Facies and Thickness of the Upper Paleozoic and Triassic Sediments of Southland

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Abstract

THE stratigraphy of the Southland Upper Paleozoic-Triassic sequence is illustrated by columns. Facies changes indicate the former existence of an old landmass beyond the southern margin of the Southland Syncline and a geosyncline beyond the northern margin. Two major marginal unconformities are described. The north-east thickening of the Lower Permian and Triassic beds is shown by isopach maps. The relation of the beds to the geosyncline and to the Otago Schist is discussed. Rocks of the same age exhibit progressive increase in metamorphism and deformation towards the Otago Schist and the thicknesses of the Upper Paleozoic and Triassic beds indicate a corresponding increase in depth of burial.

INTRODUCTION

THE Upper Paleozoic-Mesozoic marine sequence of New Zealand is well-exposed in the Southland Syncline which lies between the Fiordland massif in the south-west and the Otago chlorite-schists in the north-east. A section across this syncline from Waipahi to Mataura Island was presented and described by Wood (1953). Later mapping on the southern flank in the Taringatura Hills, Wairaki Downs, Takitimu Mountains and Longwood Range and partial re-mapping on the other flank in the Taringatura Hills and Eyre Mountains has enabled a further section to be drawn some 70 miles to the north-west. The sections are shown on the Geological Map of Southland (Fig. 1) and illustrated in Fig. 2.

Wood (1953: 111) demonstrated stratigraphic thickening of the Upper Paleozoic-Triassic marine sequence from the southern flank of the Southland Syncline at Mataura Island to the northern flank at Waipahi. Unconformities in this sequence were described, the chief of these being the Upper Paleozoic and Lower Triassic unconformities at Waipahi. These two unconformities were also inferred at Mataura Island.

STRATIGRAPHIC INTRODUCTION

Correlation of the Southland Upper Paleozoic-Triassic rocks is shown in the accompanying stratigraphic columns (Fig 8). The stratigraphy of the northern flank of the Southland Syncline is shown in Columns 4 and 5, and of the southern flank in Columns 1, 2, 3 and 6. The Tuapeka and Waipahi Groups and correlatives are conveniently considered as belonging to the Te Anau Group (Wellman, 1952: 18). The Productus Creek, Mataura Island and Arthurton Groups are correlated with the Maitai Group (Wellman, 1952: 18) Only the Triassic part of the Hokonui System (Marwick, 1953: 5) is shown in Fig. 8—the Balfour and Gore Series. The Jurassic beds of the Hokonui System are largely eroded in Southland and have not been included in the stratigraphic columns. The Gore Series has been further subdivided for the purpose of this paper into the Lower and Upper Gore Series. The former is defined as those beds overlying the Maitai Group, but underlying beds of the Kaihikuan Stage, whereas the latter includes two stages, the Kaihikuan and Oretian.

Throughout this paper the term "unconformity" is used for time not represented by strata, whether or not a plane of angular discordance is present.

The Southland Upper Paleozoic and Triassic rocks are subdivided into the local stratigraphic divisions shown on the left of Table 1 with the corresponding European division shown on the right.

Table 1.

NEW ZEALAND				EUROPEAN		
System	Series	Stage	Group	System	Series	Stage
HOKONUI (Triassic part only)	Balfour	Otapirian Warepan Otamitan		TRIASSIC	Upper	Rhaetian Norian Carnian
	Gore	Up. {Oretian Kahikuan L. {Etalian Pre-Etalian			Middle	Ladinian Anisian
					Lower	Scythian
			Maitai and Equivalents	PERMIAN	Lower	Artinskian
			Te Anau and Equivalents	CARBONIFEROUS		

Change in Facies

Facies changes in the Upper Paleozoic-Triassic sequence indicate the former existence of an old landmass beyond the southern margin of the Southland Syncline and a geosyncline beyond the northern margin. Three different facies in this sequence have been recognised; the coarse shelf, fine shelf, and redeposited or geosynclinal facies.

Pre-Maitai Rocks

The Pre-Maitai beds in the Southland Syncline can be divided to show their approximate time relationships as in Table 2.

Table 2.

Southern Flank	Northern Flank	
Takitimu Group	Waipahi Group Tuapeka Group	Te Anau Group
Longwood Complex	Otago Schist	

These divisions represent contrasting fine shelf and geosynclinal facies. The rocks on the southern flank are dominantly coarse pyroclastic sediments with andesitic flows and sills. On the other hand the rocks on the northern flank are chiefly fine green feldspathic and tuffaceous greywackes, and only the relatively thin upper part of the Te Anau Group contains any appreciable amount of coarse pyroclastic sediments and intrusions.

The Longwood Complex has been mapped by Dr. H. J. Harrington, N.Z. Geological Survey (pers. comm.) and shown to consist of sediments with fragments of the Pelecypod *Maitaia,* pyroclastic rocks, pillow lavas, and shallow intrusions of gabbro, diorite and biotite granite. Associated with the igneous intrusion are thermally metamorphosed sedimentary and pyroclastic rocks similar to those at Bluff, described by Service (1937).

The Takitimu Group comprises moderately indurated red and green pyroclastic breccias, spilitic and andesitic tuffs, red, green, purple and grey sandstone and mudstone, spilitic pillow lavas, flows of vesicular andesite, and sills, chiefly of andesite, micro-diorite and diorite. Some multiple sills are of micro-granite and micro-syenite. Dykes are rare *Maitaia* fragments are rare, but widely scattered; other macrofossils are very rare and have been found at only five localities in the Takitimu Mountains and an additional locality is known at Greenhills, near Bluff (Service, 1937: 207). The fossils include *Euryphyllum, Spirifer, Strophalosia, Chonetes, Deltopecten* and *Nuculana.*

The Tuapeka Group consists of subschists, and green feldspathic and tuffaceous greywackes. The dominant rock type is green-grey flinty greywacke sandstone in thick graded bands, banded mudstone and sandstone with fragments of black argillite. The conglomerates are mainly of the intraformational slate-pebble type, notable for the large proportion of green siliceous "paste" in the matrix (Wood, 1953: 107). Calcareous beds, red tuffs, shallow basic intrusions and conglomerates have been found, but are rare. The rocks are typical geosynclinal greywacke beds. No marine fossils have been found in this group.

The Waipahi Group is probably conformable to the Tuapeka Group and comprises red and green pyroclastic breccias, grey-black banded argillite, gritty purple or green tuffaceous sandstone, lithic and vitric tuff, spilitic pillow lavas, sills of dolerite and keratophyres, and sheet intrusions of gabbro and serpentine at the top. *Maitaia* fragments occur sporadically but are rare. No other macrofossils have been found. The lower greywacke sandstones are notable for the amounts of haematite in the matrix, and this criterion is the basis of subdivision between the Waipahi and Tuapeka Groups (Wood, 1953: 108).

Although the Takitimu Group is 70,000ft in thickness, more than three-quarters of this thickness consists of igneous flows, sills, and thick beds of pyroclastics, and truly clastic sediments do not exceed 14,000ft. On the other hand the Te Anau (Waipahi and Tuapeka) Group, 46,000ft in thickness down to the Chl_2 schist subzone, consists mainly of clastic sediments, the bulk of the shallow intrusions and any coarse pyroclastic beds being confined to the upper part (Waipahi Group). The varying amounts of clastic and pyroclastic sediments on opposite flanks of the Southland Syncline suggest that the volcanic activity that gave rise to these beds took place in the south-west along the southern margin of the geosyncline.

Wood (1956: 42) has shown that much of the landmass supplying the sediments of the Waipahi Group consisted of diorite, tonalite, dolerite, and probably basalt, andesite, keratophyre and sedimentary rocks such as greywacke and slate. These rock types are typical of those in the Takitimu Group.

Thick banded and graded greywacke sandstone and mudstone in the Tuapeka Group on the northern flank of the Southland Syncline are probably the redeposited equivalents of the Takitimu Group on the southern flank for they show the effects of submarine slumping and erosion by turbidity currents (Kuenen and Migliorini, 1950). The composite fragments of the less altered greywacke sandstone of the Tuapeka Group consist of felsite, andesite, keratophyre, greywacke and haematite shale (Wood, 1953: 107). Wood (1956: 70) has shown that the Tuapeka Group has been derived from a landmass consisting mainly of greywacke and slate, andesitic and dioritic rocks, and albitic volcanics. These rock types are typical of those in the Takitimu Group. The Tuapeka Group and the metamorphosed sediments of the Otago schist, were evidently deposited in deep water nearer to the axis of the geosyncline.

The Pre-Maitai beds on the southern flank of the Southland Syncline (see Table 2) underlie the Productus Creek beds of Lower Permian age (Fletcher, Hill and Willett, 1952: 7), and are thus considered to be Carboniferous in age. Similarly the Pre-Maitai beds on the northern flank of the Southland Syncline (see Table 2), may be Carboniferous in age, for they underlie the Permian Arthurton Group, which is a correlative of the Productus Creek and Maitai beds (Wellman, 1952: 20 and Wood, 1953, 108-9).

Maitai Rocks

Although the geosynclinal facies of the Maitai is not now preserved over the Otago Schist, the lithology of the remaining Maitai beds at various localities within the Southland Syncline shows the greatest and most significant facies changes. At Ohai, Productus Creek and Mataura Island, the beds of the Maitai Group constitute a coarse facies, and consist mainly of coarse-grained andesitic tuffs, sandstone, limestone and conglomerate. At Mossburn, and according to Mr Grindley, N.Z. Geological Survey (pers. comm.) in the Eglinton Valley, the beds are finer and are predominantly grey-banded mudstone and tuffaceous sandstone (generally called "grey-banded argillites") with grey-black limestone lenses at the base, similar in lithology to the beds included in the Maitai Group at Nelson (Wellman, 1952: 18). The coarse facies apparently represents rapid filling almost to wave base at that time. The fine facies on the other hand was deposited in deeper water, more distant from the old landmass, as shown by the finer grain size and regular fine rhythmic bedding. Wellman (1952: 16) suggested that there was rapid filling by sediments nearly to wave base in all parts of the geosyncline throughout its period of subsidence This does not apply to these beds nor similar beds in the Te Anau Group.

The conglomerates of the coarse facies are derived from the Te Anau beds and associated igneous intrusions on the southern flank of the Southland Syncline, which were exposed at that time in the old Permian landmass to the south-west. The coarseness of the conglomerates and lack of graded bedding in the sediments at Productus Creek indicate the proximity to the old landmass (suggested by the position of the zero isopach in Fig. 5). The absence of pillow lavas and coarse pyroclastics in the Maitai beds and the scarcity of tuffs in the fine facies indicates that volcanic activity in the south-west was much reduced during this time.

Triassic Rocks

In contrast to the facies changes exhibited in the Te Anau and Maitai beds almost no lateral change can be discerned in the Triassic marine sediments. However, in general there are more conglomerates along the southern margin of the Southland Syncline than there are on the northern margin.

The coarseness of the Triassic sediments, abundance of fossils, the presence of fragmentary plant remains and lack of graded bedding all suggest that the sediments were laid down in shallow water not far distant from the margin of the old landmass. The sediments near Mossburn and the North Range nearby (Coombs, 1950: 434) may have lain close to the outer edge of the shelf for they show effects of submarine slumping and erosion by turbidity currents (Kuenen and Migliorini 1950), and graded bedding is more evident.

Lithic and vitric tuffs are prominent in the Lower Gore Series, but the dominant rock type is coarse, tuffaceous sandstone with occasional pebbly beds. Some of the lower coarse sandstone near Lumsden and Mossburn on the northern flank of the Southland Syncline, contain conspicuous angular fragments of reddish-brown tuffaceous mudstone. Macrofossils are rare in the Lower Gore Series and are known from only six localities, namely at Kaka Point, near Nugget Point, Pukerau, near Waipahi, East Peak, near Gore, Morley Stream, Malakoff Hill and Letham Burn. The last three are located in the Wairaki Downs Morley Stream is the type locality for the Etalian Stage, characterised by a ceratitic ammonite fauna; fossils of this age have been found outside the Wairaki Downs at only one locality, near Gore (Wood, 1956: 55). A fauna including brachiopods and ceratitic ammonites, has been found recently near Malakoff Hill below beds of the Etalian Stage and, according to Dr. Fleming, Paleontologist, N.Z. Geol. Surv. (pers. comm.), the brachiopods can be correlated with those found at Pukerau, near Waipahi. Both these faunas occur in the basal conglomerate. A different fauna including ammonoids ? in the same basal conglomerates occurs near Productus Creek.

The sediments of the Etalian Stage in Wairaki Downs consist mainly of dark blue-grey banded mudstone containing several species of ammonites. Beds of similar lithology underlying the Kaihikuan Stage of the Gore Series in the North Range and Western Hokonui Hills (the "Black Marls" of Cox and McKay, 1878: 28) have not yielded an ammonite fauna but are probably of the same age. Elsewhere, on the northern limb of the syncline, the Etalian beds are represented by moderately coarse tuffaceous beds.

Beds of the Kaihikuan Stage (Upper Gore Series) are predominantly fine blue-grey sandstone and fine volcanic breccia. They are the lowest Triassic beds in which fossils are abundant at most places. At Little Wairio Hill, the Kaihikuan beds consist of thick conglomerate, overlain by carbonaceous blue-grey sandstone and mudstone with thin coaly lenses and mottled tuffaceous sandstone. The lithology of this thin sequence suggests that the old Triassic shoreline was not far distant to the west.

The sediments of the Oretian Stage (Upper Gore Series) in the Southland Syncline are conspicuous for the development of thick beds of vitric and mottled lithic tuffs. Wood (1953: 110) first noted cobbles derived from the Fiordland Complex in the basal conglomerate of this stage at Waipahi. In the Wairaki Downs and the Taringatura Hills pebbles from the Fiordland Complex has been found only in beds of the Otamitan and younger stages.

Beds of the Otamitan Stage (Balfour Series) consist mainly of dark blue-grey siltstone and mudstone with, less commonly, tuffs and tuffaceous sandstone.

Beds of the Warepan Stage (Balfour Series) are thin and impersistent within the Southland Syncline, due to unconformities at the base of the Warepan and Otapirian Stages. The unconformities have been illustrated by Wood (1953, 111) and can be inferred from the geological maps of Ongley (1939) and Mackie (1935). The key fossil *Monotis richmondiana* has been found only at Nugget Point (Mackie, 1935), Kaihiku Range (Ongley, 1939), Western Hokonuis (Cox and McKay, 1878), Taringatura district (Coombs, 1950), and in the S E Hokonui Hills, near Hedgehope. The latter locality lies close to Jurassic beds and their proximity may be due to post-Warepan unconformities. The Warepan beds in the northern Taringatura Hills and western Hokonui Hills are thicker than elsewhere in Southland. They are obviously clastic and lack primary tuffs. The dominant rock type is blue-grey coarse sandstone and pebble conglomerate. The Triassic conglomerate pebbles other than obviously pyroclastic ones, are all derived from underlying sedimentary groups and igneous complexes which formed the old Triassic landmass on the southern margin of the geosyncline. The composition varies slightly from place to place; for instance, volcanic components predominate in the Lower Gore Series, but plutonic pebbles are common in the basal conglomerates at Productus Creek, Waipahi (Wood, 1953: 109), and Clinton (Ongley, 1939: 32). The volcanic activity was still sited along the southern margin of the geosyncline in Triassic time. Variations in the composition of Triassic sediments between pyroclastic and clastic indicate fluctuations of volcanic activity. However, there was an overall decrease in volcanic activity from pre-Etalian to Otapirian time. As noted by Wood (1953: 112 and 1956: 70) and Coombs (1954: 90) there was a change from basic to acidic tuff accompanying this decrease.

Within the thin sequence of Jurassic beds preserved in Southland only the lower part is marine, while the upper part is both littoral and terrestrial (Wood, 1953: 112-113). The occurrence of coal-bearing cross-bedded arkosic sandstone, breccia, conglomerate and magnetite sands, south of Mataura Island, indicate the south-west provenance of the Jurassic sediments and the presence of an old granitic landmass along the southern margin of the Southland Syncline. The paucity of tuffs in the Jurassic beds indicate that the volcanic activity along the southern margin of the geosyncline was even further reduced compared with late Triassic time.

MARGINAL UNCONFORMITIES

In the Southland Upper Paleozoic-Mesozoic marine sequence numerous unconformities have been mapped, but only two are known to have regional importance: the unconformity between the Te Anau Group and the Maitai Group, and the one between the Maitai Group and the Hokonui System. The Te Anau-Maitai and Maitai-Hokonui unconformities decrease in magnitude towards the north-east. This is further evidence of the south-west provenance of the Upper Paleozoic and Triassic beds. The facies changes between the southern and northern flanks of the Southland Syncline correspond to a change from interrupted marine deposition near the margin of the old landmass in the south-west to continuous marine deposition towards the Otago Schist and the axis of the geosyncline to the north-east.

The Te Anau-Maitai unconformity was first revealed by the derived Te Anau cobbles (including a fossiliferous one) in the basal beds of the Maitai Group at Waipahi (Fig. 8, Column 5) on the northern flank of the Southland Syncline (Wood, 1953). The basal beds of the Maitai Group at Ohai, Productus Creek and Mataura Island (Fig. 8, Columns 2, 3 and 6) on the southern flank contains derived cobbles from the Te Anau Group matching those at Waipahi, but no fossiliferous cobbles have been found. At Mossburn (Fig. 8, Column 4), on the northern flank, the Te Anau and Maitai Groups are apparently conformable, the absence of volcanic or plutonic intrusions in the Maitai Group being the chief criterion of subdivision (Wellman, 1952: 19 and Wood, 1953: 108).

The Maitai-Hokonui unconformity is more marked along the southern flank of the Southland Syncline at Wairio, Ohai and Productus Creek (Fig. 8, Columns 1, 2 and 3) where beds of the Hokonui System overlap both the Takitimu and Productus Creek Groups. At Mataura Island (Fig. 8, Column 6) a similar unconformity is present. Unconformity at Waipahi (Fig. 8, Column 5) is indicated by derived fossiliferous cobbles of both the Te Anau and Maitai Groups in the basal beds of the Hokonui System (Wood, 1953: 109).

The contact between the Maitai Group and the basal beds of the Hokonui System has not been located with certainty at Mossburn, but for the present is placed beneath massive volcanic conglomerate which overlies the grey-banded argillites of the Maitai Group in a series of small hills on the east bank of the Oreti River, two

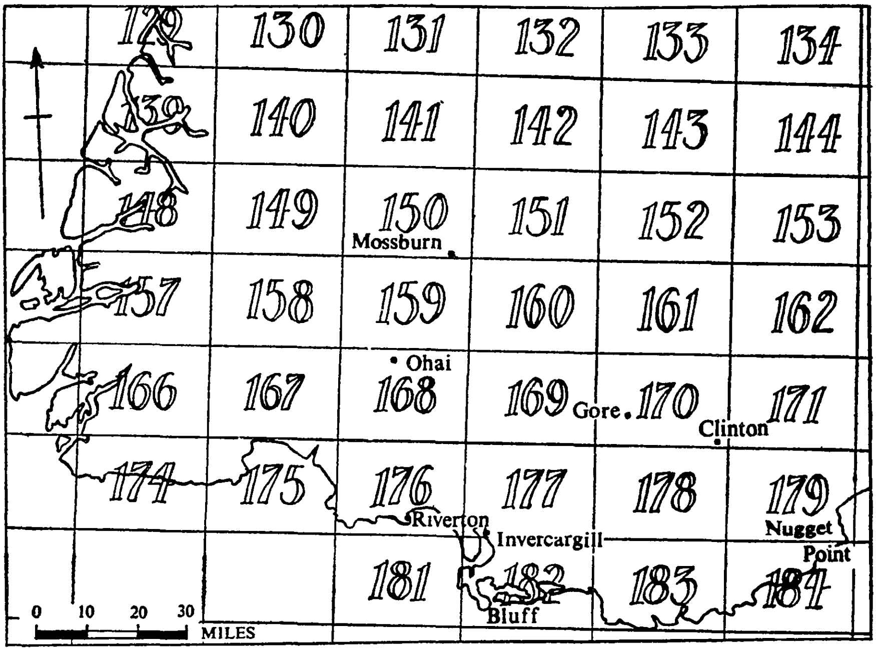

FIG. 3.—New Zealand Lands and Survey Provisional One Mile Sheet District boundaries of part of Otago and Southland.

miles north-west of Mossburn. A minor break at a corresponding stratigraphic position has been observed by Mr. G. W. Grindley, N.Z. Geol. Surv. (pers. comm.), in the Countess Range, east of the Eglinton Valley, 32 miles north-west of Mossburn.

CHANGES IN THICKNESS

Isopach maps have been drawn for the Maitai Group, the Upper and Lower Gore Series and the Balfour Series. The isopach maps are based on measured thicknesses at the localities named in the stratigraphic columns in Fig. 8. Additional information has been obtained from localities in the Eglinton Valley (Mr. Grindley, N.Z. Geol. Surv., pers. comm.), West Hokonui Hills (Cox and McKay, 1878, Marwick, 1953, and Campbell and McKellar, *in press*), Eastern Hokonui Hills (Watters, 1950), Gore (Wood, 1955), Kaihiku Range (Ongley, 1939) and at Nugget Point (Mackie, 1935; Wood, 1953; and Campbell, 1955).

The overturned, and vertical to near-vertical beds in the northern flank of the Southland Syncline thin downward, and this cannot be shown conveniently on an isopach map with the beds in their present position. The points marking the thickness have been shifted north to positions occupied before the beds were folded The amount of shift is shown by the distortion of the National one mile sheet district boundaries. Similar southern distortion is shown in the area of near-vertical beds south-west of the gently dipping beds on the southern flank of the Southland Syncline. A map of Otago and Southland showing one mile district boundaries is included at the same scale as the isopach maps (Fig. 3).

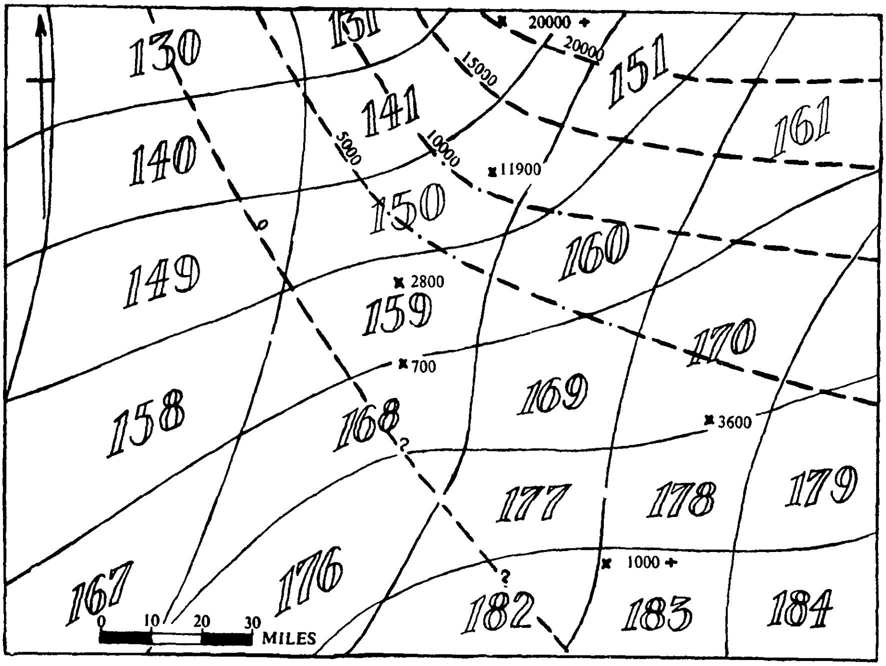

Fig. 4.—Isopach Map of Maitai Group Isopach interval is 5,000ft, zero isopach approximates to position of old shore-line. The scale is the same as Fig. 3

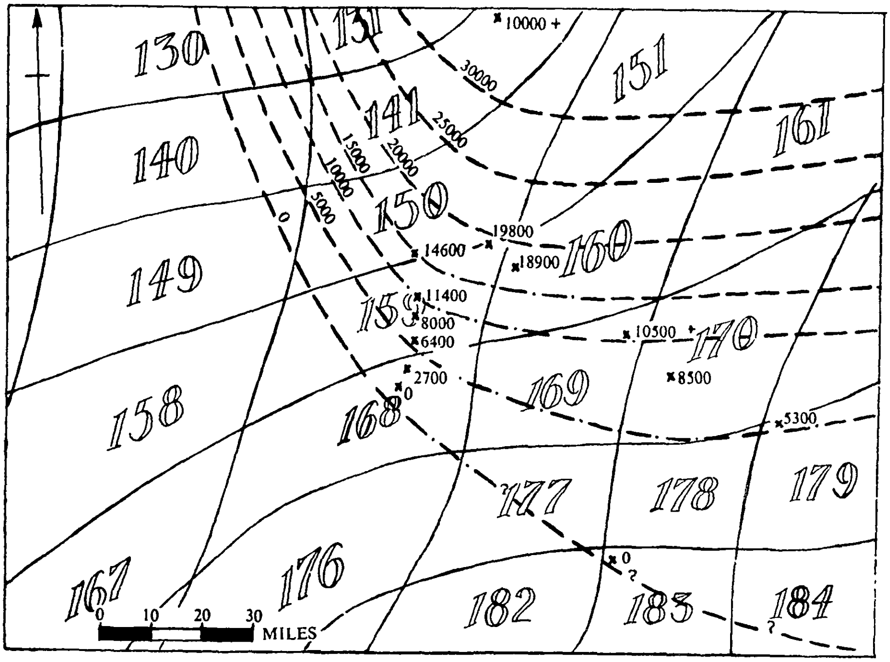

Fig. 5.—Isopach Map of Lower Gore Series. Other details as for Fig 4

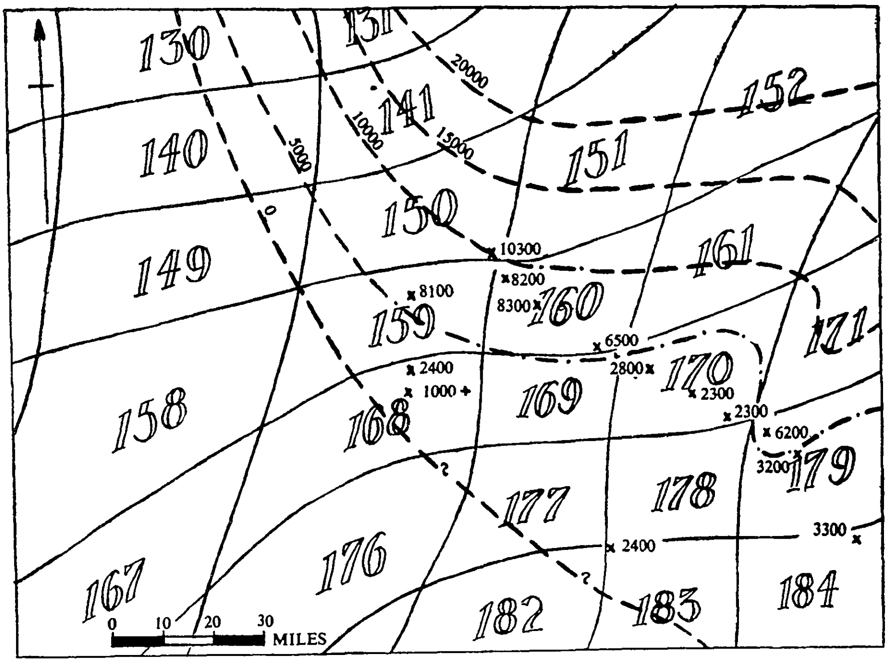

FIG 6.—Isopach Map of Upper Gore Series. Other details as for Fig. 4.

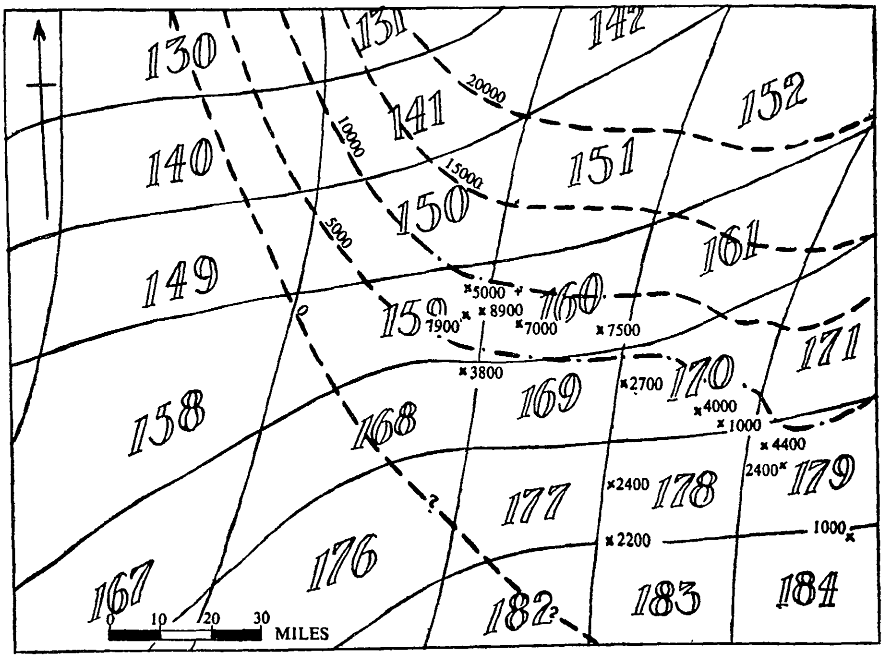

FIG. 7.—Isopach Map of Balfour Series. Other details as for Fig. 4.

The stratigraphic columns (Fig. 8) and the isopach maps (Figs. 3, 4, 5, 6 and 7) illustrate the progressive north-east thickening in the Lower Permian-Triassic sequence. The rate of thickening increases towards the north-west as shown by the progressive crowding of the isopachs in that direction.

The north-east thickening is accompanied by a change from interrupted marine deposition near the margin of the old landmass in the south-west to continuous marine deposition towards the Otago Schist and the axis of the geosyncline to the north-east As already shown these changes between the southern and northern flanks of the Southland Syncline are also accompanied by corresponding changes in facies.

The isopach pattern is essentially the same for the Triassic and Maitai beds. This similarity suggests that the Jurassic beds, which were probably laid down in the same geosyncline, thicken in the same direction.

RELATION TO SCHIST

Structural Relationship

The features used in mapping the structure of the pre-Tertiary rocks of Southland are essentially the same as those used by Wood (1953: 113), and include sedimentary grading, slump-bedding and secondary or drag-folds.

The geological sections, from the Longwood Range in the south-west to the Eyre Mountains in the north-east (Fig. 2, Section A-A′) and from Mataura Island to Waipahi (Fig. 2, Section B-B′), show the structure of the Southland Syncline with its steeper dips and overturned older strata along the north-east limb. The near-vertical dips beyond the gently dipping beds on the south-west limb are also illustrated. On the north-east limb the degree of overturning is much greater in the pre-Maitai beds. Wood (1953: 113) has shown that the beds near Waipahi dip between 55° and 35° to the north-east and have been rotated through 125° and 145°. However, in the Eyre Mountains the degree of overturning is not so great, and the beds have been rotated 110° to 130°. Wood (1953: 113) records two isoclinal folds with limbs dipping 40° to 50° N.E. in the Tuapeka (part Te Anau) Group near Waipahi. At least five isoclinal folds with limbs dipping 45° to 80° N.E. have been mapped in the same group near Mossburn. The large isoclinal folds are on a regional scale but are best considered as drag-folds on the Otago Schist Anticlinorium. The degree of deformation, as shown by the number of drag-folds, amount of shearing and density of jointing in the rocks increases progressively towards the Otago Schist.

Minor folds are present on the southern flank of the Southland Syncline. In the Twinlaw Range and along the eastern flank of the Longwood Range the lower beds of the Takitimu Group are plicated in minor assymetric open folds with moderately steep limbs. The folds pitch at a low angle south-eastward in the same direction as the axial pitch of the Southland Syncline. The fold structure at Mataura Island, initially mapped by Wood (1953: 113), and now shown in modified form in Fig. 2 (Section B-B′), may be part of this belt of folds underlying the southern margin of the Southland Plain.

Rank and Thickness Relationships

It has already been shown that Maitai and Triassic beds in the Southland Syncline thicken towards the Otago Schist and once overlay it. The Te Anau beds pass downward into the Otago schist without any sign of unconformity. The Jurassic beds probably thicken in the same way. The measured thickness of the Upper Paleozoic and Triassic in the Mossburn Section along the southern margin of the Otago Schist is 95,000ft down to the top of the Chl_2 schist sub-zone. Extrapolating this rate of thickening toward the north-east the thickness of the sediments over the

Otago schist must have been greater than 18 miles. As already pointed out by Wellman (1952: 18) the total thickness of sediments that form the Otago schist is enormous and can be measured in miles.

The metamorphism of the sediments in the Upper Paleozoic-Mesozoic sequence in the Southland Syncline increases progressively towards the north-east and the Otago Schist. In spite of the great thickness, the lower beds of the Takitimu Group are no more indurated than coeval strata, along the northern flank of the Southland Syncline. This may be explained by the subsequent deposition of a thin Lower Permian-Triassic sequence on the Takitimu Group.

Wellman (1952: 17) has suggested that there is progressively increasing depth of burial for rocks of the same age towards the schist. This condition has been proved on the southern margin of the Otago Schist, and it is reasonable to assume that the less altered sediments on the northern margin thicken south-westward and are derived from the north-east. This would indicate that the beds represented by the Otago Schist lie within the axial region of the New Zealand Geosyncline.

Extensive zeolitization of Lower Mesozoic tuffs at Taringatura on the northern flank of the Southland Syncline has been described by Coombs (1954: 92) and was considered by him to be related to mild rise of temperature following burial and to originally entrapped water. Coombs considered that this general tendency for increase in alteration towards the base of the section could not be extended to account for the formation of the Otago Schist. The present writer suggests that the alteration of the tuffs constitutes only part of a larger overall metamorphism in a geosyncline. The close correlation between the progressive increase in metamorphism, deformation, and thickness of sediments towards the Otago Schist suggests that depth of burial played just as important a part in the zeolitization of the tuffs as in the formation of the chlorite schist.

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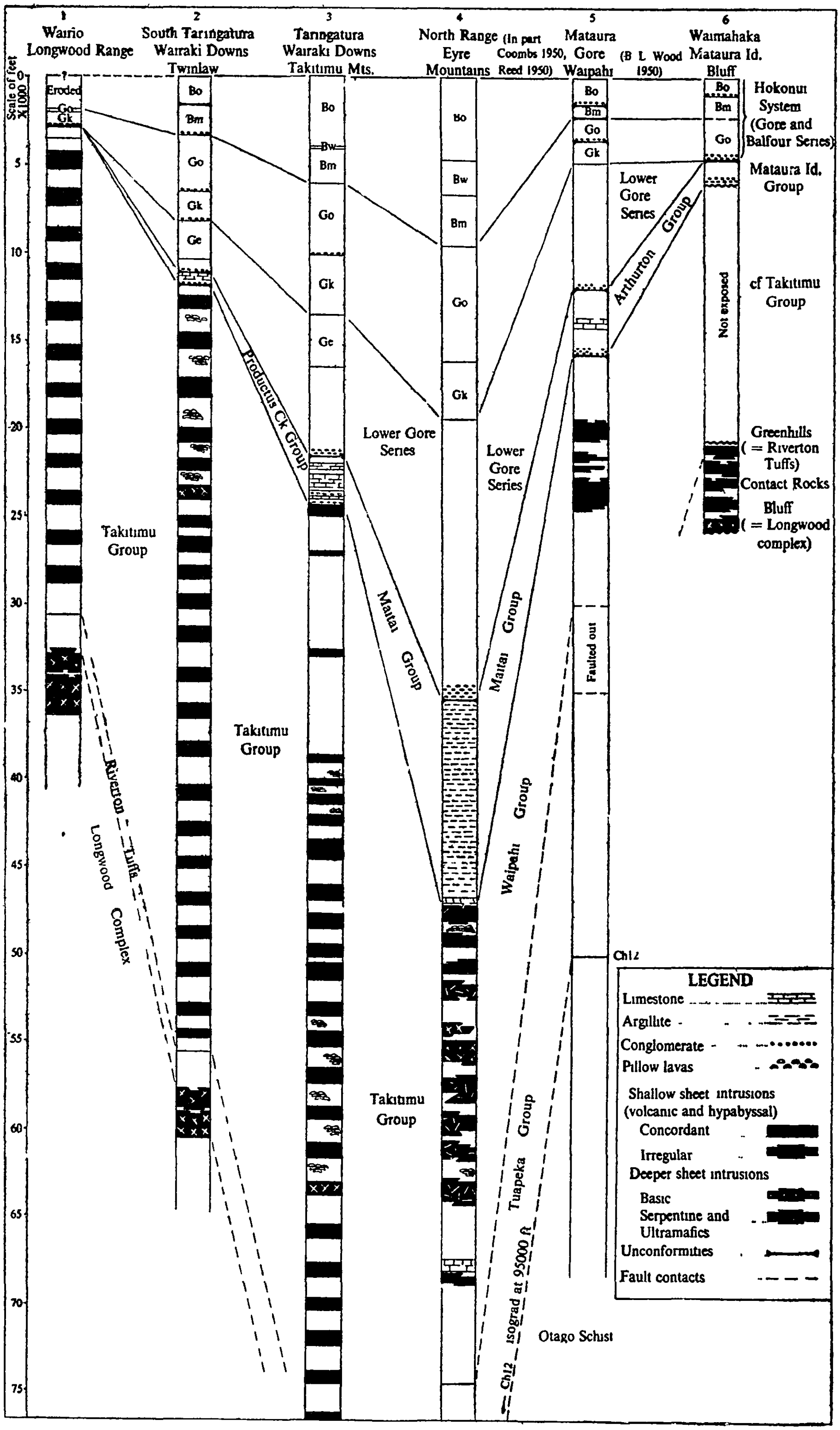

Fig. 8 —Stratigraphic Columns The symbols (e g , Ge) are those proposed for the Hokonui System by Marwick, 1953.