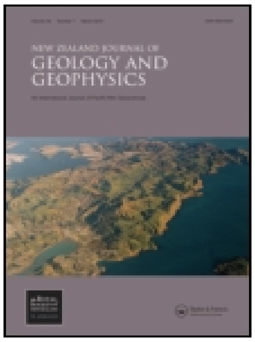

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Stratigraphy and structure of the Devonian rocks of Inangahua Outlier, Reefton, New Zealand

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Abstract The complex tectonics of the Early Devonian Inangahua Outlier makes a stratigraphic succession for the 1450 m thick Reefton Group difficult to establish. Remapping indicates that 4 thin limestone formations (**Forgotten Limestone, Lankey Limestone, Yorkey Limestone**, and **Pepperbush Limestone**) alternate with 4 thicker mudstone formations (**Bolitho Mudstone, Adam Mudstone, Ranft Mudstone**, and **Alexander Mudstone**). This sequence is in tectonic slide contact with a thick sequence of sandstone beneath (**Murray Creek Formation**) and a thinner sandstone above (**Kelly Sandstone**). The ages of the sandstones relative to each other and to the mudstone/limestone sequence are at present uncertain. The tectonic contacts are roughly parallel to bedding, and the sliding has caused intense brecciation of the sandstones and, in 1 case, the mudstones.

Murray Creek Formation is a regressive sequence with muddy, laminated, lower shoreface quartzarenites at the base, grading up into beach or upper shoreface orthoquartzites at the top. Kelly Sandstone formation is similar to the top of the Murray Creek Formation.

The alternating limestone and mudstone succession represents at least 4 rhythms of transgression and regression. Three muddy shelf biofacies rich in *Reeftonella, Acrospirifer*, and molluscs, respectively, migrated shorewards with each transgression and seawards with each regression. The muddy biofacies lay seawards of a coral and stromatoporoid-rich carbonate zone which passed landwards into shelly limestone. The lithology of Yorkey Limestone suggests that the coral and stromatoporoid belt passed into break-point bar sands along the Devonian shoreline. Like the muddy biofacies belts, the carbonate lithologies also migrated laterally. A source area to the north seems probable for this part of the Reefton Group.

During the Tuhua Orogeny, the Reefton Group was folded, although only part of a single syncline has been preserved in Inangahua Outlier. The form of breccias associated with slide contacts suggests that sliding may have occurred later than the fold event. The folded Reefton Group and tectonic slides were downfaulted into Greenland Group strata along major north–south faults, with associated lesser northeast–southwest transverse faulting, probably during the Rangitata Orogeny. Further movement along the boundary faults occurred after deposition of Cenozoic coal measures, probably during the Kaikoura Orogeny.

Keywords Devonian; Reefton; Inangahua Outlier; Reefton Group; stratigraphy; structure; biofacies; paleoenvironments; new stratigraphic names; Forgotten Limestone; Lankey Limestone; Yorkey Limestone; Pepperbush Limestone; Bolitho Mudstone; Adam Mudstone; Ranft Mudstone; Alexander Mudstone; Murrary Creek Formation; Kelly Sandstone

INTRODUCTION

Only 2 areas of Devonian rocks are known in New Zealand. Although both occur within the Western Province (Cooper 1979) of the South Island, one at Baton river, the other near Reefton, each is geographically separate and geologically different. Boulders of Early Devonian fossiliferous sediment have also been found in morainic deposits in the Lake Haupiri region (Johnston et al. 1980) but the source is uncertain.

Near Reefton, sandstone, mudstone, and limestone lithologies are present (in that order of importance) and are collectively known as the Reefton Group. Outcrops are confined to 4 outliers downfaulted into Ordovician Greenland Group rocks (Fig. 1), but only 2 have substantial areal extent.

Previous research

Interest in the Devonian rocks of Reefton was initiated in 1872 when a number of fossils collected

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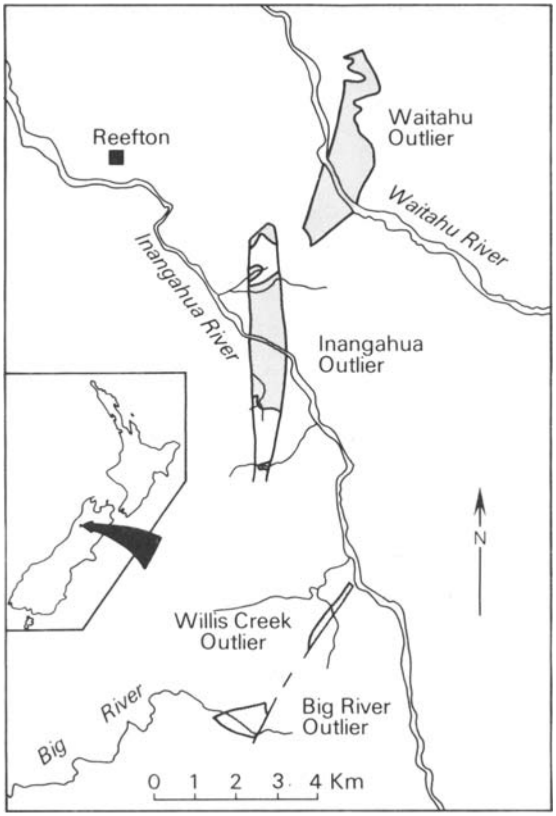


Fig. 1 The Devonian outliers of the Reefton district: Inangahua Outlier, this publication; Big River and Willis Creek Outliers after Suggate (1957); Waitahu Outlier after Hegan (1970).

by a Reefton prospector, Mr Theodore Ranft, were placed on display at the Christchurch Exhibition. After seeing the fossils, James Hector, then Director of the New Zealand Geological Survey, decided to visit Reefton the following year. During his brief visit, Hector was able to trace fossiliferous rock from Rainy Creek north as far as Murray Creek. He tentatively suggested a Devonian age for the rocks on the basis of brachiopod fossils within them. It was also his opinion that the Devonian rocks were older than the "non-fossiliferous" Greenland Group, because they appeared to underlie them.

As a result of Hector's visit, Alexander McKay was instructed to go to Reefton in 1874 for the purposes of finding the extent of the Devonian outcrop, making a detailed collection of the fossils, and defining the nature of the contact between the Devonian rocks and the Greenland Group.

Apart from Cox's brief comments on Reefton geology following his visit there with McKay in 1875 (Cox 1877), McKay's initial report (1883) gave the first detailed stratigraphy of the area. He defined the limits of the Devonian outcrop and indicated that, in addition to the north–south Reefton outcrop in the Inangahua River valley, there was also a separate north–south belt of Devonian rocks stretching from Waitahu River north to Boatman's Creek. McKay also considered that the Greenland Group rested unconformably on the Devonian strata.

Henderson (1917) was mainly concerned with the auriferous Greenland Group (Aorere Series), but regarded the contact between it and the Devonian strata as faulted. Contrary to McKay and Hector, Henderson regarded the auriferous rocks as older than the fossiliferous Devonian rocks because the gold-bearing quartz veins so common in the Greenland Group were not present in the Devonian strata, and also because the Tertiary coal measures were chiefly preserved where the Devonian strata had been downfaulted into the Greenland Group. Henderson pointed out that the peripheral faults of the Devonian outcrops showed a similar trend to the quartz lodes in the Greenland Group and suggested that their pattern may have been initiated during the same stress phase. Since then Cooper (1974) has collected graptolites from the Greenland Group of the Reefton area, and firmly established an Early Ordovician age.

Attention later focussed on the fauna of the Devonian rocks, particularly that of the mudstones and limestones (Allan 1935, 1947; Hill 1956; Fleming 1957; Cockbain 1965; Prokop 1970; Bradshaw 1974), but a clearly defined stratigraphy was not established until 1957 when Suggate published the Reefton bulletin. Suggate proposed that the Devonian beds had been folded into a syncline with 1 limb overturned, whose "axis" was roughly parallel and east of Yorkey Creek.

During 1969, one of us (BDH) mapped the Devonian outcrops in far greater detail (Hegan 1970). Later, during a programme of stratigraphic fossil collecting, and considerably aided by a recent burn-off of secondary scrub, the co-author (MAB) completely remapped the area and discovered that the stratigraphy of the 2 main outliers had been disturbed by major tectonic slides. This had been further complicated by later normal faulting, to produce a complex outcrop pattern (Fig. 2).

STRATIGRAPHY

The area mapped is steep (rising to 930 m) with a relatively heavy bush cover, and outcrops are often confined to stream beds. The clearing of bush during gold and coal mining activities, on the southwest

Table 1 The stratigraphy of the Reefton Group and its correlation with Suggate's succession (1957).

Stratigraphy this paper	Approximate thickness (metres)	Correlation with Suggate (1957)
Kelly Sandstone	140	= *part Lower Reefton Quartzite*
	tectonic contact	
Alexander Mudstone	min. 35	
Pepperbush Limestone	min. 14	
Ranft Mudstone	110	= *part Reefton Mudstone*
Yorkey Limestone	90	= *part Reefton Limestone*
Adam Mudstone	200	= *part Reefton Mudstone*
Lankey Limestone	93	= *part Reefton Limestone*
Bolitho Mudstone	120	= *part Reefton Mudstone*
Forgotten Limestone	35	
	tectonic contact	
Murray Creek Formation	615 max. present	= *part Lower Reefton Quartzite* = *Upper Reefton Quartzite*

side of Inangahua River and adjacent to the lower reaches of Stony Creek, has been followed by the growth of impenetrable scrub. During 1978, the slopes on the southwest side of Inangahua River were burnt off and planted with young pine trees. It was from the outcrops revealed that the presence of tectonic slides and block faulting was first established.

Initially 4 formations were described by Suggate (1957), but detailed remapping suggests a natural repetition of the limestone and mudstone lithologies and the existence of 10 formations. New formational names are proposed to avoid confusion (Table 1). The formations are described in order of succession.

MURRAY CREEK FORMATION (new)

NAME AND TYPE SECTION: After Murray Creek which crosses part of the formation at the northern end of the outlier. The type section is in Stony Creek from the tectonic contact with the Forgotten Limestone at L30/201952* eastwards to faulted contact with Greenland Group at L30/206955.

DISTRIBUTION AND THICKNESS: Murray Creek Formation is a fault-bounded sequence of arenaceous rocks that crop out along the east side of the outlier. It is the thickest formation with a minimum thickness of 615 m. The exposures in Stony Creek provide the most complete succession, but critical information is also provided by outcrops along the road section.

CONTENT: There is a general upward decrease in mud content, from a thick succession of bioturbated muddy sandstones near the base of the formation to orthoquartzite at the top, with red beds and highly fossiliferous sandstones in-between.

The lowest lithofacies is massive sandy limestone that forms a strong escarpment close to the eastern boundary fault at Stony Creek. Fossils are rare but include poorly preserved bivalves, brachiopods, and bryozoans.

The following bioturbated muddy sandstones (Fig. 3) are varied and include thinly laminated fine-grained quartzarenites and grey siltstones, with occasional broad and shallow channels, well exposed in Stony Creek above the highest waterfall (L30/202953). Sand laminae are often discontinuous (seldom more than 3 cm thick) and are probably isolated ripples. The muddy sandstone beds are locally interbedded with sharply bounded orthoquartzite horizons (< 2 m). Loose boulders rich in disarticulated *Pleurothyrella venusta*, often with valves facing the same way, are from this part of the sequence.

Other muddy sandstones occur as massive beds that grade up from a light grey base to a finer, darker top. Vertical burrows, up to 10 mm in diameter and occasionally showing meniscus structure, penetrate down from the darker top and may reach 1.5 m in length. Burrow infill has the same composition as the upper part of the bed, which is notably rich in sulphides. The burrows appear to have formed during deposition of the upper part of the bed rather than after it. Poorly preserved bivalves,

*Grid references are based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260).

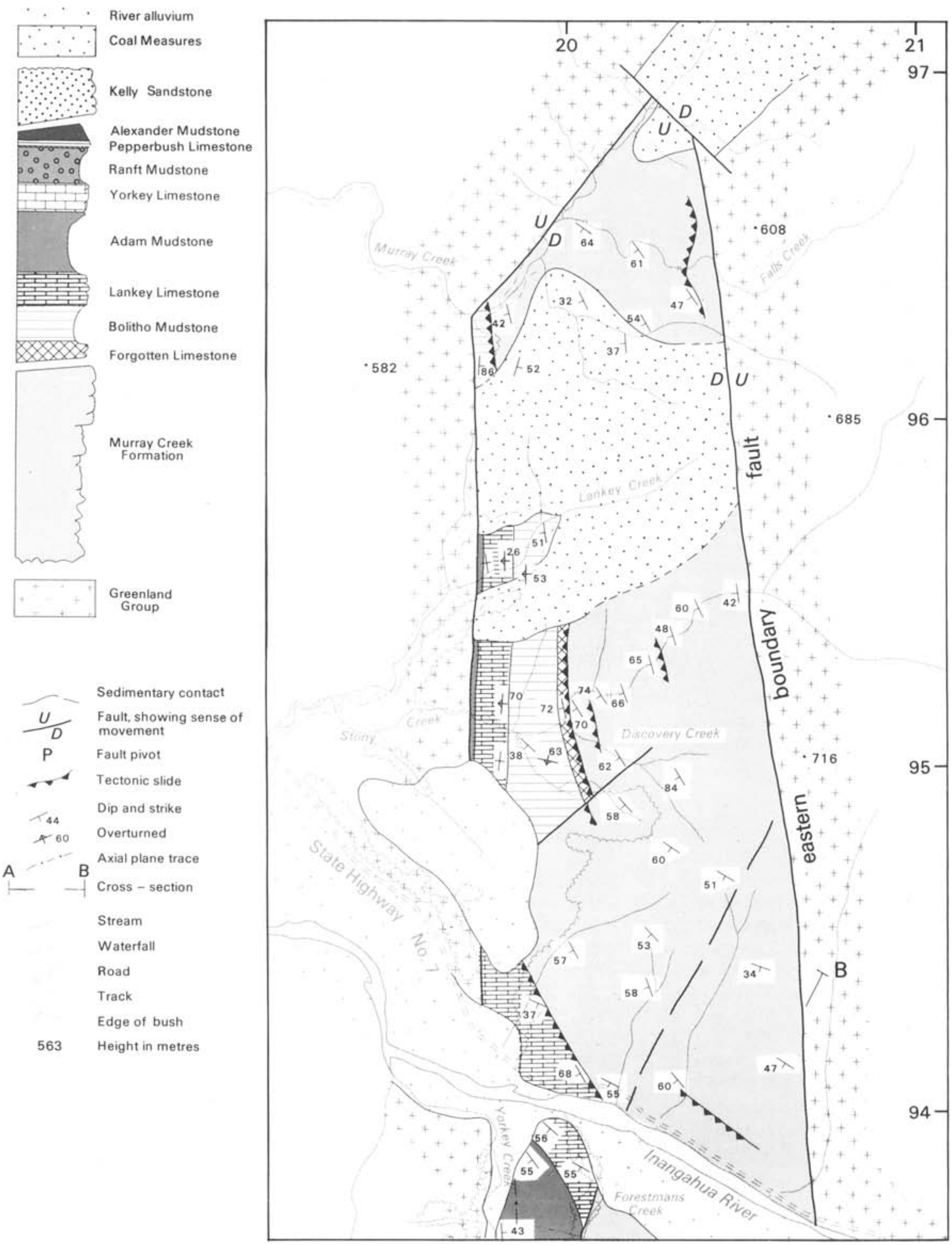
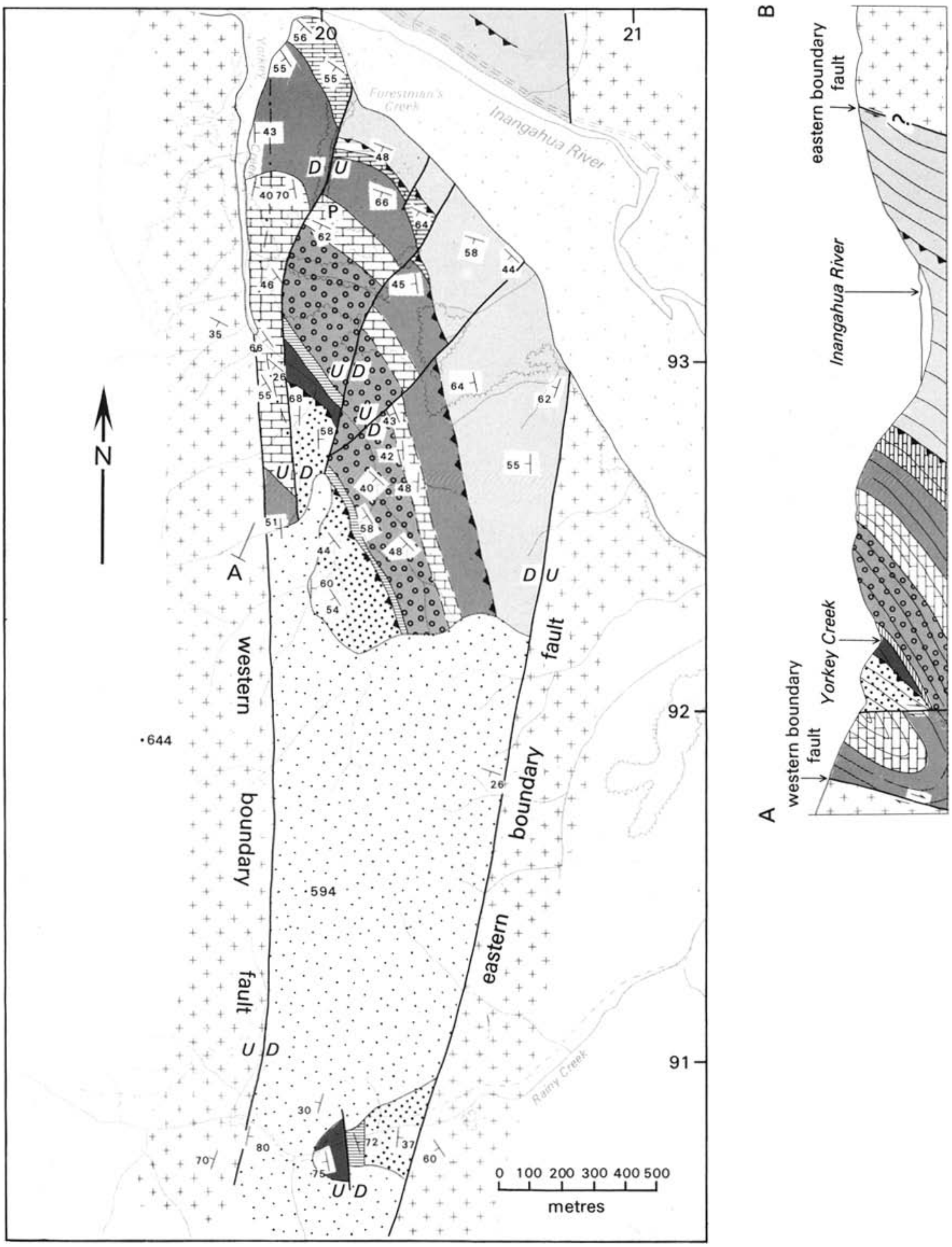


Fig. 2 Geological map and cross section of the Inangahua Outlier. Map co-ordinates relate to the thousand metre grid of the 1:50 000 topographic map series (NZMS 260) sheet L30—Reefton.



N
A
B
20
21
93
92
91
Forestman's Creek
Inangahua River
Yorkey Creek
Rainy Creek
western boundary fault
eastern boundary fault
·644
·594
P
D U
U D
0 100 200 300 400 500
metres
eastern boundary fault
Inangahua River
Yorkey Creek
western boundary fault

Fig. 3 Bioturbated, laminated muddy sandstones from the lower part of Murray Creek Formation, Stony Creek.

brachiopods, and crinoid debris were found at the tops of the beds. This lithology is well exposed in a small quarry (L30/204938) and on the left bank of Inangahua River (L30/205934).

Highly fossiliferous, fine to medium-grained sandstones become common towards the top of the muddy quartzarenites and tend to weather with a rusty yellow tinge. They contain a varied fauna that is different to the earlier *Pleurothyrella*-dominated horizons. Shells are crowded into layers, seldom more than 20 cm thick, which are interbedded with harder, unfossiliferous sandstone. The lithofacies is well exposed on the left bank of Inangahua River near the water race (L30/204933). The fossils exist as internal and external moulds, but show poor detail due to the coarse grain size of the matrix.

A single horizon in the road section (L30/203927) is composed entirely of molluscs (nuculoid, nuculanid, pteriomorph and edentulous bivalves, bellerophontids and gastropods), but most fossil bands are dominated by brachiopods (terebratulids, orthids, chonetids, strophomenids) accompanied by the occasional pteriomorph bivalve, trilobite fragment, and tentaculitid (see Appendix 1). Bioturbation is indicated by disturbed streaks of dark silt.

Siltstones up to 15 m thick occur within the sequence between the upper part of the muddy sandstones and the lower part of the succeeding orthoquartzite. Fossils occur in thin seams about 1 cm thick and include disarticulated pteriomorph bivalves, brachiopods, crinoid debris, and tentaculitids. These siltstones occur in Discovery Creek* (L30/203949) and at the road section 45 m below the slide contact with Lankey Limestone (L30/202941).

A pronounced unit of unfossiliferous, well-bedded to massively bedded, red, fine-grained quartzarenite and siltstone, up to 25 m thick, occurs at the transition from predominantly muddy quartzarenite to predominantly pure quartzarenite. Lamination within the beds is generally obscure, although faint small-scale cross lamination is occasionally visible. The colouration is interrupted locally by reduction spots. The red sediments may be interbedded with thin, irregular and discontinuous layers of hard, pale quartzarenite (e.g., 6–7 cm thick) deposited as ripples. Best exposures are in Stony Creek immediately upstream of the second waterfall (L30/203952), but this lithology also crops out in Discovery Creek and in the left bank of Inangahua River.

A thick succession of white orthoquartzites (fine to medium grained quartzarenites) that forms strong escarpments is found in the highest part of Murray Creek Formation (Fig. 4). Although small-scale cross bedding and ripple lamination may be present, internal lamination is generally obscure. The occurrence of *Skolithos*, which is very common at some horizons, suggests shallow-water deposition.

The orthoquartzites may be interbedded with fossiliferous sandstones. These have thin muddy bases containing *Rusophycus* and trilobite scratch marks, and interference-rippled tops disturbed by small burrow exit holes 5 mm in diameter (e.g., quarry on left bank Inangahua River, L30/204934).

Medium-bedded orthoquartzites may also be interbedded with thinly laminated white sandstone and micaceous grey siltstone that show coarsening-upward cycles (e.g., side of water race on west side of Inangahua valley, L30/203935).

The total thickness of the orthoquartzites is variable and this may be a result of tectonic sliding. The orthoquartzites appear remarkably thick and consistent in Murray Creek (approx. 600 m) where they occupy the entire outcrop except for the mudstone in the west. Young (1964) records 8 hard quartzarenite bands separated by softer, less-pure horizons in this area. However, in Stony Creek, pure quartzarenite is relatively thin (approx. 150 m). It thickens again southwards on the hill above the road section and on the west side of the Inangahua

*Name not approved by the New Zealand Geographic Board.

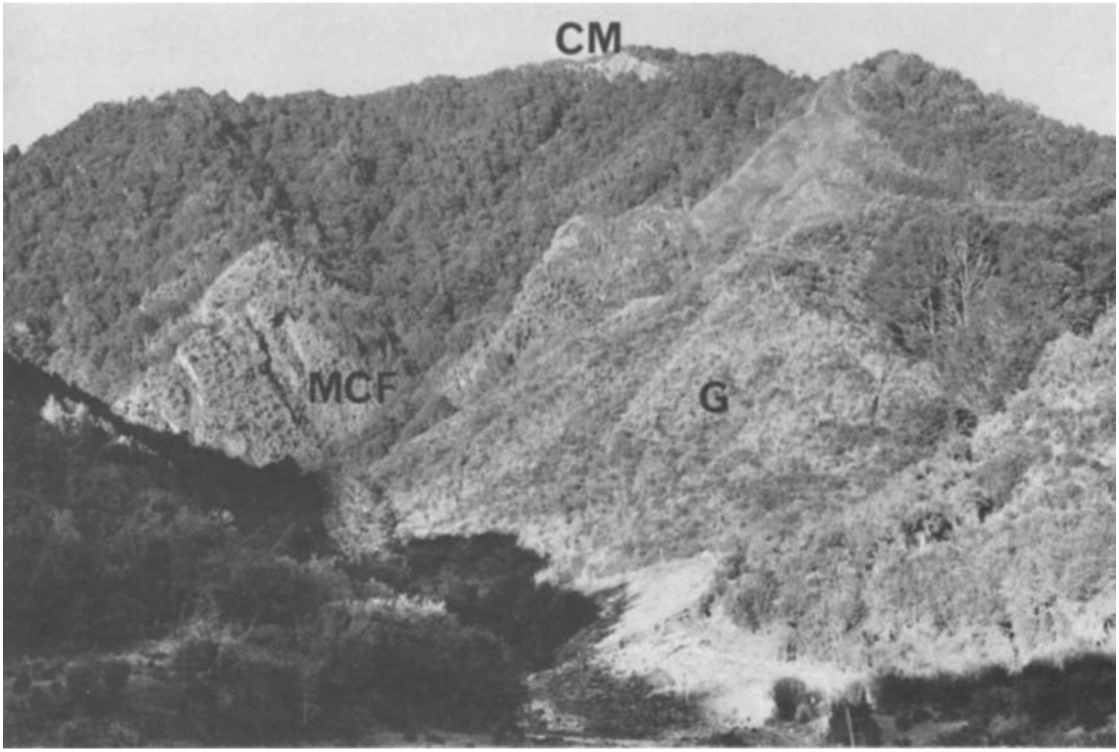


Fig 4 Devonian outcrops in the left bank of Stony Creek looking east. The clean quartzarenite units of Murray Creek Formation (MCF) have caused the prominent scarps in the middle distance. The coal measure (CM) cliffs visible below the highest point on the skyline rest on Greeland Group (G) and lie east of the eastern boundary fault.

valley, although here the lithofacies are more variable, with an increased number of fossiliferous horizons.

Where visible, the base of the formation is in fault contact with the Greenland Group. Similarly, at the top of the formation, supposedly younger formations are in tectonic contact. In Stony Creek, a tectonic slide separates Murray Creek Formation from Forgotten Limestone; and in the road section and on the ridge dividing Yorkey Creek and the Inangahua valley, a slide separates Murray Creek Formation from Lankey Limestone.

A beach and shoreface environment is indicated for this formation.

FORGOTTEN LIMESTONE FORMATION (new)

NAME AND TYPE SECTION: Allan (1935) first recorded this limestone, but later workers appear to have disregarded its significance. The type section is on the north side of Stony Creek from the tectonic contact with Murray Creek Formation at L30/201952 up the hillside to L30/201953.

DISTRIBUTION AND THICKNESS: The Forgotten Limestone Formation applies to the calcareous beds, 35 m thick, that underlie the Bolitho Mudstone and which are known only in Stony Creek. These beds were noted by Allen (1935) in his geological sketch map of Stony Creek and by Suggate (1957, p. 29). Hegan (1970) regarded them as a calcareous facies of the Bolitho Mudstone in natural contact with Murray Creek Formation. Recent fieldwork indicates that this limestone forms a strong mappable feature, and as a unit it is quite distinct from adjacent formations. For this reason it is regarded as a separate formation from the Bolitho Mudstone.

CONTENT: The lower part of the formation consists of thinly interbedded muddy limestone and calcareous fine-grained sandstone that exhibit slightly irregular ripple lamination. The limestone becomes more massive upwards. Sparse fossils include disarticulated crinoid debris, brachiopod shells, and very small solitary corals.

In Stony Creek, the top of Forgotten Limestone grades naturally up into Bolitho Mudstone, but the

Fig. 5 Fossil band in Adam Mudstone dominated by *Acrospirifer coxi*. The internal moulds show slight tectonic distortion. Similar *Acrospirifer* bands are found in Bolitho Mudstone.

base (L30/200952) is in tectonic slide contact with Murray Creek Formation and locally includes a lower mudstone unit up to 5 m thick. On the valley side south of Stony Creek (L30/201949) the lower thinly bedded limestone is cutout by the tectonic slide that separates massive limestone from quartzarenite.

A shallow, nearshore environment is suggested.

BOLITHO MUDSTONE FORMATION (new)

NAME AND TYPE SECTION: Named after the gold prospecting Bolitho brothers who, between 1906 and 1940, worked the Bolitho Mine in basal coal measures directly above this mudstone in Lankey Creek. The type section is from the natural contact with Lankey Limestone in Stony Creek at L30/198951, obliquely up the hillside across the outcrop to faulted contact with Murrary Creek Formation at L30/200948.

DISTRIBUTION AND THICKNESS: Bolitho Mudstone is the lowest of a series of richly fossiliferous mudstone formations that are interbedded with limestones. Outcrops of Bolitho Mudstone are confined to the Lankey and Stony Creek region, and the formation is cutout further south by the tectonic slide that separates Murray Creek Formation from Lankey Limestone. The formation is approximately 120 m thick.

CONTENT: Bolitho Mudstone is monotonous, dark grey, and massive, with occasional siltstone or micrite lenses. Bedding is obscure except where picked out by fossil bands. Fresh outcrops are visible in the sides of the old mill race in Stony Creek (L30/198952).

Fossils (see Appendix 1) are locally common and occur mainly in bands up to 5 cm thick. Any 1 of these bands is dominated by 1 particular fossil, as noted by Allan (1935) (e.g., Fig. 5). Bands composed almost entirely of *Reeftonella neozelanica* or *Acrospirifer coxi* occur in the water race above Stony Creek close to the base of Lankey Limestone. More recently, bands containing a rich mixture of bivalves (*Nuculoidea, Phestia, Actinopteria, Palaeodora, Cypricardinia*), orthoconic nautiloids, gastropods, disarticulated crinoids, and *Chonetes nigricans* (many of which are bored) with the occasional valve of other brachiopods, were found on the valley side south of Stony Creek.

At its base, Bolitho Mudstone grades down into Forgotten Limestone, and at its top it grades upwards through 5 m of mudstone and silty micrite into Lankey Limestone. Best exposures are in the sides of Stony Creek and near the track to Bolitho Mine in Lankey Creek.

Most of the fossils decribed by Allan (1935) which he used to suggest a middle Siegenian to early Emsian age for the Reefton fauna, were from Bolitho Mudstone.

An offshore shelf environment is indicated.

LANKEY LIMESTONE FORMATION (new)

NAME AND TYPE SECTION: After Lankey Creek, the main tributary of Stony Creek, where this limestone forms striking features. Type section is in Lankey Creek from the natural contact with Adam Mudstone at L30/198956, east to the natural contact with Bolitho Mudstone at L30/197956.

DISTRIBUTION AND THICKNESS: Lankey Limestone crops out from the west bank of Inangahua River and road section, north to Lankey Creek. The most complete sequence is found in Lankey and Stony Creeks; further south the lower part of the formation and the underlying Bolitho Mudstone are

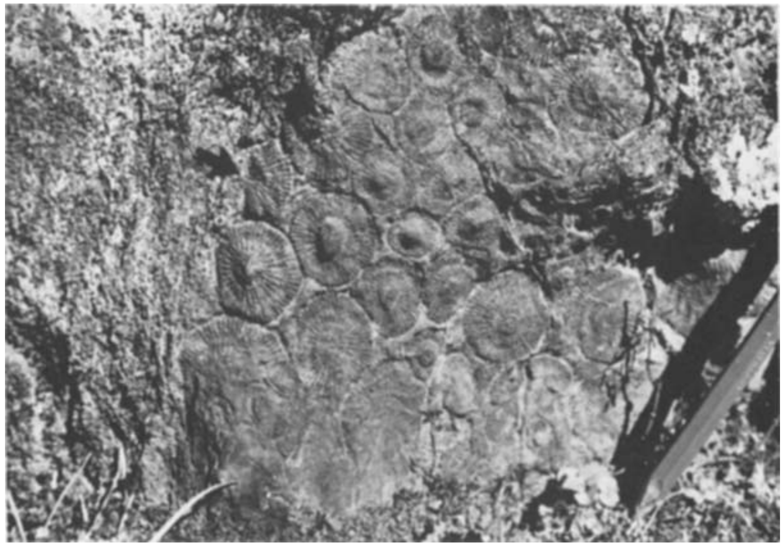


Fig. 6 *Tipheophyllum* colonies preserved in Lankey Limestone on the left bank of Inangahua River above the water race. Note the broken corallite on the left side of the colony (arrow). Pencil for scale lower right.

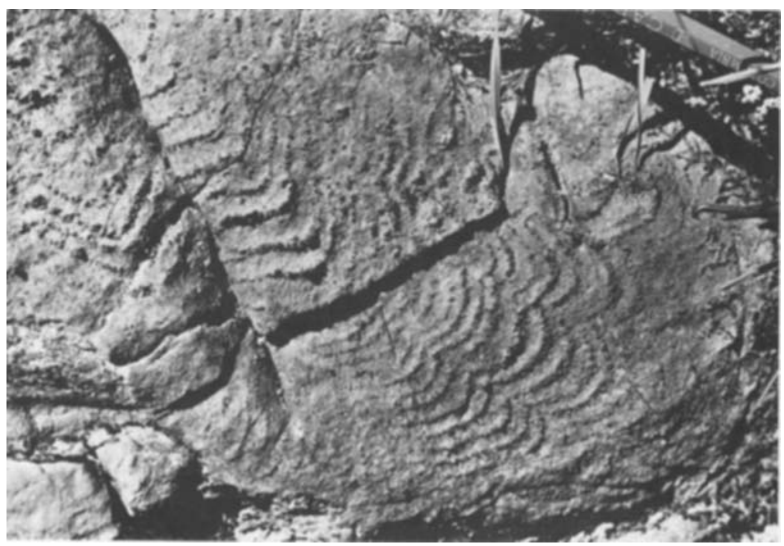


Fig. 7 Large stromatoporoid growth in Lankey Limestone on the left bank of Inangahua River above the water race. Pencil for scale upper right.

cutout by the tectonic slide. A maximum thickness of 93 m is preserved.

CONTENT: Lankey Limestone Formation is divided by a fine-grained, well-sorted quartzarenite unit that is locally bioturbated and varies in thickness from 3 m in Lankey Creek to 10 m in Stony Creek (Suggate 1957) and 9 m in the road section. Above the left bank of Inangahua River, the middle quartzarenite is only 1.2 m thick, but it has a chaotic appearance and may have been tectonically reduced.

The lower Lankey Limestone is a biorudite, in places exceptionally rich in coral colonies and stromatoporoid growths. These are especially clear at the bottom of the weathered cliffs above the water race on the left bank of Inangahua River (L30/203935) (Fig. 6, 7). While some coral colonies could be in their position of growth, others are upside down, although their good preservation suggests that they have not travelled far. No reef structures were observed.

Fallen blocks of the lower limestone on the north side of Stony Creek show broken coral colonies, small stromatoporoid growths, and isolated brachiopod shells and solitary corals that have been encrusted by thin stromatoporoid sheets (usually on 1 side only).

Where stromatoporoid colonies are numerous and appear to be in their position of growth (all lamellae and upper surfaces are convex uppermost), corals and brachiopods are rare. The stromatoporoid colonies are separated by biosparite, and are abruptly overlain by laminated biomicrite and silty micrite, in turn followed by silty biosparite containing small, cylindrical stromatoporoid growths.

The lower biorudite grades up into well-bedded silty biomicrite containing numerous disarticulated brachiopod shells (the majority being the same way up), disarticulated crinoid stems, the occasional rolled and abraded coral, and sheet-like fenestellid growths.

After the sandstone interval, well-bedded biosparite limestone (predominantly shells) with silty layers grades up into an upper biorudite with large stromatoporoid growths and some coral colonies.

Lankey Limestone grades down into Bolitho Mudstone over 5 m, and up into Adam Mudstone through well-rounded, fine-grained, quartzose sandstone rich in *Reeftonella.*

According to Allan (1935) and Hill (1956) the coral fauna of Lankey Limestone (see Appendix 1) suggests a Middle Devonian age.

A shallow, clear-water environment is indicated.

ADAM MUDSTONE FORMATION (new)

NAME AND TYPE SECTION: After the Adam brothers, 2 early prospectors who discovered gold in Rainy Creek. A continuous type section is not clear, but a respresentative section is found on the hillside west of Inangahua River, from natural contact with Lankey Limestone at L30/203932, to natural contact with Yorkey Limestone at crest of hill at L30/202933.

DISTRIBUTION AND THICKNESS: Adam Mudstone is found only on the southwest side of Inangahua River and in Yorkey Creek. The formation is a predominantly massive and monotonous silty mudstone with poorly defined bedding and minor siltstone and sandstone. Maximum thickness is 200 m.

CONTENT: The lowermost beds are fine and sandy, where the formation grades up from Lankey Limestone, and contain brachiopods. The development of this basal sandy lithofacies varies. In Lankey Creek, approximately 15 m of mixed bioturbated muddy and clean fine-grained sandstone with well-rounded grains, containing scattered, disarticulated brachiopod shells, occurs above the top of Lankey Limestone. In Stony Creek, a previously recorded (Henderson 1917; Allan 1935; Suggate 1957) indeterminate thickness of poorly exposed brachiopod-bearing sandstone occurs between the top of Lankey Limestone and the western boundary fault. This was relocated during field mapping and is approximately 10 m thick. It contains both fossiliferous bioturbated sandstone with ?*Tanerhynchia* and unfossiliferous locally red-stained sandstone. On the west bank of Inangahua River, Lankey Limestone passes up into fossiliferous (mainly *Reeftonella*) fine-grained quartzose sandstone and siltstone, only about 5 m thick, which suggests that there is pronounced southwards thinning of the basal arenaceous lithofacies of Adam Mudstone. A distinctive band full of *Acrospirifer coxi* (Fig. 5) occurs not far above the base of the mudstone lithofacies. Fossil bands in the central part of the formation contain a variety of molluscs, crinoidal and byrozoan debris, and some brachiopods (see Appendix 1).

Near the top of the formation, mudstone passes up into approximately 10 m of cross-bedded, ripple laminated, fine-grained quartzose sandstone, in beds up to 12 cm thick. There is a gradation over a few metres up into the overlying Yorkey Limestone with the appearance of limestone interbeds.

An offshore shelf environment is indicated.

YORKEY LIMESTONE FORMATION (new)

NAME AND TYPE SECTION: After Yorkey Creek which crosses Devonian strata along the western side of the outlier. Type section is the hillside above Yorkey Creek from the natural contact with Adam Mudstone at L30/199935 south to faulted contact with Ranft Mudstone at L30/199936.

DISTRIBUTION AND THICKNESS: Outcrops of this formation are confined to the southern part of the outlier in the Yorkey Creek region. A clear succession was not seen at any of the outcrops because of faulting and poor exposure in the bush, but a sequence at least 90 m thick appears to be present.

CONTENT: The lowermost beds, where they grade up from the sandstone lithofacies of Adam Mudstone, are exposed on the pine-planted ridge between Yorkey Creek and Inangahua River (L30/1999935) (Fig. 8). The base of the formation is placed at the first appearance of limestone interbeds, and the lower part of the formation is dominated by thinly bedded biomicrite and fine-grained quartzose sandstone (Fig. 9). This distinctive lithology is reminiscent of the Forgotten Limestone. The limestone may show internal lamination,

Fig. 8 Westward dipping beds of the lower Yorkey Limestone on the ridge between Yorkey Creek and Inangahua River soon after scrub burn-off in 1978. The slope is now planted with pine trees. The crags are of thinly bedded limestone, and the rising ground below them is underlain by quartzose sandstone at the top of the Adam Mudstone.

or a "blebby" appearance caused by conjoined, thin-shelled brachiopods containing a more sandy infill. Slight channelling is visible in some of the siltier beds. The interbedded fine-grained sandstones are cross bedded and up to 12 cm thick. There is a distinct change upwards to a massive biomicrite in beds 1 m or more thick, with layers up to 30 cm thick crammed with thick disarticulated shells (mainly brachiopods). This shelly lithofacies (Fig. 10) is well exposed on the ridge and in sink holes at the head of Forestman's Creek* (L30/201934) where it has been downfaulted against the lower laminated beds.

In the type area, Yorkey Limestone is markedly coral and stromatoporoid free. However, boulders from Yorkey Creek (New Zealand Geological Survey collection number GS5751), identified by Hill (1956) as containing *Favosites* sp. and *Cladopora* sp., are probably from more southerly outcrops of the formation. About 500 m further south the limestone contains large transported colonies of corals and stromatoporoids.

A high energy, nearshore environment is indicated.

RANFT MUDSTONE FORMATION (new)

NAME AND TYPE SECTION: Named after Theodore Ranft, an early prospector whose Devonian fossils were sent to the Christchurch Exhibition in 1872, arousing James Hector's interest in the Reefton area.

*Name not approved by the New Zealand Geographic Board.

Fig. 9 Thinly bedded limestone and sandstone at the base of Yorkey Limestone. Note the thicker-bedded (cross laminated) quartzose sandstone above the hammer, and the well-developed stylolites in the limestone beds below the hammer. North end of ridge between Yorkey Creek and Inangahua River.

Fig. 10 Typical appearance of the upper Yorkey Limestone on the ridge separating Yorkey Creek and Inangahua River. The limestone is massively bedded and crammed with thick, disarticulated brachiopod shells.

Due to poor exposure, no type section has been allocated. A reasonable reference section may be found in a tributary of Yorkey Creek, from the faulted contact with Yorkey Limestone at L30/199936, east to the natural contact with Yorkey Limestone at L30/202932.

DISTRIBUTION AND THICKNESS: Ranft Mudstone crops out in the upper reaches of a tributary of Yorkey Creek (L30/200933) and in the middle and upper reaches of Yorkey Creek itself (L30/202929). A minimum thickness of 110 m is indicated.

CONTENT: Ranft Mudstone is dark grey and massive, with relatively few thin fossil bands. Sparite-rich siltstone layers may be present. The fauna (see Appendix 1) includes orthoconic nautiloids, crinoid ossicles, *Acrospirifer*, *Reeftonella*, and homalonotid trilobites. Bands rich in either *Acrospirifer* or *Reeftonella* occur near the coral-rich facies of Yorkey Limestone in the upper reaches of Yorkey Creek.

The lower contact with Yorkey Limestone is not exposed, but loose blocks suggest that clastic material increases through the upper Yorkey Limestone, and that brachiopods are replaced by dense assemblages of tentaculitids before gradation up into a mudstone lithofacies. At the top, the mudstone grades up into about 5 m of muddy sandstone then 2 m of clean quartzarenite immediately below the contact with Pepperbush Limestone.

An offshore shelf environment is suggested.

PEPPERBUSH LIMESTONE FORMATION (new)

NAME AND TYPE SECTION: After the pepper bush, a native shrub that grows profusely on hillside outcrops of this formation in Yorkey Creek. No clear type section is possible, but a representative section can be seen in Yorkey Creek at L30/201925 and a short way upstream. Lithological characters are also visible in large fallen blocks in the river bed further downstream.

DISTRIBUTION, THICKNESS AND CONTENT: Interbedded, thinly laminated biomicrite and siltstone crop out in the central part of Yorkey Creek. The beds are reminiscent of the lower Yorkey Limestone and are unfossiliferous. Individual laminae are a few centimetres thick, and the siltstones are frequently graded. The formation is distinguished from Yorkey Limestone by its much smaller thickness (c. 14 m) and its lack of fossils.

A thinly and irregularly bedded muddy limestone, containing small bryozoan growths and crinoid debris, that crops out in the centre of the Rainy Creek Outlier, has been tentatively mapped as part of this formation, although the 1.5 km of coal measures cover between this and the Inangahua Outlier makes correlation uncertain.

A shallow, nearshore environment is suggested.

ALEXANDER MUDSTONE FORMATION (new)

NAME AND TYPE SECTION: Named after Alexander McKay who completed the first field mapping programme on Devonian rocks of the Reefton area. Due to poor exposure, no type section has been allocated. A representative section can be found in Yorkey Limestone at L30/199930, upstream to the natural contact with Pepperbush Limestone at L30/201929.

DISTRIBUTION, THICKNESS AND CONTENT: Alexander Mudstone may be the youngest formation of the Inangahua Outlier. It is found only in the middle reaches of Yorkey Creek (e.g., L30/199929) where it is distinguished by its massive, calcareous nature and its scattered content of large fossils (see Appendix 1). These include articulated shells of *Glossites*, strophomenids, *Reeftonella*, *Acrospirifer*, together with orthoconic nautiloids, delicate fragments of crinoid pinnules, and long crinoid stems. Alexander Mudstone grades rapidly up from Pepperbush Limestone and is in tectonic slide contact with the overlying Kelly Sandstone. It is at least 35 m thick.

Steeply dipping mudstones in the western part of the Rainy Creek Outlier may belong to the formation, although they are rather more muddy and less calcareous than further north. Detailed work on the brachiopod fossils may show whether this correlation is correct.

A deeper offshore shelf environment is suggested.

KELLY SANDSTONE FORMATION (new)

NAME AND TYPE SECTION: After James Kelly, an early prospector, who discovered gold near the head of Murray Creek. Type section is in the upper reaches of Yorkey Creek, from the tectonic contact with coal measures above a steep waterfall at L30/200923.

DISTRIBUTION, THICKNESS AND CONTENT: In the upper reaches of Yorkey Creek and also on the western side of its middle reaches, a highly quartzose sandstone unit overlies both Alexander Mudstone (L30/201921) and Pepperbush Limestone (L30/203926) with a tectonic slide contact.

The sandstones are white and pink, medium to fine-grained, well-bedded and recrystallised quartzarenites. Cross bedding and ripple marks may be locally visible, but no fossils were observed other than indeterminate trace fossils. However, Suggate (1957) records a fossiliferous calcareous sandstone at the top of the sequence in the head of Yorkey Creek. In this same area, the quartzarenites are overlain by thick Cenozoic coal measure sandstones. Minimum thickness is 140 m.

The Kelly Sandstone may also crop out in the eastern part of the Rainy Creek Outlier, where eastward-dipping quartzarenite is faulted against ?Pepperbush Limestone and passes east into muddy, sometimes calcareous sandstone with brachiopod fossils.

A beach and upper shoreface environment is suggested.

PALEOENVIRONMENTS OF THE REEFTON GROUP

The paleoenvironments of the alternating limestone and mudstone sequence are considered separately from those of the Murray Creek and Kelly Sandstone Formations as there is no natural contact between them.

Limestone and mudstone sequence

Within the alternating limestone and mudstone sequence a clear motif is provided by the biostratigraphy of the 2 best exposed mudstones (Bolitho and Adam Mudstones) and the interbedded limestones (Lankey and Yorkey Limestones respectively). The motif suggests alternating regressive and transgressive phases with reversals occurring within formations rather than at their contacts.

The Bolitho Mudstone appears to be a typical, fine-grained, predominantly low-energy shelf sediment that graded shorewards into lime-rich bioclastic and sandy beach sediments. Fossil bands of 3 distinctive types occur within the mudstone:

1. *Reeftonella neozelanica* bands near the top and bottom, closest to overlying and underlying limestones.
2. *Acrospirifer* bands occurring above the lower *Reeftonella* and below the upper *Reeftonella* bands.

(Only 1 taxon is particularly dominant in each of these 2 types of band, and is sometimes exlusive.)

3. Higher diversity bands in the middle of the formation containing infaunal deposit-feeding and burrowing bivalves, epifaunal bivalves, and lesser numbers of brachiopods.

These 3 types of bands show a rhythmic pattern and are interpreted as biofacies parallel to the margin of the carbonate zone and shoreline (Fig. 11). Each fossil band represents a phase of mass mortality, sorting, and disarticulation that was probably associated with major storm events.

Following Walther's Principle (See Middleton 1973), the organisms closest to limestone sedimentation would be the least tolerant of detrital mud, in this case the terebratulid *Reeftonella*. *Acrospirifer* formed a biofacies further offshore, while in the main basin of detrital mud deposition, a high-diversity fauna of molluscs, echinoderms, and brachiopods thrived. The mixed faunal bands represent periods of maximum submergence.

Exactly the same pattern is present within the Adam Mudstone. A basal arenaceous unit that is thickest in the north thins to 5 m of fine-grained sandstone and siltstone rich in *Reeftonella* with some *Acrospirifer*. Mudstone beds a little higher contain *Acrospirifer*-dominated bands, whereas faunas with a high diversity, and the notable

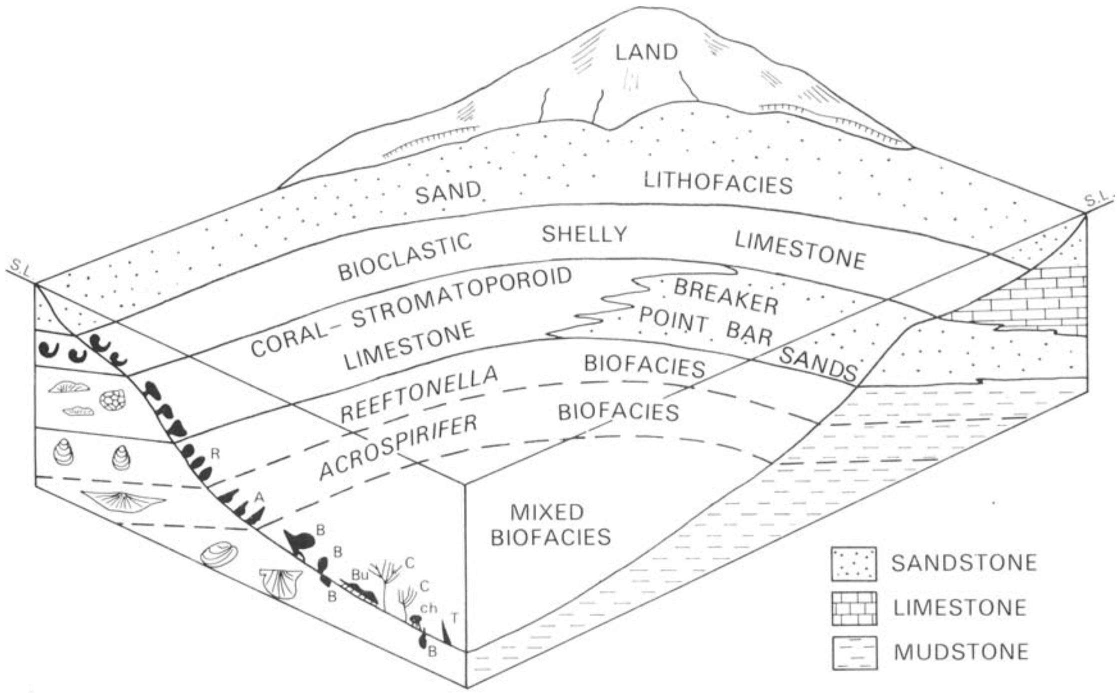


Fig. 11 Block diagram to illustrate the depositional relationships of the biofacies and lithofacies represented in the Reefton Group. R = *Reeftonella*, A = *Acrospirifer*, C = crinoid, Ch = *Chonetes*, B = bivalve, T = *Tentaculites*, Bu = *Burmeisteria*.

appearance of deposit-feeding bivalves, occur only within the centre of the formation and mark the maximum of the transgressive phase (Fig. 12).

A similar vertically symmetrical sequence can be seen within the intervening Lankey Limestone. In this limestone, the upper and lower biorudite units are closest to contacts with the adjacent mudstone formations, and well-bedded, shelly, biosparite and micrite either follows or precedes the quartzarenite unit in the middle of the formation. This strongly suggests that, during the regressive cycle initiated in the middle of Bolitho Mudstone deposition, there was seawards migration of a coral-stromatoporoid belt, followed by a higher-energy zone characterised by disarticulated shells, and finally by a well-sorted sand belt that was closest to the shore. The onset of another transgressive cycle is reflected in the repetition of the limestone facies in reverse order at the top of the Lankey Limestone.

A similar change of lithofacies within Yorkey Limestone was probably associated with the end of a regressive cycle that began in the preceding Adam Mudstone. The gradation of mudstone up into fine-grained, well-rounded clean quartzarenite at the top of Adam Mudstone Formation suggests the development of a break-point bar that may have been laterally equivalent with a coral-stromatoporoid biostromal lithofacies (Fig. 11). The thinly bedded biomicrite and sandstone of the lower Yorkey Limestone probably represents the shorewards interfingering of a sand bar and a high-energy carbonate-rich zone in which the massive, shell-rich upper biosparite was deposited. The lateral replacement of a biorudite facies with a break-point bar facies is supported by the appearance of corals and stromatoporoids in Yorkey Limestone in the south of the outcrop area. There is some indication of increased detrital material at the contact of Yorkey Limestone with Ranft Mudstone, with replacement of brachiopods by tentaculitids suggesting the onset of another transgressive cycle.

When this model is extended to the remainder of the mudstone/limestone sequence, with the lower part of each mudstone formation representing a transgressive cycle and the upper part a regressive cycle, whilst the reverse is true for the limestone formations, it is apparent that 4 regressions and transgressions are represented (Fig. 12). The upper units are too poorly exposed in bush-covered country to show the cycles in detail. However, identifiable exposures conform to the pattern.

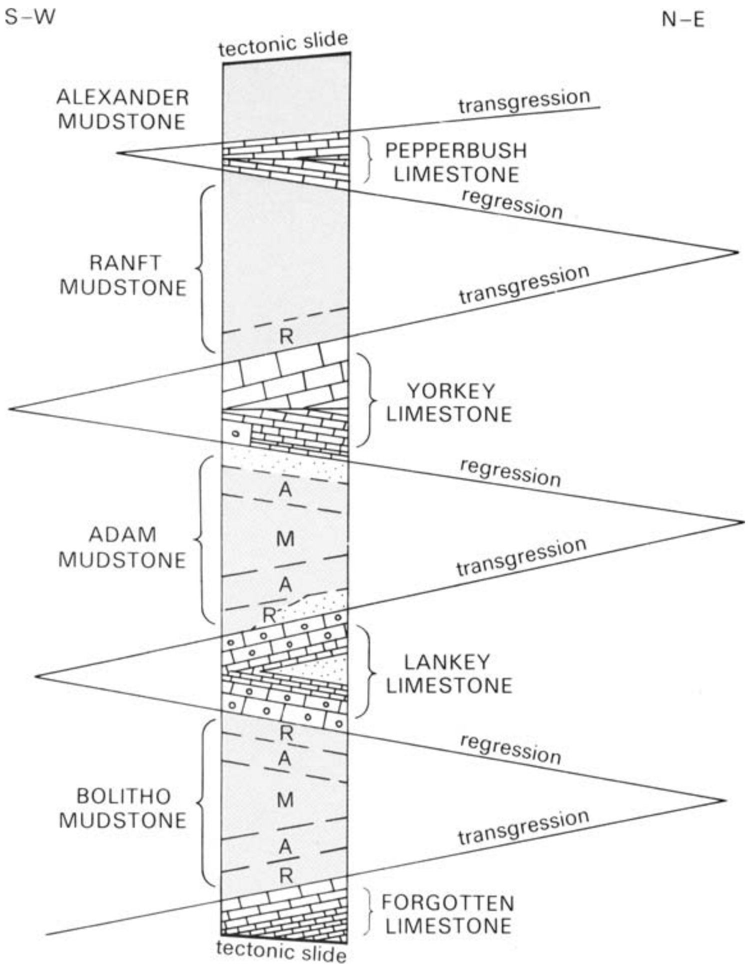


Fig. 12 Diagrammatic representation of the Reefton Group succession demonstrating the lateral migration of successive litho- and biofacies during transgressive and regressive cycles. R = *Reeftonella*, A = *Acrospirifer*, M = mixed.

Murray Creek and Kelly Sandstone Formations

Despite small tectonic slides within Murray Creek Formation, there is a definite change upwards from relatively muddy, angular, quartzose sandstones at the base to orthoquartzites at the top, with fossiliferous siltstones, fossiliferous sandstones, and red beds successively between. The entire formation appears to be a thick, predominantly regressive sequence, with lower shoreface, muddy, laminated sandstones near the bottom of the succession grading up into beach or upper shoreface orthoquartzites at the top. Alternating fossiliferous and nonfossiliferous orthoquartzites probably formed in the upper shoreface after disruption of bottom communities by storms. Very thin mud interbeds with *Rusophycus* suggest trilobite activity during calmer intervals. The unfossiliferous red sandstones may represent the point of maximum regression, and could have formed from oxidation of beach sands stranded above sea level. The siltstone units, with their characteristic very thin fossil bands containing large pteriomorph bivalves, brachiopods, and crinoidal debris, are either lagoonal in origin or, more likely, represent a minor transgressive phase that allowed upper shelf muds to spread shorewards.

Kelly Sandstone Formation appears to be largely of beach or upper shoreface mature quartz sands.

TECTONIC HISTORY

The tectonic history of the area is highly complex. Mapping confirms the existence of a faulted syncline in Yorkey Creek, as suggested by Suggate (1957) and Hegan (1970).

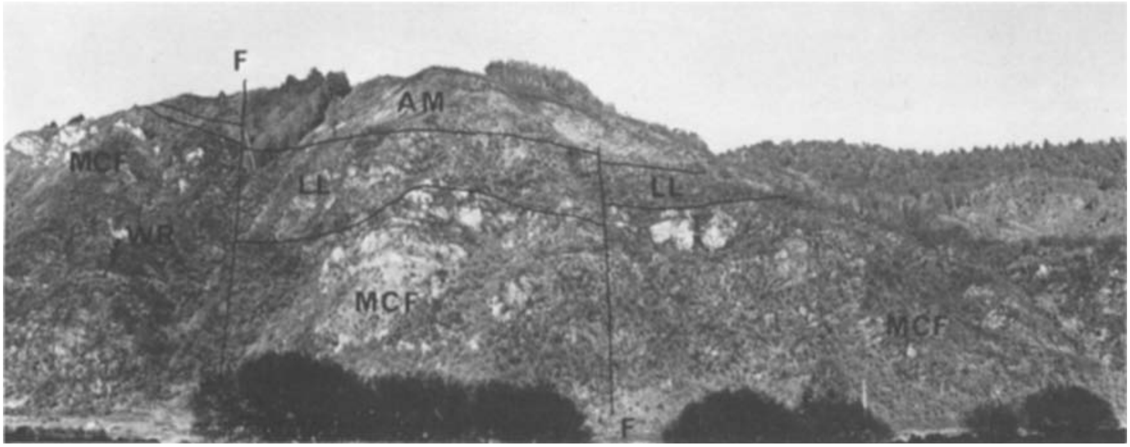


Fig. 13 View of the left bank of Inangahua River from State Highway No. 7 after scrub burn-off in 1978 and before replanting. The Progress water race (WR) crosses the hillside and locally affords good exposure. The tectonic slide between Lankey Limestone (LL) and Murray Creek Formation (MCF) is clearly seen and is displaced by several small faults (F). The pale prominent bluffs below the slide are composed of extensively brecciated quartzarenite. The trees on the skyline to the right of the highest point mark the position of Yorkey Limestone, and the smooth slope below is underlain by Adam Mudstone (AM).

Suggate regarded the quartzarenite on the west bank of Inangahua River as the youngest formation preserved in the syncline, whereas Hegan considered the quartzarenites in the middle reaches of Yorkey Creek to be the youngest beds. Mapping has demonstrated that the sandstones on the west bank of Inangahua River belong to Murray Creek Formation, which has been displaced by faulting, and the orthoquartzites in Yorkey Creek appear to be in tectonic slide contact with adjacent beds. Their relative age is uncertain.

The most convincing evidence for the syncline is the change in strike and dip of Yorkey Limestone and Adam Mudstone near the mouth of Yorkey Creek, and the anomalous width of the Yorkey Limestone outcrop a little further south. Overturned beds of quartzarenite in a tributary of Yorkey Creek (L30/201927) may be either part of an overturned limb of the same syncline or, more probably, the result of local distortion against the adjacent fault.

Three major tectonic slides can be determined within the succession, and all are associated with orthoquartzite units that are highly brecciated. The slides are concordant with bedding, and movement has been bed-over-bed slip with local ramping.

The clearest slide separates the southern occurrences of Lankey Limestone from Murray Creek Formation and is well exposed on the west bank of Inangahua River (Fig. 13). The limestone appears little affected, but the orthoquartzite below is brecciated for at least 30 m below the contact and has an amorphous texture with scattered, more coherent blocks. There is some evidence of movement in the arenaceous interval within the limestone, where it locally takes on a highly chaotic appearance. North of Inangahua River, the slide appears to change horizon and exposes 2 older formations, Bolitho Mudstone and Forgotten Limestone, which are tectonically cut out further south. Small-scale folds deforming an earlier slaty cleavage in Bolitho Mudstone south of Stony Creek may have been caused by this change of horizon.

An upper tectonic slide is present near the head of Yorkey Creek where recrystallised and brecciated orthoquartzite rests upon Pepperbush Limestone. The limestone is clayey in appearance at the contact. This slide also appears to change horizon northwards (Fig. 2).

The lowest slide zone is within Murray Creek Formation and may consist of several small slides. Well-bedded quartzarenite is interbedded with conformable but intensely brecciated quartzarenite that tends to weather more easily (Fig. 14). Minor breccia horizons are common within Murray Creek Formation east of the road.

The breccia associated with the slides is composed of angular fragments of quartzarenite set in a progressively finer matrix of breccia (Fig. 15). The confinement of breccia to the sandstone formation appears to be due to its much greater competency and brittle fracture, compared to the calcareous and muddy units that they abut, which behaved more plastically. However, a well-defined horizon was

Fig. 14 Escarpment of orthoquartzarenite of Murray Creek Formation on the north side of Falls Creek. The beds that dip westwards from the highest point are relatively massive and coherent, but the sandstones below the overhang have weathered more easily, are highly brecciated, and mark the position of a tectonic slide within Murray Creek Formation.

observed within Adam Mudstone Formation at L30/202935, with angular mudstone clasts in a finer matrix of mudstone breccia. Sliding appears to have occurred relatively early in the history of the area, as later faulting has produced brecciation of limestone against mudstone (e.g., L30/199933) and the production of pug rather than breccia in quartzarenite against limestone (L30/199927). The direction of sliding is uncertain, but the step-like change in horizon suggests possible thrusting from the west. Because of the obvious lithification of the sandstones involved, and the minor folding of an earlier cleavage in Bolitho Mudstone, it is probable that the slides postdate the folding of the Reefton Group. However, the slides predate the northeast–southwest normal faults that traverse the Devonian outcrop. Folding and thrusting probably occurred as different events of the Tuhua Orogeny (Middle–Late Devonian).

Mapping suggests that the northeast–southwest normal faults are older than the coal measures since they do not displace them. This is supported by a similar trending fault near Willis Creek (south of the area mapped—see Fig. 1) which faults Tuhua granite against Greenland and ?Reefton Group rocks, but which predates the younger coal measures. At least 1 of the northeast–southwest faults is a scissor fault, with different relative movement on either side of the pivot (see Fig. 2). Because the fault obliquely crosses the Reefton outcrop from 1 boundary to the other, a scissor fault would be consistent with movement along a transverse line of weakness during downfaulting of the Inangahua Devonian rocks, suggesting that both the transverse and boundary faults may be contemporaneous, originating probably during the Rangitata

Fig. 15 Brecciated quartzarenite below the tectonic slide separating Murray Creek Formation from Lankey Limestone on the west side of Inangahua River. The breccia consists of angular fragments, some much larger than shown here, set in a finer matrix of breccia. The breccia beds are interbedded with more normal quartzarenite.

Fig. 16 Coal measure sandstones cropping out a few metres east of the western boundary fault in the bed of Rainy Creek. The sandstones young east (to left) and are nearly vertical. A sliver of Greenland Group sediment (G) occupies the space to the left of the westward dipping surface and is edged by a coarse-grained sandstone dike (D) up to 10 cm thick. The dipping surface is taken to reflect a westward dipping attitude of the western boundary fault.

Orogeny. Significant post-Devonian and pre-Cenozoic faulting is further supported by the fact that coal measures rest on both Greenland and Reefton Group rocks in any given area, indicating relative displacement prior to the Cenozoic. Reactivation of the boundary faults during the Kaikoura Orogeny is indicated by truncation and offset of coal measure outcrops (as at L30/198923). The steepening of dips and local overturning in Lankey and Stony Creeks has already been attributed to the proximity of the western boundary fault (Suggate 1957). A similar phenomenon was seen in Rainy Creek where coal measures lie almost vertically against the western boundary fault (Fig. 16). The steep westerly dip of a fault plane below a slice of Greenland rocks caught up in coal measures immediately east of the western boundary fault suggests that the boundary fault may be a reverse fault.

At some localities, exposure of the boundary faults was obviously much better in the past when coal mining was more active that it is today. Henderson (1917), who was particularly interested in these faults, notes (p. 76) good exposures of the eastern boundary fault along the Progress water race on the left bank of Inangahua River with "crushed argillite" (Greenland Group) "apparently dipping under shattered quartzite" (Reefton Group), suggesting a steep, westerly dipping fault plane. Henderson also records a narrow zone of pug and shattered rock separating Greenland Group and Devonian rocks along the western boundary fault in Yorkey and Lankey Creeks, and the banks of Inangahua River, and a wide zone of crushed Greenland and coal measure rocks along the north end of the outlier in Murray Creek.

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APPENDIX 1

Faunal lists for the formations of the Reefton Group

The Devonian fauna of the Reefton Group is in the process of being systematically described, and the following faunal lists are therefore incomplete, although they are the most detailed to date.

MURRAY CREEK FORMATION

Brachiopods
Pleurothyrella venusta Boucot et al.
Cryptonella sp.
Allanetes neozelanica Boucot & Johnson

Molluscs
Phestia sp.
Nuculoidea sp.
Leiopteria sp.
Grammysia sp.
cf. *Straparollus* sp.
cf. *Loxonema* sp.

Miscellaneous
Burmeisteria sp.
Tentaculites sp.

Trace fossils
Rusophycus ichnosp.
Skolithos ichnosp.

FORGOTTEN LIMESTONE

Corals
Hexagonaria sp.
solitary, indet.

Brachiopod
orthid

Echinoderm
crinoid debris

BOLITHO MUDSTONE

Brachiopods
Chonetes maoria Allan
Chonetes nigricans Allan
Stropheodonta huttoni Allan
Leptostrophia reeftonensis Allan
Reeftonia marwicki Allan
Mauispirifer hectori Allan
Acrospirifer coxi (Allan)
Tanerhynchia parki (Allan)
Reeftonella neozelanica (Allan)

Molluscs
Nuculoidea sp.
Phestia sp.
Palaeodora reeftonensis Fleming
Actinopteria mackayi Fleming
Pterinopecten (Pseudoaviculopecten) casterorum Fleming
Cypricardinia crenistra (G & F. Sandberger)
cf. *Nargunella* sp.
Palaeotaxodont deep burrower
Orthoconic nautiloids
Bellerophontids

Arthropods
Burmeisteria (Burmeisteria) huttoni (Allan)
Burmeisteria (Digonus) expansus (Hector)

Corals
Pleurodictyum cf. *problematicum* Goldfuss

Miscellaneous
Crinoid stems and debris

Bryozoans
Ostracods
Cornulites sp.
Hyolithid

LANKEY LIMESTONE

Corals
Hexagonaria allani Hill
Hexagonaria sp.
Zaphrentis sp.
Favosites sp. cf. *Emmonsia carmini* (Stewart)
cf. *Cladophora* sp.
Tipheophyllum bartrumi (Allan)
Favosites murrumbidgeensis Jones
Thamnopora reeftonensis Hill

Stromatoporoids
Anostylostroma clarum (Pocta)
Stromatospora sp., cf. *S. hupschii* (Bargatzky)

Bryozoans
Fistulipora cf. *trifoliata* Schluter
Lioclema(?) *reeftonensis* Allan
Fenestella sp.

Miscellaneous
Pleurothyrella venusta Boucot et al.
Actinopteria sp.
Crinoid debris
Dechenella mackayi Allan

ADAM MUDSTONE

Bivalves
Palaeodora reeftonensis Fleming
Actinopteria mackayi Fleming
Glossites sp.
Phestia sp.
Nuculites sp.
Sphenotus sp.
Paleoyoldia sp.
Nuculoidea sp.

Brachiopods
Acrospirifer coxi (Allan)
Mauispirifer hectori Allan
Orbiculoidea (Lingulidiscina) sp.
Lingula sp.
?Leptostrophia reeftonensis Allan
Reeftonella neozelanica (Allan)
Tanerhynchia sp.
Chonetes sp. A

Miscellaneous
Crinoid debris
Orthoconic nautiloids
Bryozoans
Burmeisteria (Digonus) expansus (Hector)

YORKEY LIMESTONE

Corals
Favosites sp.
?Cladopora sp.

Miscellaneous
indet. brachiopods
Tentaculites sp.

RANFT MUDSTONE

Molluscs
Nuculoidea sp.
Actinopteria sp.
Phestia sp.
Orthoconic nautiloids

Brachiopods
Pleurothyrella sp.
Chonetes sp.
Reeftonella neozelanica (Allan)

Miscellaneous
Burmeisteria sp.
Dechenella mackayi Allan

Echinoderms
Crinoid debris
?Megistocrinus reeftonesis Prokop
?Hexacrinites sp.

PEPPERBUSH LIMESTONE

Bryozoans (Rainy Creek)
Crinoid debris (Rainy Creek)

ALEXANDER MUDSTONE

Molluscs
Glossites sp.
Modiolopsid bivalve
Actinopteria sp.
Bellerophontid
Orthoconic nautiloids

Brachiopods
Reeftonella neozelanica (Allan)
Large strophomenids
Acrospirifer sp.

Miscellaneous
Crinoid pinnules
Crinoid stems