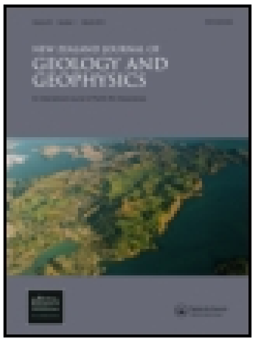

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Margaret A. Bradshaw

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Stratigraphy and structure of the Lower Devonian rocks of the Waitahu and Orlando Outliers, near Reefton, New Zealand, and their relationship to the Inangahua Outlier

MARGARET A. BRADSHAW
44 Glenharrow Avenue
Christchurch 4, New Zealand

Abstract In the Waitahu River catchment, 1255 m of Lower Devonian Reefton Group sediments are downfaulted into Ordovician Greenland Group rocks to form two outliers of contrasting size (Waitahu and Orlando Outliers). Of the eight formations present, seven have been correlated with those of the neighbouring Inangahua Outlier (in order of younging: Murray Creek Formation, Lankey Limestone, Adam Mudstone, Yorkey Limestone, Ranft Mudstone, Pepperbush Limestone, and Kelly Sandstone) while a new formation is preserved at the top of the sequence (**Track Mudstone**). The stratigraphic sequence in the Inangahua and Waitahu Outliers is essentially the same, and includes thick sandstones at the bottom and top of the succession, with an alternation of nearshore limestone and offshore mudstone formations in between. The Waitahu sequence is more continuous and is not broken by tectonic slides. Beach to shelf paleoenvironments are inferred, as for the rocks of the Inangahua Outlier, but the Track Mudstone is interpreted as a nonmarine lagoonal deposit. There are, however, significant differences within the Waitahu sequence, such as the absence of Bolitho Mudstone and Forgotten Limestone, both of which are present in the Inangahua Outlier. Thicker Lankey and Yorkey Limestones, bioturbated shoreface silty units in the Ranft Mudstone, replacement of Alexander Mudstone by lower Kelly Sandstone, and the nonmarine Track Mudstone, all suggest that the Waitahu area lay closer to the Early Devonian shoreline than did the Inangahua region.

The Devonian outliers are bounded by two types of faults. Some are subparallel to bedding in the Reefton Group and are associated with bedding-parallel breccia zones, while others are steep, crosscutting faults. The low dip of some boundary faults, and the relationship of cleavage to calcite veins, suggests that the Reefton Group was emplaced over the Greenland Group along low-angle faults during an early extensional regime. The Reefton Group, together with its bounding faults, was then folded into a tight, south-plunging syncline during a compressive phase of the ?Middle to Late Devonian Tuhua Orogeny. The structure was further modified by warping and steeply inclined displacements during the Rangitata and Kaikoura Orogenies, so that the outlier became defined by a mixture of bedding-parallel and crosscutting faults.

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Keywords Lower Devonian; Waitahu Outlier; Orlando Outlier; Reefton Group; Track Mudstone; structure; paleoenvironments; stratigraphy; Tuhua Orogeny; new stratigraphic names

INTRODUCTION

Devonian sediments are rare in New Zealand, and outcrops are confined to the Reefton and Baton River areas (Bradshaw 1988). At Reefton, Devonian rocks of the Reefton Group are downfaulted into the Ordovician Greenland Group to form five separate outliers (Fig. 1). In the middle reaches of

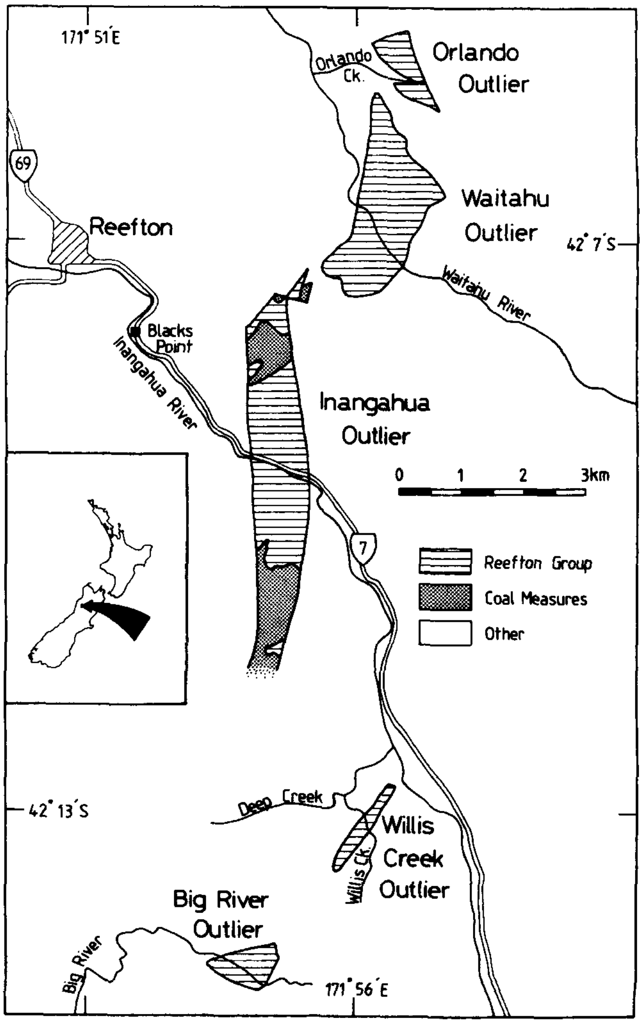

Fig. 1 Devonian Reefton Group sediments near Reefton preserved as five outliers downfaulted into Ordovician Greenland Group sediments, and locally overlain by Tertiary coal measures. The three northern outliers have been remapped (Bradshaw & Hegan 1983 and this paper) whereas the Big River and Willis Creek Outliers are after Suggate (1957).

the Waitahu River valley, the Reefton Group crops out as two unequal-size outliers; a larger Waitahu Outlier in the south, which is bisected by the Waitahu River, and a smaller Orlando Outlier to the north. Topography in the area mapped ranges 250–775 m above sea level.

Access up the Waitahu Valley is by a forestry track that begins at the edge of the lower Inangahua Valley flats near the Dauntless Coal Mine, and crosses the Devonian outcrop along the true right bank (Fig. 2). Access is also possible via a walking track that leads off State Highway 7 in the Inangahua Valley, over Murray Saddle and down to the Waitahu River. A partially overgrown mining track also crosses the outcrop between the Waitahu side of Murray Saddle and an obscured mine in a tributary of Healey Creek. Although recorded on a map by Henderson (1917), this track is not shown on more recent maps.

The Waitahu outliers are in mature native bush of the Victoria State Forest Park. Exposure is generally poor and is best on creek sides and along ridge crests. Hillsides underlain by the Reefton Group, especially by sandstone and limestone, are steeper and more densely vegetated than those underlain by Greenland Group rocks.

Relationship to Greenland Group

All contacts between the Reefton and Greenland Groups are faulted. The two groups are usually easy to distinguish because of the Greenland Group's greater metamorphism, stronger deformation, and the presence of gold-bearing quartz veins. Greenland Group mudstones are distinctly phyllitic compared to those of the Reefton Group, and Greenland Group sandstones, although quartzose like those of the Reefton Group, are more micaceous, much more poorly sorted, and muddy. Laird & Shelley (1974) undertook a detailed examination of well-exposed Greenland Group rocks downstream of the Devonian outcrop and considered them to be a turbidite sequence deposited on a submarine fan or fans. This is in marked contrast to the shelf and nearshore facies of the Reefton Group. It is highly likely that the Reefton Group was deposited unconformably upon Greenland Group, although this has never been observed. The exact age of the Greenland Group was unknown until Cooper (1974) discovered Early Ordovician graptolites from a thin black mudstone close to the eastern boundary fault of the Waitahu Outlier.

Whereas small, moderately tight folds associated with slaty cleavage are common within the Greenland Group, the Reefton Group shows only large-scale structures.

Previous research

Previous geological research on the Devonian rocks of the Reefton district, largely relating to the Inangahua Outlier, was summarised by Bradshaw & Hegan (1983). Compared to the Inangahua Outlier, the Waitahu Outlier has received relatively little attention.

Devonian rocks were first recorded in the Waitahu River area by McKay (1883). Henderson (1917) listed 365 m of limestone, quartzite, and mudstone, but Suggate (1957), while recognising that these lithologies were similar to his quadripartite succession in the Inangahua Outlier, considered that the two areas could not be reliably correlated.

In the Waitahu area, Suggate mapped the Devonian rocks as two outliers: a larger one to the south and a smaller one at the head of Orlando Creek. Hegan (1970), who was the first to map the Devonian at Reefton in detail, considered that the Devonian rocks of the Orlando Creek area were continuous in outcrop with those of Suggates's southern outlier.

In the Inangahua Outlier, clear exposures had become available after burn-off of secondary scrub around 1978, allowing the recognition of 10 formations and a good stratigraphic understanding of the 1450 m thick sequence (Bradshaw & Hegan 1983). Eight of these formations comprise an alternation of thin limestones and thicker mudstones that is faulted between two thick quartzite formations.

A provisional map and stratigraphy for the Waitahu region, showing correlation with the Inangahua Outlier, was included by Bradshaw (1988) in a review paper on the Devonian rocks of New Zealand. Conclusions drawn there are superceded by this paper, and the map has been revised.

Age

Until recently, most Devonian fossil collections from Reefton had been made from a few well-known Inangahua Valley localities in Murray Creek Formation, Bolitho Mudstone, and Lankey Limestone. Age determinations have been based largely on brachiopod faunas in the absence of goniatites and graptolites (Allan 1935, 1947; Boucot et al. 1963; Gill et al. 1966), with less reliable determinations from coral and stromatoporoid faunas (Hill 1956; Cockbain 1965). Siegenian, Emsian, and Eifelian ages were variously suggested by these authors, with a preference for Siegenian or Emsian. Conodonts, extracted from the Lankey Limestone in the Waitahu Valley, were too poorly preserved to allow conclusive identification but appear to indicate a Lower Devonian age (Jenkins 1967). A different microfauna derived from the Lankey Limestone of the Inangahua Outlier (Stony Creek) includes *Spathognathodus* cf. *canadensis*, also fish scales of *Notolepis striata*, regarded by Macadie (1985) as having a pre-Emsian aspect. Further micropaleontological work will need to be done to resolve the exact age of the Reefton Group, but from the brachiopod faunas of the lowest formations, a Pragian age seems likely (Strusz 1972).

Previously, little material had been collected from the Waitahu outcrops, but new exposures of a richly fossiliferous mudstone were made during the cutting of the Waitahu forestry track in the early 1970s. These contain a diverse fauna, including the first record of the palaeotaxodont bivalve *Notonucula* from the Devonian of New Zealand (Bradshaw 1974, 1977; Bradshaw & McCartan 1991). Substantial biostratigraphical collections have since been made from both the Waitahu and Inangahua Outliers (Bradshaw in prep.).

STRATIGRAPHY

Of the 11 Devonian formations mapped in the Inangahua Outlier (Bradshaw & Hegan 1983), seven can be recognised in the Waitahu Outlier (Fig. 2). These are: Murray Creek Formation, Lankey Limestone, Adam Mudstone, Yorkey Limestone, Ranft Mudstone, Pepperbush Limestone, and Kelly Sandstone. Correlation is based on the assumption that there is no major change in lithology over the short distance that separates the two outliers. The significance of minor changes in lithology and cut-out of three formations (Forgotten Limestone, Bolitho Mudstone, and Alexander

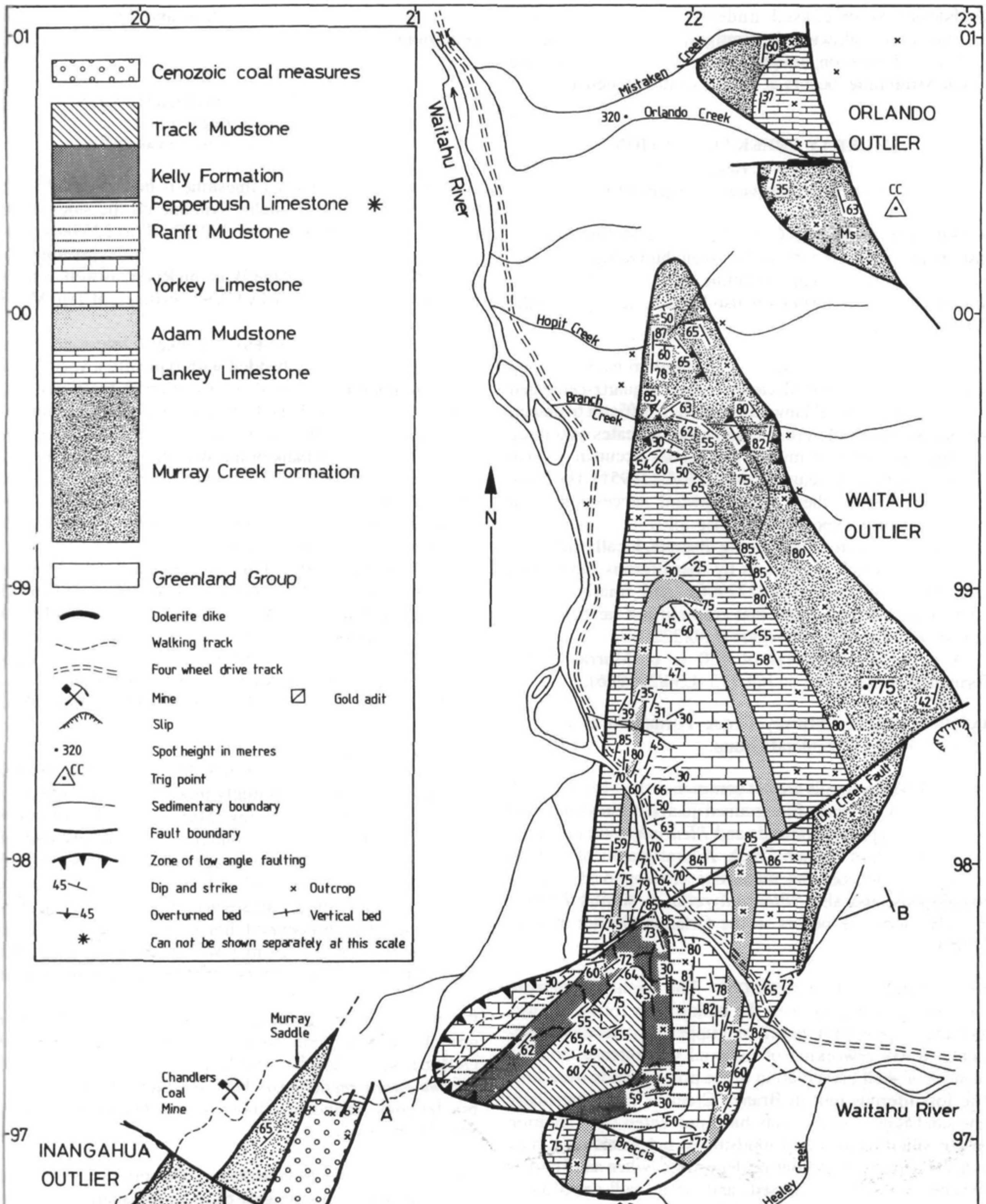

Fig. 2 Detailed geological map of the Orlando and Waitahu Outliers. The northern tip of the adjacent Inangahua Outlier is also shown. The grid is based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260).

Mudstone) is discussed under the heading, Paleoenvironments, following the stratigraphic descriptions.

A new formation unique to the Waitahu Outlier, the **Track Mudstone**, occurs at the top of the sequence.

MURRAY CREEK FORMATION

(Bradshaw & Hegan 1983)
(Part Orlando Quartzarenite, Hegan 1970)

DISTRIBUTION: Murray Creek Formation is found in the eastern and northern parts of the Waitahu Outlier, forming the eastern limb of a major syncline, and part of its hinge in Branch Creek. The formation also forms a large part of the Orlando Outlier.

DESCRIPTION AND THICKNESS: The predominant lithology is fine- to medium-grained, cream coloured, quartz-cemented quartzarenite. Internal lamination is often difficult to detect, but occasional ripple cross-lamination indicates younging direction. Bioturbated muddy sandstones occur in Branch Creek* (left branch, near junction, L30/222995†). Half way up Branch Creek, there is an upward succession from massive, poorly exposed quartzose siltstone, into a thin, rather sandy limestone containing discrete, locally silicified shell layers, which is overlain by fossiliferous sandstones and sandy siltstones (L30/222990), and finally by red sandstones and mudstones that crop out not far below the contact with Lankey Limestone (L30/222989).

A minimum thickness of 450 m of Murray Creek Formation is preserved on hill 775 (L30/225986).

BASAL CONTACT: Murray Creek Formation is in fault contact with the Greenland Group.

FAUNA: Macrofossils are not common in the Murray Creek Formation. A very pure fine-grained quartzarenite containing cyptonellid-type terebratulids and *Pleurothyrella* occurs in the left branch of Branch Creek. A stratigraphically lower sandy siltstone contains numerous schizophorids, orthid brachiopods, and also ?*Pleurothyrella*. A similar *Pleurothyrella* sandstone occurs in the Orlando Outlier at L30/222010.

ENVIRONMENT OF DEPOSITION: The highly quartzose sandstone which comprises the bulk of this formation was probably deposited in beach and upper shoreface environments, where reworking of material was intense, and the chances of shell preservation in the porous sands were low. The fossiliferous unit in Branch Creek is in an unusually fine sandstone, and this may have prevented shell solution before silicification. Red mudstones and sandstones may indicate periods of nonmarine deposition, when sand bodies became exposed or oxidised, and when well-oxygenated muds were deposited in back-bar lagoons. Bioturbated muddy and calcareous sandstones close to the contact with the overlying Lankey Limestone, and also lower in the sequence, suggest a deepening of water, with less wave action and the establishment of an active infauna consistent with the development of middle and lower shoreface conditions.

LANKEY LIMESTONE FORMATION

(Bradshaw & Hegan 1983)
(Part Waitahu Limestone, Hegan 1970)

DISTRIBUTION: Lankey Limestone is best exposed in the hinge region of the Waitahu Syncline on the sides of the ridge trending northwest from hill 775 (L30/225986) to the mouth of Branch Creek (L30/215996). It is also found on the southwestern side of the Waitahu River, as well as in the head of a tributary of Healey Creek northeast of Trig M718.

DESCRIPTION AND THICKNESS: Lankey Limestone for the most part is massively bedded with typically a very coarse biorudite texture, and local silicification of fossil material. Interbedded stratified shelly limestone is also present, but its relationship to the biorudite is difficult to determine. Outcrops on the left bank of the Waitahu Valley adjacent to the riverbed (L30/222973) contain interbedded coral and shell-rich layers. Here, a 0.2 m thick layer of clean sandstone grades up into shelly sand, then into shelly limestone. The formation also contains a thick unit of well-sorted medium-grained quartzarenite. This is especially clear at the northwestern end of the forestry track section (L30/216985) where 20 m of quartzarenite, in natural contact with 33 m of Lankey Limestone, is faulted against Greenland Group. This sandstone has been interpreted as a member within the limestone rather than as Murray Creek Formation.

A minimum thickness of 110 m of Lankey Limestone is preserved.

BASAL CONTACT: Horizons of bedding-concordant welded sandstone breccia were initially thought to mark a tectonic contact with the underlying Murray Creek Formation (Bradshaw 1988). However, outcrops immediately south of Branch Creek (L30/219995) suggest a natural passage from Murray Formation into Lankey Limestone through several metres of alternating calcareous, bioturbated, quartzose sandstone. The brecciated horizons appear to involve quartzarenite units c. 20 m lower in the succession. The base of the limestone is placed at the first limestone horizon.

FAUNA: Lankey Limestone contains stromatoporoid growths, rugose coral colonies (*Tipheophyllum bartrumi* (Allan) see Suggate 1957, p. 34), tabulate corals (*Thamnopora reeftonensis* Hill, see Suggate 1957, p. 34), brachiopods, abundant crinoid debris, bryozoan colonies, and rare bivalves.

ENVIRONMENT OF DEPOSITION: The presence of corals and stromatoporoids suggest clear-water, shallow offshore shelf conditions of deposition. These colonies reach greater sizes than those observed in the Inangahua Outlier (e.g., stromatoporoids 0.6 m diameter, coral colony 0.86 × 0.7 m) although none were convincingly in situ. This, together with the formation's greater thickness (110 m cf. 93 m) suggests a closer proximity to shoreline bioherms. This may be supported by the interbedded quartzarenite unit exposed near the western margin of the outlier, which is twice as thick as a similar interbedded sandstone in the Lankey Limestone of the Inangahua Valley.

*Name not approved by the New Zealand Geographic Board.
†Grid references are based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260).

Fig. 3 Thin, ripple laminated, interbedded sandstone (dark grey) and limestone (pale grey) in Yorkey Limestone. Right bank Waitahu River below forestry track, L30/217983.

ADAM MUDSTONE FORMATION

(Bradshaw & Hegan 1983)
(Kirwan Mudstone, Hegan 1970)

DISTRIBUTION: Adam Mudstone occurs in the hinge and on both limbs of the Waitahu Syncline. Best exposures are along the northwestern part of the forestry track section (L30/217983), although here the width of the mudstone outcrop has been reduced by minor faulting.

DESCRIPTION AND THICKNESS: The formation is predominantly massive, monotonous, dark grey silty mudstone with poorly defined bedding and minor siltstone and sandstone horizons. Fossils are mostly confined to thin, decalcified seams. The forestry track exposure shows the top of the formation grading up into at least 3 m of fine-grained, quartzose sandstone that contains current-oriented tentaculitids.

Adam Mudstone has a maximum thickness of 120 m.

BASAL CONTACT: The lower contact with Lankey Limestone is gradational over a few metres, either through massive calcareous siltstone (forestry track section), or through fine-grained, muddy, quartzose sandstone (southwest side of Waitahu River).

FAUNA: Adam Mudstone is very fossiliferous and has produced some of the richest Waitahu faunas. *Acrospirifer* is particularly abundant in the lower part of the formation, but bivalves become common c. 20 m above the base in the forestry track section. Bivalve-rich horizons also contain orthoconic nautiloids, brachiopods, especially chonetids, trilobites, and crinoid ossicles. Fossils show less distortion when they occur in thin, calcareous (often nodular) beds, than they do in the cleaved, muddier beds. *Hipparyonyx*-like brachiopods were observed at several localities.

This formation has yielded the only fish macrofauna known from the Reefton area, a left anterior ventrolateral plate of an *Arctolepid arthodire* described by Macadie (1985) who mistakenly attributed it to the Murray Creek Formation. Suggate (1957, p. 33) records *Acrospirifer coxi* and *Reeftonella neozelanica* from a mudstone in the Waitahu Valley that is likely to be the Adam Mudstone.

ENVIRONMENT OF DEPOSITION: The high mud content, together with the variety and nature of the associated fauna, is consistent with an offshore shelf environment. The fine-grained quartzose sandstone at the top of the formation is likely to have formed in the shallower water of a breaker point bar situation, where shells of *Tentaculites* became oriented by water movement.

YORKEY LIMESTONE FORMATION

(Bradshaw & Hegan 1983)
(Part Waitahu Limestone, Hegan 1970)

DISTRIBUTION: Yorkey Limestone is best exposed in the forestry track section at L30/218982. In the eastern limb of the Waitahu Syncline the limestone extends across to the left bank of the Waitahu River. It also occurs in the Waitahu–Murray track north of Trig M718 in the western limb.

DESCRIPTION AND THICKNESS: The formation is typically a bedded, shelly biomicrite (Fig. 3). The lower part is sandy and thinly bedded, with scattered brachiopod shells. Laminae are graded with sandy bases and fine-grained biomicrite tops. The beds show interference ripples and hummocky cross-stratification.

The lower laminated sandy limestone grades up through layered units crammed with shells, into massive, purer, fine-grained limestone, in beds at least 1.5 m thick (Fig. 4). The massive limestone contains relics of diagenetically dissolved shells.

Yorkey Limestone has a minimum thickness of c. 150 m. It can be easily distinguished from Lankey Limestone by its more obvious bedding and by its shell content. Although coral and stromatoporoid growths have been observed near

Fig. 4 More massively bedded Yorkey Limestone to the south of Fig. 3 at L30/218981.

the top of the formation, these are uncommon and generally small.

BASAL CONTACT: Yorkey Limestone grades up abruptly from the sandy top of the Adam Mudstone. The base of the formation is placed at the first limestone interbed.

FAUNA: Fossils include spriferid and terebratulid brachiopods, *Orbiculoidea*, and abundant crinoid debris. Bedding planes occasionally have small surface grooves and stuffed burrows.

ENVIRONMENT OF DEPOSITION: The presence of interference ripple lamination and hummocky cross-stratification in biomicrite suggests deposition in a shallow, high energy environment in which shells were frequently pulverised by wave action. A breaker point sand bar, built out by longshore drift, may have separated the area of limestone deposition from the muddy shelf further offshore. Little detritus entered the basin of limestone deposition, apart from fine sand washed over the bar during storms.

RANFT MUDSTONE FORMATION

(Bradshaw & Hegan 1983)
(Part Waitahu Limestone, Hegan 1970)

DISTRIBUTION: Ranft Mudstone is found only on the left bank of the Waitahu River, where it crops out in the hinge and on both limbs of the Waitahu Syncline.

DESCRIPTION AND THICKNESS: The formation is poorly exposed in the bush where it is commonly represented by soft, orange-weathered siltstone, although when fresh, the mudstone is typically massive, calcareous, and blue-grey in colour. The top of the formation is bioturbated, and this texture is best seen in ephemeral riverbed outcrops between L30/219977 and L30/220977 (Fig. 5). For the most part, Ranft Mudstone is unfossiliferous except for rare, thin, shell horizons. At the top of the formation is a fine-grained, thinnly bedded, well-sorted quartzarenite immediately below the succeeding limestone.

A minimum thickness of 150 m is estimated.

BASAL CONTACT: The contact with Yorkey Limestone is not exposed, but near its base the Ranft Mudstone is silty, thinly bedded, and with sparse ripple lamination.

FAUNA: Rare fossil horizons contain orthid and chonetid brachiopods, and rare conularids (e.g, L30/218979). This fauna is distinctive and also occurs at L30/219971. The burrows preserved near the top of the formation have thin mud linings, suggesting excavation by mud-filtering organisms. The sandstone unit at the top of the formation contains brachiopods and *Tentaculites*.

ENVIRONMENT OF DEPOSITION: Sediments near the bottom and top of this formation exhibit more shallow-water features than do those in the middle part of the formation. This suggests that monotonous, muddy, offshore shelf conditions prevailed for most of Ranft Mudstone deposition, during which thin layers of shells were swept out onto the shelf during storms. Shorewards, there was ripple lamination and a high degree of infaunal burrowing, probably in a shoreface environment.

PEPPERBUSH LIMESTONE FORMATION

(Bradshaw & Hegan 1983)

DISTRIBUTION: Pepperbush Limestone is probably present on both limbs of the Waitahu Syncline but outcrops occur only in the Waitahu riverbed near the hinge region at L30/219977.

DESCRIPTION AND THICKNESS: Pepperbush Limestone comprises thin interbedded sandstone and limestone laminae with layers of disarticulated brachiopod shells. Hummocky

Fig. 5 Highly burrowed sandy mudstone near the top of the Ranft Mudstone. Beds young towards the top. Riverbed, left bank Waitahu River, L30/219977.

cross-stratification may be present, and stylolites are common. Minimum thickness is little more than 10 m.

BASAL CONTACT: Pepperbush Limestone grades up from the calcareous, bioturbated siltstone of the upper Ranft Mudstone through a unit of fine-grained, thinnly bedded, well-sorted quartzarenite. The base of the formation is placed at the first bed of limestone.

FAUNA: Disarticulated brachiopod shells.

ENVIRONMENT OF DEPOSITION: The lithology is similar to the lower part of the Yorkey Limestone, and a comparable high-energy, nearshore environment is suggested.

KELLY SANDSTONE FORMATION

(Bradshaw & Hegan 1983)
(Orlando Quartzarenite, Hegan 1970)

DISTRIBUTION: Kelly Sandstone is found only on the left bank of the Waitahu River, where it crops out on both limbs and in the hinge of the Waitahu Syncline.

Kelly Sandstone is predominantly a uniform, fine- to medium-grained, well-bedded, parallel or ripple laminated, cream coloured, quartz-cemented quartzarenite. Beds are commonly 0.1–0.3 m thick, and outcrops are in places heavily veined with quartz. The lower part of the formation contains well-bedded quartzarenite with thin fissile claystones. Minimum thickness is c. 140 m.

BASAL CONTACT: Kelly Sandstone grades up from the Pepperbush Limestone through thinly interbedded, muddy, quartzose sandstone with thin green siltstones.

FAUNA: No body or trace fossils have been observed in the Kelly Sandstone Formation.

ENVIRONMENT OF DEPOSITION: The highly quartzose nature of this formation indicates intense reworking of material by waves, consistent with a beach or upper shoreface environment.

TRACK MUDSTONE FORMATION (new)

(Track Mudstone, Hegan 1970)

TYPE SECTION: In the bed of the true left branch of a forked left bank tributary of the Waitahu River between L30/217975 and L30/216974, near the second hairpin up from the valley floor on the Murray Creek walking track, Waitahu Outlier.

DISTRIBUTION: Track Mudstone is found only in the core of the Waitahu Syncline, and crops out along the walking track to Murray Saddle and in the sides of the old mining track higher up the hillside.

DESCRIPTION AND THICKNESS: The formation comprises predominantly red and green siltstones, with minor green sandstones, in beds c. 0.3 m thick. Minimum thickness is difficult to estimate, but appears to be c. 125 m. Internal layering of any kind is generally obscure. Desiccation cracks may be present in the more silty rocks.

BASAL CONTACT: Track Mudstone grades abruptly up from Kelly Sandstone with increasing mud laminae and decreasing sand layers.

FAUNA: No body or trace fossils have been observed in these sediments.

ENVIRONMENT OF DEPOSITION: The predominantly red aspect of this formation and its total lack of either a macrofauna or ichnofauna, suggest a nonmarine environment

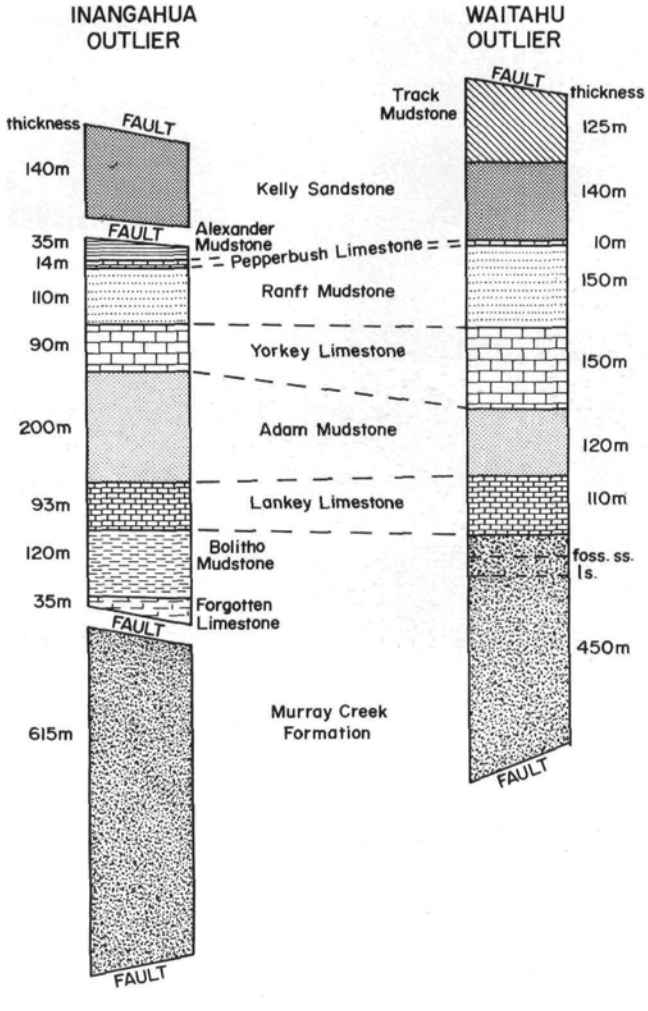

Fig. 6 Composite sections of Reefton Group in the Inangahua and Waitahu Outliers to show comparative thicknesses.

consistent with deposition in a back-beach-bar-lagoon under oxidising conditions.

ORLANDO OUTLIER

The Orlando Outlier is not well exposed, but appears to contain Murray Creek Formation and Lankey Limestone, and is possibly part of the western limb of a syncline. Murray Creek Formation includes muddy quartzarenites that contain a *Pleurothyrella*-dominated brachiopod fauna. The affinity of easterly dipping massive mudstone near the top of the ridge south of the head of Orlando Creek (L30/225004) is unclear, and these rocks have been mapped as part of the Murray Creek Formation.

PALEOENVIRONMENTS

Bradshaw & Hegan (1983) described the Inangahua Outlier sequence as an alternation of shallow, nearshore limestones and deeper offshore shelf mudstones faulted between two thick formations of mature, beach or upper shoreface sandstones (Fig. 6). Changes in microlithofacies and bottom faunas in the alternating mudstone and limestone sequence were interpreted as reflecting four transgressive and regressive cycles (see also Bradshaw 1988). The sandstone interval within the Lankey Limestone, for example, marked the maximum of a regressive cycle, when shoreface sandstones prograded over areas of shallow-water limestone deposition. The mollusc-rich horizons in the middle of the mudstone formations marked the maximum of a transgressive cycle, when unrestricted outer shelf muds, with mixed benthic communities, spread shorewards over more restricted mud areas supporting monospecific benthic communities. Well-sorted quartzarenite units between the mudstone and limestone units (e.g., between Adam Mudstone and Yorkey Limestone) were interpreted as a break-point bar facies, resulting from longshore drift, that was laterally equivalent to the coral-stromatoporoid lithofacies.

An identical alternating sequence of limestone and mudstone is present in the Waitahu Outlier, but with fewer formations, and with less tectonic disturbance (Fig. 6). Natural contacts exist between the limestone/mudstone sequence and the underlying and overlying quartzarenite formations. Lithology is used as the basis for correlation between the two areas, particularly of the Lankey and Yorkey Limestones, which retain their distinctive character throughout the Reefton area and appear to be reliable marker horizons.

The most significant difference between the successions of the two watersheds is that below the Lankey Limestone in the Inangahua sequence there is a thick mudstone (Bolitho Mudstone) and a thin, crinoidal limestone (Forgotten Limestone), which are in tectonic contact with Murray Creek Formation. In the Waitahu Valley, however, there appears to be a sedimentary contact (passage zone) between Murray Creek Formation and Lankey Limestone. Well-sorted, clean, quartzose sandstones are replaced rapidly upwards by biomicrite, which becomes increasingly coral and stromatoporoid rich. There is no indication of mudstone lying between the two formations, or of a discrete limestone.

The Murray Creek Formation in Branch Creek (Waitahu Outlier), not far below its upper contact, contains a very thin, sandy limestone associated with a thin, massive, poorly exposed quartzose siltstone. One possible interpretation is that in the Waitahu area the Bolitho Mudstone has been replaced shorewards by thick, well-sorted, fine-grained quartz sandstones and siltstones, and that the Forgotten Limestone has been replaced by sandy limestone, all interbedded within the Murray Creek Formation. The Waitahu succession would therefore appear to represent sediments deposited closer to land.

Similarly, the sandstone interval within the Lankey Limestone is 100% thicker than in the Inangahua area, and coral and stromatoporoid growths reach much larger sizes. These, too, suggest closer proximity of the Waitahu area to the Early Devonian coastline.

In the Waitahu Outlier, the lower and upper parts of the Ranft Mudstone are bioturbated siltstone, or very fine grained sandstone, containing a distinctive brachiopod fauna. Only the central part of the formation is similar to the more massive mudstones of the Inangahua Outlier. This indicates an increase in silt and sand component northeastwards, while the marked bioturbation is consistent with shoreface conditions where the sediment/water interface was firmer than in an open shelf environment.

Closer proximity to the shoreline is also suggested by reduction of marine mudstone in the upper part of the

Waitahu sequence in favour of shoreface sandstones. In the Inangahua Outlier, Pepperbush Limestone is followed by 35 m of Alexander Mudstone, which is in tectonic contact with the overlying Kelly Sandstone. This mudstone is absent in the Waitahu Outlier, where Pepperbush Limestone grades abruptly up into Kelly Sandstone with increasing sandstone and decreasing limestone laminae.

The gradation of Kelly Sandstone into the overlying unfossiliferous red and green siltstones of the Track Mudstone may indicate a period of regression. Similar red rock types were observed in the Murray Creek Formation of both outliers, and may indicate short-lived episodes of nonmarine conditions associated with progradation of a sandy coastline.

STRUCTURE

The structure of the northern part of the Waitahu Outlier is straightforward, but the area south of the Dry Creek Fault is more difficult to explain. Dips and strikes in the southern area indicate a change in orientation of the main fold and also some cross-deformation.

Boundary faults

The boundary faults of both outliers are highly variable, and some appear to be composites of earlier low-angle faults and later steeper faults.

At one time, the southern boundary of the Waitahu Outlier was better exposed, as Henderson records (1917, p. 76) "On the left bank of the Waitahu, on the upper track, the eastern junction of the Devonian and Aorere beds (Greenland) is well shown, and is manifestly a fault-fissure filled with crushed rock and containing an intrusive dyke" (site of old mine at end of upper track).

The western boundary of the Waitahu Outlier is a steep fault with overturning or steepening of adjacent Devonian strata. When the forestry track was first cut, a vertical fault zone was clearly visible at the western end of the Devonian section.

Hegan (1970) mapped the Waitahu and Orlando Outliers as a single, continuous structure, and considered that the eastern boundary throughout its length was a low-angle, westward-dipping normal fault. Remapping suggests that this boundary is really a combination of low-angle and high-angle faults. For instance, in Branch Creek at L30/223995, the boundary is a low-angle (30°), westward-dipping fault. Brecciation has pulverised Reefton and Greenland Group rocks so that they appear similar to welded breccia zones in the Inangahua Outlier. Local folding of cleavage in Greenland rocks suggests westward movement of overlying Devonian beds down the fault plane (Hegan 1970).

Between Branch Creek and a point north of Hopit Creek* the fault boundary is a steep, northwest-trending fault that swings west to merge into the the western boundary of the outlier.

In the Orlando Outlier the northern boundary is a steep ENE-trending fault followed by part of Mistaken Creek*. The eastern boundary is unexposed, but is probably a younger, steeply dipping fault. The western boundary, however, is a low-angle, eastward-dipping fault with significant brecciation of adjacent beds. Greenland Group rocks crop out in the bed of Orlando Creek, with Devonian rocks higher on the steep valley sides (L30/223006). After being offset by a northeast transverse fault, the boundary swings southeast, where sparsely fossiliferous Devonian sediments can be observed overlying Greenland Group along the hillside, almost as far as the watershed.

Transverse faults

East of hill 775, the Waitahu Outlier is offset by the northeast-trending Dry Creek Fault, which crosses the Waitahu Outlier and probably causes the active slip area south of hill 775. In the bed of Dry Creek* the fault is associated with a breccia of angular mudstone blocks in a lithified, featureless sandstone matrix, which suggests that the fault is relatively early. The displacement of the low-angle eastern boundary fault along the Dry Creek Fault may have resulted from the reactivation of an earlier tear fault.

As described above, a transverse fault clearly offsets the low-angle western boundary fault of the Orlando Outlier. Henderson (1917, p. 76) commented that in Orlando Creek "a large fault-zone contains great boulders of Devonian limestone between walls of Aorere (Greenland) rocks. Associated with this fault is a diabase dyke". The fault explains why Lankey Limestone, which overlies Murray Creek Formation north of Orlando Creek, is absent south of the creek, where only quartzarenite and mudstone occur, as the distance involved is too short for such a large facies change.

Folds

The recognition of two lithologically distinct limestones in the Waitahu Outlier indicates a single south-plunging syncline rather than the multiple folds of Hegan (1970), who mapped only one limestone.

North of the Dry Creek Fault, cleavage/bedding relationships and stereographic projections indicate that the Reefton Group has been deformed into a large north–south-trending syncline plunging about 50° south, with an angular hinge. Four formations can be traced around the hinge of the fold on the bush-covered hillside south of Branch Creek.

South of the Dry Creek Fault, a second, less steeply plunging, syncline nests within the main Waitahu fold (Fig. 7), and forms most of a tongue-like lobe displaced to the west. The northern limit of this second structure is the steep Dry Creek tear fault. The lobe is bound to the south by another steep fault, but the structure here is unclear due to poor exposure.

In the hinge region of the main syncline, the Lankey Limestone possesses a strong, steeply inclined cleavage at right angles to bedding, consistent with development during folding. In places, this cleavage shows conjugate kink folding resulting from a later period of deformation.

The Adam and Ranft Mudstones are also strongly cleaved in the hinge region (Fig. 8), with distortion of fossils in the former. Where Yorkey Limestone forms the core of the syncline near the forestry track, a well-developed stylolitic cleavage is visible in the thinly bedded lower part of the formation, and is particularly clear in river-level outcrops below the track (L30/217983). The cleavage appears confined to limestone laminae and is not obvious in the more sandy layers of the same bed (Fig. 9). At the forestry track locality, cleavage is almost at right angles to bedding, trending 168°, with a steep southwesterly dip. Cleavage

*Names not approved by the Geographic Board.

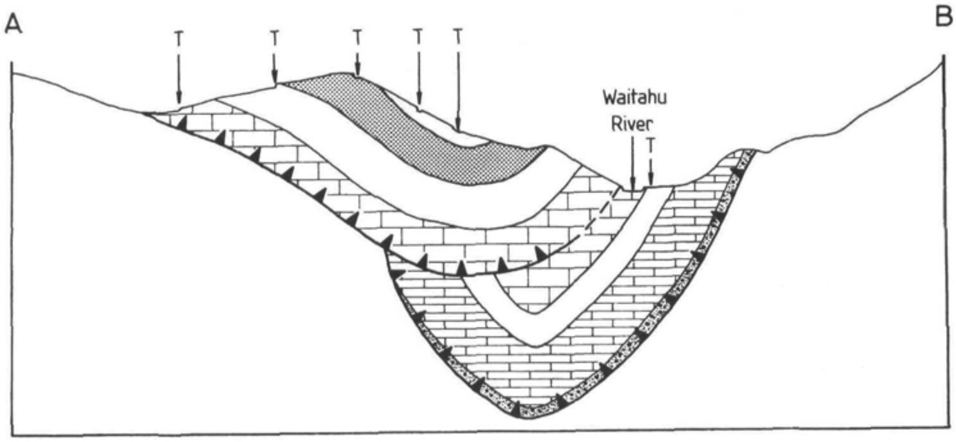

Fig. 7 Interpretive cross-section along line A–B of Fig. 2. T = track. For key to ornament see Fig. 2.

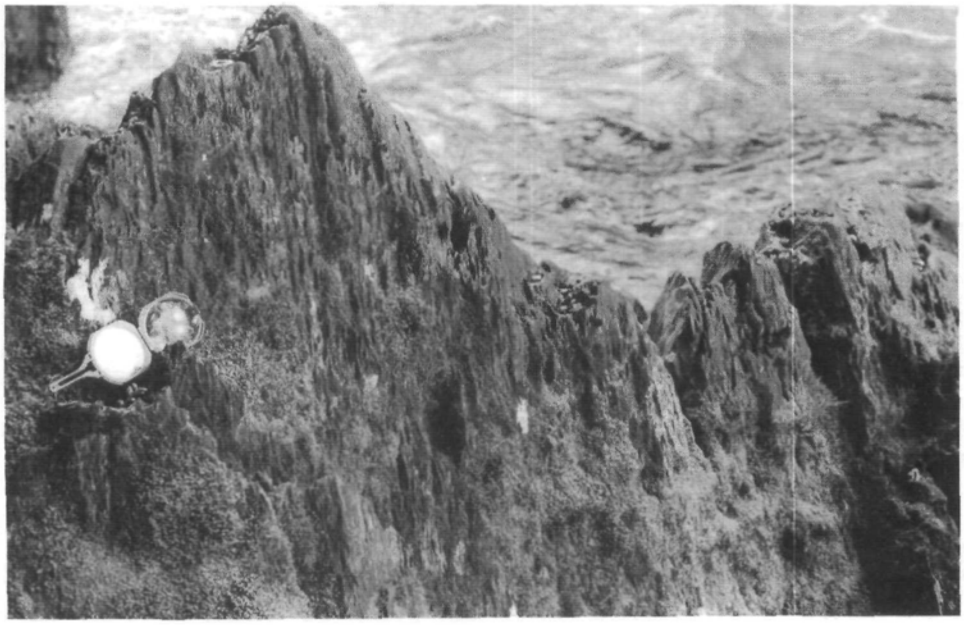

Fig. 8 Outcrops of cleaved Ranft Mudstone in the hinge of the Waitahu Syncline. Riverbed, left bank Waitahu River, L30/ 218978.

bedding intersections indicate a fold axis trending 172° and plunging 48°S.

The stylolites postdate earlier sets of conjugate calcite veins which exhibit displacement by bed-over-bed slip. Veins show local offset or dissolution along the stylolites.

Structural interpretation

The best interpretation for the structure of both the Waitahu and Orlando Devonian rocks is that they comprise different parts of a complexly deformed tectonic slice resting on the Greenland Group. Tectonic slides comprising bedding-parallel faults, and inclined ramps marked by severe brecciation, were described in the Inangahua Outlier (Bradshaw & Hegan 1983), where they were tentatively interpreted as thrusts that postdated folding. Subsequently, Bradshaw (1988) suggested that they may instead represent earlier extensional deformation.

In the Waitahu Outlier, bedding-parallel brecciation is particularly well-developed at the Reefton Group – Greenland Group interface, and to a lesser extent within the Murray Creek Formation in Branch and Hopit Creeks, where the horizons appear to follow round the hinge of the syncline. The structure strongly suggests that tectonic sliding and emplacement of the Reefton Group predated folding, but it is not possible to resolve whether the movement was thrusting or low-angle normal faulting. Evidence from conjugate joint sets and layer-parallel slip prior to cleavage development is also consistent with tectonic sliding before most of the folding.

It is possible that extension, concurrent with the intrusion of ?Middle to Upper Devonian granites (377 Ma, Muir et al. 1994), produced low-angle normal faults, with associated brecciation, in a pile of lithified Early Devonian sediments and their Greenland Group basement. A subsequent period of compression, probably related to a later stage of the Tuhua Orogeny, produced the Waitahu Syncline and its associated cleavage. Downfaulting of Devonian rocks into the Greenland Group is likely to have occurred during the late Mesozoic Rangitata Orogeny, with further downfaulting during the Cenozoic. The Dry Creek Fault may be one such Cenozoic feature that displaced part of the Waitahu Syncline (Fig. 7).

Fig. 9 Stylolitic cleavage, visible in pale lime-rich layers of the Yorkey Limestone, does not extend into the interbedded sandier units. Pencil for scale at bottom. Riverbank exposures below the forestry track section, L30/217983.

RELATIONSHIP OF THE WAITAHU OUTLIER TO THE INANGAHUA OUTLIER

Only 350 m separate the southwestern end of the Waitahu Outlier from the faulted northern tip of the elongate Inangahua Outlier near Murray Saddle (Fig. 2)

Unlike the Waitahu outcrops, the Devonian rocks of the Inangahua Outlier are overlain by significant outcrops of Cenozoic coal measures, which are truncated by the boundary faults. The tapering northern end of the Inangahua Outlier has been displaced eastwards near Chandlers Mine, so that the offset northeast–southwest-trending boundary fault defines the eastern margin of the coal measure basin. This fault was once probably followed by the Murray Creek road, and was described by Henderson (1917, p. 76) as being a wide crush zone of "Greenland" and Tertiary rocks continuously exposed to Murray Saddle. Remapping shows the fault lying part way up a steep hillside where coal measures, resting on Greenland Group, have been faulted against Murray Creek Formation (previously mapped as Cenozoic coal measures). The Devonian quartzarenites possess a strong platy fabric that parallels the fault line, and which dips very steeply to the northwest. The fault crosses the Waitahu watershed east of Murray Saddle, and, here, Murray Creek Formation sandstones form the closest outcrops of Inangahua Devonian to the Waitahu Outlier.

SUMMARY

1. The Devonian strata of the Waitahu River area crop out as two distinct outliers downfaulted into Ordovician rocks.
2. The stratigraphy of the Waitahu region is comparable to that of the Inangahua Outlier to the southwest but contains fewer tectonic breaks.
3. Slight changes in facies within some formations, and omission of three other formations, suggest that the Waitahu sequence lay closer to the Early Devonian shoreline than did the Inangahua sequence.
4. Both areas were subjected to low-angle faulting of a pile of undeformed, lithified sediment to produce breccia zones.
5. The sequence then became compressed into roughly north–south folds with angular hinges and an axial cleavage, probably during the Tuhua Orogeny.
6. Downfaulting of Reefton Group into Greenland Group rocks, also transverse faulting and minor warping of the succession, probably occurred during both the Mesozoic Rangitata Orogeny and the late Cenozoic Kaikoura Orogeny.

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REFERENCES

Allan, R. S. 1935: The fauna of the Reefton beds (Devonian) New Zealand. *New Zealand Geological Survey paleontological bulletin 14*: 72 p.

Allan, R. S. 1947: A revision of the Brachiopoda of the Lower Devonian strata of Reefton, New Zealand. *Journal of paleontology 21*: 436–452.

Boucot, A. J.; Caster, K. E.; Ives, D.; Talent, J. A. 1963: Relationships of a new Lower Devonian terebratuloid (Brachiopoda) from Antarctica. *Bulletin of American paleontology 46 (207)*: 81–151.

Bradshaw, M. A. 1974: Morphology and mode of life of the bivalves *Nuculoidea vespa* n. sp. and *Nuculoidea umbra* n. sp. from the Devonian of New Zealand. *New Zealand journal of geology and geophysics 17*: 447–464.

Bradshaw, M. A. 1977: New faunas from the Devonian of Reefton. Abstract, Geological Society of New Zealand 22nd annual meeting. Otago University Printery.

Bradshaw, M. A. 1988: New studies on the Devonian of New Zealand. *In*: McMillan, N. J.; Embry, A. F.; Glass, D. J. *ed.* The Devonian of the world. *Canadian Society of Petroleum Geologists memoir 14, vol. 1*: 773–782.

Bradshaw, M. A.; Hegan, B. D. 1983: Stratigraphy and structure of the Devonian rocks of Inangahua Outlier, Reefton, New Zealand. *New Zealand journal of geology and geophysics 26*: 325–344.

Bradshaw, M. A.; McCartan, L. 1991: Palaeoecology and systmatics of Early Devonian bivalves from the Horlick Formation, Ohio Range, Antarctica. *Alcheringa 1*: 1–41.

Cockbain, A. E. 1965: Note on Devonian stromatoporoids from Reefton. *New Zealand journal of geology and geophysics 8*: 745–751.

Cooper, R. A. 1974: Age of the Greenland and Waiuta Groups, South Island, New Zealand. Note. *New Zealand journal of geology and geophysics 17*: 955–962.

Gill, E. D.; Boucot, A. J.; Johnson, J. G. 1966: The brachiopod genus *Maoristrophia* Allan (Lower Devonian, Strophomenacea) redescribed. *Proceedings of the Royal Society of Victoria 79*: 355–361.

Hegan, B. D. 1970: The stratigraphy and structure of part of the Devonian strata near Reefton, New Zealand. Unpublished M.Sc. thesis, lodged in the Library, University of Canterbury, Christchurch.

Henderson, J. 1917: The geology and mineral resources of the Reefton Subdivision, Westport and north Westland Divisions. *New Zealand Geological Survey bulletin 18*: 232 p.

Hill, D. 1956: The Devonian corals of Reefton, New Zealand. *In*: Palaeozoic corals from New Zealand. *New Zealand Geological Survey paleontological bulletin 25*: 5–14.

Jenkins, D. G. 1967: Conodonts in New Zealand. Letter. *New Zealand journal of geology and geophysics 10*: 302–303.

Laird, M. G.; Shelley, D. 1974: Sedimentation and early tectonic history of the Greenland Group, Reefton, New Zealand. *New Zealand journal of geology and geophysics 17*: 839–854.

Macadie, C. I. 1985: Devonian fossil fishes of Reefton, New Zealand. *New Zealand Geological Survey record 9*: 73–75.

McKay, A. 1883: On the geology of the Reefton District, Inangahua County. *New Zealand Geological Survey reports of geological exploration during 1882 (15)*: 91–153.

Muir, R. J.; Ireland, T. R.; Weaver, S. D.; Bradshaw, J. 1994: Ion microprobe U-Pb zircon geochronology of granitic magmatism in the Western Province of the South Island, New Zealand. *Chemical geology (isotope geoscience section) 113*: 171–189.

Strusz, D. L. 1972: Correlation of the Lower Devonian rocks of Australasia. *Journal of the Geological Society of Australia 18*: 427–455.

Suggate, R. P. 1957: The geology of the Reefton Subdivision (Reefton sheet, S38). *New Zealand Geological Survey bulletin 56*: 148 p.