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Late Cenozoic Geology of the West Coast Shelf between Karamea and the Waiho River, South sland, New Zealand

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Late Cenozoic Geology of the West Coast Shelf between Karamea and the Waiho River, South Island, New Zealand

by

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ABSTRACT

The structure of the west coast shelf is dominated by a major fault lying close to the shoreline - the Cape Foulwind Fault. This fault extends at least from Kahurangi Point to Jackson Head and may well extend north across the western entrance to Cook Strait and southward to Milford Sound, where it probably merges with the Alpine Fault.

The Cape Foulwind Fault is closely associated with an en echelon series of open folds collectively called the Karamea Bight Anticline. The folds lie immediately east of the fault, which is very steep, but may have reverse slip and an easterly dip. The amount of strike slip, if any, is not known.

Late Pleistocene and Holocene sediments of the Hawera Series rest unconformably on folded and faulted Tertiary and early Pleistocene rocks. The Hawera sediments are generally not faulted or folded, but conceal many fault scarps and erosional features cutting the older rocks below. The Hawera sequence includes many local unconformities, filled gullies, and channels, as well as buried glacial deposits south of Hokitika.

Apart from Hokitika and Cook submarine canyons, the present shelf is everywhere now undergoing sedimentation.

INTRODUCTION

This report describes the stratigraphy, structure, and late Cenozoic history of the continental shelf between Karamea and the mouth of the Waiho River off the west coast of South Island, New Zealand. The sedimentary and structural patterns of the Karamea Bight area north of Cape Foulwind (van der Linden and Norris 1974) are well-known; the inner part of the shelf was cut in Tertiary and lower Quaternary folded strata during mid-Pleistocene low sea levels and subsequently covered by late Pleistocene and Holocene marine sediments. A similar stratigraphic sequence can be recognised in the shelf south of Cape Foulwind. Furthermore, the seismic characteristics of some of the Tertiary units such as the limestones are so distinctive and prominent that they can be recognised in the profiles with some confidence. However, such distinctive stratigraphic horizons are not present in all profiles, and dating beds in such cases remains somewhat speculative owing to incomplete

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stratigraphic and paleontologic data.

The upper Quaternary sediments typically increase in thickness seaward, forming a delta-like plain floored by formations lenticular in cross-section with maximum thicknesses varying from about 40 m to more than 300 m. The smallest maxima occur near Cape Foulwind and the greatest off the glaciated coast in the southern part of the area.

Although very little published information exists on the geology of the west coast shelf south of Cape Foulwind, considerable data have been collected by the New Zealand Oceanographic Institute and by the following companies, Esso Exploration and Production (N.Z.) Ltd, the Marine Mining Corporation, the New Zealand Petroleum Co. Ltd, Shell-BP-Todd Oil Services Ltd, and Magellan Petroleum (N.Z.) Ltd. As most of the proprietary part of this information has recently become available to the general public, it seems useful to publish a summary interpretation of the data collected in order to assist others interested in the geology of the area. The area covered in this study is shown in Fig. 1. The information used comes from a variety of sources, outlined below.

The Marine Mining Corporation obtained a mineral exploration concession on parts of the shelf west and south of South Island in the late 1960s. Their investigation sought to assess the potential of any submerged placer deposits for gold and other heavy minerals. Marine Mining Corporation contracted with Alpine Geophysical Associates to conduct a continuous sparker profile and sampling programme in the concession areas. This report is concerned, in part, with that portion of their concession area lying off the west coast of South Island.

Esso in 1968–69 conducted a seismic profiling using an Aquapulse energy system, to evaluate the petroleum and natural gas potential of the west coast area [Esso Exploration and Production (N.Z.) Ltd, 1968 : Geophysical report P.P.L. 712 (South Greymouth). Unpublished Petroleum Report P.R. 400, N.Z. Geological Survey Library, and 1969 : Final report of marine seismic surveys P.P.L. 711 (Offshore Karamea). Unpublished Petroleum Report P.R. 701, N.Z. Geological Survey Library]. Magellan Petroleum [Magellan Petroleum (N.Z.) Ltd, 1971 : Marine seismic survey, Westland area, review incorporating N.Z. Petroleum Co. data of a 1971 survey, unpublished Petroleum Report P.R. 575, N.Z. Geological Survey Library] obtained about 400 km of reconnaissance sparker profiles in 1969, and in 1970 an additional 160 km of air-gun profiles, in areas they considered to be of greatest interest.

Shell-BP-Todd [Shell-BP-Todd Oil Services Ltd, 1967 : Marine seismic reconnaissance survey – Greymouth offshore, N.Z. (written by M.H. Fland, *in* unpublished Petroleum Report P.R. 548, N.Z. Geological Survey Library] in 1966 investigated an area of about 3900 km² off Greymouth using standard explosive reflection profiling. In addition, N.Z. Oceanographic Institute cruises have produced sub-bottom profiles of parts of the area.

LIMITATIONS OF THE DATA

The interpretations in this paper are tentative because there is only one independent check in the form of a drill hole [Haematite Petroleum (N.Z.) Ltd, 1970 : Haku-1 drill hole, unpublished Petroleum Report P.R. 553, N.Z. Geological Survey Library]. There is no piston coring against which the interpretations may be evaluated. Apart from some shell and wood samples turned over to the N.Z. Geological Survey for carbon-14 dating (S. Nathan, personal communication 1976), the drill samples and descriptions obtained by Alpine Geophysical Associates appear to be lost or destroyed. Furthermore, the seismic profiles are often imperfect, with gaps in critical places, and although they are closely spaced, particularly those made by Alpine Geophysical Associates, minor folds, faults, and channels are difficult to trace from one profile to the next. Moreover, a structural feature shown on a single profile gives no evidence of trend, and its strike can be inferred only by reference to known local or regional trends. For the most part, the structural grain in the west coast area parallels the trend of the coast, and this pattern is assumed to be dominant offshore as well as on shore.

The N.Z. Oceanographic Institute records include only line drawings of the Alpine profiles; none of the original seismic profiles was available. These line drawings and oil company isopach maps of strong reflective horizons and basement contour maps were used in this report. While it may be presumed that both were prepared with skill and care, they involve elements of interpretation which may either emphasise or omit details present in the original records. Time did not permit a re-interpretation of the oil company profiles, and the original Alpine profiles appear to have been destroyed. Unfortunately, the depth of penetration in many of the more recent N.Z. Oceanographic Institute profiles is not great enough to provide an independent check of the Alpine or oil company data. However, the boomer profiles made by the N.Z. Oceanographic Institute and discussed by van der Linden and Norris (1974) tie in reasonably well with the structural features mapped by Alpine and Esso in the area north of Cape Foulwind.

The locations of the seismic profiles on which this report is based are shown in Fig. 2 (in pocket at back).

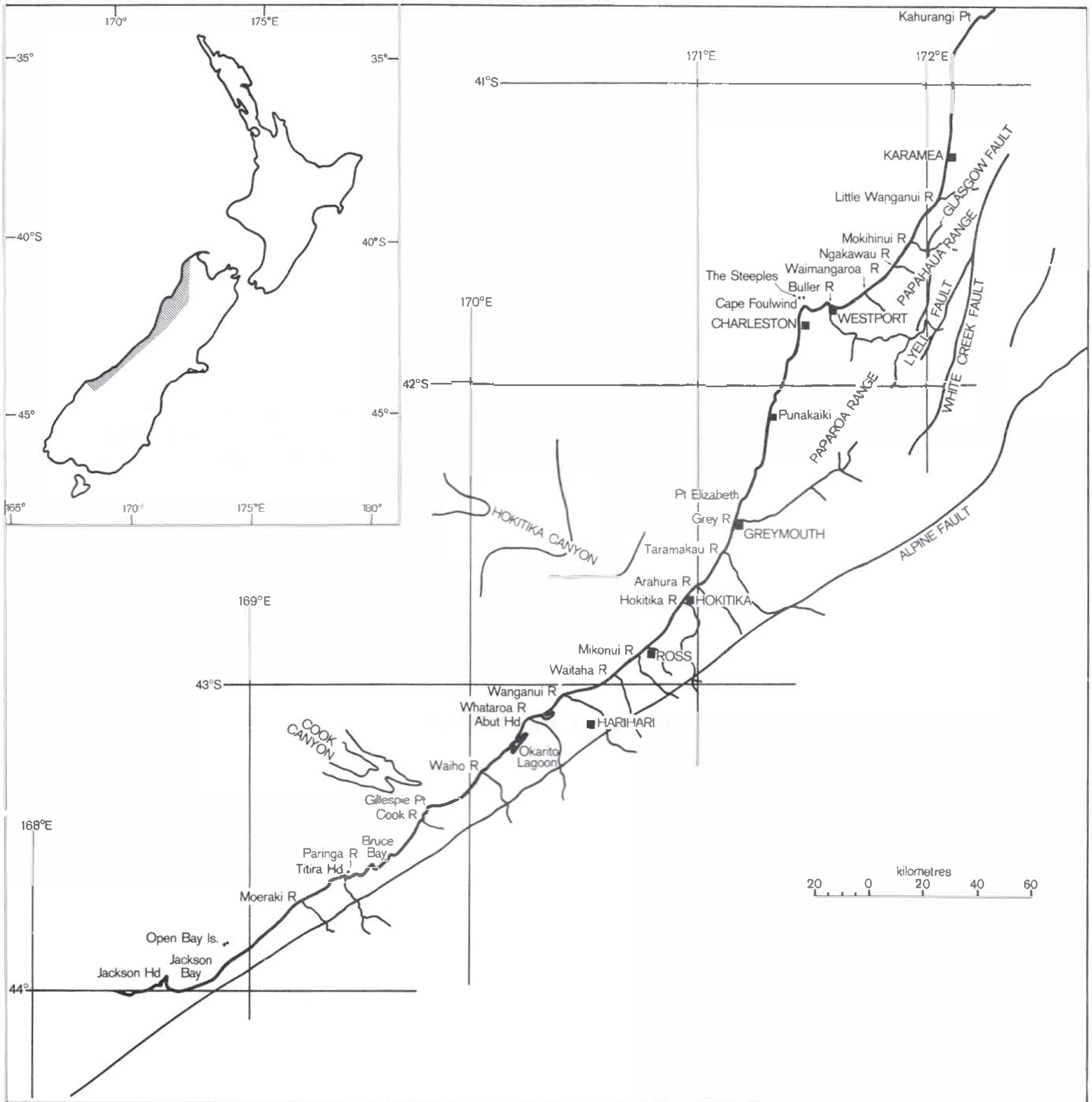

FIG. 1. Map of the area covered by this report, showing the place names used in the text. Locality map inset.

Apart from those used as a basis for the work of van der Linden and Norris (1974), the N.Z. Oceanographic Institute profiles were all obtained with a 3.5 kHz profiler, and the Alpine profiles with a dual-channel sparker using a 50 J and 200 J power supply.

Much of the information included in this report is derived from the closely spaced Alpine sparker lines, though the deeper stratigraphic and structural information was provided by oil exploration company isopach and structure contour maps.

NAVIGATIONAL CONTROL AND LAYOUT OF THE PROFILES

Control for the N.Z. Oceanographic Institute lines was provided by a Doppler navigation system utilising satellite data and an IBM Model 6000 computer which provided positions accurate to the nearest 50 m. The Alpine profiles were controlled by a precision ranging system with automatic track plotter. Land-based radar transponder beacons were installed at a number of trig stations established by the New Zealand Department of Lands and Survey. Esso positions were located by means of Shoran using two land-based stations. New Zealand Petroleum Co. Ltd also used Shoran equipment. Shell-BP-Todd used a Decca Hi-Fix unit with automatic track plotter, and Magellan used an ITT Sat-Nav system. Shore-based systems provide the best accuracy, allegedly to the nearest 5 or 10 m.

The majority of the Alpine sparker profiles were oriented normal to the shoreline, extending seaward about 8 km from a starting position in water about 10–15 m deep and ending at depths of 100–125 m. None of them extended to depths greater than 170 m, and consequently none reached the shelf break which generally occurs at about 225 m depth. Most of them, although approximately normal to the shore, were laid out in such a way as to cross near their mid-points, and additional lines were run parallel to shore and in other orientations when local conditions made it appropriate. The N.Z. Oceanographic Institute profiles, having been made incidental to other studies, are less systematic, and include six lines across the shelf into deeper water beyond the shelf break as well as connecting lines parallel to shore between the inshore ends of several of the shelf crossings. The Esso lines include a series of parallel traverses about 10 km apart and extending normal to the shore for 30–80 km, with additional lines at right angles to these, more or less parallel to the coast. The Esso profiles cover the shelf from north of Karamea to Greymouth, and from Abut Head south to the mouth of the Moeraki River. New Zealand Petroleum surveyed much of the coastal plain and the shelf out to the 3-mile limit between Punakaiki and Jackson Bay. Shell-BP-Todd investigated the area from Point Elizabeth to Abut Head, and Magellan Petroleum duplicated much of the area south of Greymouth. The survey lines are shown in Fig. 2.

PHYSIOGRAPHY OF THE SEA FLOOR

Most of the shelf in the area covered in this report is smooth and relatively featureless, covered nearly everywhere by a blanket of late Quaternary sediment. The only notable exceptions are the channels belonging to the submarine Hokitika and Cook Canyon systems, and a small area north-west of Cape Foulwind where an irregular exposure of probable crystalline basement rock occurs (Fig. 3). There are few obvious scarps, either erosional or tectonic. No submerged shorelines interrupt the sea floor, and there is no distinctive surficial evidence of glacial features such as moraines even on that part of the shelf south of Greymouth that was certainly glaciated. There are no prominent deltas related to existing rivers, though the younger sediments are broadly deltaic in form.

Apart from the canyons, the only notable topographic feature on the shelf between Karamea and Jackson Bay is a prominent seaward bulge in the shelf offshore from Ross and just south of the inshore end of Hokitika Canyon. This bulge is most clearly defined by the 50 m contour which lies 7 or 8 km from shore both north and south of the feature and 24 km offshore at the tip of the bulge. Contours as deep as 750 m show a seaward deflection in this area (Fig. 4).

The shelf bulge probably formed a low-lying blunt headland during the lowest glacial sea levels. Though the cutting of Hokitika Canyon has doubtless exaggerated the abruptness of the feature, it must in large part antedate the canyon cutting. The canyon truncates sedimentary beds underlying the bulge including all but the most recent deposits.

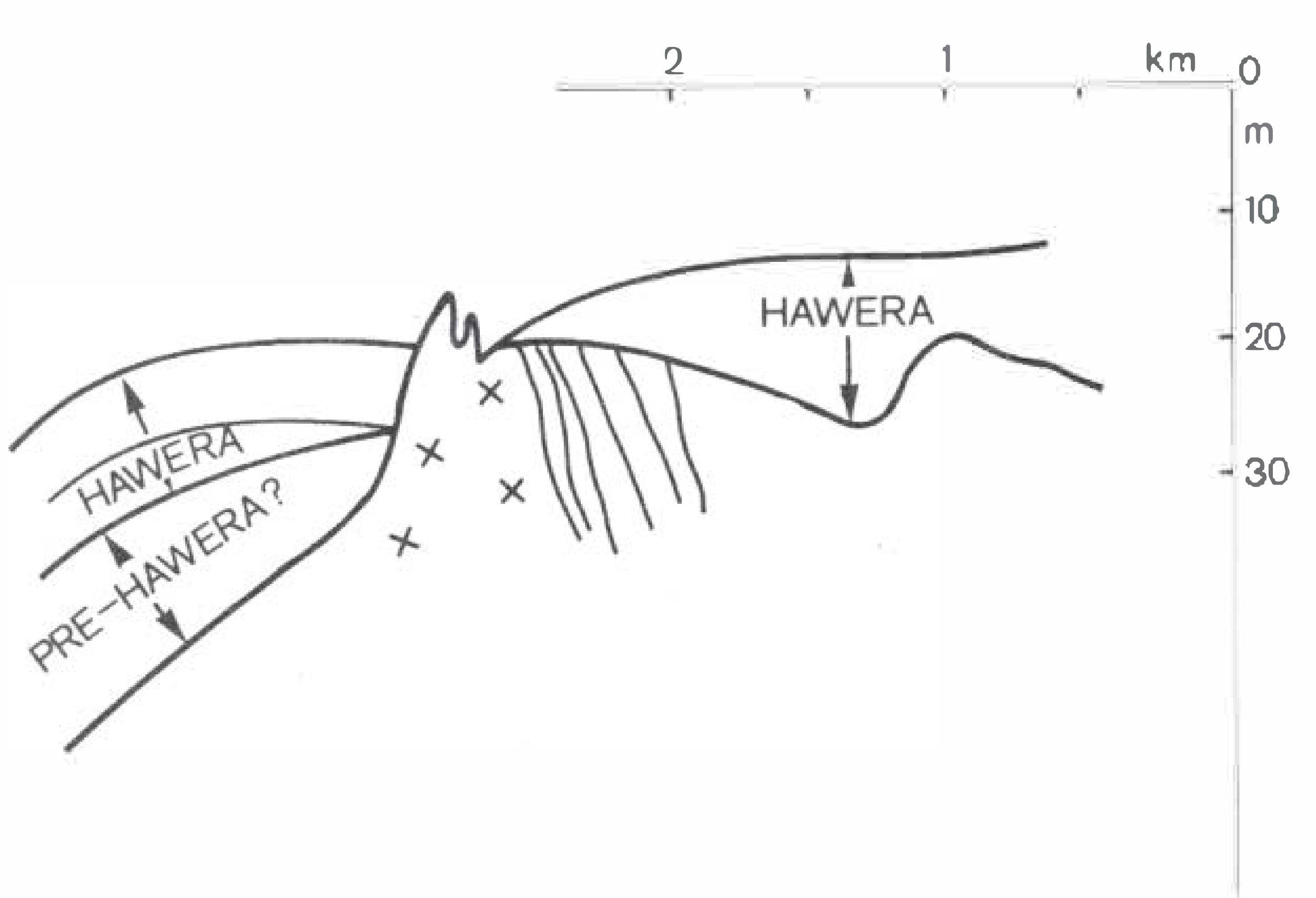

FIG. 3. Basement exposed on the sea floor about 2.5 km north-west of the Three Steeples, Westport area (Alpine Geophysical profile).

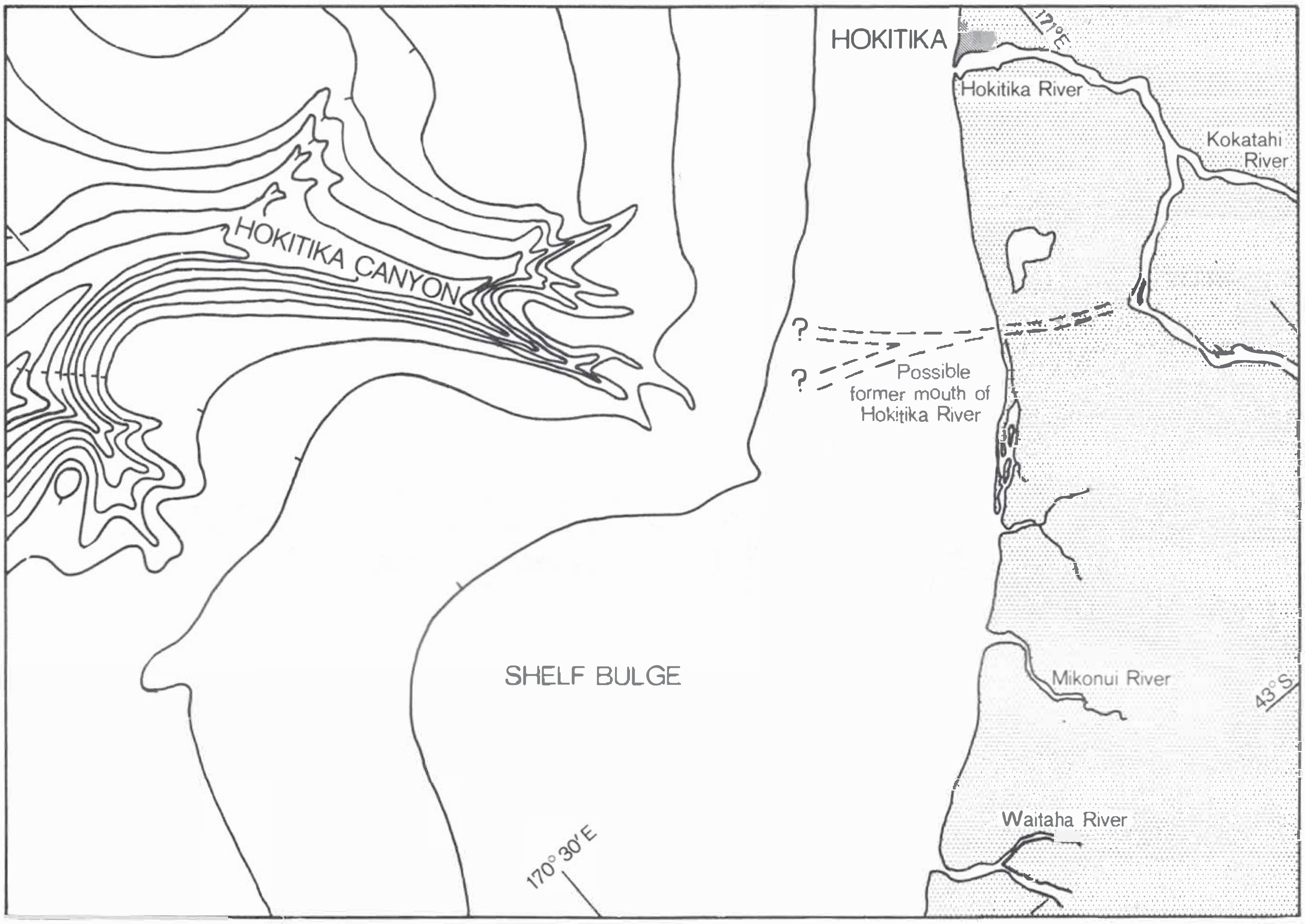

FIG. 4. Bathymetry of the seaward bulge in the shelf south of Hokitika Canyon.

SUBMARINE CANYONS AND GULLIES

Existing canyons are confined to the area off Hokitika where an extensive system of canyons and branching channels occurs. Some branches are recognisable as close as 8 km from shore intersecting the 50 m contour, although additional finer details remain to be mapped. The general form of Hokitika Canyon is well known, however (Eade 1972; Norris, in press). Some of its channels are deeply cut into the lower Quaternary and Tertiary bedrock, but others appear wholly confined to the less consolidated upper Quaternary (Hawera) deposits (Fig. 5).

Hokitika Canyon, particularly its outer end, is not yet fully surveyed, but it is known to extend seaward at least 80 km from shore. Its head lies about 8 km off the mouth of the Totara River which enters the sea about 22 km south of the borough of Hokitika. The canyon begins at a depth between 25 and 50 m, and remains clearly evident to the limits of the existing surveys at about 1250 m depth, near the base of the continental slope. Future work may prove it to be considerably longer than this and to extend to greater depths. At least four or five tributary valleys are evident as well as several minor branching channels near the canyon head.

From mid-shelf, which is at a depth of about 150 m, Hokitika Canyon floor lies a further 150 m down. Near the shelf break, at about 225 m, the canyon floor is about 250 m deeper than its rim, a depth which persists into deeper water.

The location of Hokitika Canyon is not obviously related to any large land stream. It is possible that the large Hokitika River once entered the sea near the present mouth of the Totara River, perhaps joining the Mikonui and Waitaha Rivers to form a deltaic feature which later became the shelf bulge referred to earlier (Fig. 4). If this is the case, it must have occurred before deposition of the Loopline Formation (Suggate 1965), which consists of glacial deposits formed during the Otiran glaciation. These now block any such hypothetical river route and have a relief of as much as 75 m (Warren 1967).

Though present understanding of submarine canyon origin suggests that it is unlikely that Hokitika Canyon

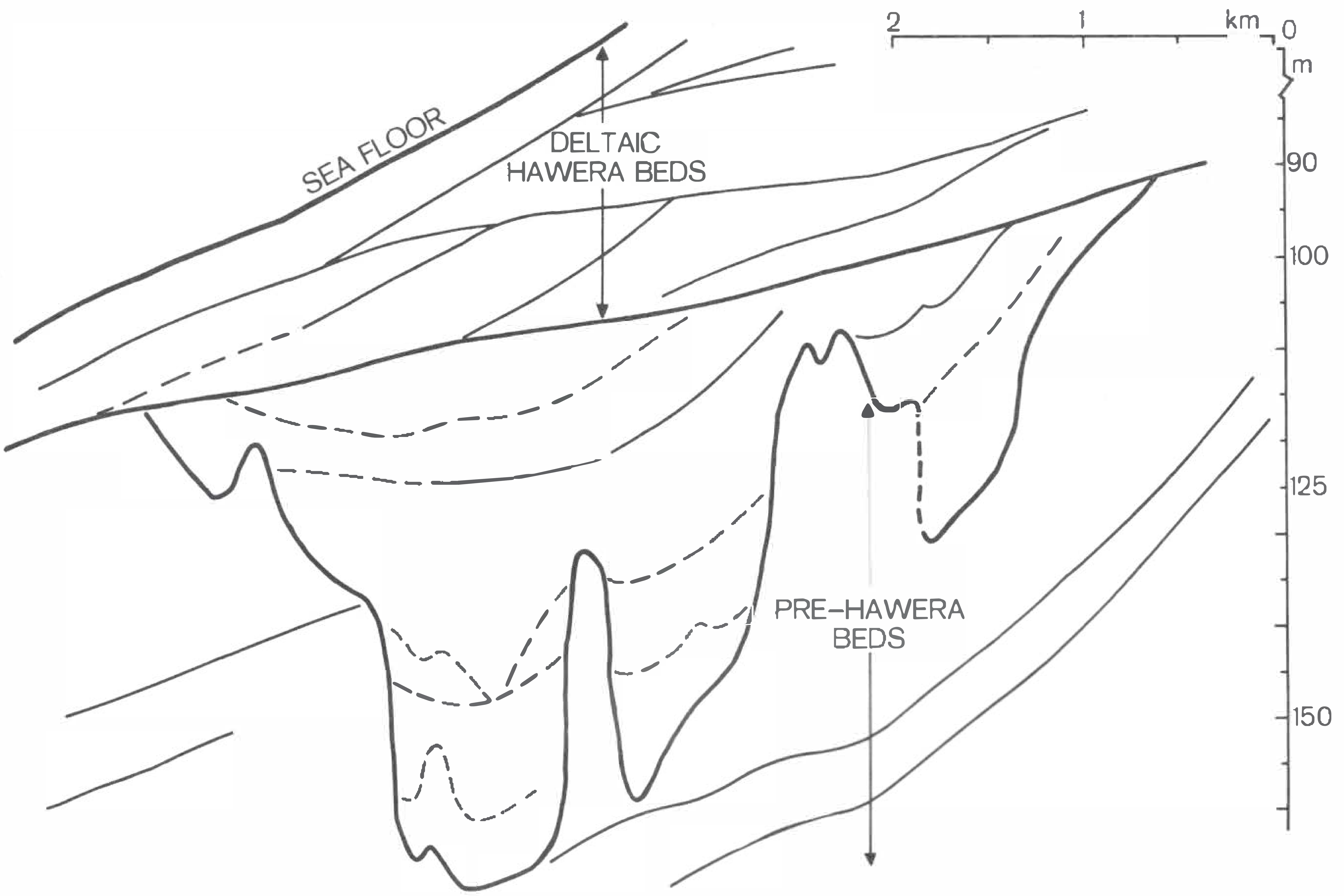

FIG. 5. Buried channels cut in pre-Hawera sediments, off mouth of the Arahura River near Hokitika (Alpine Geophysical profile).

was cut by land streams, it is possible that turbidity currents, associated with sediment load contributed by streams, played a role in its formation. Crowell (1952) has shown that some submarine canyons head at points on the coast where littoral curents and their sediment loads are deflected seaward by projecting headlands or shallow submarine ridges.

At present, between Hokitika and Okarito Lagoon, most bay mouth bars which partly enclose the coastal lagoons open to the sea at their southern extremities. This suggests that the littoral currents which deposited the bay mouth bars generally moved southward along the coast. If these conditions existed in the past when sea levels were lower, any south-drifting current would have encountered the blunt headland south of Hokitika and been deflected into what is now the head of Hokitika Canyon.

If the canyon owes its position to the former headland it is puzzling why it remains open today, because no topographic barrier now exists to deflect littoral currents into it, nor is any river now actively forming a deltaic structure near its head. Furthermore, most littoral currents today move northward along the coast (S. Nathan, personal communication, 1976). Nevertheless, the submerged former headland may still affect some longer swells, and therefore currents, in such a way as to deflect some littoral flow into the canyon. Bathymetry, however, offers little indication of such currents, as only vague channels leading into the canyon occur between 25 and 50 m, and there are no channels at less than 25 m. Furthermore, active canyons in other parts of the world rather commonly head within a few hundred metres of the shore. The mere fact that the canyons are open across a shelf almost everywhere receiving young sediments suggests that the canyon system is subjected to the cleansing action of currents, if not to the erosive power of turbidity flows.

Cook Canyon (Eade 1972; van der Linden and Hayes 1972), although not yet surveyed in detail and south of the area covered by the detailed Alpine surveys, heads about 3 km off the mouth of the Cook River. It turns south-westerly about 40 km from shore and thence follows a south-westerly course, roughly parallel to the coast, but diverging to the west. It can be traced as a recognisable feature to a depth of 4250 m at a position about 150 km west of Cascade Point. The total known length of this canyon is about 250–300 km (van der Linden and Hayes 1972).

FOSSIL AND BURIED FEATURES

Buried topography present in the shelf sediments is of erosional, tectonic, or depositional origin. The erosional features are mainly either submarine canyons and gullies or old shoreline angles and their associated sea cliffs. The old shoreline angles are often difficult to distinguish from fault-produced features. Depositional features include old beaches or bay mouth bars, but the most common are the buried moraine deposits off the glaciated area.

BURIED SHORELINES

In the unpublished analysis of the Alpine sparker profiles, probable submerged and buried shoreline angles are reported at 18–24, 41, 50–61, 67–72, 75 and 107–116 m below sea level. My independent examination of the profiles confirms that the most submerged shorelines cluster at about 41, 50–58, 70–80 and 100–110 m, the 70–80 m shoreline often overlapping with the 67–72 m shoreline. These levels have been measured as close as possible to the base of the shoreline angle where that can be recognised with confidence, but in many cases the change in slope is so gradual that the choice of a particular depth is quite subjective.

As is usually the case on land, these old shorelines cannot be traced for long distances, though they are often persistent enough to be easily recognised, especially the younger ones. For example, on the inner shelf north of Cape Foulwind, for about 25 km there is a well defined buried scarp, probably partly wave-cut, varying in height from 20 to 50 m (Figs 6, 7a). The base of this scarp now lies about 150 m below sea level, which indicates some down-warping if the maximum lowering of sea level during the last glacial age was only about 125 m, as postulated by Curray (1965). Incidentally, the famous non-marine alluvial gold deposits mined at Jones Flat near Ross in south Westland, were worked to about 100 m below sea level (Morgan 1908) which certainly corroborates appreciable sea level lowering in the west coast area.

In addition, many fossil shorelines are indicated by what appear to be buried beaches, usually manifested on the profiles as reflectors defining bodies with lenticular cross-section (Fig. 7b) interrupting the usual depositional pattern, rather than as a well defined shoreline angle with a sea cliff.

Cullen (1967) reviews evidence for changing sea levels in New Zealand during the past 11 000 years and provides a graph of the changes which are thought to have occurred. Curray (1966) has proposed more general curves for the past 20 000 years. Application of these curves to those submerged shorelines off the west coast presumed to be younger than 20 000 years, and corrected for an assumed 25 m of downwarping spread evenly over the past 20 000 years, gives the provisional results shown in Table 1.

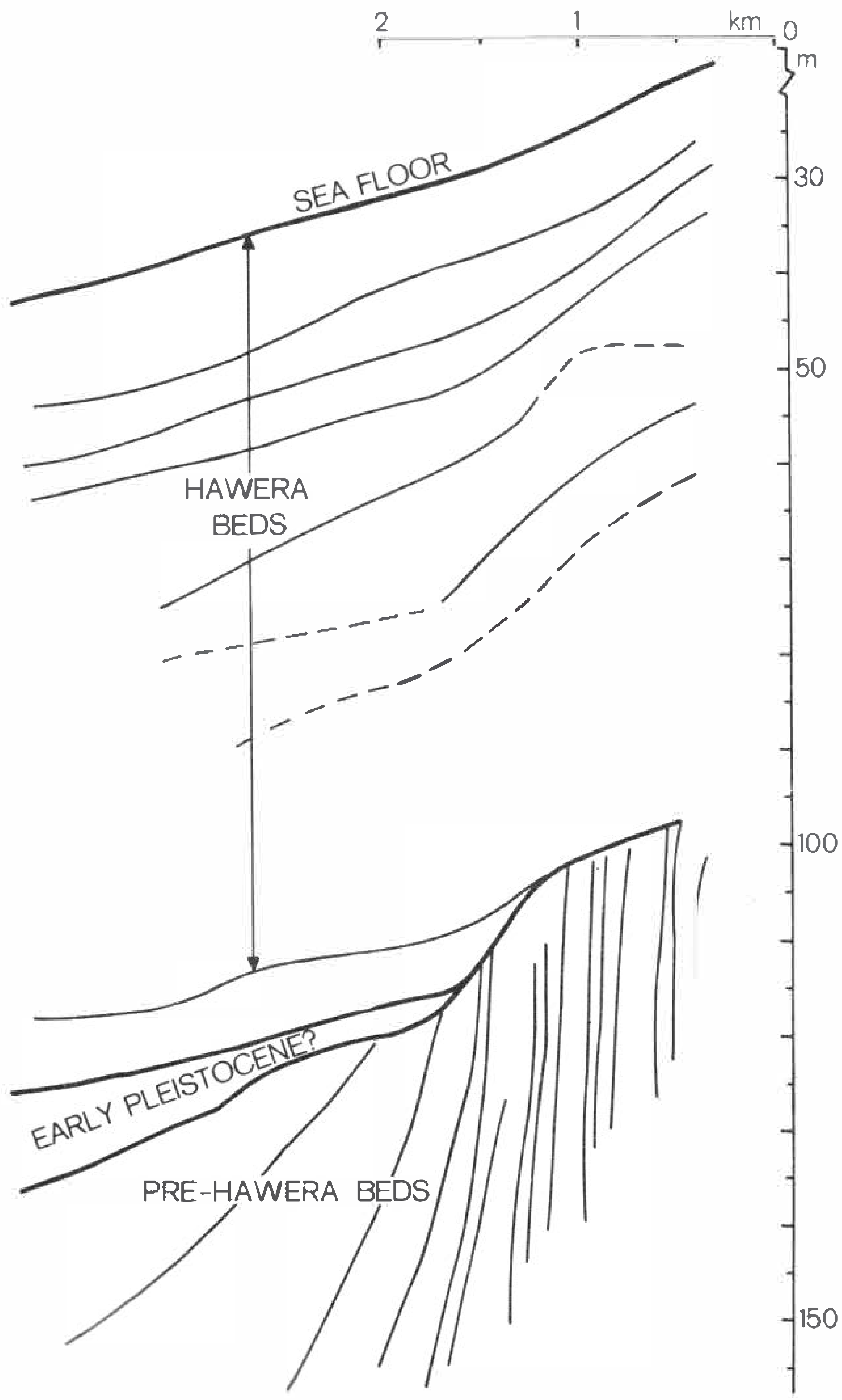

FIG. 6. Buried wave-cut scarp or shoreline angle off mouth of Fox River near Charleston (Alpine Geophysical profile). This feature may also coincide with the Cape Foulwind Fault Zone.

TABLE 1. Age of west coast submerged shorelines.

Depths below present sea level, m	Years before present
18–23	7 500–8 000
41	8 500
50–58	9 800–10 200
67–80	10 400–11 000
100–110	14 000–16 000

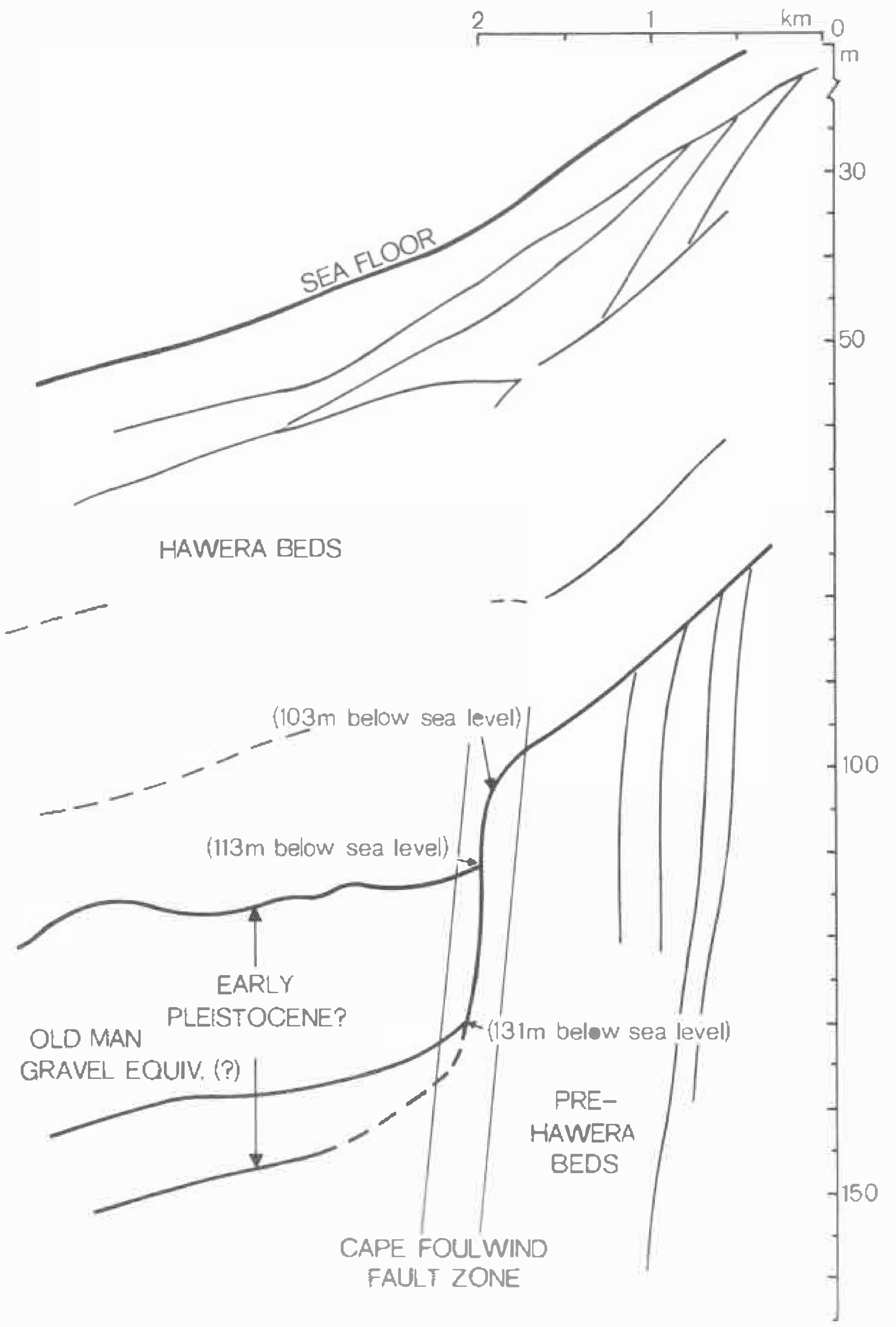

FIG. 7a. Buried shoreline angle (?) and Cape Foulwind Fault scarp off 9-Mile Beach near Cape Foulwind (Alpine Geophysical profile).

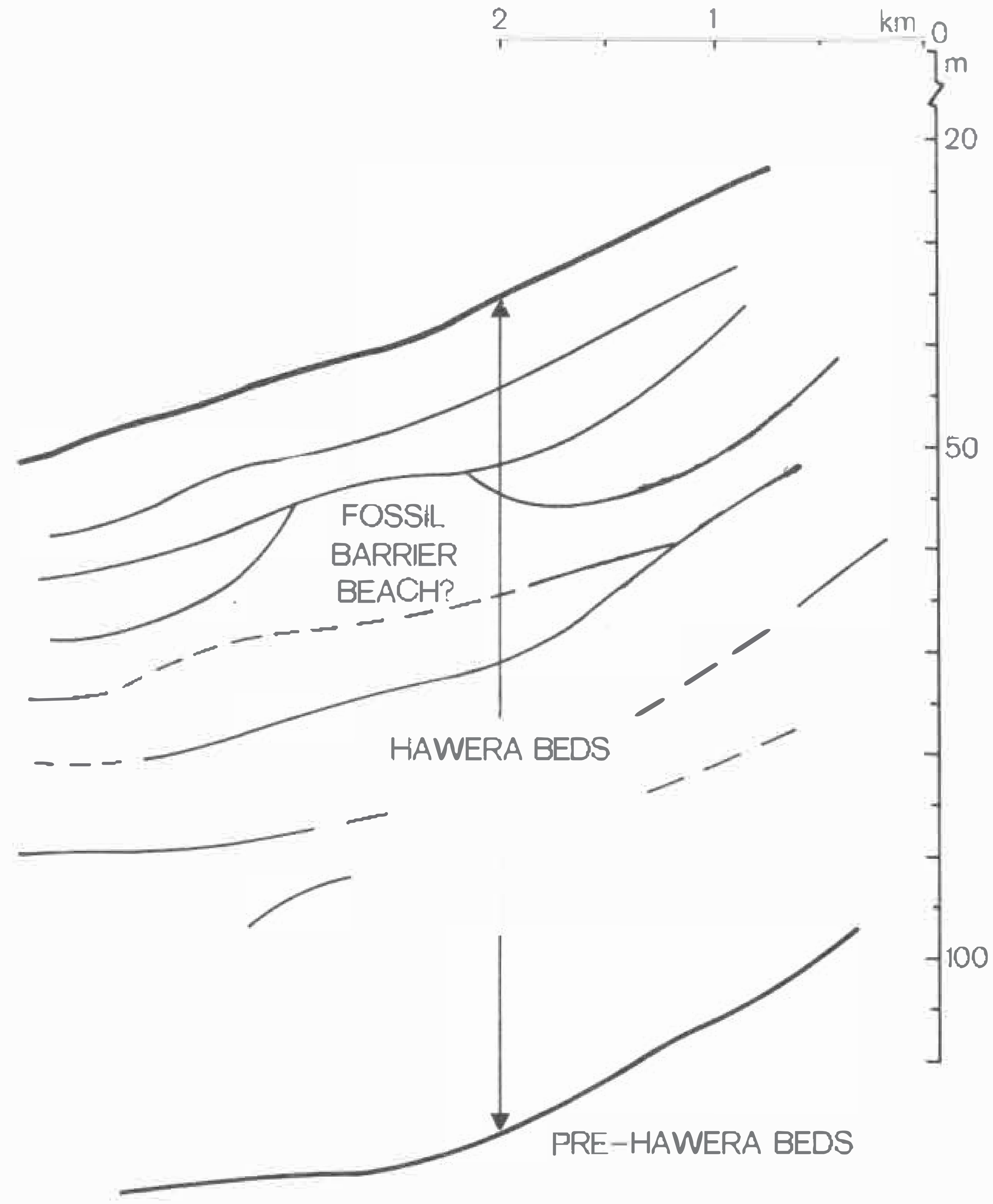

FIG. 7b. Fossil barrier beach (?) in Hawera sediments off Charleston (Alpine Geophysical profile).

Until the supposed submerged and buried beaches are dated by carbon-14 or by other means, these ages should be considered provisional, and use of them to determine rates of sedimentation and canyon erosion would be speculative. It is also worth noting that elevated terraces on land indicate late Quaternary uplift. This would seem to require some sort of a flexure near the coast seaward of which downwarping was the most recent event. Lewis (1974) discusses the origin of such a flexure and describes New Zealand examples.

In the area off Westport, a prominent feature which occurs in several profiles is believed to be a buried fault scarp, though it may have doubled as a buried shoreline. This feature is as high as 50 m in some places. Its upper edge lies at a depth of 95–125 m, and its base is as much as 146 m below present sea level. The fact that it shows clearly on a number of profiles separating rocks of sharply differing dip (Fig. 8a, b) indicates that it is primarily a fault-produced scarp, and perhaps secondarily a submerged shoreline cliff.

For these to be submerged shorelines no unusual or excessive tectonic activity would have been required. Apart from the one example at 146 m below sea level, all are readily encompassed by the widely accepted Pleistocene sea level curves, which indicate a maximum lowering of about 125 m during the past 19 000–20 000 years. The one exception may be the result of renewed or localised activity along the fault.

BURIED CHANNELS AND CANYONS

Filled and buried gullies and canyons, some more than 100 m from rim to trough, occur at many places on the west coast shelf. Some are deeply cut into Tertiary and lower Quaternary strata and others appear to be confined to the generally unconsolidated upper Quaternary deposits (Fig. 5). It is evident that apart from the development of the Hokitika and Cook Canyon systems, the erosional regimen which produced these canyons and gullies has been replaced by a depositional regimen which is now smoothing the seafloor and obliterating former irregularities. Although existing gullies and canyons of the Hokitika and Cook systems show that deposition has not yet obscured the results of local erosion, it does not necessarily follow that active erosion continues in the

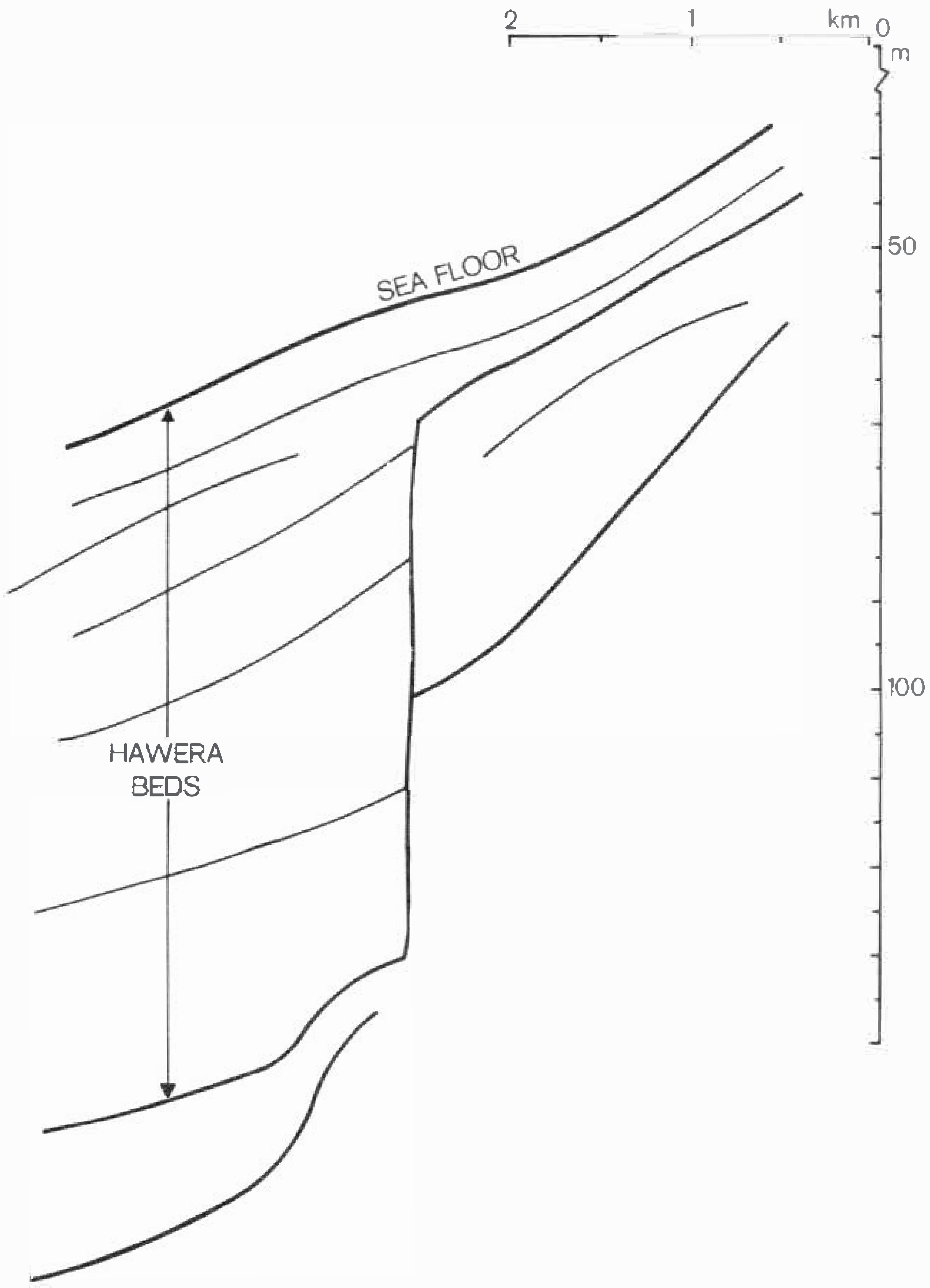

FIG. 8a. Buried trace of Cape Foulwind Fault west of the Three Steeples, Cape Foulwind area (Alpine Geophysical profile).

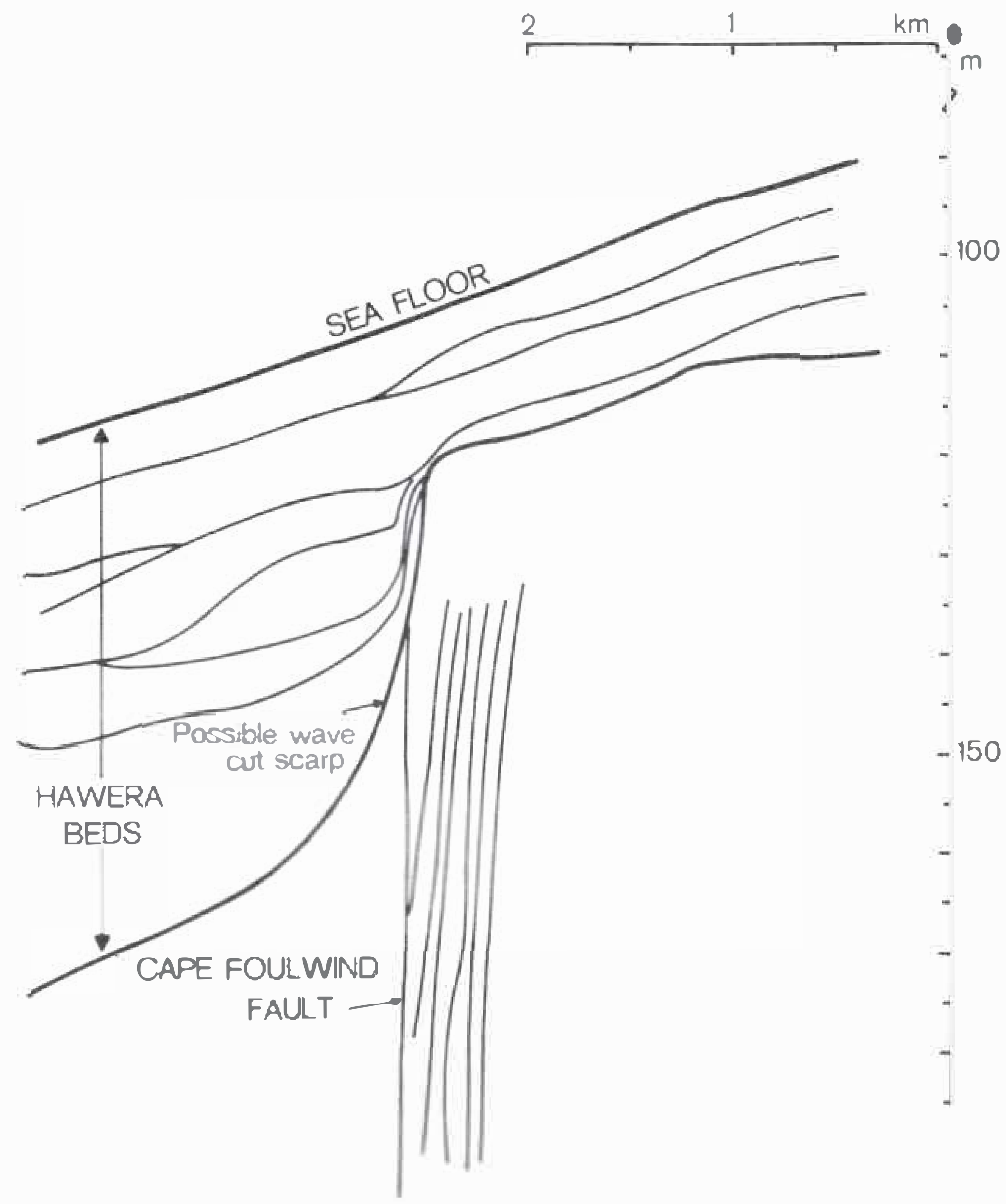

FIG. 8b. Buried trace of Cape Foulwind Fault and possible wave-cut scarp, about 19 km north-west of Westport (Alpine Geophysical profile).

canyons. A close and possibly repeated examination of the channels is required to determine what is now happening in them. Because the N.Z. Oceanographic Institute and Alpine profiles crossing the canyons reveal little or no sediment fill on the canyon floors, it is likely that erosion, or at least flushing of the canyons, continues.

Buried channels or canyons occur at many places off the west coast, but most abundantly in the deposits off the mouths of the Taramakau and Arahura Rivers between Greymouth and Hokitika. It is puzzling that prominent buried channels are so large and numerous off these rivers and relatively scarce off larger rivers such as the Hokitika, Grey, and Buller (Table 2).

Streams with large discharge would be expected to have a correspondingly greater ability to produce turbidity flows capable of cutting and maintaining gullies and channels, but the situation is obviously not this simple.

The buried channels in question are frequently cut into the upper Quaternary deposits to a depth of 30 m, and some are as much as 100 m deep. Some appear to extend through the upper Quaternary Hawera Series deposits into folded, presumably lower Quaternary and Tertiary deposits below. A few of the larger buried channels can be traced for as much as 5 km, being crossed by several of the sparker profiles. Few of these larger buried channels show any clear relationship to present river mouths.

TABLE 2. Estimated average discharges of west coast rivers.*

River	Average discharge, l/s
Buller	515 450
Grey	294 300
Hokitika	233 700
Whataroa	180 380
Wanganui	113 696
Mokihinui	105 125
Taramakau	104 685
Waitaha	97 730
Arahura	42 230

Furnished by H.E. Clarke, Westland Catchment Board 1976.

Though there remain many questions about the origin and distribution of these buried channels, it seems probable that, during the time sea level was rising after the last retreat of the glaciers, streams delivered markedly increased sediment loads to the coast. This in turn generated the conditions necessary for turbidity flows more frequently than has been the case since the sea reached its present level 6000–8000 years ago. Certainly, it is likely that the rapid retreat of the ice must have exposed large tracts of bare gravel and other sediment to streams swollen by melting ice. Perhaps these areas remained bare for a time because they were exposed more rapidly than advancing vegetation could anchor and cover them.

Irrespective of what might have caused the change from seafloor erosion to deposition, it is virtually certain that this change accompanied the retreat of the ice. Any remaining evidence of glacial deposition or erosion on the shelf is, like the gullies and most of the canyons, buried beneath a blanket of post-glacial sediment.

BURIED GLACIAL FEATURES

South of Hokitika, distinctive reflectors which have been interpreted as moraines are recorded in some of the Alpine sparker profiles. Glacial deposits are well developed on shore in this area, and Warren (1967) observes that, during the last glacial stage, ice twice advanced to and beyond the present coastline south of the Mikonui River. While most profiles show only a single morainal horizon (Fig. 9a, b), some show several, all presumably Otiran. The possibility of older glacial deposits existing on the shelf cannot be ruled out, but it is thought unlikely because on land they survive only in higher, protected places. Any left on the seafloor would have been subjected to intense erosion during the subsequent changes of sea level and glacial advances of Otiran age, unless they happened to be protected by downwarping of the outer shelf. Any evidence of earlier Quaternary glaciations would only be preserved in beds equivalent to the Old Man Group on shore and lying below the pre-Hawera unconformity (Warren 1967). No such evidence is provided by the profiles available, though there appears to be more than one glacial horizon in the Hawera sediments.

Whether the deposits producing these particular reflectors in the Alpine profiles are truly glacial in origin cannot be finally settled until samples of them are obtained by coring or drilling. They appear to be glacial for two reasons. Firstly, their characteristic reflectors are confined entirely to that portion of the shelf known to have been reached by ice advances, no such reflectors being seen in any of the profiles made north of the Mikonui River (25 km south of Hokitika), although Suggate (1965) suggests that the Waimea glaciers may have terminated on the shelf between the mouth of the Mikonui River and Hokitika. Secondly, the irregular nature of the reflectors suggests an unbedded or irregularly bedded and heterogeneous material with variable reflecting qualities such as might be found in a moraine.

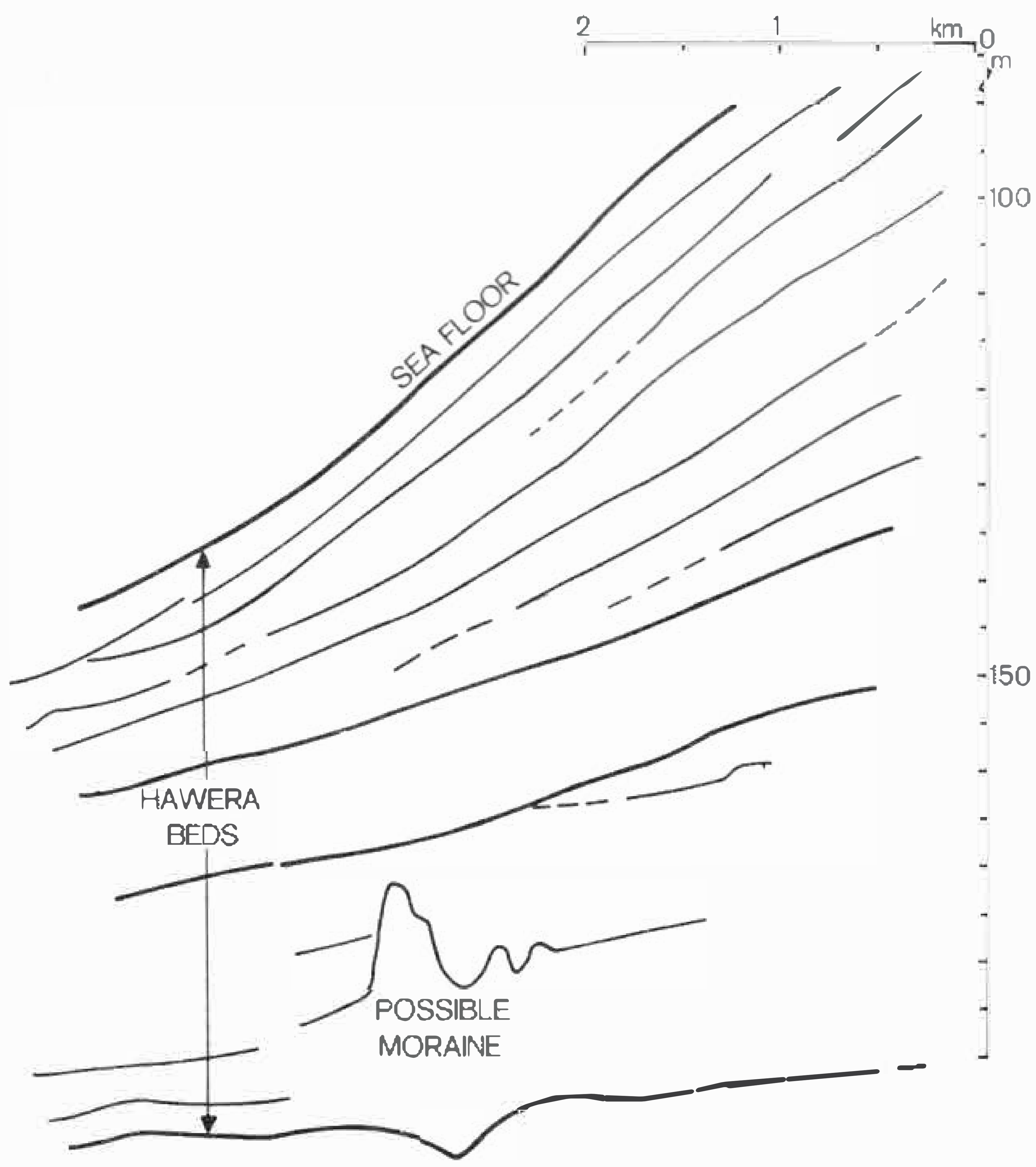

FIG. 9a. Buried glacial moraine about 7.5 km off Okarito Lagoon (Alpine Geophysical profile).

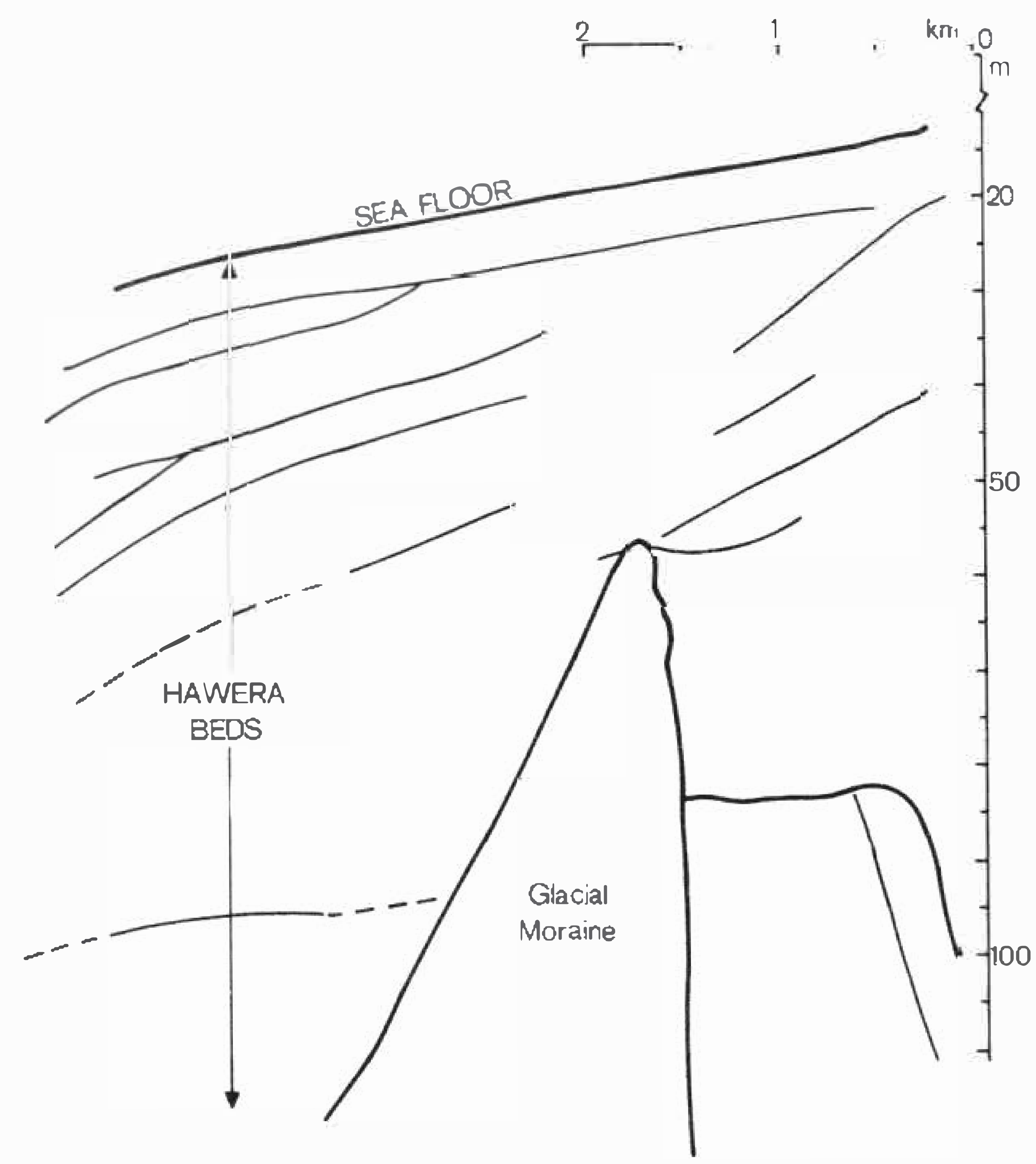

FIG. 9b. Buried glacial moraine about 3 km off mouth of the Whataroa River (Alpine Geophysical profile).

Correlation of the supposed morainal deposits from one profile to another is quite uncertain. It is not uncommon to find evidence of morainal deposits on only three of five adjacent profiles. It is not known whether this is due to changes in sediment composition which render it instrumentally impossible to recognise the deposit as a moraine, or whether these gaps are due to erosional removal of morainal material. Selective erosion of former moraines is plausible, if not probable, in an area drained by so many large rivers.

Despite these imperfections in the record, there seem to be five more or less distinct areas which have concentrations of moraine material. Three of these are elongated parallel to the coast, suggesting that they are terminal moraines. Of the remaining patches, one is evident on only one profile and its shape is therefore indeterminate, and the other is more or less elliptical in plan (Fig. 10a–c).

No bathymetric features on any of the N.Z. Oceanographic Institute, Alpine, or oil company profiles suggest the existence of exposed moraines on the present seafloor. All appear to be buried, though much of the inner shelf from the Mikonui River southward must once have had such features. Some of these moraines must once have been nearly 100 m high, as they commonly reach such heights on land close to the shore. Though they would have been vigorously attacked by waves during the post-glacial rise in sea level, it is difficult to see how such massive features could have been totally obliterated or buried, but the sparker profiles show only the buried moraines.

STRUCTURAL GEOLOGY

The regional structure of the west coast shelf and adjacent coastal plain is dominated by two elongate, parallel blocks (three north of Westport), separated from one another by north to north-east trending tectonic zones of combined folding and faulting (Fig. 11). The faults generally have a reverse throw, an easterly dip, and

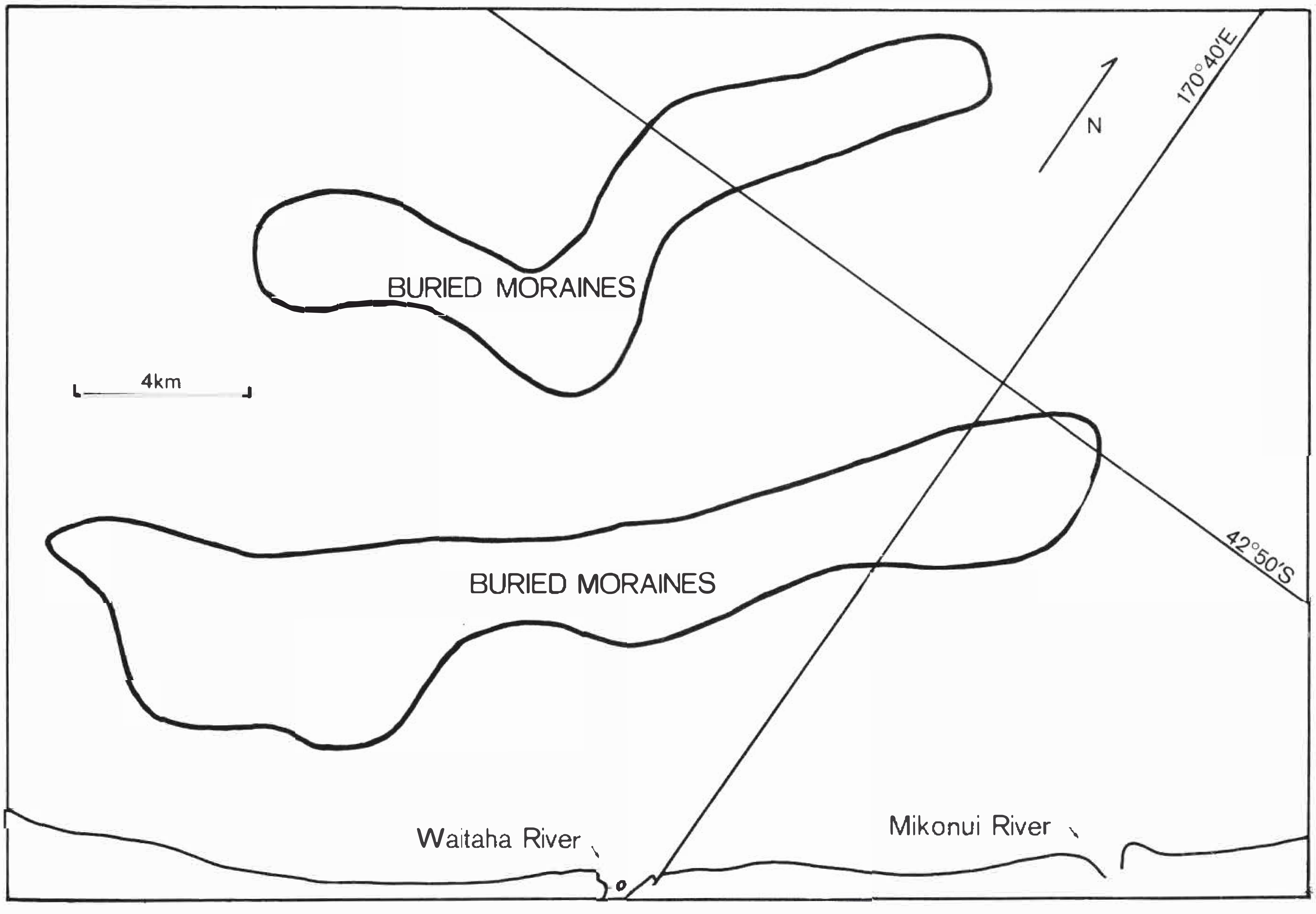

FIG. 10a. Distribution of buried glacial moraines on inner shelf near mouth of the Waitaha River.

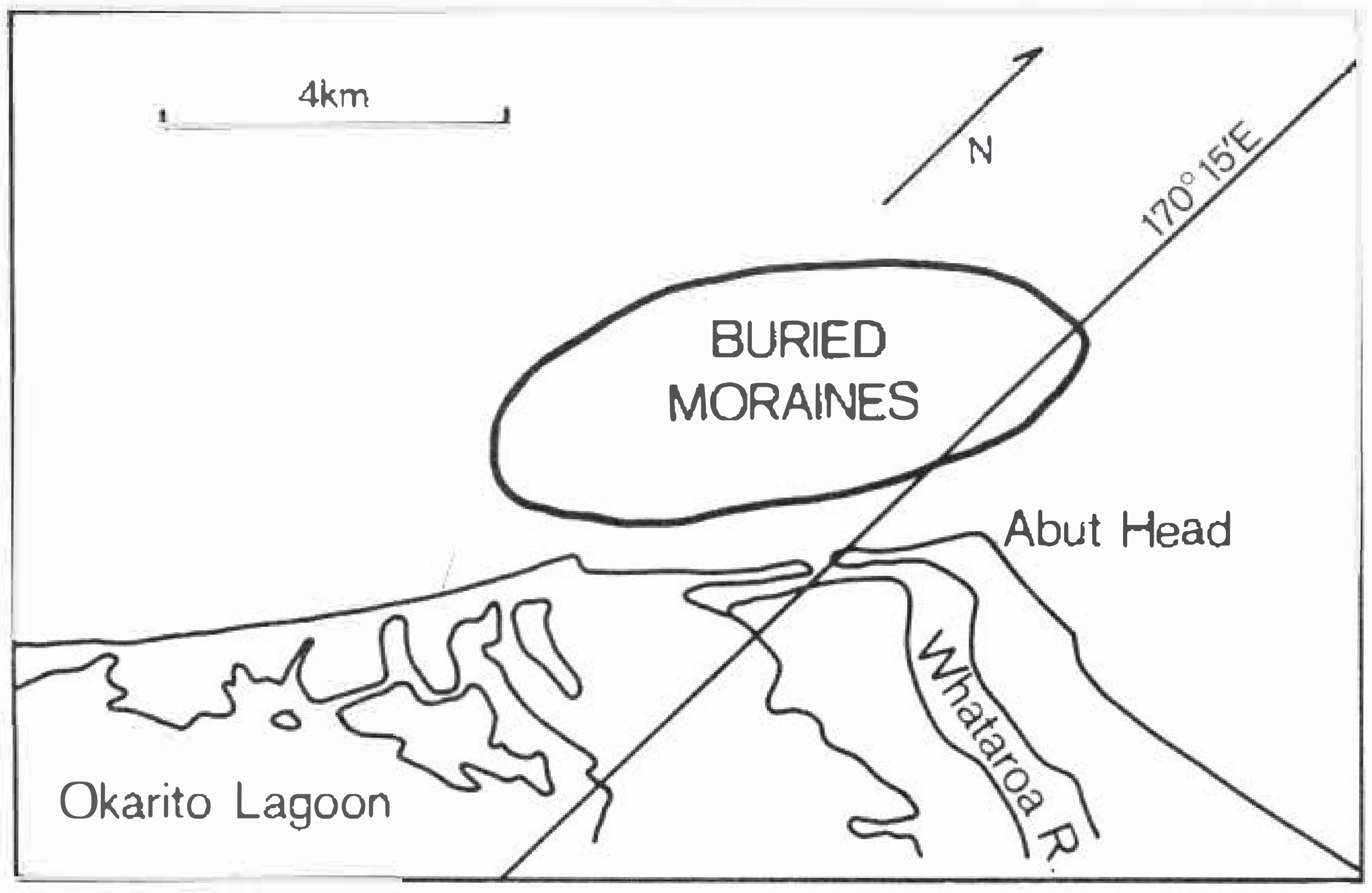

FIG. 10b. Distribution of buried glacial moraines on inner shelf near Abut Head.

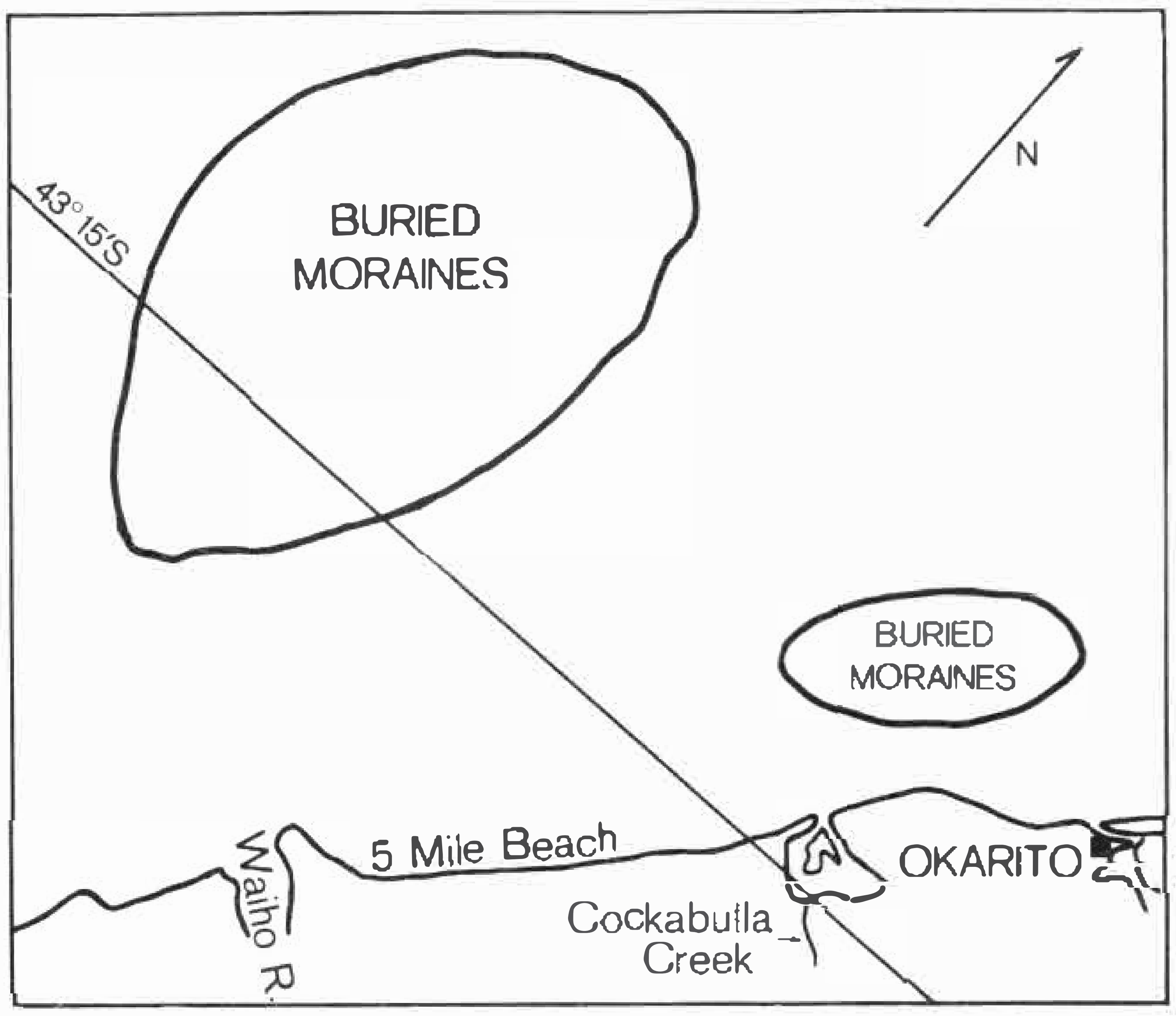

FIG. 10c. Distribution of buried glacial moraines on inner shelf near Okarito and the Waiho River mouth.

possibly strike-slip offset (Laird 1968), though strike-slip offset has not been demonstrated conclusively yet for any faults west of the Alpine Fault. The associated folds within the Tertiary and Quaternary rocks are tightly compressed and even overturned in the eastern block, being generally asymmetrical with steeper western limbs. The blocks to the west show much less deformation. Within the sedimentary cover on each block, moreover, folding is generally more intense on the western edge than on the eastern edge. S. Nathan (personal communication, 1976) points out that these fault blocks are composed chiefly of massive crystalline rocks covered by readily deformed Tertiary and Quaternary sedimentary beds.

A marked unconformity is evident in a number of Alpine sparker profiles in which undisturbed sediments rest on folded or faulted rocks below. This pattern is particularly well displayed in the northern part of the area and has been described by van der Linden and Norris (1974) in Karamea Bight. Brown *et al.* (1968) state that rapid uplift during the mid-Pleistocene Kaikoura Orogeny resulted in a marked unconformity between the deposits belonging to the Hawera Series and older rocks, some assignable to the Wanganui Series (Pliocene–early Pleistocene) and some to older formations. There is little doubt that this unconformity, so widely observed on land, is the same as that recorded in seismic profiles obtained off the west coast. It is therefore a very useful time-line in deciphering the geologic history of the western shelf of New Zealand.

A second unconformity, of which there is only sporadic evidence offshore, separates relatively un-indurated sedimentary rocks from either crystalline metamorphic or igneous rocks or from highly indurated sedimentary rocks, such as the Cretaceous Hawks Crag Breccia. Near Cape Foulwind, where crystalline basement lies near the surface and is exposed along the shore, it consists of the Constant gneiss of probable Devonian age (Aronson 1968) and associated Foulwind granitic rocks of similar age. Nonconformably resting on these crystalline rocks are the non-marine sedimentary rocks of the Arnold Series of Eocene age (Bowen 1964). Elsewhere on the western shelf, the so-called "economic basement" referred to by the oil companies, may consist of highly indurated Mesozoic, Paleozoic, or older sedimentary rocks in addition to true crystalline rocks.

Such old indurated sedimentary rocks are represented on shore near Ross by an extensive exposure of the probable Ordovician Greenland Group of greywackes and argillites (Cooper 1974). These rocks were also identified as the basement in the Haku-1 drill hole off Barrytown (Wodzicki 1974). Similar rocks crop out in the southern Paparoa Range north of Greymouth where they reach the coast, and in the southern Papahaua Range east of Westport (Bowen 1964). Although it is probable that such rocks make up much of the basement on the west coast shelf, their extent is not known, and apart from the Haku drill hole, even their existence is not firmly established.

FOLDING

A persistent folded zone called the Karamea Bight Anticline by van der Linden and Norris (1974) was described from boomer profiles made north of Cape Foulwind (Fig. 11). This structure was traced by them for 150km from north of Kahurangi Point to Cape Foulwind. Land exposures of the eastern limb of the fold occur at Cape Foulwind, where east-dipping Eocene to Miocene rocks are present resting unconformably on crystalline basement; at Charleston, where a structural high occurs; and near Punakaiki, where Bowen (1964) shows an anticlinal fold closely following the coastline for about 11 km before striking out to sea again. On the basis of oil company basement maps, this anticline and its companion syncline to landward appear to be truncated by the Cape Foulwind Fault (Nathan 1975), into which they strike at an acute angle off Punakaiki. The Karamea Bight Anticline and the Cape Foulwind Fault are closely associated for at least 220km and perhaps even more. The former is clearly an important element of the regional structure, though it is neither a tightly compressed fold nor a single continuous structure. It is

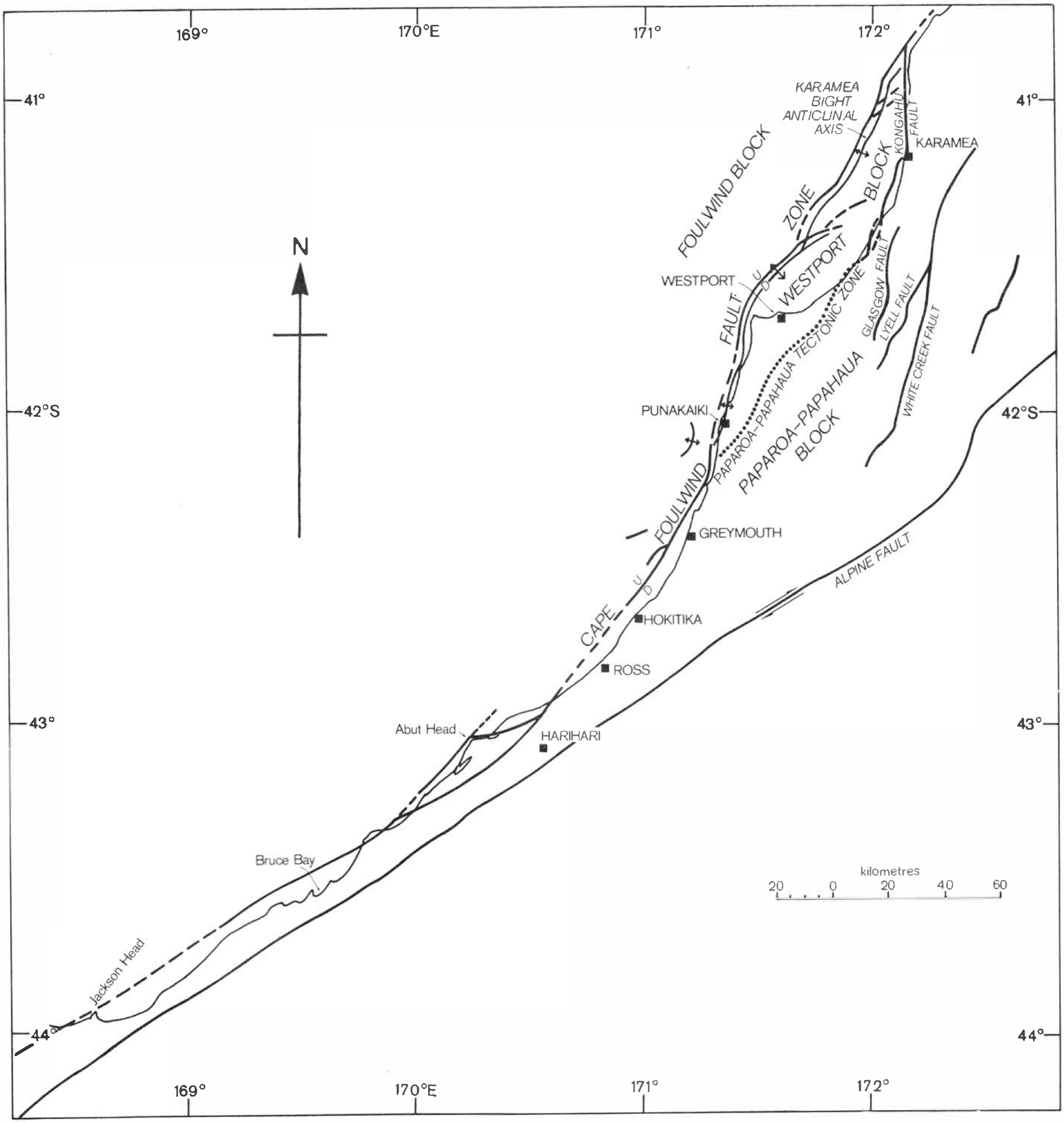

FIG. 11. Map of the main structural features of the shelf, Karamea to Jackson Head.

rather a series or chain of en echelon folds lying along the eastern side of the Cape Foulwind Fault.

Offshore from Punakaiki another minor anticlinal fold is evident in the pre-Hawera rocks as well as in the basement surface. This fold lies about 8 km offshore and follows an arcuate curve with its convex side towards shore (Fig. 11).

A number of Alpine profiles show other folds in the pre-Hawera rocks, but none is traceable for more than about 12 km. The majority appear on only one of the sparker profiles and cannot be matched with features shown in the basement topography. Where traceable, most of the offshore fold axes strike between 10 and 25 degrees east of north. Moreover, it is clear that the block west of the Cape Foulwind Fault is much less deformed than the block to the east of it.

Freund (1971) in his investigation of the Hope Fault in northern South Island, calls attention to the association of obliquely trending synclinal folds with the Hope Fault. Grant-Taylor (1967) notes a similar association of folding and faulting in the Wellington area. Although Freund agrees that there is some evidence that faulting occurred first and that the folds are secondary structures, he thinks it more likely that both folds and faults are different consequences of the same underlying cause. While the Karamea Bight Anticline and the Cape Foulwind Fault zone are almost parallel, their relationship seems generally analogous to the association of folds and faults mentioned above.

FAULTING

Faulting is indicated on the Alpine profiles by abrupt changes in dip or by a sharp break in the continuity of beds (reflectors). On the oil company basement maps faulting is also indicated by abrupt changes in depth to basement. Some features mapped as faults locally pass into sharp monoclinal folds and others are closely associated with buried sea cliffs or shoreline angles. If the feature in question is marked by a discontinuity of bedding that can be traced from profile to profile but varies in depth, then a fault origin is more likely than an erosional origin. Sea cliffs and shoreline angles should maintain a similar elevation from profile to profile.

The most important fault shown by the Alpine and oil company profiles is the Cape Foulwind Fault (Fig. 11) which may extend as much as 560 km from near Kahurangi Point southward to beyond Jackson Head. It could also be described as a fault zone; the oil company basement maps suggest that it is composed of a number of closely spaced but en echelon segments north of Greymouth at least, and S. Nathan (personal communication, 1976) points out that detailed mapping in south Westland suggests that it becomes a very wide fault zone there.

Mutch and McKellar's mapping (1964) suggests that segments of this fault are exposed on land at Tititira Head and on either side of the Moeraki River mouth. South of the Moeraki River the fault zone appears to strike out to sea, passing close to the Open Bay Islands and joining a fault zone extending south from Jackson Head for about 11 km, also mapped by Mutch and McKellar (1964). However, S. Nathan (personal communication, 1976) questions the existence of faulting near Jackson Head. Although this seafloor segment has not been established by any profiles, its existence seems possible. There is some likelihood that this large fault zone continues south close to shore, eventually merging with the Alpine Fault zone near the entrance to Milford Sound, although there is, at present, little firm evidence that the Cape Foulwind Fault extends south of Haast. It nevertheless seems probable that the Cape Foulwind Fault zone extends as much as 560 km along the west coast of South Island, and there is a possibility that it may continue northward across the western entrance of Cook Strait to join either the Cape Egmont Fault (van der Linden 1971) or a parallel fault.

Immediately west of the Cape Foulwind Fault, the depth from sea level to basement varies from less than 1950 m off Cape Foulwind to more than 2250 m off the mouth of the Little Wanganui River about 50 km to the north. Southward, off Punakaiki, it lies 2200 m below sea level. Still farther south, in the vicinity of the Cook River mouth, the basement surface on the seaward side of the fault descends to as much as 4500 m below sea level. In contrast, on the east side of the fault, the basement surface is very close to or at the surface from Cape Foulwind south to near Greymouth; Bowen (1964) shows land exposures at several places near the shoreline. In addition, various types of basement — Foulwind granitic rocks and Greenland Group greywackes and argillites — are exposed close to the fault on its east side at the Mikonui River, between the Waitaha and Wanganui Rivers, near the mouth of the Waiho River, and at several other places as far south as Jackson Bay. Though the surface of the basement is much higher on the eastern side of the Cape Foulwind Fault zone than on the western side, it is quite irregular and in some places is quite deeply buried. For example, the basement surface on the landward side of the fault lies about 900 m below sea level off the mouth of the Mokihinui River, descending to near 1900 m off Karamea. These values are summarised in Table 3. These data show that the basement surface is vertically separated by as much as 4000–5000 m in some places, but at other places, often only a few kilometres away, the apparent offset is much less. This marked variation appears to be due to differential uplift of the pre-Tertiary basement and folding of the overlying Tertiary succession, and possibly to an unknown amount of strike-slip movement on the fault. Some of the variation may be due also to the initial relief on the basement before the overlying sedimentary blanket was deposited. In short, although there is insufficient information at hand to allow an accurate determination of either the vertical or horizontal offset on the Cape Foulwind Fault, it is clear that the west side is relatively depressed. Whether the fault is dextral or sinistral, or even has any transcurrent movement, is unknown. Most nearby faults on land with similar strike have a reverse offset and a sinistral pattern of movement.

It seems likely that the Cape Foulwind Fault has a reverse slip and conforms generally to the pattern seen on many other faults in northern South Island including the Awatere, Clarence, Alpine, and Jollies Pass (Bowen 1964). The White Creek Fault, usually credited with causing the 1929 Murchison earthquake, and the Inangahua Fault, along which the 1968 Inangahua quake originated (Adams *et al.* 1968), both show sinistral as well as reverse offset — both earthquakes were accompanied by prominent ground shortening. Similarly, the Paparoa Tectonic Zone which extends along the coast from about Greymouth to Westport, is nearly everywhere a high-angle thrust (Laird 1968).

Although the Cape Foulwind Fault is obviously a young feature, cutting beds of late Tertiary and early Quaternary age, evidence for late Quaternary activity is much less obvious. As far as the Alpine sparker profiles and the N.Z. Oceanographic Institute 3.5 kHz acoustic records go, they contain very little evidence of continued offset, as upper Quaternary beds seem to continue undisturbed across the fault nearly everywhere. There are a few profiles, however, in which there is a slight suggestion of continued vertical offset (Fig. 12). Strike-slip is much more difficult to recognise on the profiles and, if such movement has been significant during the later history of the fault, it could easily go undetected on the profiles.

Between 1940 and 1964, about 15 shallow-focus earthquakes of Richter magnitude 4.0 and over have had epicentres on the seafloor between Kahurangi Point and Greymouth (Eiby 1970). Perhaps half to two-thirds of these show a crudely linear pattern corresponding roughly to the trace of the Cape Foulwind Fault. This shows only that recent tectonic activity is occurring in the vicinity of the fault, and it may be premature to suggest that these earthquakes provide clear evidence of continuing activity on the Cape Foulwind Fault.

CRUSTAL BLOCKS

The seafloor between Westport and Kahurangi Point is divided into three crustal blocks bounded by zones of folding and faulting (Fig. 13). The easternmost block lies almost entirely on land and includes the Paparoa Range between Greymouth and the Buller River and the Papahaua Range north of the Buller. The western margin of this block has long been regarded as a fault, mainly on physiographic evidence. However, a study by Laird and Hope (1968) recognises faulting only north of the Ngakawau River — The Kongahu Fault. They suggest instead that the western boundary of the range is mainly an overfold. Laird (1968) suggests that the overfold north of the Buller River may be traced into the Paparoa Tectonic Zone south of that river.

The Esso maps of offshore basement structure show that the crustal block lying between the Paparoa-Papahaua block and the Cape Foulwind Fault is an eastward tilted slab bounded on both sides by faults or sharp folds. This is here referred to as the Westport block and although folding is evident along both its margins, it is most evident on its western edge. These western folds comprise the series of anticlines which collectively have been called the Karamea Bight Anticline by van der Linden and Norris (1974).

Esso basement maps also extend some distance to the west of the Cape Foulwind Fault and show that the seaward slab — here referred to as the Foulwind block (Fig. 13) — is likewise depressed and moderately folded along its eastern edge where it is in contact with the Cape Foulwind Fault. The surveys do not extend far enough west to reveal either the location or nature of the western boundary of the Foulwind block. If the pattern seen in the Westport block is similar to that in the Paparoa-Papahaua block to the east, the Papahaua-Paparoa Tectonic Zone may prove to be a series of tight folds lying landward of a zone of en echelon or overlapping faults, much like the association between the Karamea Bight Anticline and the Cape Foulwind Fault.

TABLE 3. Depths in metres to basement surface from sea level, along east-west lines across the Paparoa Tectonic Zone and Cape Foulwind Fault.

East-west line through	East side Paparoa Tectonic Zone	West side Paparoa Tectonic Zone	East side Cape Foulwind Fault	West side Cape Foulwind Fault	at Longitude 171°E
Karamea River mouth	—	2350	1890	2500	1740
Little Wanganui River mouth	1680	2440	1840	2260	1770
Mokihinui River mouth	negligible	2350	920	1890	2070
Waimangaroa River mouth	negligible	1710	0	1950	2070
Belfast Creek mouth (42°S lat.)	negligible	?	0	2170	1890
Canoe Creek mouth (42° 12'30"S lat.)	—	?	negligible	1560	1980
Point Elizabeth	—	?	?	1830	2110
Gillespie Point			shallow	4150	
Heretaniwha Point (43° 35'S lat.)			shallow	4570	
Tokakoriri Creek mouth (43°42'S lat.)			negligible	4400	

UNCONFORMITIES

The most prominent unconformity occurs between nearly undisturbed marine sediments of probable late Quaternary age (Hawera Series) and folded and erosionally truncated beds of late Tertiary and early Quaternary age (Wanganui Series and older). Warren (1967) recognised the importance of this unconformity in the Hokitika area and refers to it as a regional unconformity on both sides of the Alpine Fault. However, evidence from land shows clearly that both folding and faulting have continued to the present time, although there has evidently been insufficient time as yet to impose much folding on the youngest (Hawera) sediments.

The angular unconformity between Hawera beds and the older deposits is displayed best on sparker profiles made in the middle and northern parts of the area (Fig. 14) and most poorly south of Hokitika Canyon, where the combined thickness of the youngest marine and glacial Quaternary beds is so great that penetration to the lower Quaternary and upper Tertiary beds was not achieved by sparker profiling.

The erosional surface on which the unconformity is developed is locally irregular. For example, the Alpine sparker profiles suggest that differential erosion of tilted sedimentary beds sometimes amounts to as much as 15 m. In some profiles local channelling produces a relief of 100 m or more.

In the area between Cape Foulwind and Punakaiki, only the inshore end of the unconformity is developed on tilted or folded sedimentary rocks; the outer ends of the profiles show that upper Quaternary beds are generally conformable with the older sediments.

Numerous, less conspicuous unconformities occur within the upper Quaternary deposits. These result from the development of gullies, channels, and various bedding irregularities as well as unconformable relationships where nearly flat beds overlie probable glacial moraines. All these can be considered as local unconformities.

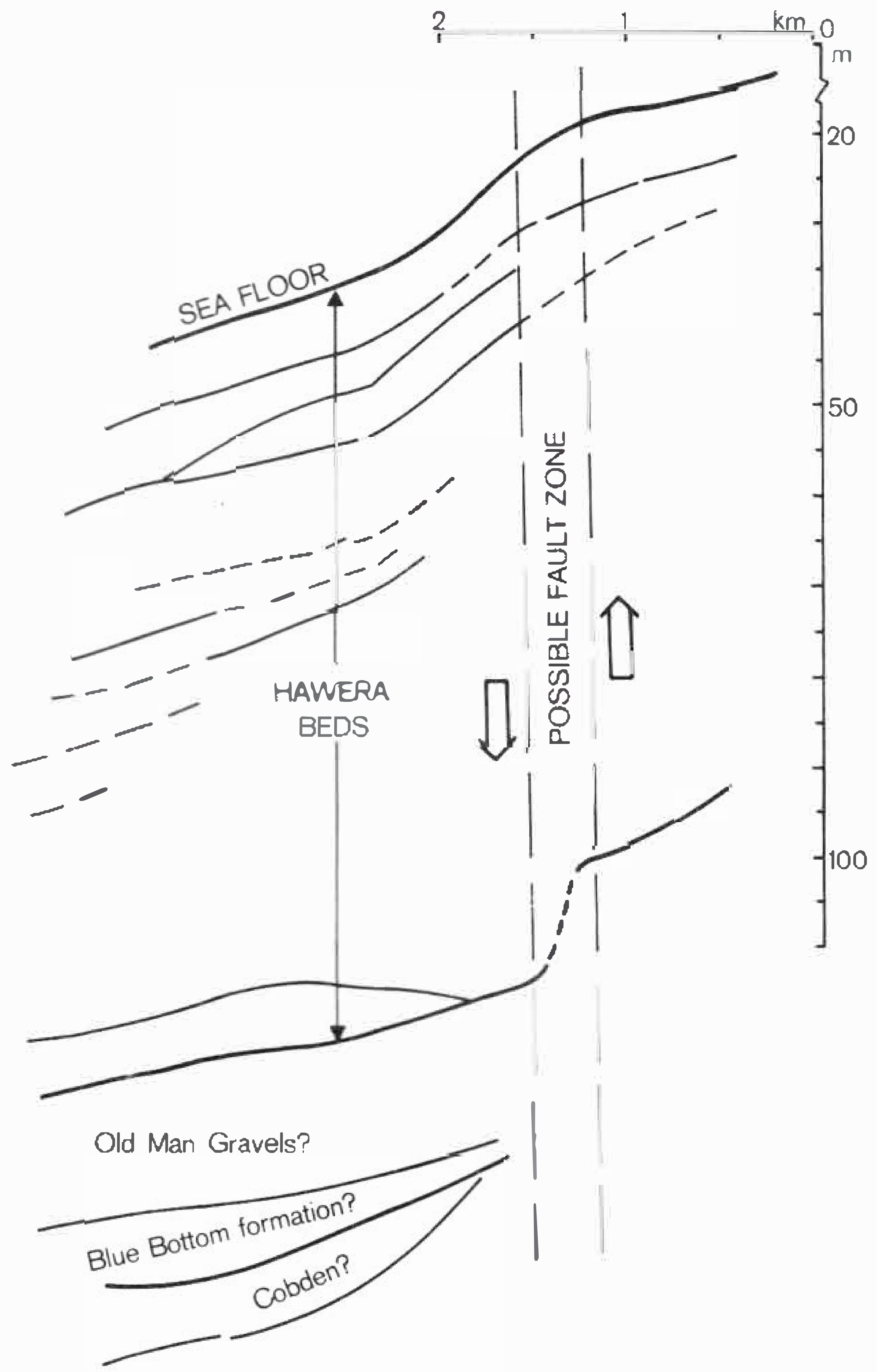

FIG. 12. Possible deformation of Hawera beds by movement on Cape Foulwind Fault, off Punakaiki (Alpine Geophysical profile).

STRATIGRAPHY

Matching the stratigraphic record deduced from seismic profiles with that known on land is an uncertain exercise. A series of cores collected north of Cape Foulwind and described by Norris (1972) gives some very limited information, but no cores or drill hole samples of any kind were available from seafloor localities south of Cape Foulwind, apart from the Haku-1 drill hole off Barrytown. Nonetheless, the presence of three distinctive and widespread seismic reflectors, one of which was sampled in a test drill hole on the Arahura River east of Hokitika (Laird 1968), provides some basis for establishing the stratigraphic framework for the west coast shelf, although Nathan's (1974) work makes it clear that the offshore Cretaceous and Cenozoic stratigraphy is in need of complete reinterpretation, a task beyond the scope of this paper.

There are, nevertheless, three prominent and widespread reflectors: (1) The top of the "economic basement" in oil company parlance. This refers to crystalline igneous and metamorphic rocks as well as to the indurated greywackes and argillites of pre- late Cretaceous age. (2) The top of the crystalline limestones of Oligocene or Miocene age off north Westland, generally assigned by the oil companies to the Cobden and related formations. These formations are now

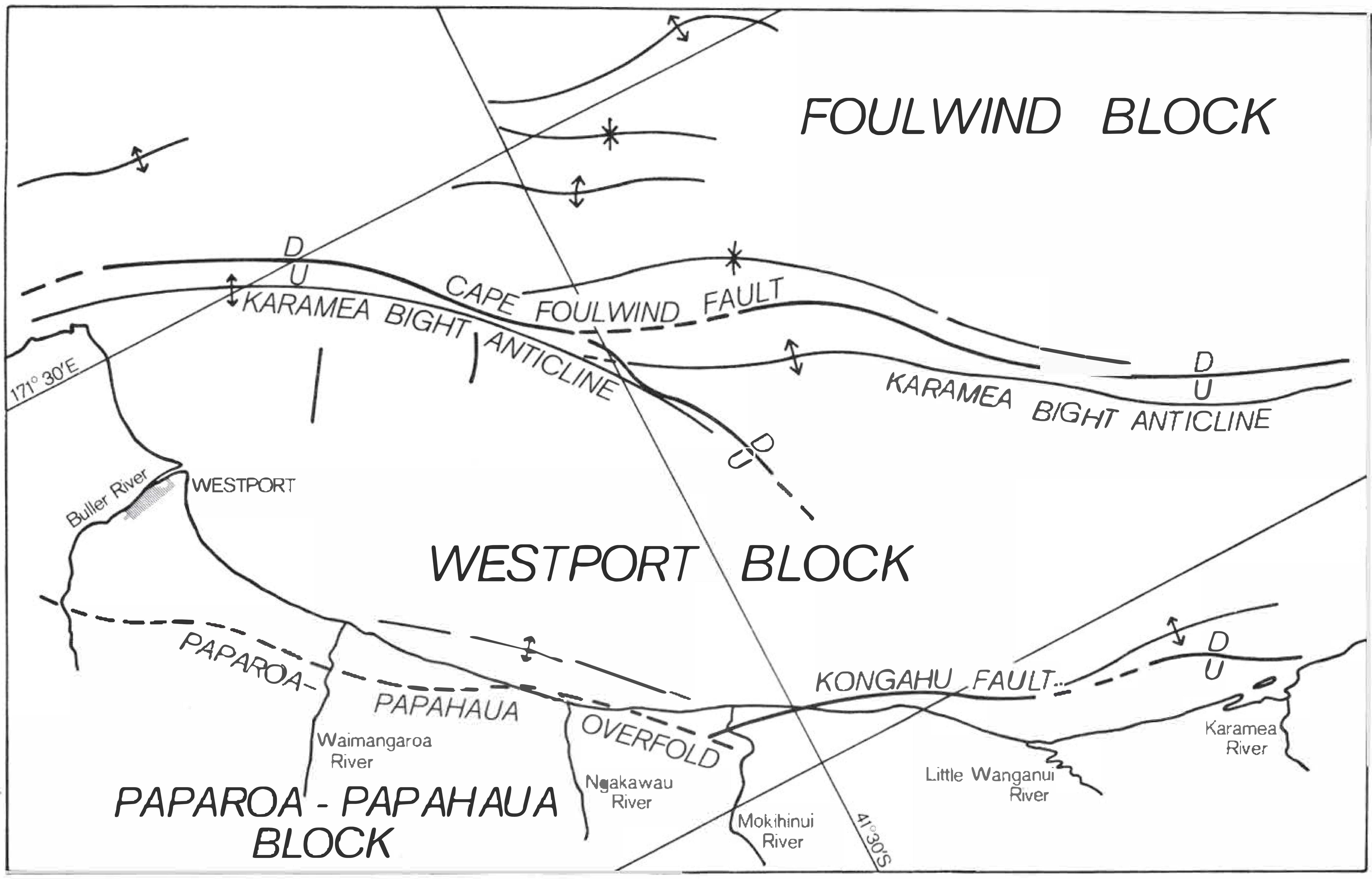

FIG. 13. Map showing main crustal blocks, Westport area.

included in the Nile Group (Nathan 1974), but Nathan (personal communication) also points out that in south Westland, there are other limestones of Paleocene, middle Miocene, and late Miocene age with which Nile Group rocks have often been confused. This reflector also represents, in a number of places, an erosional unconformity between early and late Tertiary rocks. (3) The erosional unconformity of middle Pleistocene age, separating the generally folded early Pleistocene and late Tertiary rocks from the nearly undisturbed and unconsolidated late Pleistocene and Holocene sediments of the Hawera Series.

Reflectors within the Hawera sediments are occasionally strong or distinctive. These represent such things as glacial moraines and the conformable contact between the non-marine Old Map Gravels and the underlying marine Blue Bottom Group.

BASEMENT

Maps, prepared by Esso, show the depth to basement in their concession areas, but do not cover the portion of the shelf between Greymouth and Abut Head. In addition, these maps make no attempt to distinguish between the four types of basement known on land: (1) the ?Cambrian-Ordovician Greenland and Waiuta Group greywackes and argillites, (2) the early Cretaceous Porarari Group, (3) the Charleston Metamorphic Group of Precambrian age, and (4) the Foulwind (formerly Tuhua) granites (Nathan 1976) of probable lower Paleozoic to Carboniferous age. The gneiss and granite were long regarded as Precambrian, but studies by Aronson (1968) suggest a Devonian to Carboniferous age for the granites.

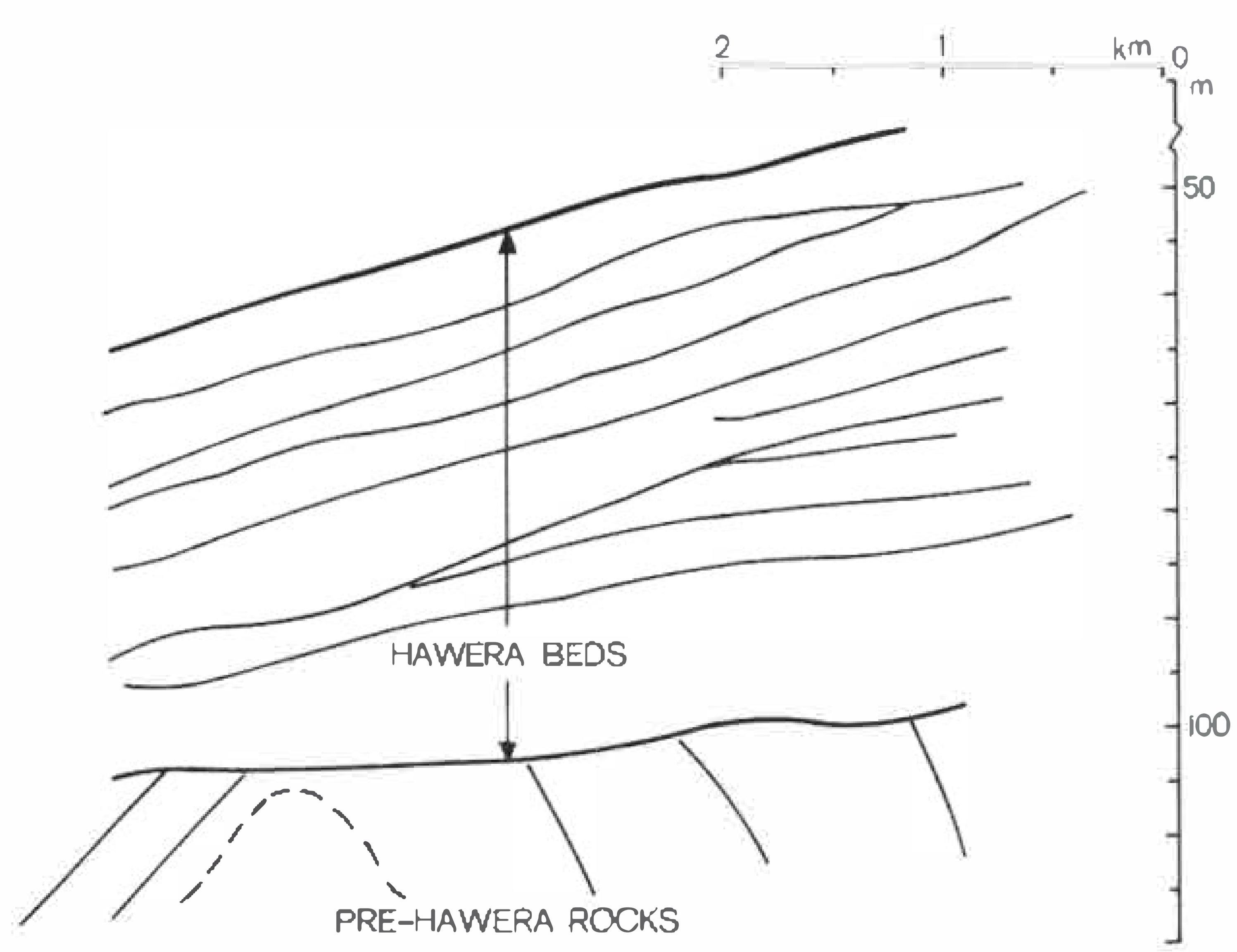

FIG. 14. Angular unconformity between Hawera and older beds, off mouth of the Ngakawau River (Alpine Geophysical profile).

In coastal areas, apart from a few localities between Cape Foulwind and Point Elizabeth, basement rocks are not exposed and generally lie some hundreds or thousands of metres below the surface. Even offshore from coastal exposures of crystalline basement, the Tertiary and Quaternary sedimentary deposits form an unbroken blanket over the basement on all profiles except for a small area about 1 km long located 2.5 km north-east of the Three Steeples rocks off Cape Foulwind. The Three Steeples are granite (Morgan and Bartrum 1915). Here, three of the Alpine sparker profiles and at least one N.Z. Oceanographic Institute sampling line indicate a sea floor exposure of basement (Fig. 3) in a location which coincides with a basement high shown on the Esso maps. Regrettably, no samples have been collected from this exposure, so it is not known which type or types of basement occur there. The nearby occurrence of granite at the Steeples and granite and gneiss at Cape Foulwind make it likely that the exposed basement is composed of these crystalline rocks rather than greywacke and argillite, the nearest exposure of which lies about 20 km inland from Westport.

Between 1965 and 1970, ten holes were drilled off the west coast of New Zealand. One of these drill holes, Haku-1, located at 42° 12'30"S, 172° 16'45"E, about 3 km offshore from the Barrytown area, penetrated basement which has been correlated by Wodzicki (1974) with Greenland Group rocks exposed on shore about 6 km distant. These crystalline rocks were encountered at a depth of 1672 m in this hole.

LATE CRETACEOUS AND EARLY TERTIARY ROCKS

On land, the late Cretaceous and early Tertiary part of the section is composed chiefly of quartzose coal measures with minor amounts of volcanic rocks resting unconformably on the various types of basement, assigned by Nathan (1974) to the Mawheranui Group. The coal measures are overlain by marine, Oligocene rocks of the Arnold and Landon Series, usually calcareous siltstones and sandstones at the bottom (the Rapahoe Group of Nathan (1974)), and hard, often crystalline limestones such as the Cobden Limestone of the Nile Group at the top. Because these crystalline limestones are particularly strong seismic reflectors, detection of any bedding or even the basement surface below, has proved difficult. It nevertheless appears from the various seismic profiles that about 1000 m of late Cretaceous and early Tertiary sedimentary rocks commonly occur on the west coast shelf. Magellan Petroleum geologists prepared an isopach map of this stratigraphic interval for the shelf area lying roughly between Abut Head and the mouth of the Moeraki River. They found that the rocks constituting this stratigraphic interval reach a maximum thickness of about 3300 m off Gillespie Point. This thickness decreases fairly regularly to about 1350 m 15–20 km offshore. Although similar isopach maps were not available for other west coast shelf areas, it seems probable that there is a general tendency for these rocks to thin seaward.

Not only are the crystalline limestones uncommonly strong reflectors, but in many places they represent the surface of an unconformity which Warren (1967) regards as a regional feature signifying the beginning of the Kaikoura Orogeny. Nile Group rocks including the Cobden Limestone are exposed at a number of places along the coast from Greymouth to Cape Foulwind. Although this reflecting horizon was matched by New Zealand Petroleum with what they identified as Cobden Limestone in a drill hole near Harihari, more recent work indicates that there are some marked differences in the stratigraphy of north and south Westland. It is likely, therefore, that the unconformity does not coincide everywhere with the top of the Cobden Limestone.

Furthermore, a similar reflecting surface has been reported by Andrews and Eade (1973) from the Egmont Terrace at the western approach to Cook Strait. They indicate that the reflector there is developed on rocks that can be correlated with deposits of late Eocene and early Miocene age in north-west Nelson. It seems more likely, however, that their reflector matches the unconformity which Grindley (1961) places below early Miocene terrestrial sediments and above deformed Oligocene and older rocks.

The New Zealand Petroleum Company has prepared contour maps of the surface of what they identify as the Cobden Limestone, for the shelf between near Greymouth and Abut Head. These maps show a gently undulating, folded surface in which folding is more intense near the Cape Foulwind Fault, but which is nonetheless remarkably flat in gross form over a considerable area. West of the Cape Foulwind Fault, depths to the top of what was identified by the oil companies as Cobden Limestone (but may well be an older rock) vary from as little as 1800 m off of the Taramakau River to nearly 2000 m off the mouth of the Waiho River. Between Abut Head and Point Elizabeth and extending about 40 km offshore, all depths to the top of this reflector lie within these limits.

LATE TERTIARY AND EARLY QUATERNARY ROCKS

On land, according to Nathan (1974), the Nile Group rocks are sharply divided from the overlying marine Blue Bottom Group (predominantly a blue-grey siltstone). The Blue Bottom Group is assigned by Nathan (1974) to the Pareora, Southland, Taranaki, and Wanganui Series and its age ranges from Miocene to Late Pliocene. Warren (1967), considering the Hokitika area, calls attention to the fact that the non-marine Old Man "Gravels" conformably overlie the Blue Bottom "Formation" and observes that these units are usually folded together. He also reports that these same units are either buried or removed everywhere south of the Mikonui River. Suggate (1965) comments that the upper part of the Old Man "Gravels" is unfossiliferous and that it is possible to separate it from the overlying Hawera Series deposits only on geomorphic or tectonic grounds. Sparker profiles often show a strong reflecting surface between the flat-lying Hawera beds and the folded Old Man and Blue Bottom Groups below. The intensity of folding dies out to seaward on a number of the profiles and the Hawera sediments are there essentially parallel with the older beds, although probably separated from them by an erosional surface.

LATE PLEISTOCENE AND HOLOCENE DEPOSITS

All undisturbed beds beneath the present seafloor that rest on folded or faulted rocks or are separated from older rocks by a strong reflector, are assigned to the Hawera Series and presumed to be of late Pleistocene and Holocene age. Warren (1967) points out that this time interval on the west coast embraces three major glaciations.

The gross form of the Hawera shelf sediments is wedge-like or lenticular in cross-section. The sediment thickness increases from an average of about 20–30 m near shore to to about 60–70 km approximately 8 km offshore and decreases to about 30–40 m 16–18 km from the shoreline. Although sediment thickness may reach 300 m or more in some places, the most typical situation is one in which a wedge-shaped prism of sediment rests unconformably on older, folded and faulted rocks, thinning both toward shore and toward the shelf edge with a maximum in the middle part of the shelf where the water depth is about 50–60 m. Lewis (1973) points out that such prisms of sediment are among the most widespread of depositional forms off coastlines, noting that shelf sediments build outward during falling sea levels and upward during rising sea levels.

Four different forms or geometries of sediment cover occur on the west coast shelf. The fact that these forms cluster in some areas and appear to have systematic geographic distribution indicates that they have a genetic significance, although another investigator might well see in the profiles a different grouping.

The commonest type of sediment profile – Type A – is one with a bi-convex, lenticular cross-section showing a marked thickening toward the centre. The characteristics of a typical example just south of the Grey River mouth are illustrated in Fig. 15a. In this type of profile, bedding is generally subparallel to the gross form of the sediment wedge, but cross-beds consistent with sediment outbuilding are common. Examples of this type of sediment accumulation are found between the Waimangaroa River and Cape Foulwind, from near Charleston to the Arahura River, from the Hokitika River to the Mikonui River, and south of the Wanganui River.

The second type of profile – Type B – is, at its outer end very like Type A, but its nearshore portion forms, when viewed in cross-section, a thin, elongate tail of sediment, concave upward (Fig. 15b). All examples occur north of Cape Foulwind. Profiles of this type are found where the inshore portion was deposited on a shallow submarine shelf and where, as a result, the maximum sediment thickness is displaced to seaward, occurring about 13 km offshore rather than the more usual 8 km. In most other respects profiles of Types A and B are similar. A typical example, found off the mouth of the Mokihinui River, is shown in Fig. 15b.

The third type of sediment accumulation – Type C – is a rather broad, featureless sheet of sediment of generally uniform thickness with little hint of any lenticular form *within the area mapped* (Fig. 15c). All examples occur on the shelf bulge south of Hokitika Canyon. Type C profiles often include channelled or gullied surfaces, now buried, and distinctive ridged deposits which are believed to be glacial moraines (Fig. 9). Morainal ridges are common on the adjacent land area and presumably have been deposited on the shelf as well.

The fourth type – Type D – of sediment prism is a compound type in which two or more wedge-shaped accumulations overlap, the older and lower one lying somewhat farther offshore than the younger prism (Fig. 15d). The multiple nature of this type of sediment accumulation resembles a large and complex deltaic accumulation in which distributary channels tend to form overlapping bodies of sediment. Although this type of structure is evident to some degree in many west coast shelf profiles, it is most strongly developed in the area lying off the mouth of the Hokitika River.

What, then, is the genetic significance of these distinctive profiles? Clearly, all or nearly all of them show that the most recent episode of shelf sedimentation has produced prisms of sediment elongated parallel to the coast. These prisms of sediment unconformably overlie lower Quaternary and Tertiary deposits and fill numerous canyons and gullies cut into these older deposits. Deposition has so dominated the later history of the shelf that pre- middle Quaternary bedrock is rarely exposed and only two submarine canyon systems persist in the area under consideration, the Hokitika Canyon and the Cook Canyon. Because the head of Cook Canyon lies only about 3 km from the beach, it may be the only truly active erosional feature on the west coast shelf today.

Although rapid sedimentation is at present the dominant process on the west coast shelf, local differences in the environment have given rise to the distinctive patterns of deposition just described. Among these the most usual type is Type A, and in a sense all the others are departures from Type A or special cases of it. In Type A accumulations, deposits near shore are thinner where wave and current action are more vigorous and able to keep sediments in suspension. Offshore, in quieter waters, greater sediment thicknesses may accumulate, tailing off to thinner accumulations as distance from land sources increases.

The most notable exception to the usual pattern occurs at the shelf bulge south of Hokitika Canyon. Type C profiles occur here. Although the entire mass of Hawera sediments may have the usual prismatic form, neither the base nor the outer portion was surveyed by the profiling runs. Nevertheless, the uppermost layer has been spread more evenly on this area than is usual on the west coast shelf and it shows little change within the limits of the

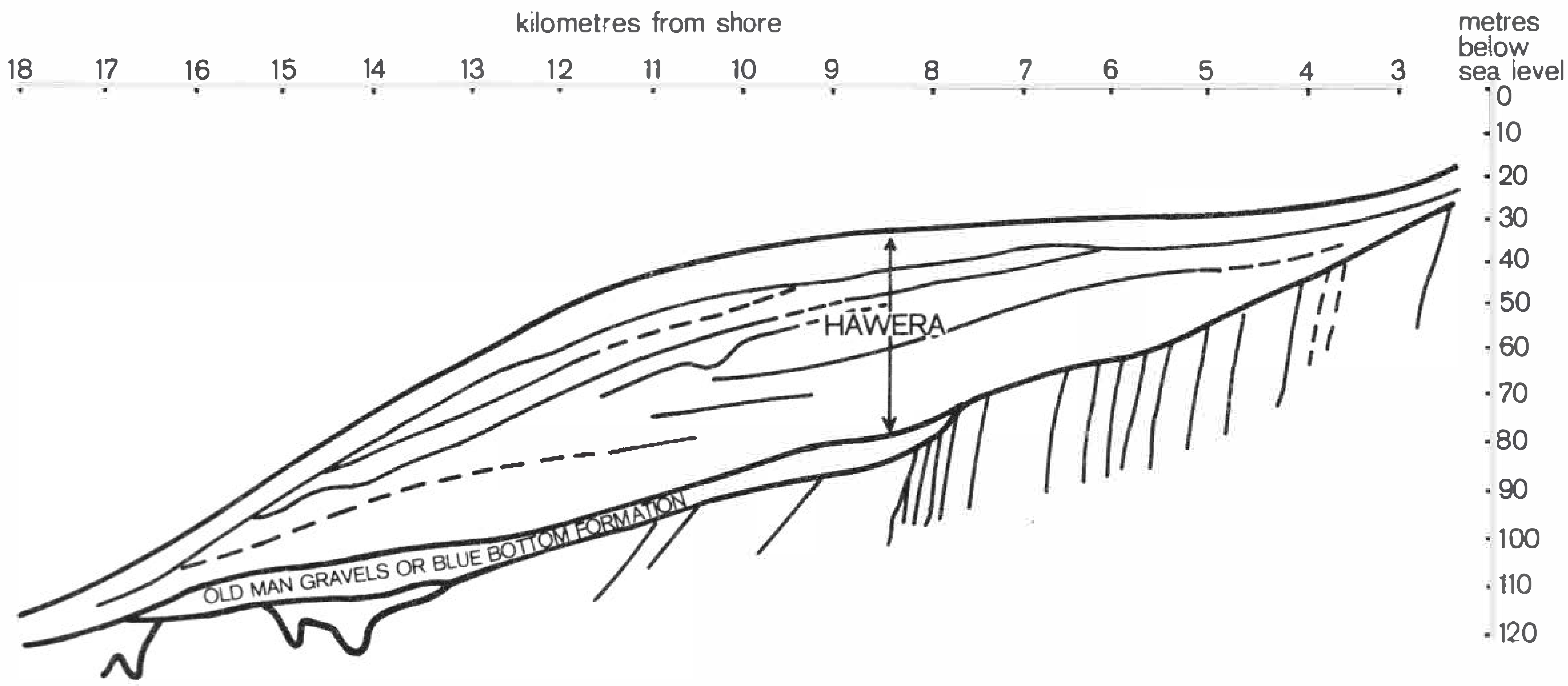

FIG. 15a. Example of Type A sediment profile, off Greymouth (Alpine Geophysical profile).

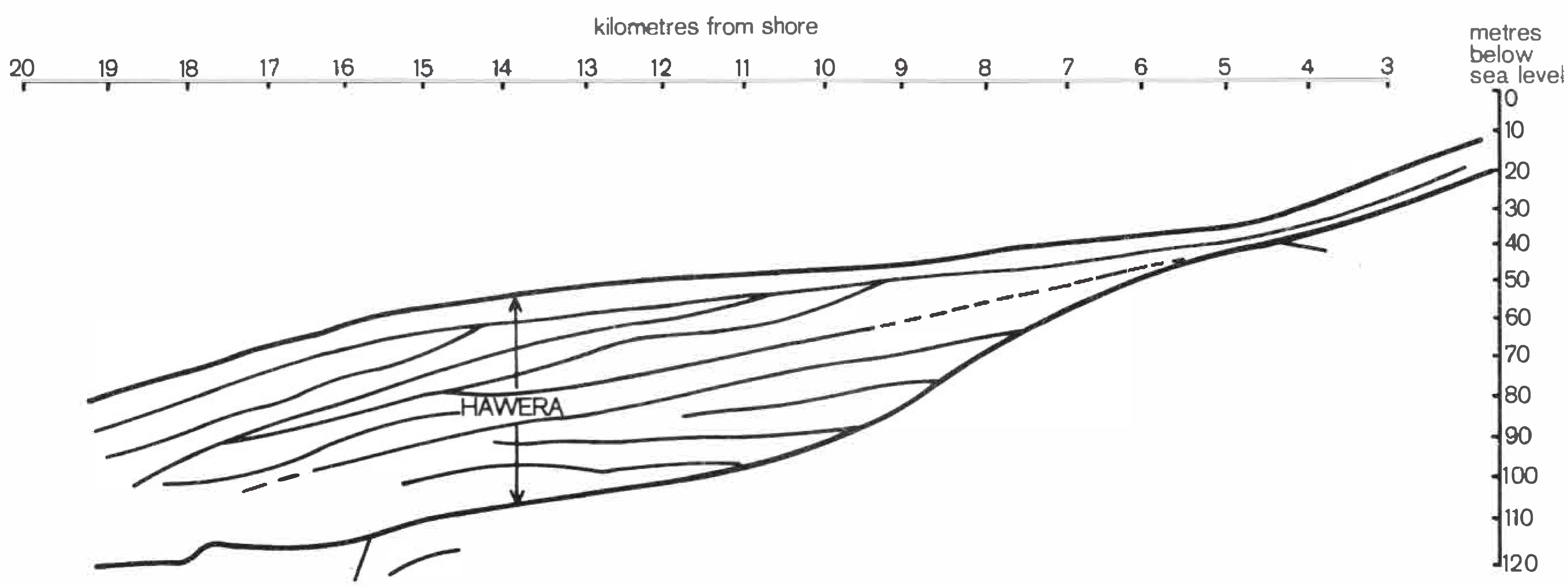

FIG. 15b. Example of Type B sediment profile, off mouth of the Mokihinui River (Alpine Geophysical profile).

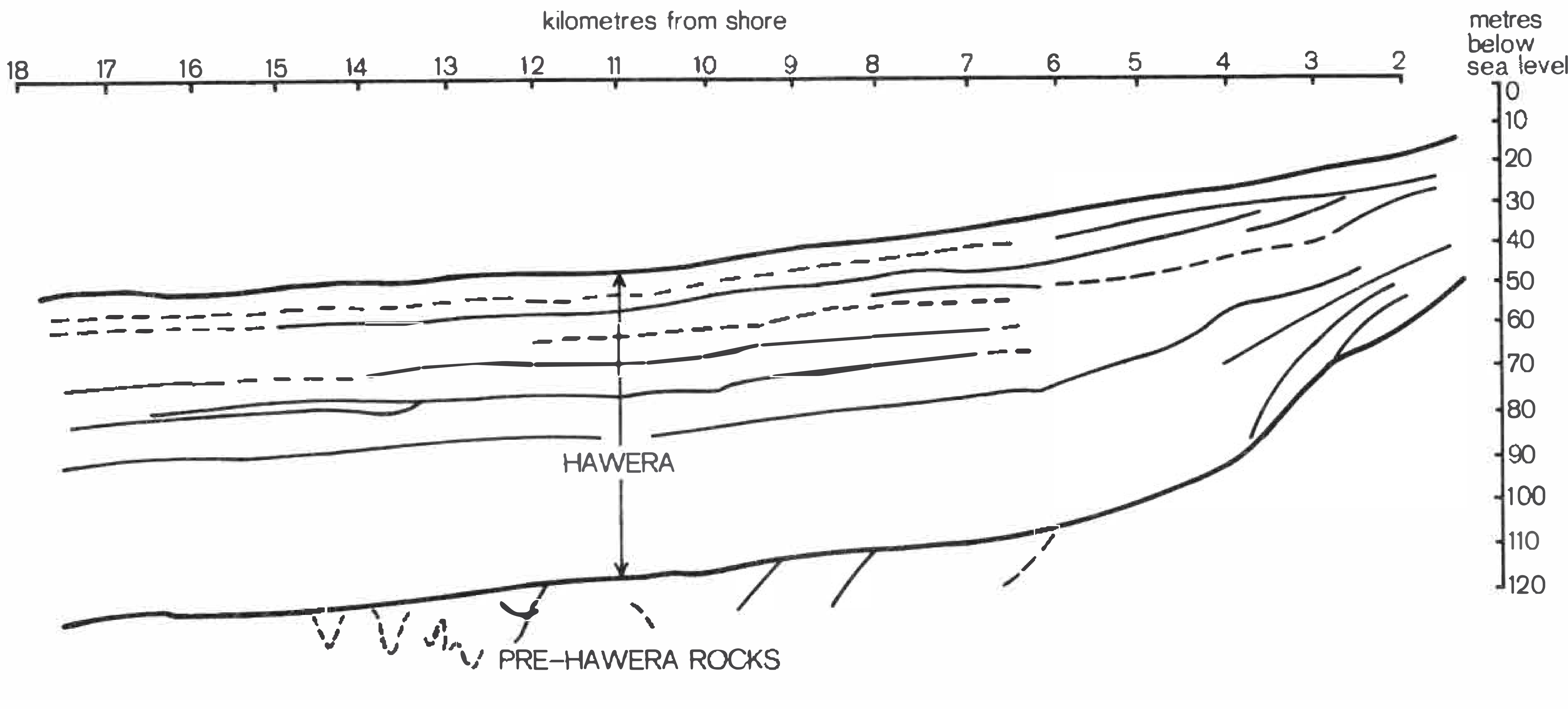

FIG. 15c. Example of Type C sediment profile, off mouth of the Mikonui River (Alpine Geophysical profile).

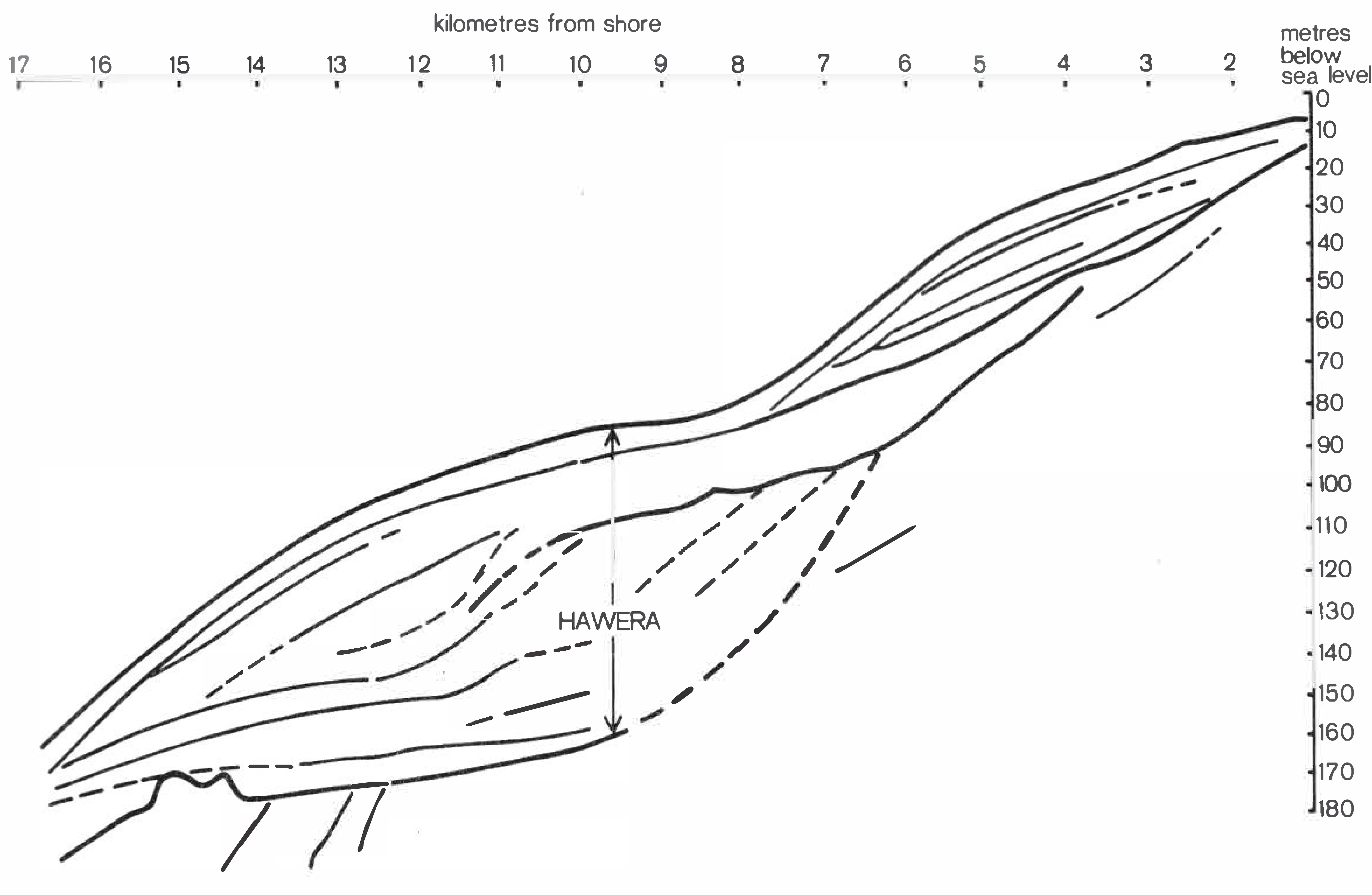

FIG. 15d. Example of Type D sediment profile, off mouth of the Hokitika River (Alpine Geophysical profile).

exposures with some confidence. Often separated from Nile Group and older rocks by a widespread unconformity are late Tertiary and early Quaternary marine sediments. Both these rocks and those of late Cretaceous and early Tertiary age appear to thin or pinch out in a seaward direction, but they often have an aggregate thickness of several thousand metres near-shore.

A third prominent unconformity separates the nearly undisturbed late Pleistocene and Holocene Hawera Series deposits from the older rocks. In most places pre-Haweran rocks are folded and in many places faulted as well. Deposition of the Haweran sediments has been so pervasive on the west coast shelf that apart from the large submarine Hokitika and Cook Canyons, older rocks and structures are nearly everywhere concealed.

The geophysical profiles reveal the presence of a major fault zone, the Cape Foulwind Fault, extending from at least as far north as Kahurangi Point southward to the vicinity of Haast, but possibly as far as Jackson Bay and beyond. The fault zone is exposed on shore for short distances south of Bruce Bay and appears to lie concealed beneath younger sediments on shore between the mouth of the Mikonui River and the mouth of the Waiho River. Elsewhere, it lies a short distance offshore. There is some indication that the fault may have an easterly dip. Associated with the fault is a vertical separation of the basement ranging from 1000 m or less in the north to possibly more than 4000 m in the south. The amount of horizontal slip, if any, is not known.

North of Cape Foulwind this fault and the Kongahu Fault/Papahaua-Paparoa Overfold divide the shelf and coastal area into three elongate blocks, each tipped downward toward the east and each characterised by en echelon folds along its margins, particularly the western margin. Folding dies out to the west, being most intense in the landward block and least so in the block seaward of the Cape Foulwind Fault.

Most of the folding as well as the movement on the faults seems to have been confined to the middle Pleistocene part of the Kaikoura Orogeny. Only minor activity has occurred since, and there is very little evidence of any disturbance of any of the offshore Haweran sediments. Even on land, most Hawera terrace gravels in the Paparoa Range are not offset by the young faults that pass beneath them.

Although much of the shelf is blanketed with flat-lying Haweran sediments varying from about 5 m to more than 120 m thick, the shelf south of the Mikonui River is covered with as much as 300 m of marine sediments interbedded with an unknown amount of glacial material.

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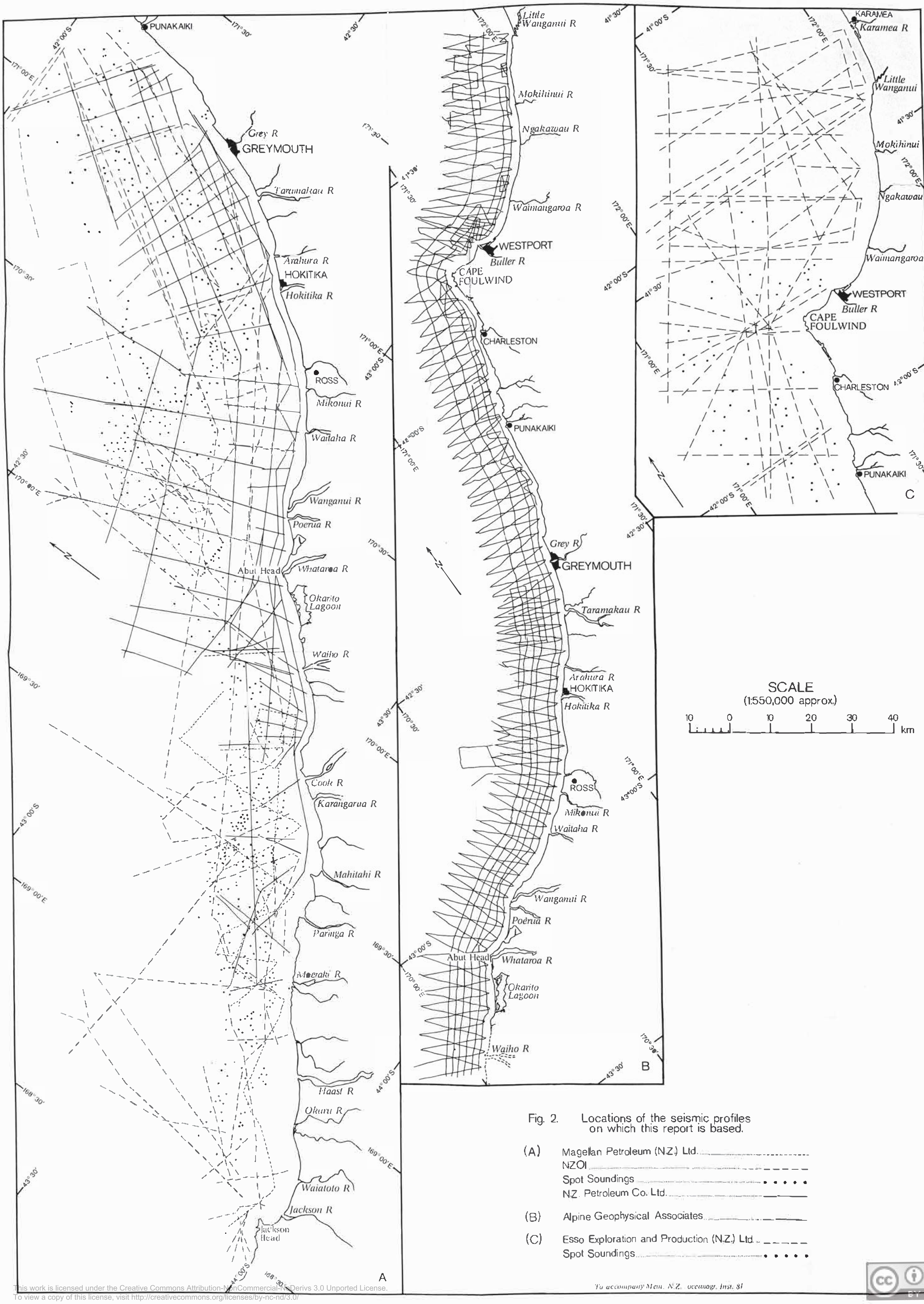

Fig. 2. Locations of the seismic profiles on which this report is based.

(A) Magellan Petroleum (N.Z.) Ltd.
NZOI
Spot Soundings
N.Z. Petroleum Co. Ltd.

(B) Alpine Geophysical Associates

(C) Esso Exploration and Production (N.Z.) Ltd.
Spot Soundings

To accompany Mem. N.Z. oceanogr. Inst. 81