit may be up to 20 m thicker than indicated; contains numerous white spheres and irregularly shaped grains of $CaCO_3$ (0·125–0·25 mm diameter), some small concentrically banded spheres of moderate yellow-green (5 GY 7/4) fine-grained material, some irregularly shaped masses of moderate red (5 R 5/4 to 5 R 4/6) and moderate reddish-orange (10 R 6/6) fine-grained material, $CaCO_3$ probably as much as 20% of rock; sample S61/639 from lower part of unit yielded Ld–P age.	30·0 +
	Total	52·9 +

The main characteristics of the tuff are its red-brown colour and bedding. In Measured Section C the tuff is dominantly silty and clayey material with some augite crystals, quartz and glauconite grains, and abundant white globules of calcite. In Measured Section D the tuff contains beds of fragmental volcanic debris not observed in Measured Section C and individual beds have a coarser appearance than those in Measured Section C.

Several angular boulders of black basalt occur as float near the base of the tuff at the north-east end of the tuff outcrop (E, Fig. 1). In thin section this rock is an olivine basalt with augite phenocrysts and is similar to basalt described by Mason (1949, p. 417).

The Tekoa Tuffs Member is 30 m thick at C (Fig. 1) and about twice that thickness at the north-eastern end of the Tekoa syncline. Fig. 7 shows the basal contact and the apparent thickening of the tuff sequence toward the north-eastern end of the syncline.

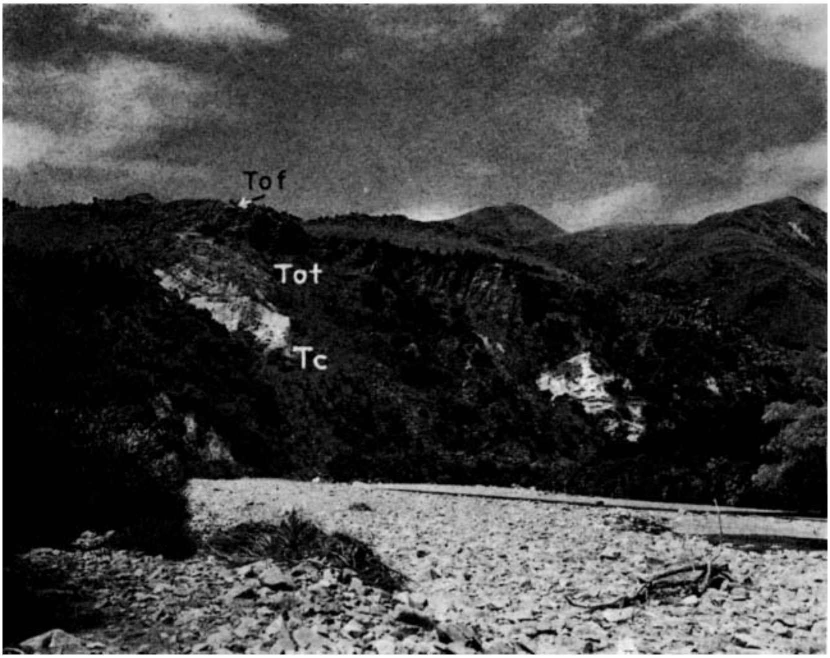


FIG. 6—Type locality of the Tekoa Tuffs Member of the Omihi Formation, on the east bank of the Mandamus River, opposite Tekoa homestead. Units delineated are: Tc—Coal Creek Formation; Tot—Tekoa Tuffs; Tof—Flaxdown Limestone.

The upper contact of the Tekoa Tuffs is interbedded with the overlying limestone through a distance of about 1–2 m. Thin sections of the interbedded limestone layers occurring at Measured Section D are identical in composition with the limestones described in the following section (Flaxdown Limestone), and washed samples of the tuff yielded gastropods, pelecypods, bryozoa fragments, crinoid columnals, augite crystals, and glauconite grains. Whole brachiopod shells also occur in some of the tuff beds of this zone.

Two samples of foraminifera from the tuffs at Measured Section D (units 1 and 3) indicate a probable Duntroonian–Otaian (Oligocene–Miocene) age for this unit. Andrews (1963, p. 244) restricts the Tekoa Tuffs to a Duntroonian age and this assignment is accepted.

Flaxdown Limestone Member. The Flaxdown Limestone Member of the Omihi Formation (Andrews, 1963, p. 245) is a hard, crystalline, white to cream coloured, massive limestone which weathers to a light grey colour. Some parts of the limestone are pinkish as a result of colouration from disseminated tuffaceous material. Concentrations of moderate reddish brown (10 R 4/6) tuff occur along stylolitic seams mainly in the lower part of the limestone. Bedding within the limestone is usually present in the lower part of the unit (Fig. 8), but the remainder of the limestone is massive and dominated by well developed weathering along fracture cleavage. The fracture cleavage is oriented normal to bedding and is shown in Fig. 9.

The Flaxdown Limestone is exposed in almost continuous outcrop around the trough-like hill whose crest it upholds and its general appearance is shown in Figs. 6, 7, and 8. Since no upper contact for the limestone is available in the study area, the character of the contact and the original total thickness of the unit are not known. Elsewhere, in Cascade Stream, about 9 km to the north-east, the Flaxdown Limestone has a bored upper surface (Mason, 1949, p. 419; Andrews, 1963, p. 247). Although no upper surface of the limestone is exposed in the Mandamus - Dove River area, there is little reason to doubt that similar boring has affected it here. The Flaxdown Limestone is approximately 18 m thick at Measured Section C (Fig. 1) and 15 m thick at Measured Section D. There is apparent uniformity of the limestone throughout its vertical sequence.

No fossils were collected from the Flaxdown Limestone for age determination and the age assignment of Waitakian (Oligocene) made by Andrews (1963, p. 246) is accepted.

Petrography of the Flaxdown Limestone. Because the compact crystalline texture prevents determination in hand specimen of the limestone components, a point count analysis was performed on 16 thin sections made from samples taken at Measured Section D (Fig. 1). The techniques of this study are discussed in a preceding section (Laboratory Procedures).

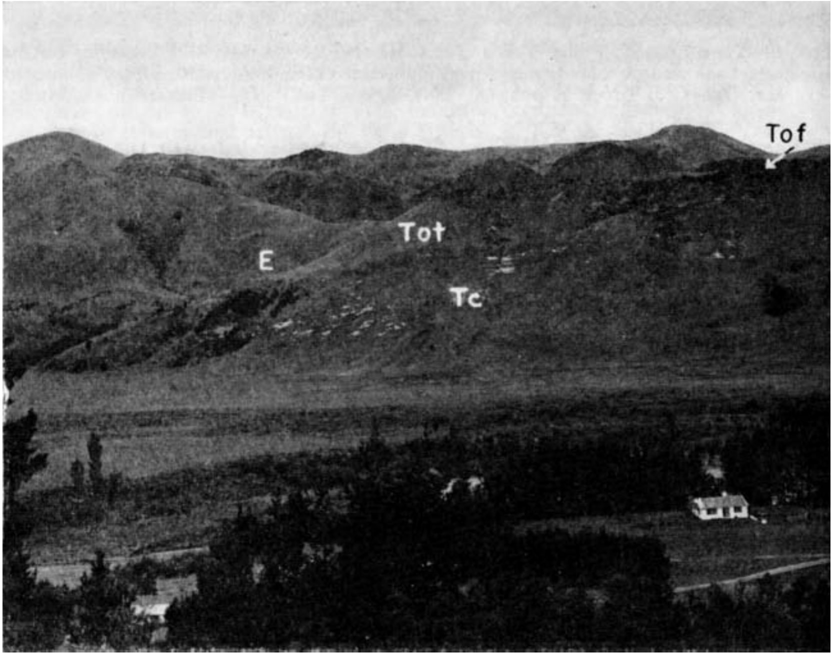


FIG. 7—North-east end of the Tekoa syncline. Units delineated are: Tc—Coal Creek Formation; Tot—Tekoa Tuffs; E—basalt float; Tof—Flaxdown Limestone.

FIG. 8—Tekoa Tuffs and Flaxdown Limestone Members of the Omihi Formation exposed on the north-west side of the Tekoa syncline. Note bedding in the lower part of the limestone.

FIG. 9—Fracture cleavage and bedding in the Flaxdown Limestone. Hammer handle parallels fracture cleavage.

The principal compositional data from the point count analysis are presented in Table 1. Minor components not reported in Table 1 are detrital quartz grains (present in 5 thin sections, maximum of 2%) and micrite (present in 9 thin sections, maximum of 4%). The skeletal types not reported in Table 1 have sporadic distribution throughout the sequence and are: brachiopod shells (9 thin sections, maximum of 4%), echinoid spines (8 thin sections, maximum of 2%), pelecypod shells (7 thin sections, maximum of 6%), sponges (4 thin sections, maximum of 2%), and ostracods (1 thin section, 1%).

Sparite (Folk, 1962, p. 66) occurs in the limestone as distinct, clear crystals of calcite which sometimes have the characteristics of void-filling calcite (Harbaugh, 1961, p. 96). Most commonly the void-filling sparite occurs in former voids of skeletal material such as bryozoa and less frequently in former voids between skeletal fragments. Only a few filled voids show either a distinct calcite crystal orientation normal to the margin or an elongation of crystal shape near the margin. An increase in crystal size toward the centre of a filled void is common. Some filled voids (particularly those between skeletal fragments) contain only a few (or even one) large sparite crystals. Some skeletal materials forming filled-void margins

TABLE 1—Principal Compositional Data Derived from Point Count Analysis of 16 Thin Sections of the Flaxdown Limestone from the Mandamus – Dove River Area (Measured Section D; Fig. 1)

Sample No.	Distance Above Base (metres)	Principal Components				Principal Skeletal Types			
		Skeletal %	Sparite %	Over-growth %	Tuff %	Algal %	Bryozoan %	Crinoidal %	Fora-miniferal %
16	11·6	54·8	30·8	10·3	0·0	28·9	34·2	26·3	5·3
15	11·0	53·4	28·8	12·3	0·0	20·5	37·7	27·9	9·0
14	10·5	67·9	17·9	9·5	0·5	27·5	38·5	22·9	6·4
13	9·8	66·8	14·6	17·4	0·4	11·9	45·0	40·4	2·0
12	8·9	70·2	20·3	9·4	0·0	14·3	34·1	34·1	4·8
11	8·1	80·0	7·8	7·3	3·2	21·2	34·3	28·1	11·6
10	7·1	66·1	25·3	6·6	0·4	3·5	64·6	19·5	4·2
9	6·4	73·4	16·7	9·1	0·4	3·4	85·1	8·6	0·0
8	5·7	71·7	14·9	12·8	0·0	7·3	63·6	19·8	1·4
7	5·3	63·8	20·8	13·5	0·6	11·5	69·0	16·1	1·1
6	4·9	77·2	12·0	8·4	1·8	8·0	72·0	15·0	2·0
5	4·5	75·5	8·4	2·8	13·4	3·8	50·7	37·7	1·5
4	3·7	63·3	15·6	16·1	4·5	6·3	56·4	29·4	0·0
3	2·7	78·8	5·4	10·3	5·4	13·9	46·7	29·9	5·0
2	1·5	78·2	11·2	8·3	1·0	17·2	35·7	38·6	5·0
1	0·8	73·1	6·0	16·1	4·8	6·6	59·2	31·3	0·8
	Average:	69·6	16·0	10·6	2·0	12·8	50·4	27·2	3·7

may have encrusting calcite (Harbaugh, 1961, p. 96) encasing the skeleton. Sparite comprises an average of 16% of the rock and is the second most abundant component of the limestone. Micrite (Folk, 1962, p. 66) is not common and occurs only as small void fillings, usually within skeletal materials.

Overgrowth calcite occurs mainly as clear, optically continuous calcite surrounding crinoid columnal fragments (Fig. 10) and averages 11% of the rock. The enclosed crinoid columnal is sometimes less than half as large as the overgrowth, but generally the overgrowth occurs as a small rim around the fragment.

Tuffaceous material occurs most abundantly in the lower part of the limestone sequence and is nearly absent in the upper third. The tuff usually occurs as rounded yellowish brown to reddish opaque masses up to 1 mm in diameter and sometimes as concentrations along stylolitic seams.

The few quartz grains observed were angular, between 0·031 and 0·25 mm in diameter and had straight or slightly undulatory extinction. No other detrital materials were noted.

Skeletal materials dominate the Flaxdown Limestone and comprise an average of 70% of the rock. Identification of skeletal types was aided by the work of Johnson (1951) and tentative identification of the algae is based on Johnson (1961).

Bryozoa constitute an average of 50% of the skeletal material and are the most abundant components of the limestone. Almost all of the bryozoa occur as fragments with a great variety of orientations in thin sections (Figs. 10 and 11). The irregular shape of nearly all fragments apparently results from skeletal fragmentation. Transverse sections across more or less circular skeletons show no breakage of the bryozoa in that plane.

Crinoid columnals make up an average of 27% of the skeletal material and occur in all orientations between transverse and longitudinal sections. Some transverse sections show the internal structure of the columnal, but most fragments are recognised only by shape and distinctive colour (Figs. 10 and 11). Almost all transverse sections of the columnals are whole, but a few are broken.

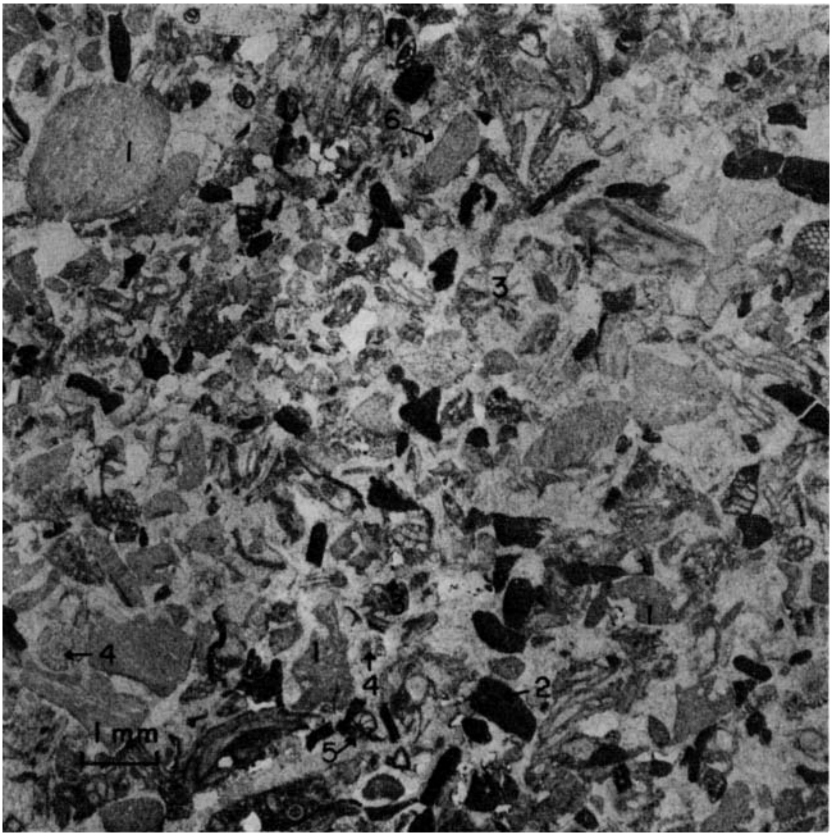


FIG. 10—Thin section of sample 15 (Table 1), Flaxdown Limestone. Materials delineated are: 1—crinoid columnal; 2—algae; 3—bryozoan; 4—echinoid spine; 5—foraminifera; 6—overgrowth. (Photograph made using thin section as negative in an enlarger without polarised light and projecting image on to Kodak direct positive print paper.)

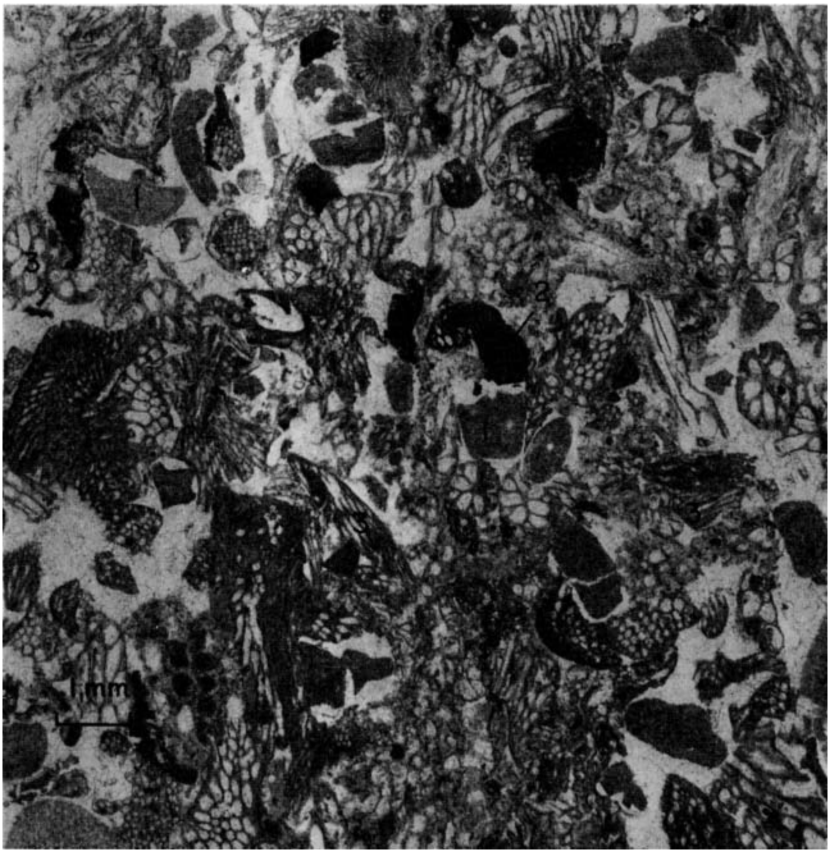


FIG. 11—Thin section of sample 9 (Table 1), Flaxdown Limestone. Materials delineated are: 1—crinoid columnal; 2—algae; 3—bryozoan. (Photograph made using thin section as negative in an enlarger without polarised light and projecting image on to Kodak direct positive print paper.)

Algae average 13% of the skeletal materials and are entirely fragmental (Figs. 10 and 11). The algae are easily recognised by their characteristic structure (Johnson, 1961) and tentative identifications of *Archaelithothamnium* and *Lithophyllum* have been made. These two genera appear to comprise nearly all of the algae although some encrusting algae were noted on a few bryozoa fragments.

Foraminifera make up an average of only 4% of the skeletal material and are the least abundant of the major skeletal constituents. Except for one or two individuals the observed foraminifera were whole, unbroken, and unabraded.

Interpretation of petrography of the Flaxdown Limestone. The composition indicated above is quite different from that suggested by Mason (1949, p. 419) (quoted by Andrews, 1963, p. 245): "The limestone M5 is made up almost entirely of comminuted shells of brachiopods and molluscs, . . ." Following the classification of Folk (1962) the rock would be called an algal crinoidal bryozoan biosparite, whereas a very similar limestone described by Moore (1957, pp. 109–11) is called (by Moore) a semi-crinoidal limestone.

The data in Table 1 suggest that the vertical sequence may have a trend toward separation into three compositional groups with boundaries between samples 5 and 6, and 10 and 11. In order to test the reality of any groupings a three-term moving average was calculated for the data in Table 1 after the data were subjected to an arc sine square root transformation (Krumbein, 1957) to "weight" the significant differences. In a three-term moving average an average value for each group of three adjacent data items is calculated. Such procedure results in no value for the two end members. The results of this test are presented in Table 2. The moving average data indicate much less positive trends than are suggested by Table 1. However, there is a definite grouping of samples in the upper third of the sequence (samples 11 and above). The upward trends in the limestone are summarised as follows:

(1) Decrease in amount of skeletal material.
(2) Decrease in amount of bryozoa and crinoid columnals.
(3) Increase in amount of algae and foraminifera.
(4) Increase in amount of sparite.
(5) Decrease in amount of tuff.

TABLE 2—Three-term Moving Average Data Derived from Transformed (arc sine square root transformation) Data of Table 1

Sample No.	Principal Components				Principal Skeletal Types			
	Skeletal %	Sparite %	Over-growth %	Tuff %	Algal %	Byrozoan %	Crinoidal %	Fora-miniferal %
16								
15	50	30	19	1	30	37	30	15
14	52	27	21	1	26	39	34	13
13	56	25	20	1	25	39	35	12
12	58	22	19	4	23	38	36	14
11	58	24	16	4	20	42	31	15
10	59	24	16	4	16	52	25	11
9	57	26	18	1	12	58	23	6
8	57	25	20	1	15	59	22	4
7	58	23	20	3	17	56	24	7
6	58	21	16	10	16	53	28	7
5	55	20	17	14	14	51	31	5
4	58	18	17	16	16	46	35	7
3	60	19	20	10	20	43	35	9
2	61	16	20	11	20	43	35	9
1								

This moving average analysis also emphasises an increase in abundance of bryozoa in samples 5–9 and a corresponding deficiency in the abundance of algae and crinoid columnals.

In addition to the compositional analysis of the limestone, an analysis was made of the grain size distribution of algae, bryozoa, crinoid columnals, and sparite crystals. The results of this analysis (Table 3) do not indicate any positive trends although the grain size spread for each item suggests a moderate degree of sorting for the fragmental materials. These data were also plotted on arithmetic probability paper and the median diameter of each item was interpolated. The results of this procedure lacked any conclusive trends and the interpolated data are not included here. Histograms of the data in Table 3 are equally uninformative and are not included here.

Waikari Formation

Pahau Siltstone Member. The Pahau Siltstone Member of the Waikari Formation (Andrews, 1963, p. 248) is exposed in a small erosional scar near the centre of the elongate hill upheld by the Flaxdown Limestone (Fig. 1). Mason (1949, p. 419) reported that no rocks younger than the Flaxdown Limestone occur here, but it is possible that the present scar did not exist when Mason did his field work and without the outcrop the siltstone is virtually undetectable. The siltstone is well indurated, massive, yellowish grey (5 Y 7/2), slightly calcareous, and sandy. It contains angular quartz grains up to 0·125 mm in diameter, some irregularly shaped glauconite grains, and occasional muscovite flakes.

Two foraminifera samples (S61/637 and S61/638) yielded a Waitakian–Otaian (Oligocene–Miocene) age for the Pahau Siltstone. This is the same age reported by Andrews (1963, p. 249). Nothing is known about the thickness or contact relationships of the unit and the areal distribution shown in Fig. 1 is largely conjecture.

GEOLOGICAL HISTORY

Fig. 12 is a summary of the sedimentary history of the Tertiary sediments in the Mandamus - Dove River area and represents a cross section through the axis of the Tekoa syncline although scale and orientation have been modified in order to best represent all components of the sedimentary model.

The greywacke and argillite sequence (Torlesse Group) observed in the Mandamus - Dove River area is most easily attributed to turbidity current deposition in a subsiding New Zealand Geosyncline. The two conglomerates (*see* p. 287) in the sequence are probably slump deposits that originated from quite different sources. The texture and composition of the coarser conglomerate suggest derivation from a river mouth deposit which was in turn probably derived from an immediate highland source. The rounding, uniformity of size, and composition of the finer grained conglomerate suggest derivation from materials subjected to considerable reworking on the foreshore.

TABLE 3—Grain Size Distribution Data for Selected Components of the Flaxdown Limestone

Component	Grain* Size	Sample Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Algae	CS		4·2												3·3	4·0	
	VF	12·5	16·7					20·0	14·3	16·7		12·9	5·6	16·7	20·0	20·0	22·7
	F	37·5	20·8	36·8	37·5	60·0	50·0	60·0	42·9	33·4		38·7	38·9	33·3	20·0	12·0	13·6
	M	37·5	8·3	26·3	25·0	40·0	12·5	20·0	14·3	50·0	100·0	35·5	38·9	33·3	36·7	48·0	36·4
	C	12·5	0·0	31·6	25·0		25·0		28·6			3·2	16·7	16·7	20·0	4·0	27·3
	VC		12·5	5·3	12·5		12·5					6·5				0·0	
	G		37·5									3·2				12·0	
Bryozoa	VF	1·5						1·7							4·8	4·3	
	F	10·3	8·0	4·7	9·9	3·0	6·9	13·3	4·9	2·7	8·6	22·0	4·6	8·8	16·7	28·3	19·2
	M	30·9	32·0	37·5	36·7	34·9	48·6	38·4	36·1	25·7	40·9	44·0	27·9	47·1	40·5	23·9	42·3
	C	47·1	46·0	45·3	36·7	39·4	40·3	43·4	49·2	47·3	32·3	34·0	54·6	39·7	33·4	39·2	38·5
	VC	10·3	14·0	12·5	14·1	22·7	4·2	3·3	9·8	23·0	15·1		11·6	4·4	4·8	4·3	
	G				2·8					1·3	3·2						
Crinoid	VF		1·9					7·1	15·8	6·7		2·4		3·3		5·9	
	F	8·3	13·0	9·8	10·8	6·1	13·3	7·1	10·5	0·0	17·9	22·0	32·5	18·0	32·0	8·8	35·0
	M	30·5	40·8	46·4	43·3	57·2	46·7	42·9	26·3	33·3	39·3	48·8	37·2	39·4	40·0	41·2	55·0
	C	55·6	29·6	29·3	40·6	32·7	40·0	28·6	47·4	40·0	28·6	22·0	25·6	34·4	28·0	41·2	10·0
	VC	5·6	14·8	14·5	5·4	4·1		14·3		20·0	14·3	4·8	4·7	4·9		3·0	
Sparite	FS	10·0	21·7	10·0	6·5	20·0	40·0	20·6	18·2	19·5	29·7	11·8	34·9	18·9	17·6	48·8	28·4
	CS	30·0	43·5	50·0	19·4	13·3	15·0	14·7	22·8	31·7	39·1	35·3	23·3	54·1	50·0	22·6	26·7
	VF	20·0	4·3	20·0	22·6	6·7	10·0	29·4	27·3	39·1	18·8	11·8	7·0	13·5	23·3	17·9	18·3
	F	10·0	17·4	10·0	29·0	33·3	20·0	11·8	9·1	9·8	10·9	41·2	18·6	8·1	8·8	4·3	10·0
	M	30·0	13·1	10·0	16·1	20·0	15·0	20·6	4·5		1·5		11·6	2·7		4·3	15·0
	C				6·5	6·7		2·9	4·5				2·3	2·7		1·2	1·7
	VC								13·6				2·3				

*Grain size class limits in mm: 0·005–FS–0·031–CS–0·062–VF–0·125–F–0·25–M–0·5–C–1·0–VC–2·0–G–4·0

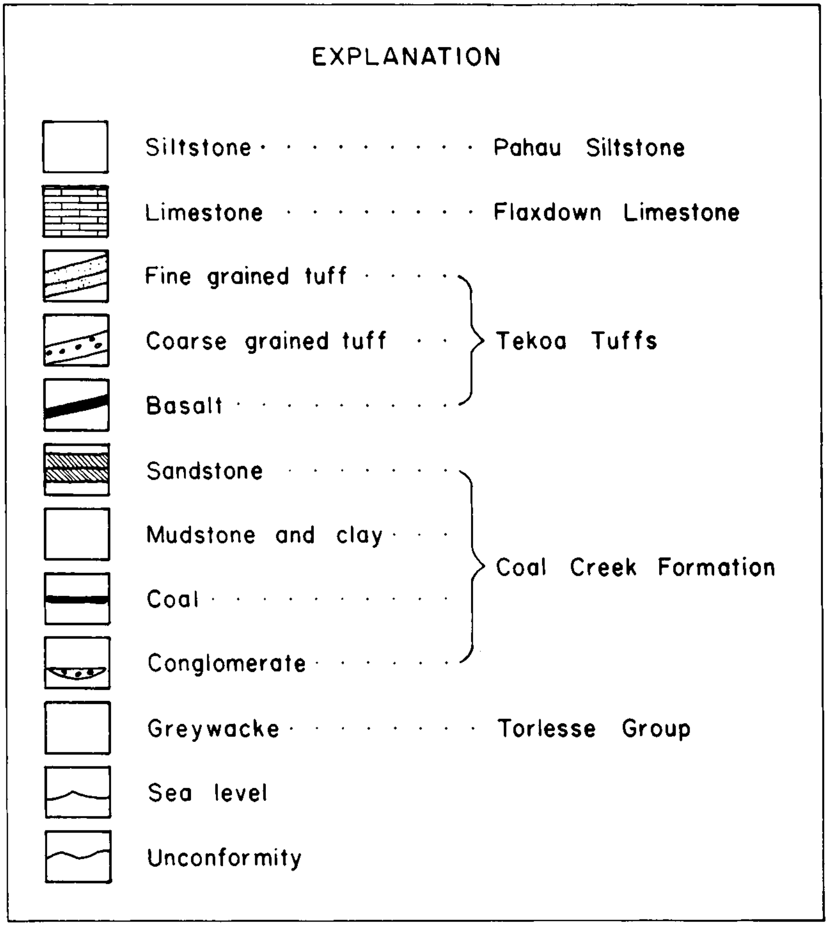
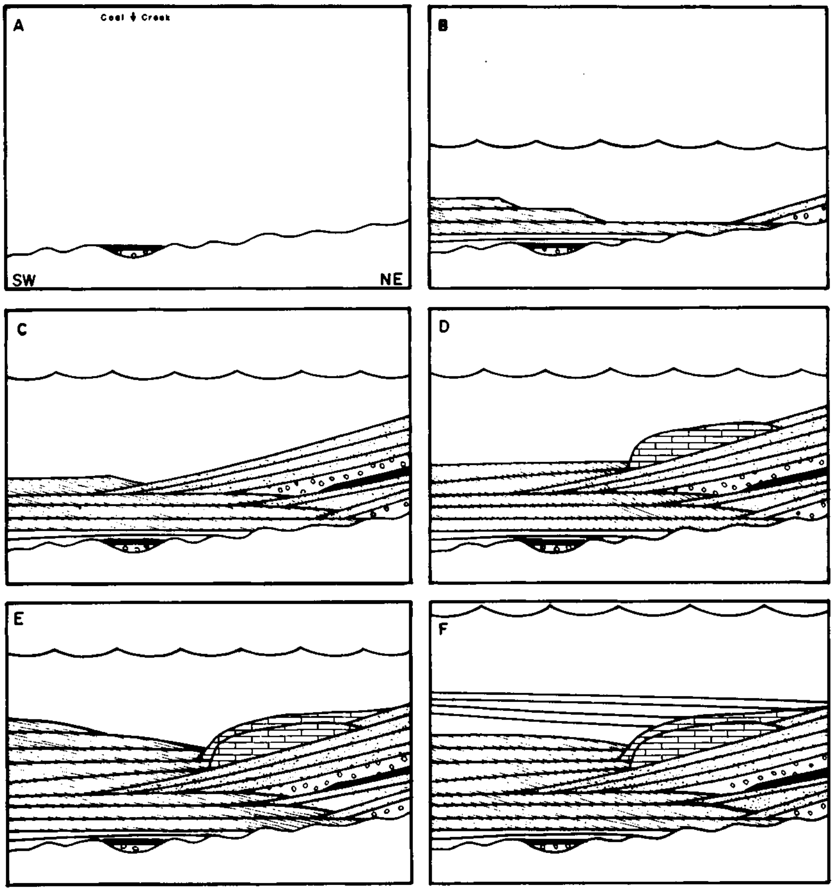


FIG. 12 (above and opposite)—Model of the Tertiary sedimentary history of the Mandamus – Dove River area. Line of cross section corresponds roughly to the axis of the Tekoa syncline. A detailed discussion of this figure is presented in text (Geological History).


A
Coal Creek
SW
NE
B
C
D
E
F

The exact time of igneous intrusion into the Torlesse Group rocks is not known, but emplacement probably occurred prior to the final stages of folding and uplift during the Late Mesozoic Rangitata Orogeny. This orogeny created an uplifted mass of greywackes, argillites, and igneous intrusives upon which a peneplain was cut prior to depositon of Cretaceous and Tertiary sediments. The local irregularity of the peneplain surface is indicated by sediment differences between Measured Sections A and B which are only a short distance apart, and a very irregular basal surface at Measured Section B.

The rocks in Measured Section A, their apparent local occurrence, and the lack of marine fossils suggest that at least units 2–7 were deposited in a fluvial environment, probably during Haumurian (Late Cretaceous) time. The similarity of the pebble lithologies with known pre-unconformity rocks of the area suggests that the conglomerates were derived locally and subjected to only short transport. The coal (unit 6) and the underlying claystone probably represent accumulation of material in an abandoned channel (Fig. 12A).

Unit 8, Measured Section A, and units 3 and 5, Measured Section B, represent deposits formed in relatively quiet marine waters. Movement of the foreshore through the area during marine transgression must have occurred without deposition unless unit 7, Measured Section A, represents a lag deposit formed during transgression. This was probably a slow transgression which resulted in the erosion of almost all deposits which may have existed on the peneplained surface and preservation of only local pockets such as occurs at Measured Section A. The occurrence of tuff (units 2 and 4, Measured Section B) indicates some local volcanic activity as early as Mangaorapan (Eocene) time.

The remainder of the Coal Creek Formation is cross-bedded, glauconitic sandstone. The steepness of the cross-bed foresets and the thickness of the beds indicate deposition by strong currents well supplied with detritus, while the similarity or orientation suggests rather uniform currents. Since the orientation of the cross-bedding indicates current movement parallel to the presumed Coal Creek Formation shoreline, the sandstones were probably deposited by northward-moving longshore currents (Fig. 12B). The competence of longshore currents to move large quantities of detrital materials is well known (Furkert, 1947; Sevon, 1966).

The dominance of quartz as the detrital part of the sediment is not particularly significant with regard to the source area and the angularity of the quartz is consistent with the size range generally present in the formation (generally less than 0·125 mm). The size range is indicative of materials which readily by-pass the beach environment and are not subjected to vigorous reworking. The occasional rounded quartz grains and the local concentrations of discoidal quartz pebbles indicate materials probably swept from the foreshore area either during storms or during shifts of source stream mouths.

The evidence for deposition of the Coal Creek Formation by strong currents suggests that the glauconite was not formed *in situ* since it is generally thought that glauconite formation requires a marine environment with slow sedimentation and slightly reducing conditions (Cloud, 1955; Burst, 1958). However, the irregular shape and fresh appearance of the glauconite grains suggest that the mineral was not derived from an older glauconite deposit. Rather, the writer thinks that the glauconite was being formed near the source of other detrital sediments seaward from the normal path of longshore currents. Periodic shifts of the longshore current (either seasonal or as a result of lateral shift in response to foreshore buildout) resulted in erosion of glauconite from its original environment of development and mixing with the detrital quartz. The abundance of burrow structures throughout the formation implies that deposition within the longshore zone was not too rapid for survival of organisms.

The sharp contact of the Coal Creek Formation with the overlying Tekoa Tuffs indicates an abrupt change in sediment source. Volcanic activity associated with the Tekoa Tuffs probably started long before any effects of such activity were felt at the Mandamus – Dove River area (Fig. 12B). Once formation and deposition of tuffaceous material became vigorous, however, build-up was sufficiently rapid to create an obstacle which diverted the course of the longshore currents and prevented encroachment of sands carried by those currents.

The centre of volcanic activity was to the north or north-east of the Mandamus – Dove River area as indicated by thickening of the Tekoa Tuffs in that direction, the basalt flow at the north-eastern end of the Tekoa syncline, and the coarser volcanic materials in the Pahau River area. This activity was presumably submarine and probably resulted in a cone-shaped mass of deposits radiating away from the centre of activity (Fig. 12C).

As a result of (1) rapid build-up of a tuffaceous sedimentary cone with an effect of shallowing the water depth, (2) diverted longshore currents, and (3) presumed increased water temperature (resulting from volcanic heat and shallowing water), organic communities became established and flourished, probably as fringing biotopes (Fig. 12D) around the volcanic centre. In the study area, only one presently observable biostrome (in the sense of Cumings, 1932) was established, but in the Pahau River area several biostromes occur as lenses in the tuff and indicate biotope development and subsequent overwhelming by volcanic materials. The organic remains most frequently noted at the base of the limestone, particularly in the interbedded tuffs, are brachiopods, and these presumably represent the first animals to establish themselves in the newly formed habitable environment. As the community developed, it was dominated by bryozoa and crinoids. More significant from the paleoecological point of view is the occurrence of the branching forms of algae *Archaeolithothamnium* and *Lythophyllum*. These algae strongly suggest water depth of less than 30 m (Johnson, 1961, p. 26) with an optimum depth of less than 10 m (Johnson, 1961, p. 251), warm temperatures, and good circulation. The fragmental nature and moderate sorting of the organic material suggest that the biotope was within the zone of agitation, but lack of any open-space structures and infilling such as are described by Wolf (1965) indicates that the biostrome was not formed in an environment as shallow as the intertidal zone. The skeletal materials preserved today therefore probably represent broken debris that accumulated on the sea floor adjacent to a growing biotope which flourished near wave base. Occasional pulses of volcanic activity contributed tuffaceous material and a few quartz grains were washed into the biotope from laterally contiguous sands.

The lack of tuff in the upper part of the limestone suggests that the volcanic activity effects diminished before the biotope became inactive. The changes in the local environment effected by this cessation, combined with the gradual deepening of the water through the subsidence (a process which must have been continuous throughout the period of Tertiary sedimentation considered here), probably created an environment in which the biotope could not survive. The increase in the percentage of foraminifera in the upper parts of the limestone (Table 1) suggests a more open marine condition than in the lower part of the unit. The burrowed upper surface of the limestone which is present in Cascade Stream represents an interval of time during which the biotope was neither growing nor being overwhelmed by detrital sediments.

During the period of tuff deposition and biotope growth, sands continued to accumulate in surrounding areas where no sediment is preserved today (Fig. 12E). Eventually the tuff and limestone deposits were overwhelmed by clastic sediments of the Pahau Siltstone (Fig. 12F).

The writer believes that a further sequence of sediments similar to that occurring in Cascade Stream (about 9 km to the north-east) was once present in the Mandamus – Dove River area and that erosion has stripped this sequence away. The writer has traversed the sequence exposed in Cascade Stream and recommends a detailed sedimentological study of those sediments as a logical continuation and conclusion to the deciphering and interpreting of the Tertiary–Pleistocene geological history of the Mandamus – Dove and Pahau Rivers area.

ACKNOWLEDGMENTS

The writer thanks the following persons who have contributed to this study: Mr A. C. Shand, Island Hills Station, Culverden, for his generous hospitality; Mr D. Jones, Geology Department, University of Canterbury, Christchurch, for preparation of thin sections, and photographic assistance; Mr G. H. Scott, New Zealand Geological Survey, Lower Hutt, for identification of the foraminifera; Mr D. J. McIntyre, Chevron Standard Ltd., Calgary, Canada, for identification of the pollen flora; Dr A. E. Cockbain, Geological Survey of Western Australia, Perth, Australia, for his helpful observations and discussions in the field; Dr M. J. Frost, British Museum of Natural History, London, for help with identification of the igneous intrusives; Dr J. D. Glaeser, Pennsylvania Geological Survey, Harrisburg, Pennsylvania, for criticising the manuscript; Mr L. Evinger, Geology Department, University of Indiana, Bloomington, Indiana, for help with the drafting; and Mrs W. D. Sevon, for typing the manuscript.

REFERENCES

ANDREWS, P. B. 1963: Stratigraphic nomenclature of the Omihi and Waikari Formations, North Canterbury. *N.Z. Jl Geol. Geophys. 6*: 228–56.

BURST, J. F. 1958: "Glauconite" pellets: their mineral nature and applications to stratigraphic interpretations. *Bull. Am. Ass. Petrol. Geol. 42*: 310–27.

CLOUD, P. E., JR. 1955: Physical limits of glauconite formations. *Bull. Am. Ass. Petrol. Geol. 39*: 484–92.

CUMINGS, E. R. 1932: Reefs or bioherms? *Bull. geol. Soc. Am. 43*: 331–52.

FOLK, R. L. 1962: Spectral subdivision of limestone types. *In* HAM, W. E. (Ed.): "Classification of Carbonate Rocks". American Association of Petroleum Geologists, Tulsa. Pp. 62–84.

FURKERT, F. W. 1947: Westport Harbour. *Trans. R. Soc. N.Z. 76*: 373–402.

GREGG, D. R. 1964: Sheet 18—Hurunui (1st edn). "Geological Map of New Zealand 1:250,000". Department of Scientific and Industrial Research, Wellington.

HAAST, J. VON. 1871: On the geology of the Amuri District, in the Provinces of Nelson and Marlborough. *N.Z. geol. Surv. Rep. geol. Explor. 1870–71 (6)*: 25–46.

HARBAUGH, J. W. 1961: Relative ages of visibly crystalline calcite in Late Paleozoic limestones. *Kansas Geol. Surv. Bull. 152*: 91–126.

HUTTON, F. W. 1877: Report on the geology of the north-east portion of the South Island, from Cook Straits to the Rakaia. *N.Z. geol. Surv. Rep. geol. Explor. 1873–74 (8b)*: 27–58.

JOHNSON, J. H. 1951: An introduction to the study of organic limestones. *Colo. Sch. Mines, Q. 46, no. 2.*

——— 1961: "Limestone-Building Algae and Algae Limestones." Colorado School of Mines. Golden. 297 pp.

KRUMBEIN, W. C. 1957: Comparison of percentage and ratio data in facies mapping. *J. sedim. Petrol. 27*: 293–7.

MASON, B. 1949: The geology of Mandamus – Pahau District, North Canterbury. *Trans. R. Soc. N.Z. 77*: 403–28.

——— 1951: The syenite and associated rocks of the Mandamus – Pahau area, North Canterbury, New Zealand. *Trans. R. Soc. N.Z. 79*: 260–75.

MOORE, R. C. 1957: Mississippian carbonate deposits of the Ozark Region. *In* LEBLANC, R. J.; BREEDING, J. G. (Eds.): Regional aspects of carbonate deposition. *Spec. Publs. Soc. econ. Palaeont. Miner., Tulsa 5*: 101–24.

SEVON, W. D. 1966: Sediment variation on Farewell Spit, New Zealand. *N.Z. Jl Geol. Geophys. 9*: 60–75.

SPEIGHT, R. 1918: Structural and glacial features of the Hurunui Valley. *Trans. R. Soc. N.Z. 50*: 93–105.

WOLF, K. H. 1965: Littoral environment indicated by open-space structures in algal limestones. *Palaeogeogr., Palaeoclim., Palaeoecol. (Neth.) 1*: 183–223.