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NEW ZEALAND

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

BULLETIN 149

SUBMARINE MORPHOLOGY EAST OF THE NORTH ISLAND, NEW ZEALAND

by

H. M. PANTIN

New Zealand Oceanographic Institute

Wellington

New Zealand Oceanographic Institute
Memoir No. 14

1963

Frontispiece — *Whites Aviation Ltd. photograph*

View north from Castlepoint (Castle Rock centre foreground) to Cape Turnagain. Castle Rock is made up of Waitotaran limestone (upper Pliocene) overlying Opoitian siltstone (lower Pliocene); the reef immediately to the north is composed dominantly of Waitotaran limestone.

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FOREWORD

The resurvey of the New Zealand coastline by the Royal New Zealand Navy is providing a valuable opportunity for the accumulation of data of concern to the marine sciences.

The bathymetric analysis of some of the information made available from surveys of HMNZS *Lachlan* is not only the basis for the present geological study but provides a definition of the morphology of shelf and slope directly applicable to problems in other fields of marine science.

Mrs P. M. Cullen has been responsible for the preliminary editing of the manuscript.

Final editing of the material for publication has been carried out by Mr M. O'Connor, Information Bureau, D.S.I.R.

J. W. Brodie, Director,
New Zealand Oceanographic Institute.

CONTENTS

FIGURES

PLATES

CHARTS

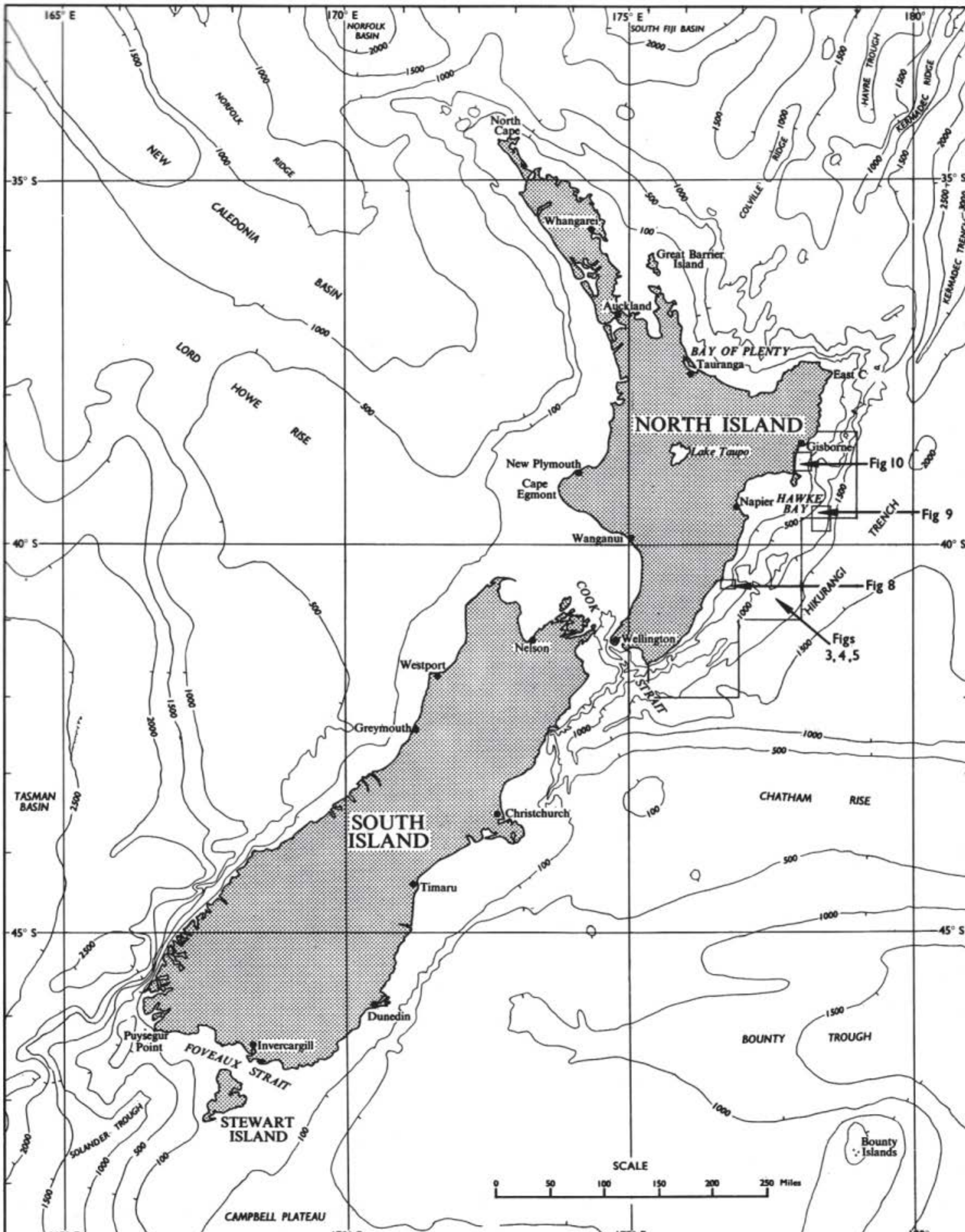

Fig. 1. Locality map. (Bathymetry from New Zealand Oceanographic Institute Bathymetric Charts 1 : 219,400; 1960.)

SUBMARINE MORPHOLOGY
EAST OF THE NORTH ISLAND, NEW ZEALAND

INTRODUCTION

Materials

The materials on which the present analysis is founded are the extensive lines of echo soundings obtained by the Royal New Zealand Navy Survey Ship *Lachlan* in the course of her present hydrographic resurvey of the coastal waters of New Zealand. Under Commander J. M. Sharpey-Schafer, R.N., 1949–51; Captain C. C. Lowry, R.N., 1951–54; Captain G. S. Ritchie, R.N., 1954–57; and Commander F. W. Hunt, R.N., 1957–60, the survey of the eastern coastal waters of the North Island has been carried from Cook Strait to Poverty Bay.

The surveys were carried out at larger scales to produce charts on a scale of 1 : 200,000. The lines of echo soundings were run E-W roughly normal to the coastline and ½ mile apart out to 100 fathoms followed by lines 2 miles apart, then by lines 5 miles apart to the limits of the area surveyed. Through the cooperation of the Commanding Officer, additional lines were run for deep bathymetric control in a number of cases. In Hawke Bay the sounding lines were traversed as a series of parallel arcs concentric on either Cape Kidnappers or Portland Island. The original echo soundings and collector tracings of unpublished soundings have been made available to the New Zealand Oceanographic Institute.

The bathymetric charts which accompany this Memoir were compiled from contourings of the large-scale survey collector sheets of soundings; these contoured sheets were then reduced to fit a base prepared on the same scale as the published hydrographic chart.

Area Covered

The area to be described is that covered by the Mahia and Turnagain charts, and the Palliser chart east of longitude 175° 25′. It forms a belt that extends 50–80 miles out to sea from the east coast of the North Island, and extends 230 miles from the mouth of the Opouawe River, near Cape Palliser, to Gable End Foreland, north of Poverty Bay (fig. 1). The coast, which forms the western boundary of the area, is very regular in trend for the first 150 miles, running steadily north-eastward from Cape Palliser to Cape Kidnappers with only minor promontories and indentations. Between Cape Kidnappers and Mahia Peninsula, the coast swings westward to form the great re-entrant of Hawke Bay, which extends up to 25 miles north-west of the general line of the coast, and measures 45 miles across the entrance between Cape Kidnappers and Mahia Peninsula. North of the irregular Mahia Peninsula, the coast trends steadily northward to the smaller re-entrant of Poverty Bay and thence north-eastward to Gable End Foreland.

Coastal Topography

In the sector between Cape Palliser and Cape Kidnappers the shore topography is uniformly rugged, with a highly dissected fluvial morphology containing numerous summits over 1,500 ft in height. Many of these summits are situated only a few miles from the coast. The landscape around Hawke Bay is variable, being fairly rugged between Cape Kidnappers and the mouth of the Tukituki River (plate I), and between Tangoio Bluff and Waikokopu, whereas the ground between the Tukituki River and Tangoio Bluff is comparatively low-lying. In this sector a stretch of alluvial plain some 20 miles wide (the Heretaunga Plains) reaches the coast and extends 20–30 miles inland. It has been built by three of the major rivers draining southern Hawke's Bay, and still carries the seaward portions of these rivers. In the hilly areas surrounding Hawke Bay summits in the immediate vicinity of the coast are not quite as high as in the country further south, and

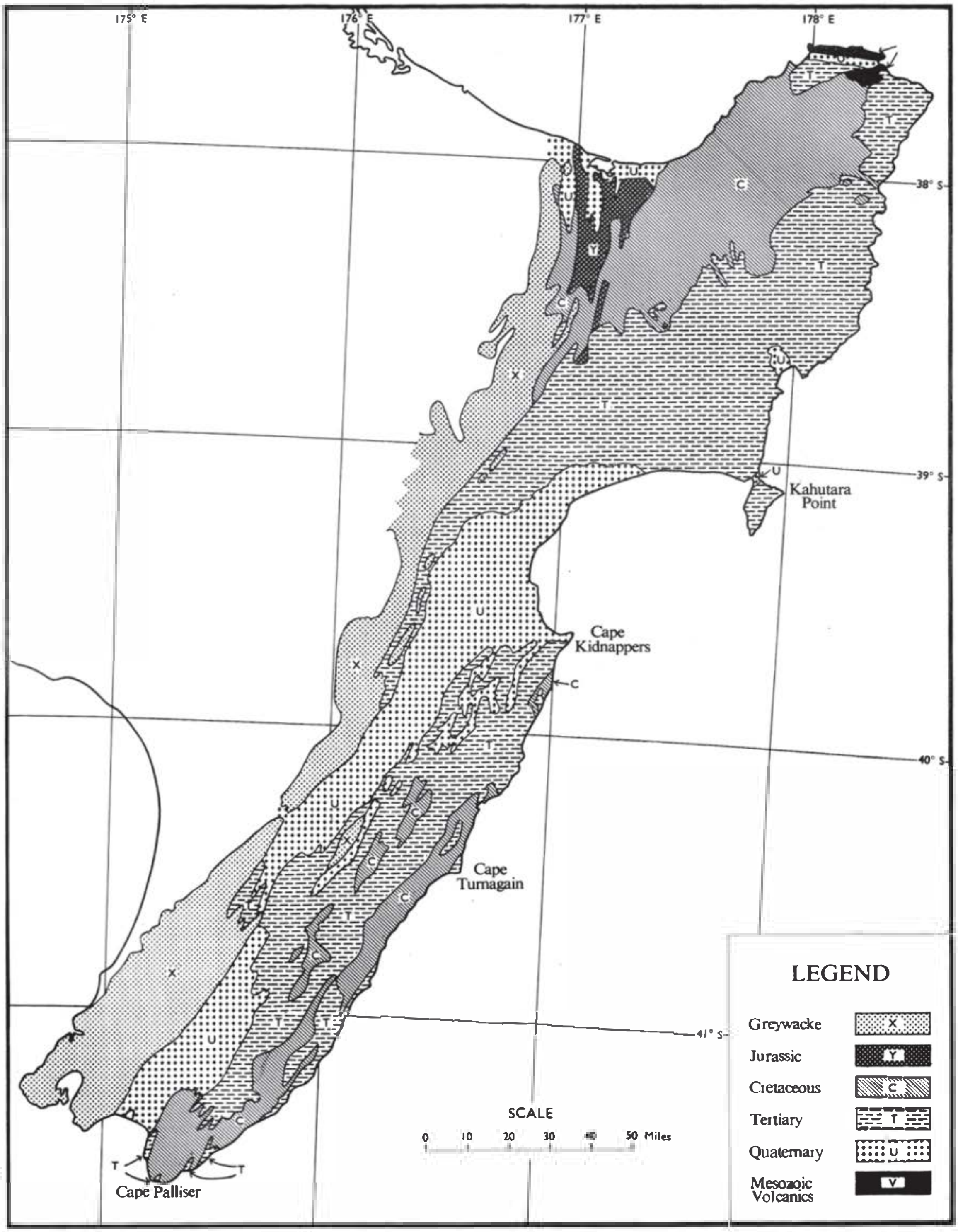

Fig. 2. Simplified geology of the eastern part of the North Island (adapted from New Zealand Geological Survey "Geological Map of New Zealand" 1958.)

Whites Aviation Ltd. photograph

Plate 1. Marine terraces around Cape Kidnappers, Hawke Bay. Cape Kidnappers consists of Opoitian siltstone; white cliffs of Castlecliffian pumiceous sandstone can be seen in the right middle distance, with the Heretaunga Plains beyond and a scarp of Waitotaran limestone in the left centre background. The Ruahine Range (Mesozoic greywacke) is just visible on the skyline.

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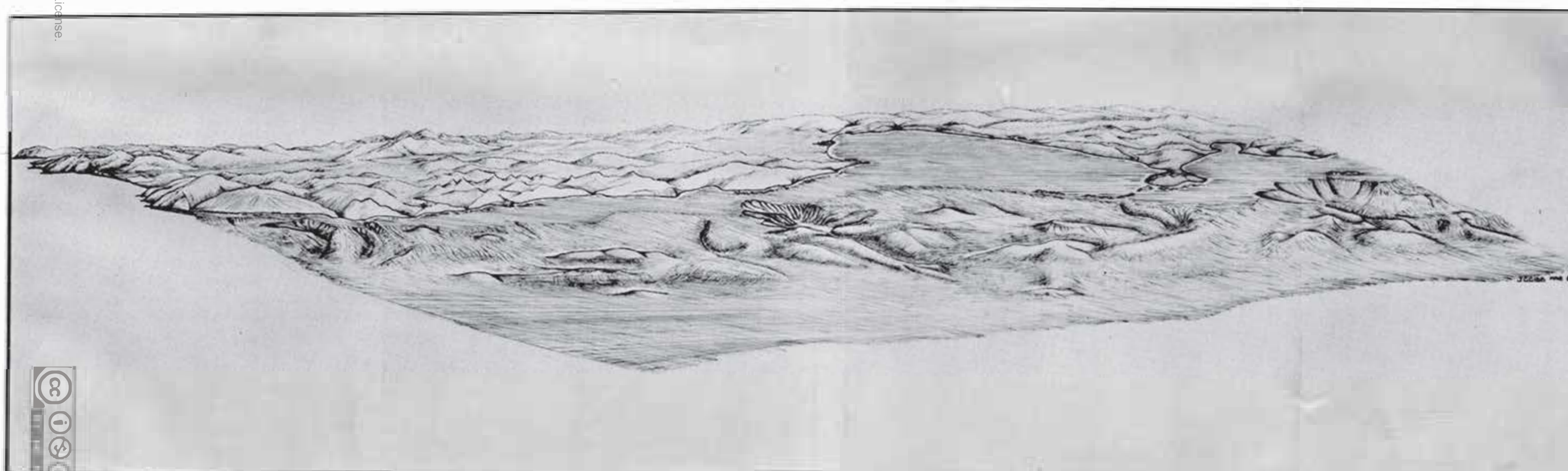
Plate 2. The tombolo at Opoutama connecting Mahia Peninsula (background) to the mainland. The planed surfaces of the peninsula are visible towards its eastern extremity; the prominent cliff near the township at the further end of the tombolo consists of Tongaporutuan (Miocene) sandstones and siltstones in alternating beds.

Photograph by H. M. Pantin

Plate 3. Panoramic view of the coast near Honeycomb Rock, showing marine benches cut in Tertiary beds. The photographs were taken from a position about 3 miles SE of Honeycomb Rock.



Drawn by J. G. Gibb

Plate 4. Oblique projection of shelf and slope off the east coast from Cape Palliser north to Gable End Foreland.

Plate 3. Panoramic view of the coast near Honeycomb Rock, showing marine
were taken from a position about 3 miles SE of Honeycomb Rock.

Plate 4. Oblique projection of shelf and slope off the east coast from

Whites Aviation Ltd. photograph

Plate 5. Large scale slumping of Nukumaruan beds (lower Pleistocene) forming high coastal cliffs 2 miles SW of the Mohaka River mouth. The beds include pebbly, tuffaceous, and argillaceous sandstones, and shelly limestone. The slumping took place as a result of the Hawke's Bay earthquake of 1931. The coastline opposite the slump has been almost completely rectified by wave action between 1931 and 1958 (the date when this photograph was taken).

do not usually exceed 1,200 ft, although higher elevations are found further inland. From Mahia Peninsula north to Gable End Foreland the coastal landscape is mainly rugged, with low-lying stretches around Poverty Bay and around the tombolo connecting Mahia Peninsula to the mainland (plate II). The highest point on Mahia is 1,200 ft, while hills near the coast between Waikokopu and Gable End Foreland rise to over 1,600 ft.

Numerous medium-sized rivers reach the sea between Cape Palliser and Porangahau, but between Porangahau and Cape Kidnappers there are only small streams, none being of sufficient size to show on the chart. Hawke Bay, on the other hand, which is in the centre of a large morphological depression, receives the five largest rivers in the area. These rivers, from south to north, are the Tukituki, Ngaruroro, Tutaekuri, Mohaka, and Wairoa. Smaller rivers enter the sea in the gaps between the Tutaekuri and Mohaka Rivers, and between the Wairoa River and Waikokopu. In the Waikokopu - Gable End Foreland sector the only important river is the Waipaoa, which flows into Poverty Bay.

Irregular cliffs up to 800 ft in height occur along the whole coast from Cape Palliser to Cape Kidnappers, except in areas such as the Porangahau estuary where low river terraces reach the sea (plate III). Cliffs are also present along the hilly portions of the Hawke Bay coast: they range up to 1,200 ft in height and are more regular than further south, particularly on either side of the Mohaka River, where the summit of the cliffs is formed by an uplifted and little-dissected marine peneplain (plate V). Along the low-lying portions of Hawke's Bay, however, there are no cliffs and the coast is formed by shingle bars, sand bars, and dunes. Cliffs reappear at Mahia, where they surround much of the peninsula and range up to 600 ft in height. The coast between Waikokopu and Gable End Foreland is again formed by irregular cliffs up to 600 ft in height, the only major interruption being the Waipaoa flats around Gisborne.

Sandy beaches extend more or less continuously along the whole coast within the area considered, but are sometimes interrupted or modified by wave-cut platforms of bedrock, which may extend some distance out to sea. Rocky stacks, for example the reef at Castlepoint (frontispiece), are numerous along some parts of the coast, particularly between Porangahau and Cape Kidnappers and also around Mahia. Marine benches at various heights are present in different sectors, but are often obscured by landslip (King, 1932, p. 72).

Coastal Geology

The geological formations outcropping along the coast in the area considered belong to sedimentary sequences ranging in age from lower Cretaceous to Holocene (fig. 2). The various formations, together with their lithologies and ages, are set out in the following table.

Age	*Formation*	*Lithology*
Holocene	Recent (and Hawera Series)	Alluvium, low terraces, swamp, sand dunes.
Pleistocene	Wanganui Series (upper)	Limestone, mudstone, sandstone, conglomerate.
Pliocene	Wanganui Series (lower)	Mudstone, sandstone, limestone.
Miocene	Taranaki Series	Mudstone, sandstone, tuff.
Miocene	Southland Series	Mudstone, sandstone, coal.
Oligocene	Pareora Series	Sandstone, mudstone, limestone.
Oligocene	Landon Series	Limestone, mudstone, sandstone, tuff.
Eocene	Arnold Series	Mudstone, greensand, coal.
Eocene-Paleocene	Dannevirke Series	Mudstone, sandstone, bentonite.
Danian-Maestrichtian	Mata Series	Argillite, sandstone, coal.
Senonian	Raukumara Series	Argillite, sandstone, coal.
Turonian-Albian	Clarence Series	Argillite, sandstone, greywacke.
Aptian-Neocomian	Taitai Series	Greywacke, argillite, breccia.

Lower Cretaceous rocks (Taitai) occupy a wide area north-east of Cape Palliser and reach the coast in two sectors between Cape Palliser and the Pahaua River. Upper Cretaceous rocks (Clarence, Raukumara, and Mata) form an extensive belt which runs from near Castlepoint to Porangahau and touches the coast in three sectors: rocks of this age also reach the coast around the mouth of the Pahaua River and at Waimarama. The lower Tertiary (Dannevirke, Arnold, Landon, and Pareora) occurs only in four small areas; near Gable End Foreland, north of Porangahau, south of Flat Point, and at the mouth of the Awhea River. The upper Tertiary (Southland, Taranaki, and lower Wanganui) is much more widespread, occupying large sectors between Gisborne and Wairoa, south of Cape Kidnappers, and from Castlepoint south. Pleistocene (upper Wanganui) beds are virtually confined to Hawke's Bay; they cover a wide area north and west of Napier, and a smaller area around Cape Kidnappers. The Hawera Series does not outcrop in significant proportions along the present stretch of coast, but Recent gravels and silts cover wide areas around Gisborne and Napier: smaller developments are also found at Porangahau and at Mahia, where

Recent sandy sediments form the tombolo connecting the peninsula to the mainland.

The degree of induration of the sandy and muddy beds in this series is variable, but, on the whole, induration becomes progressively greater with increasing age. At one end of the scale there are the soft sands and muds of the Quaternary, and at the other there are the greywackes and argillites of the lower Cretaceous. The limestones, on the other hand, become indurated much more rapidly than the associated terrigenous sediments and may form resistant beds in formations as young as the lower Quaternary.

Between Cape Palliser and Cape Kidnappers the rocks of the coastal region have suffered a considerable degree of folding and faulting, the older rocks forming horsts or anticlines rising through the younger members. The folds and principal faults are upper Tertiary to lower Quaternary in age and exhibit a regional strike running NE-SW, approximately parallel to the coast in that sector (Wellman, 1956, pp. 15 and 21). In addition to the main faults there occur a number of less extensive faults which run roughly at right angles to the main trend (Lillie, 1953, maps). North of Cape Kidnappers the tectonic trend becomes less regular and the strike of beds frequently shows no relationship to the coastline.

SUBMARINE MORPHOLOGY

Morphological Zones

The continental shelf in the present area forms a flat, gently sloping zone extending from the coast to depths ranging from 50 to 100 fathoms. This passes outwards into the continental slope, a zone of comparatively steep gradients and irregular relief, extending outwards to depths ranging from 1,500 to 1,800 fathoms (plate IV). On its outer margin the slope is bounded by the Hikurangi Trench (until recently included in the Kermadec Trench; Brodie and Hatherton, 1958, p. 22). The trench is a wide, shallow depression with very little relief, the axis lying at a depth of about 1,500 fathoms opposite Cape Palliser and descending progressively north-eastward to about 1,900 fathoms opposite Poverty Bay. These three morphological zones (fig. 3) will now be described in turn.

Continental Shelf

Width and Gradient: The shelf, whose outer limit is defined by an obvious increase in gradient, varies considerably in width. The narrowest part, only 3 miles across, is in the south opposite the Opouawe River, while the widest part, 37 miles across, lies opposite the great coastal re-entrant of Hawke Bay. The average gradient measured from the coast to the shelf edge varies from one in 40 to one in 370, but in most sectors the surface of the shelf is not uniformly flat, and one or more zones of minimum gradient are present (figs. 4, 5, 6). These submarine benches vary both in depth and degree of development. Between the Opouawe River and Uruti Point the gradient increases more or less steadily from the coast to the shelf edge, the descent being interrupted by a bench in 20–30 fathoms extending from the Kaukau Bank to the Pahaua Canyon, and by another smaller bench in about 65 fathoms just to the west of this canyon.

From Uruti Point to Cape Kidnappers the shelf is fairly uniform, although there is an unusually steep gradient in the 0–30 fathom zone between Porangahau and Cape Kidnappers: a slight bench at 40–50 fathoms occurs in the same sector. In Hawke Bay there are wide, gently sloping benches between 10–20 fathoms east of Napier, between 30–40 fathoms in the centre of the bay, and between 10–20 fathoms south of Wairoa, the latter grading into a bench between 20–30 fathoms south-west of Mahia. South-east of Mahia the shelf gradient is fairly uniform, but there is a pronounced bench opposite Poverty Bay, with a depth ranging from 25 fathoms south of Gisborne to 35 fathoms west of the Ariel Bank. There is another small inclined bench just to the east of the Ariel Bank, with a depth varying from 25 fathoms opposite Ariel Rocks to 45 fathoms opposite Penguin Rock.

Depth and Trend of Shelf Edge: The depth of the shelf edge and the abruptness of the change in gradient vary considerably from one sector to another. Opposite the mouth of the Opouawe River the shelf edge lies at about 80 fathoms, it descends to the north-east, reaching 110 fathoms opposite the Awhea River. but rises again to about 80 fathoms near the Pahaua Canyon. The change in gradient at the shelf edge is relatively abrupt at the two ends of this sector, but less so in the centre. Around the head of the Pahaua Canyon the shelf edge becomes very abrupt and rises rapidly to a depth of only 30 fathoms, falling again north-east of the canyon. Between the Pahaua and North Honeycomb Canyons it descends to 90 fathoms, but again rises rapidly to 30 fathoms and becomes sharply defined around the head of the North Honeycomb Canyon. North-east of this canyon the shelf edge descends again and becomes less well defined, lying at about 110 fathoms from the east side of the canyon north to the Adams Bank. This bank is surrounded by a well marked break in slope at 90 fathoms, but the main shelf edge resumes north of the bank at 110 fathoms and persists at this depth as far as the conspicuous irregularity situated on the outer margin of the shelf about 4 miles north-east of the Adams Bank. Between this irregularity and the Whareama Bank the shelf edge lies at about 90 fathoms and is fairly abrupt. Between the Whareama Bank and the Madden Canyon, on the other hand, the change in gradient

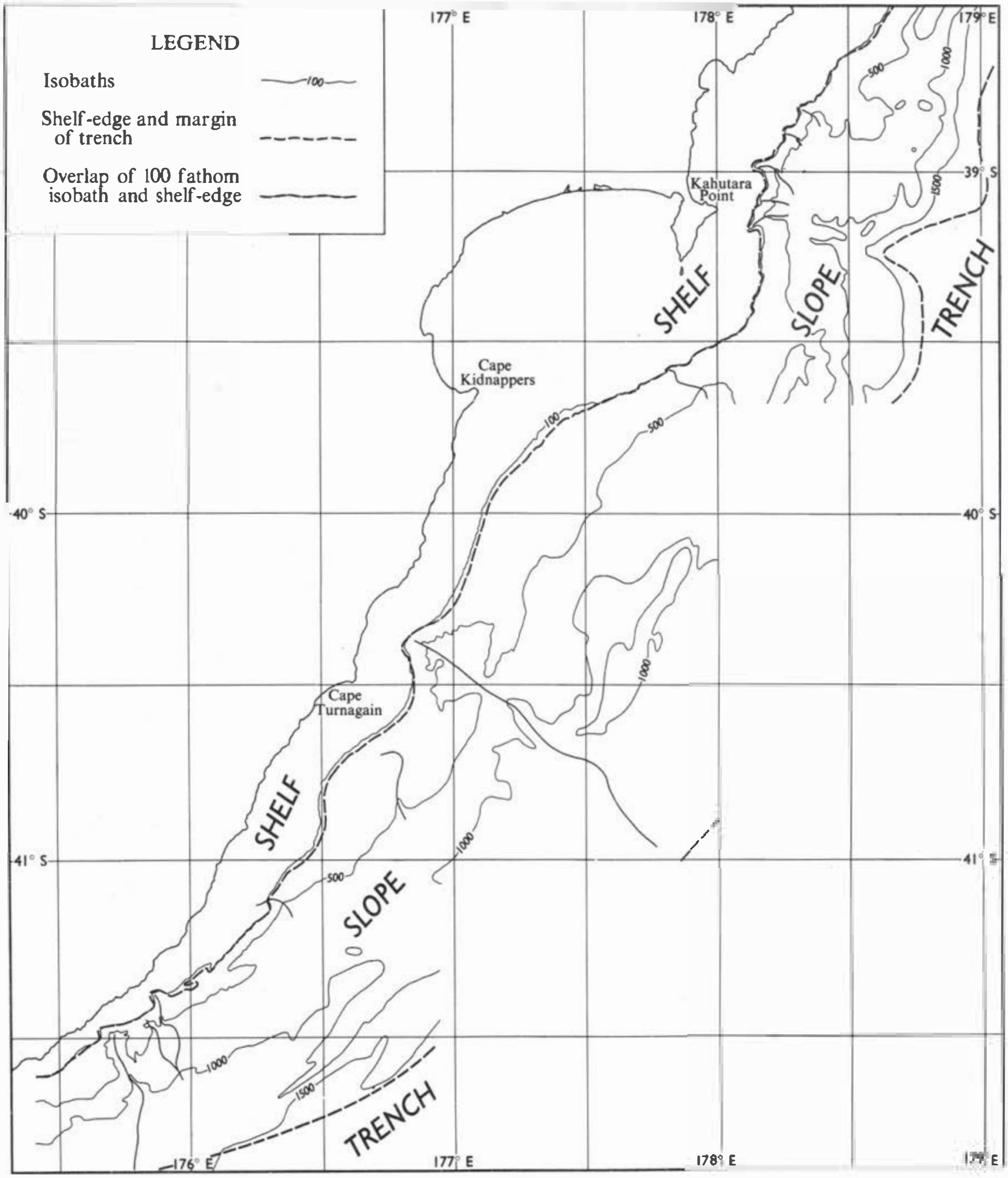


Fig. 3. Major morphological zones and canyon axes (solid lines), east coast, North Island.

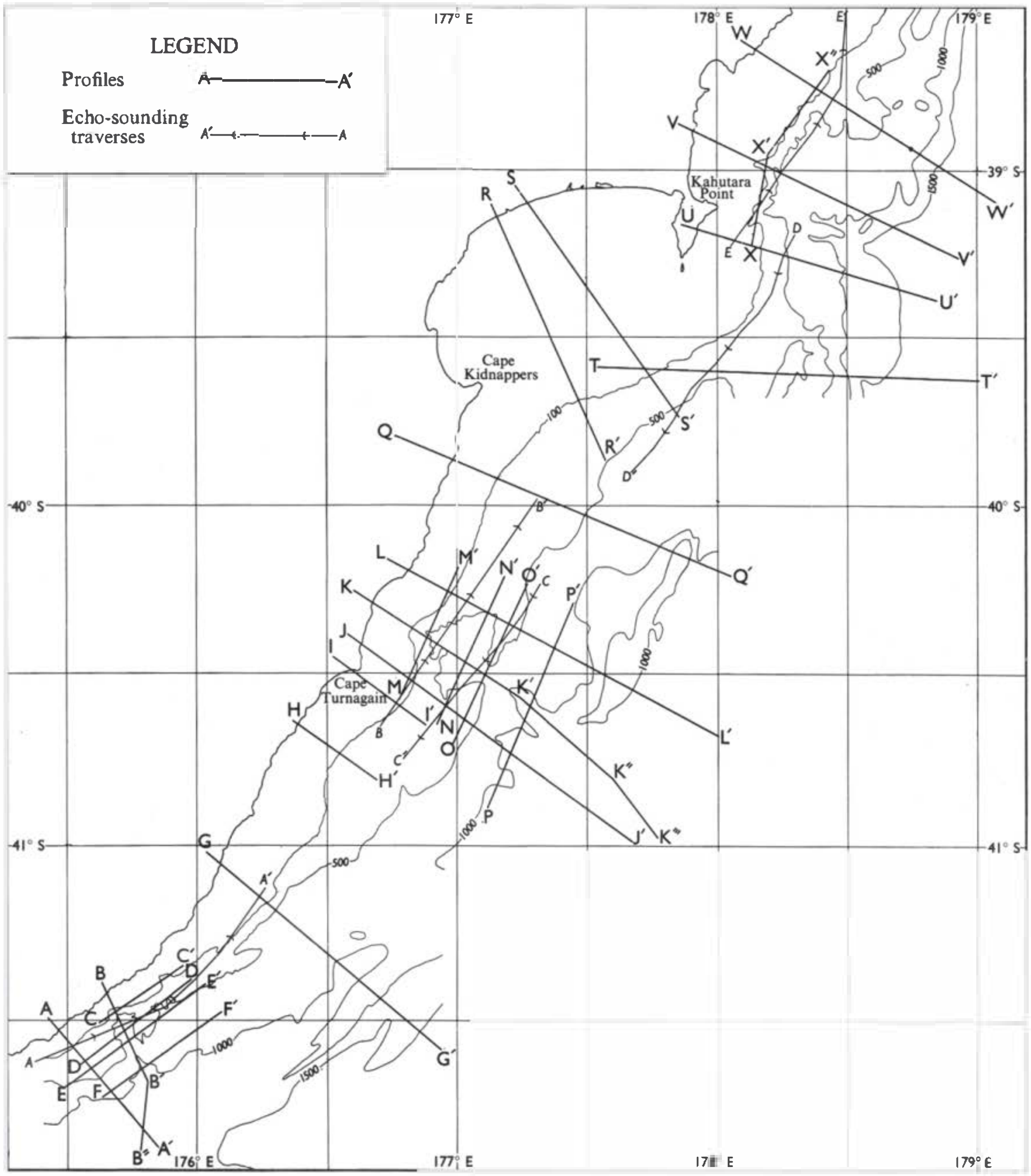


Fig. 4. Locations of depth profiles (fig. 5) and echo-sounding traverses (fig. 6).

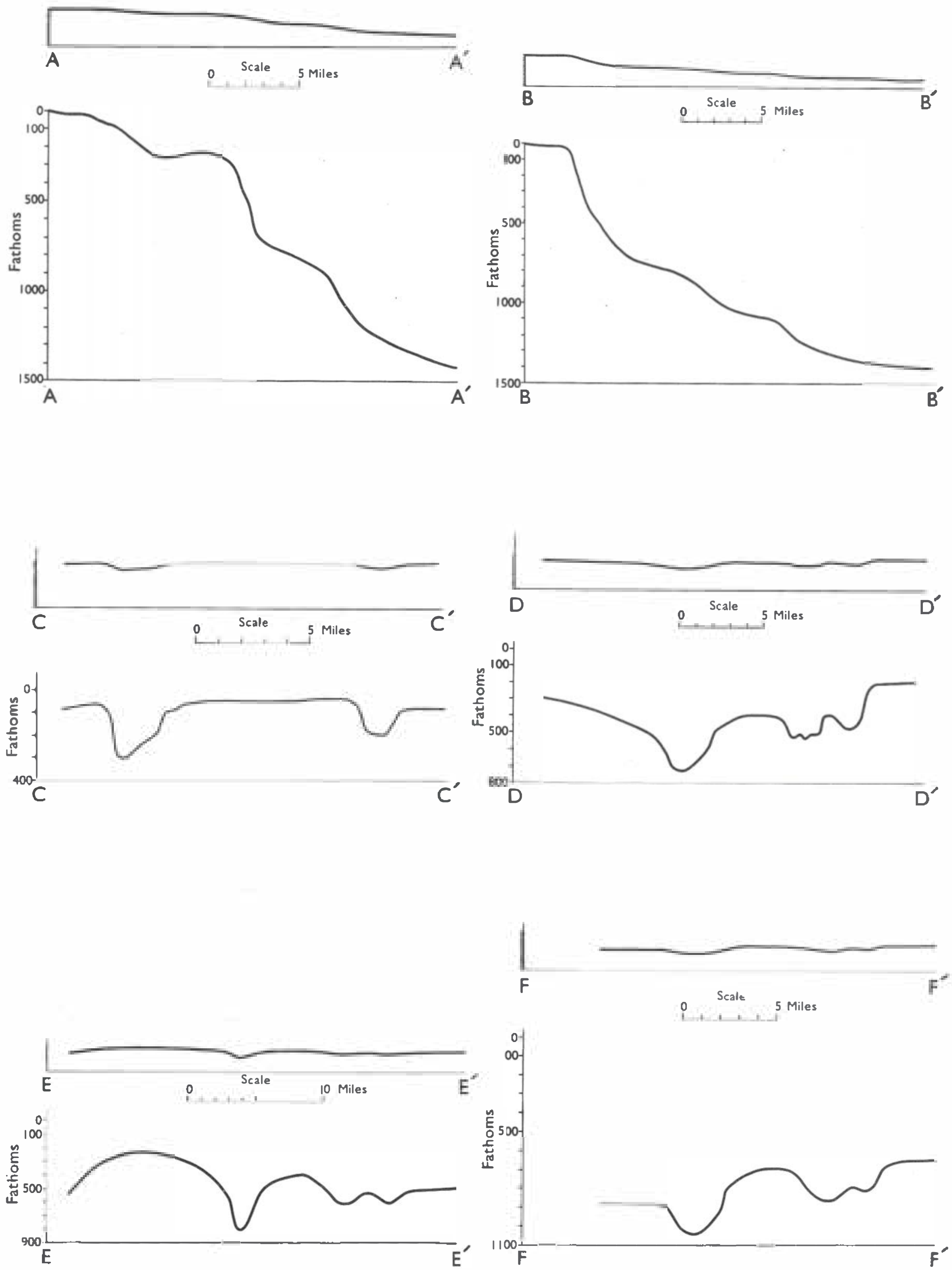


Fig. 5. Depth profiles.

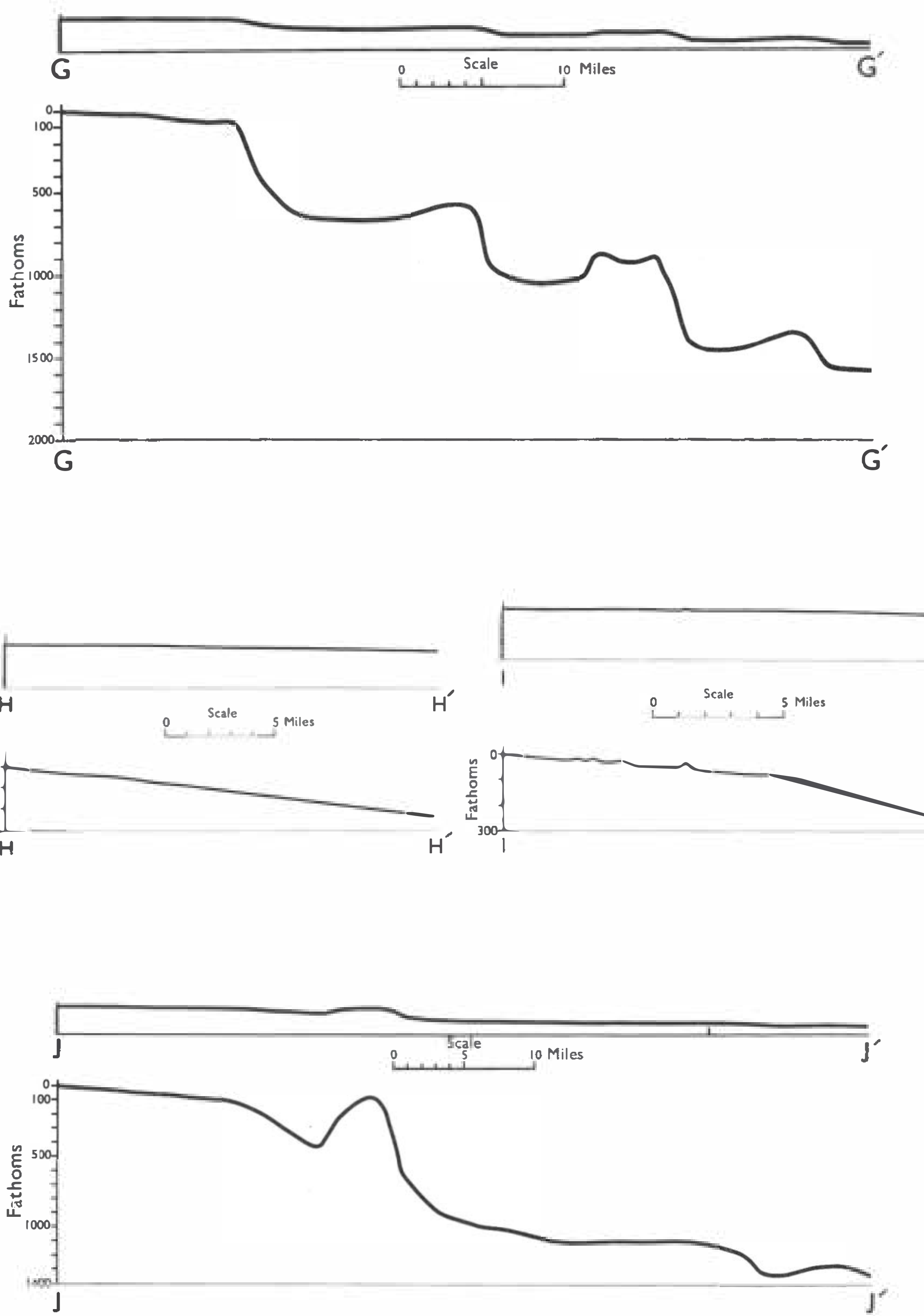


Fig. 5. Depth profiles (continued)

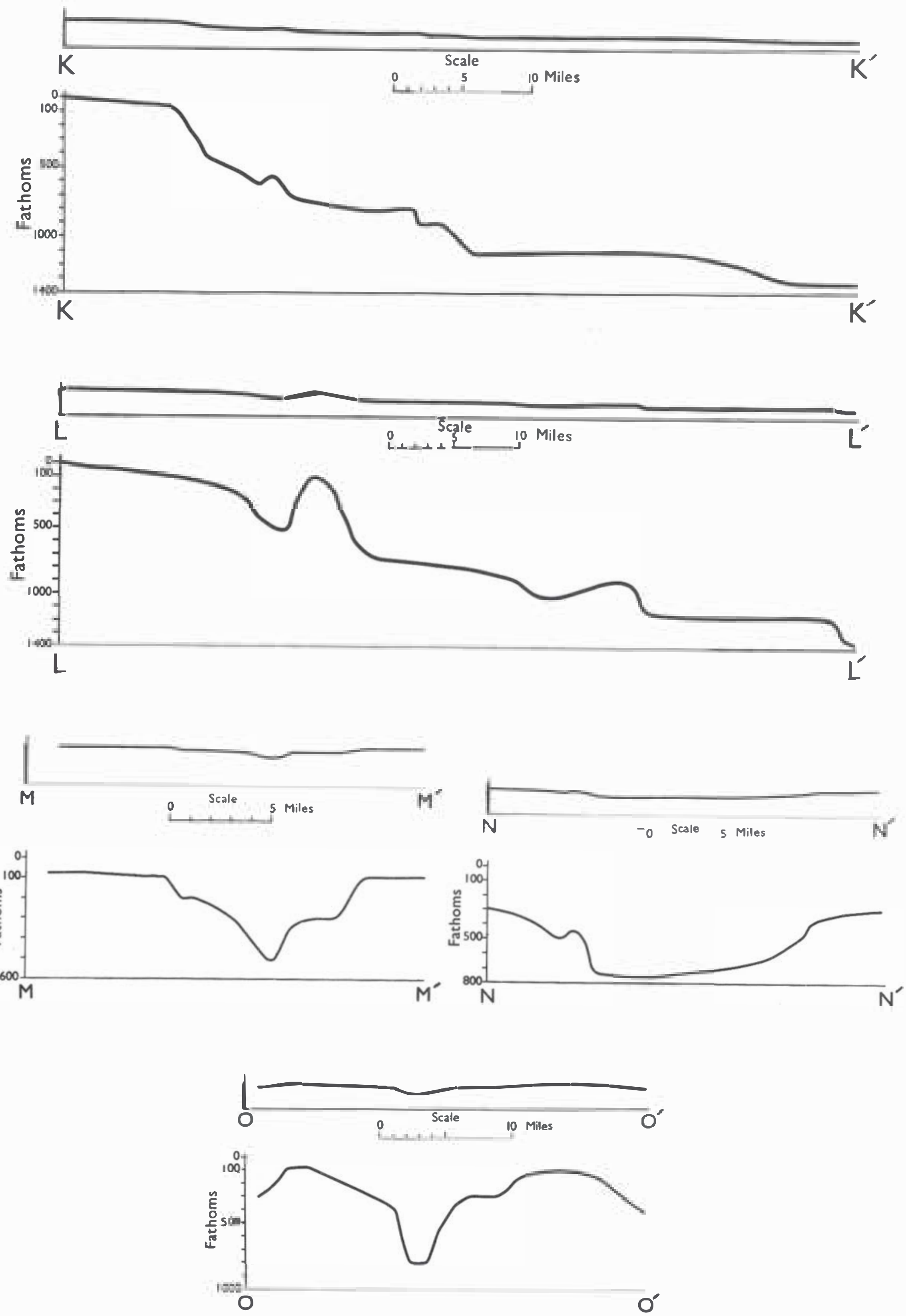
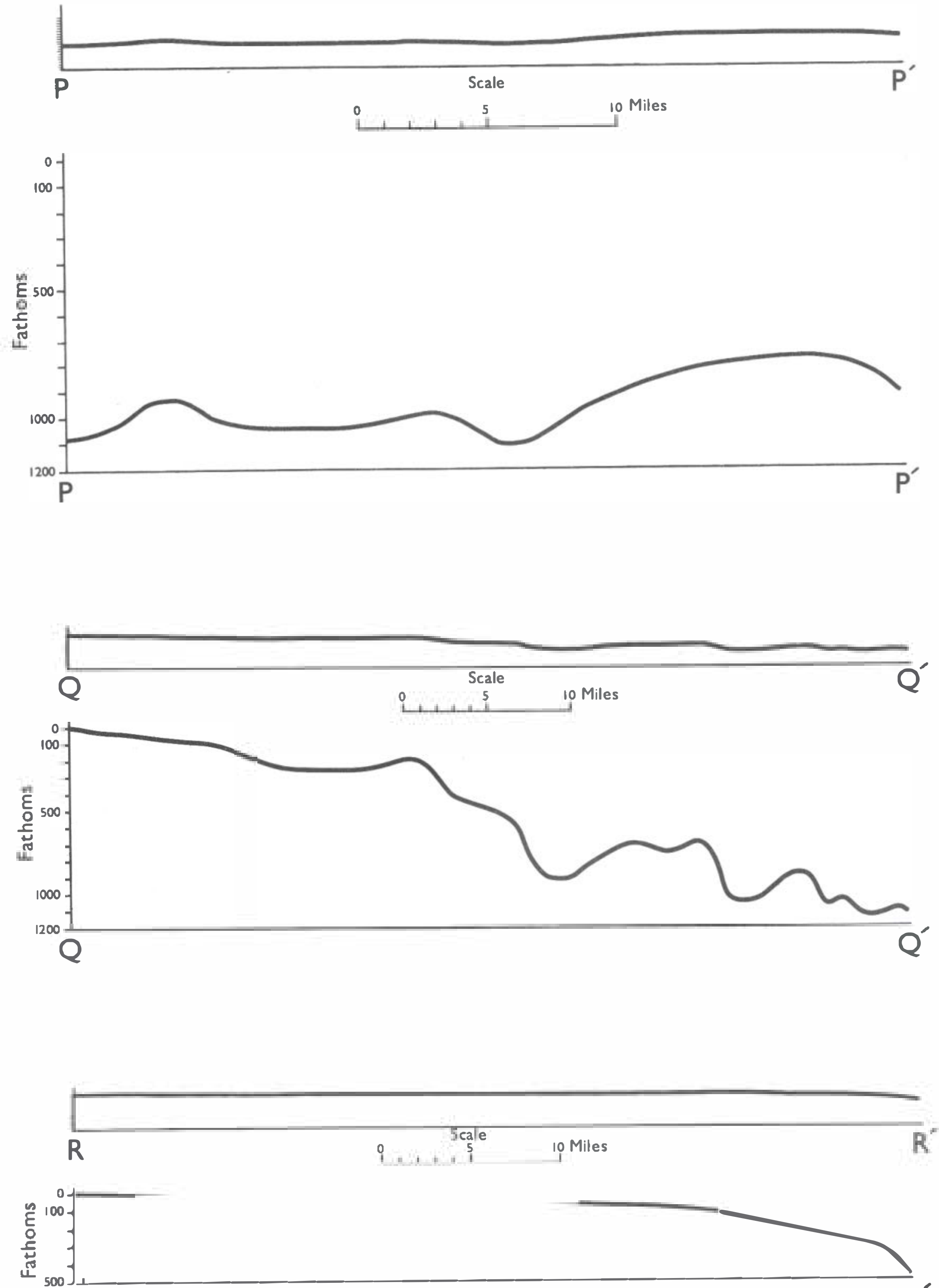


Fig. 5. Depth profiles (continued)



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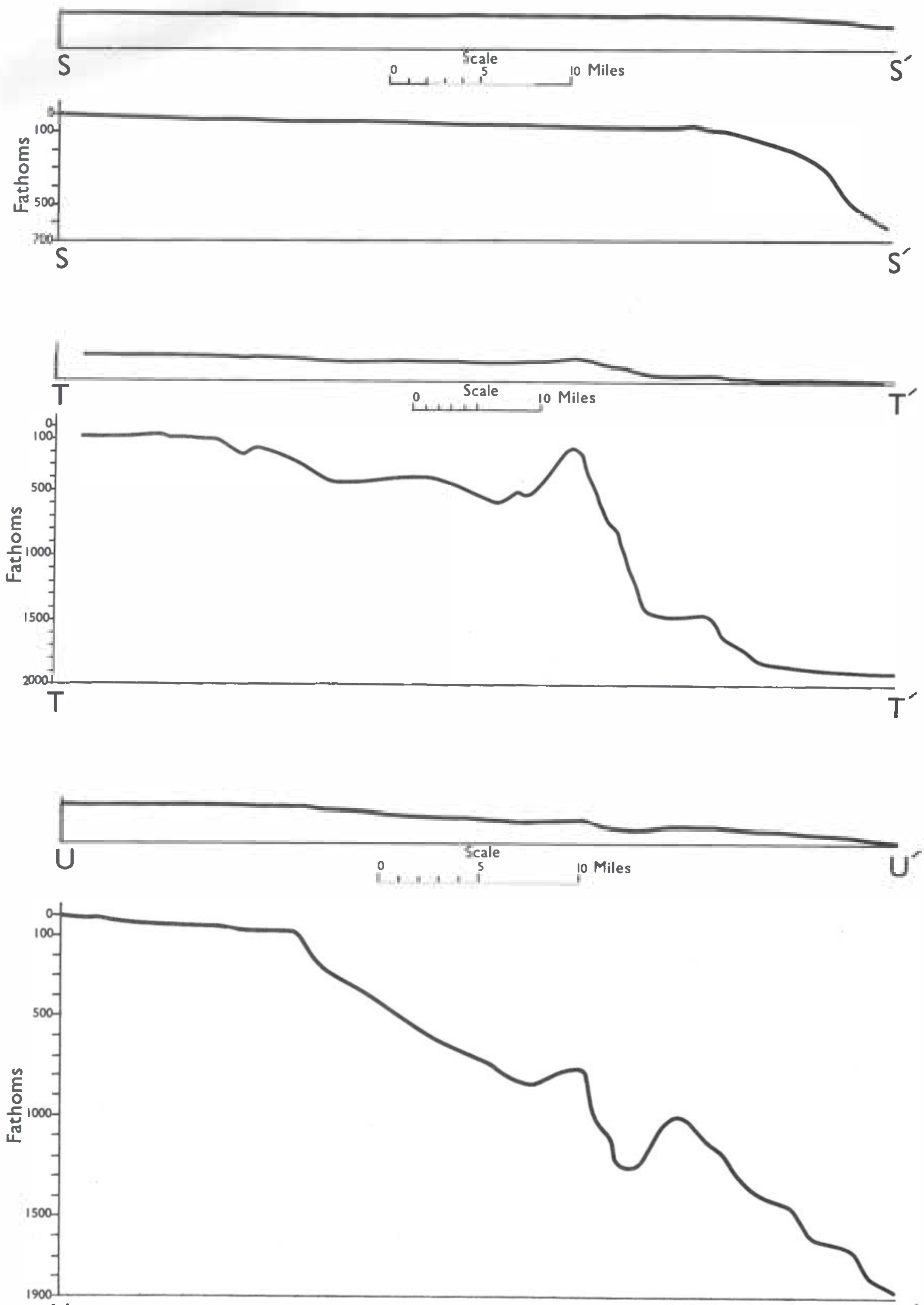

Fig. 5. Depth profiles (continued)

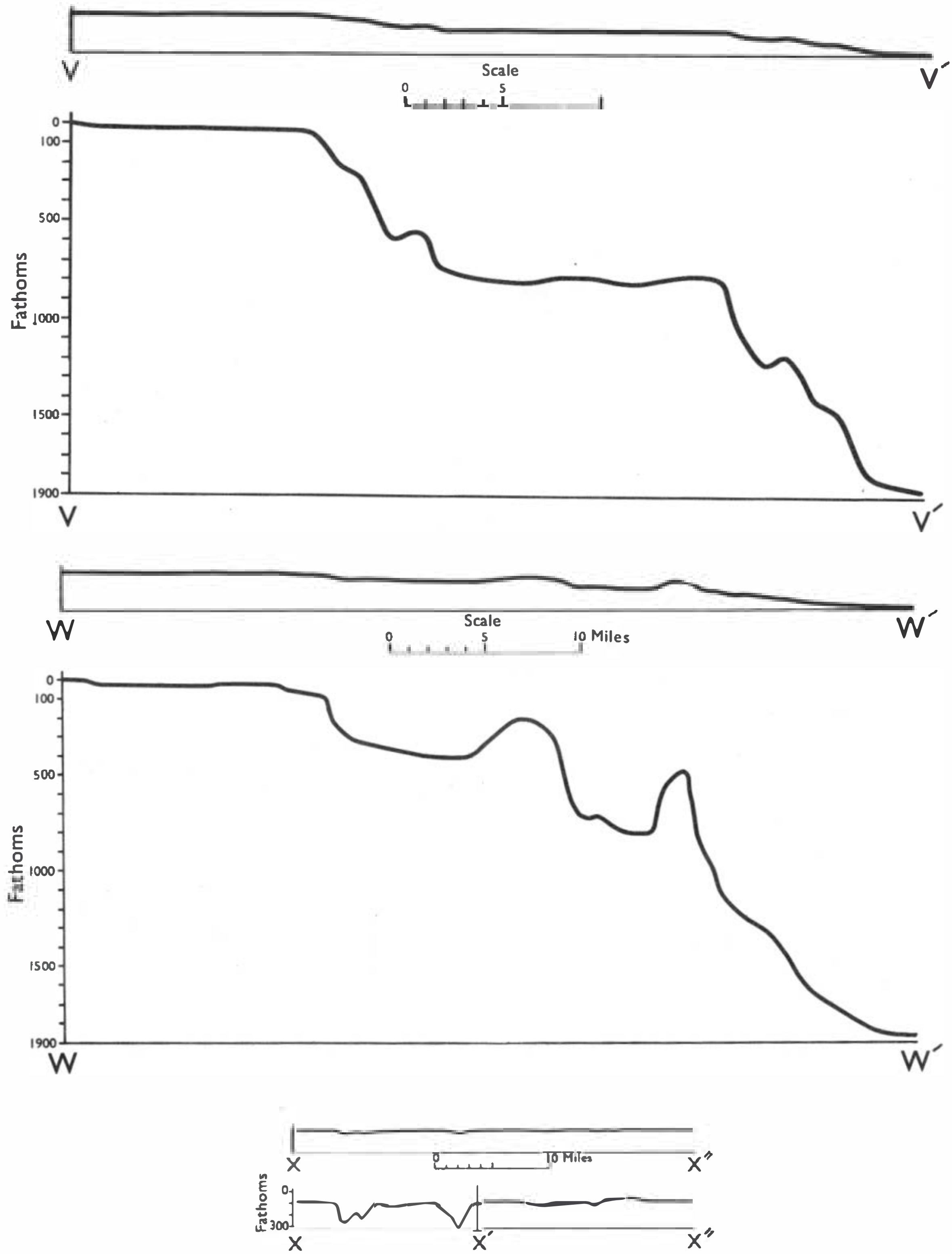

Fig. 5. Depth profiles (continued)

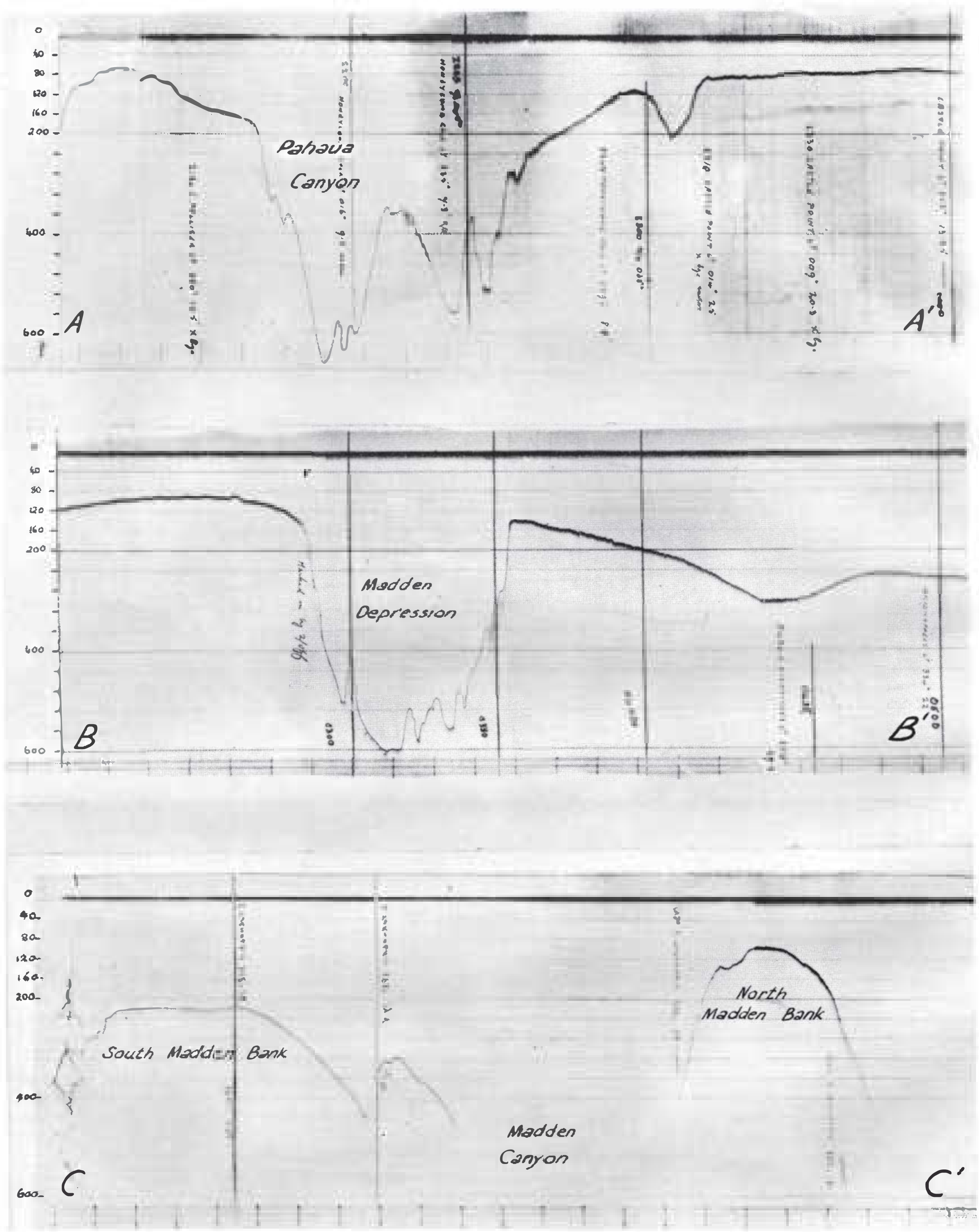

Fig. 6. Echo-sounding traverses:
AA′ Shelf and head of Pahaua and Honeycomb Canyons, between Cape Palliser and Whareama Bank.
BB′ Shelf and head of Madden Depression, between Cape Turnagain and Bare Island.
CC′ South and North Madden Banks.

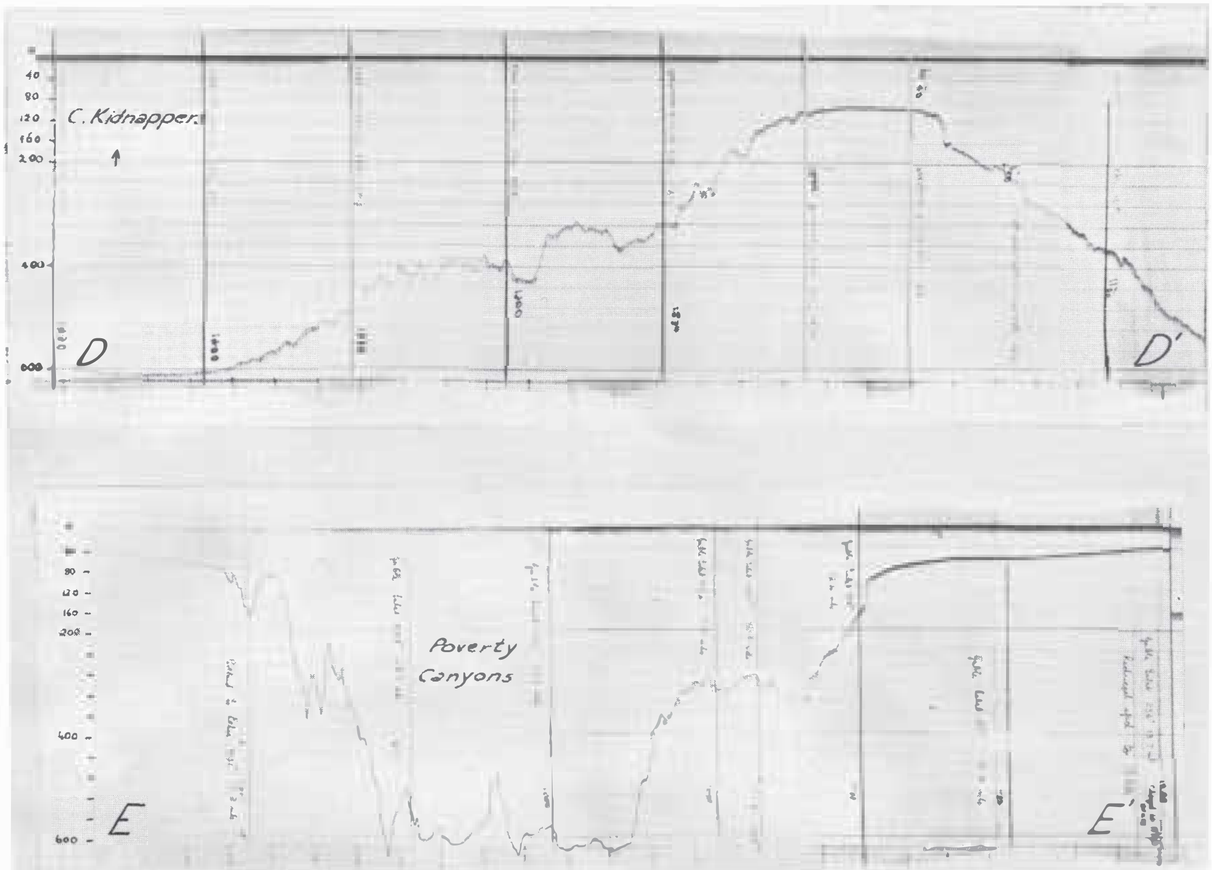

Fig. 6. Echo-sounding traverses (continued):
DD′ Offshore traverse, Cape Kidnappers to Mahia Peninsula, crossing the shelf edge off Portland Island. Note irregular nature of the slope.
EE′ Mahia Peninsula to Gable End Foreland across the head of Poverty Canyons.

occurs at about 110 fathoms and is much less abrupt than in the sector south of the bank. Around the head of the Madden Canyon the shelf edge becomes much more sharply defined and rises to 70 fathoms.

Between the Madden Canyon and the Lachlan Banks the shelf edge continues in about 110 fathoms, with a relatively slight change in gradient. Near the Lachlan Banks the change in gradient becomes more pronounced and the shelf edge rises to about 100 fathoms, continuing at the same level as far as the small offset in the shelf margin south-east of Portland Island. At this point the shelf edge suddenly rises to 90 fathoms and remains at about the same level from here to the Poverty Canyons. Between the various Poverty Canyons the shelf edge lies at 80–90 fathoms, but it rises opposite the heads of the canyons themselves, reaching in one case a minimum depth of 50 fathoms. North-east of the Poverty Canyons it continues for some distance at 90 fathoms, but descends to 110 fathoms and becomes less well defined on reaching another offset in the shelf margin east of Penguin Rock.

The trend of the shelf edge is generally straight or slightly curved, but this uniformity is interrupted by the local abrupt concavities opposite the heads of submarine canyons, by the irregularities around the Adams and Whareama Banks, and by the broader convexities which occur

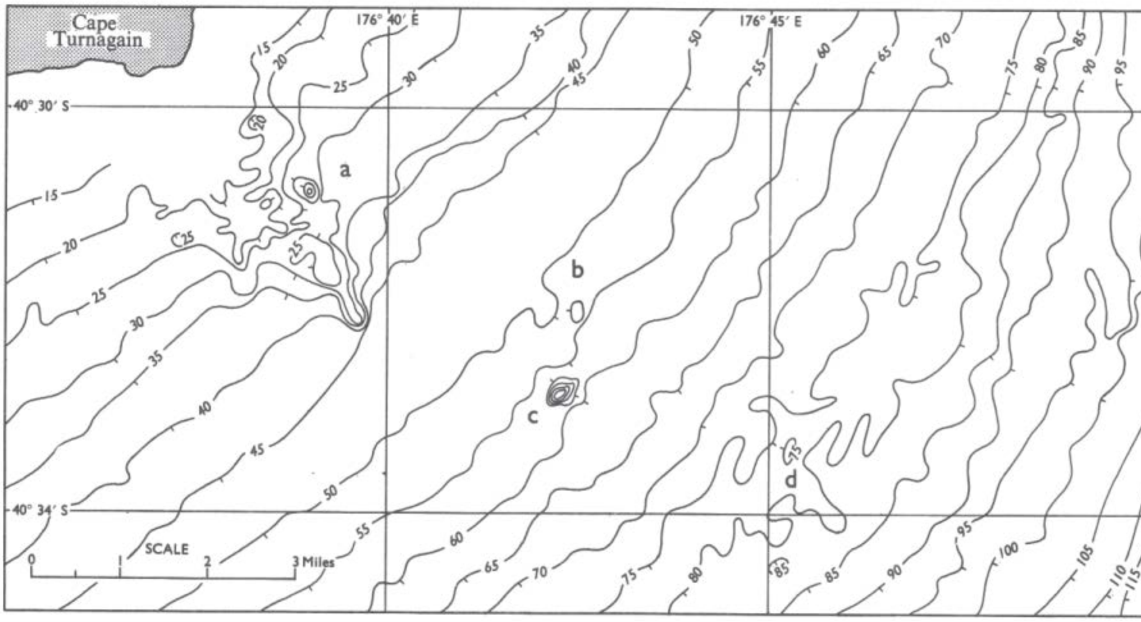

Fig. 7. Locations of small banks (a, b, c, d) off Cape Turnagain.

opposite Castlepoint, opposite Cape Turnagain, and near the Lachlan Ridge. There is also a conspicuous offset in the trend of the shelf edge across the most southerly of the Poverty Canyons. South of this canyon the trend is N-S, but on the north side the shelf edge continues about 3 miles further west and has a NNE trend.

Banks: Over most of the area the surface of the shelf is flat or gently undulating, but a number of isolated banks rise above the general level. The most important of these banks are the Lachlan Ridge, extending south-westward from near Portland Island, and the Ariel Bank, just outside Poverty Bay. Each of these banks has a very irregular surface and a pronounced elongation (N-S in the Ariel Bank, NE-SW in the Lachlan Ridge). Numerous small banks in 10–30 fathoms are found in the sector between the Opouawe River and Uruti Point, and north-east of Mahia. Banks in the 0–20 fathom zone are found along several parts of the coast, notably near the Mahia Peninsula. Opposite Cape Turnagain there is a group of small banks, which occur at various levels between the coast and the shelf edge (see fig. 7a, b, c, d).

Summit levels of the more important banks and associated islands are tabulated below; in the case of a group of banks the level of the shoalest individual summit is taken.

Table 1

Banks and Islands	Summit Level (shoalest sounding in fathoms)
1. Banks 5 miles ESE of Gable End Foreland	35
2. Small banks 13 miles ESE to 16 miles E of Gable End Foreland	67
3. Bank 8 miles SE of Gable End Foreland	27
4. Ariel Bank	5 (Penguin Rock) 2 (Ariel Rocks)
5. Banks 3 miles SE of Ariel Rocks ..	14
6. Banks 5–10 miles NE of Table Cape (Mahia Peninsula)	17
7. Small banks 8 miles SE of Table Cape	79
8. Coastal banks south of Mahia Peninsula	Above sea level (Portland Island)
9. Lachlan Ridge	37 (NE end) 54 (SW end)
10. Lachlan Banks	50
11. Bank 9 miles south by east of Cape Kidnappers	37
12. Coastal banks in the Cape Kidnappers - Porangahau sector	Above sea level (Bare Island)
13. Turnagain Banks .. a.	14
b.	49
c.	35
d.	73
14. Small bank 10½ miles ESE of Castlepoint	89
15. Bank 4 miles SE of Uruti Point ..	14
16. Whareama Bank	62
17. Adams Bank	78
18. Small banks between Whareama and Adams Banks	67
19. Bank 2½ miles SE of Honeycomb Rock	23
20. Small banks opposite head of Pahaua Canyon	11
21. Kaukau Bank	10

Continental Slope

The shelf passes outwards into the slope, an area where much steeper gradients prevail. On a broad scale the slope descends towards the Hikurangi Trench, but the descent is not continuous as the surface of the slope is very irregular, being diversified by numerous features, some with positive and others with negative relief. These features may be divided into four groups: (i) submarine canyons, (ii) sea valleys, (iii) slope depressions, and (iv) slope highs.

Submarine Canyons: Some of the features with negative relief can be clearly identified as submarine canyons. The major examples are as follows, proceeding from north to south:

Poverty Canyons (5),
Madden Canyon,
Honeycomb Canyons (2),
Pahaua Canyon.

These all appear to be true submarine canyons, formed by some gravity-operated process. They all run at wide angles to the general trend of the slope and their axes descend progressively away from the shelf edge, although this descent is irregular and is interrupted in the case of the Madden Canyon by three zones where the axis becomes virtually horizontal.

The Poverty Canyons, which are relatively small, become progressively narrower towards the shelf edge, as do the majority of submarine canyons elsewhere. The Madden, Honeycomb, and Pahaua Canyons, on the other hand, are much larger than the Poverty Canyons, and their shape is strikingly different. The Honeycomb and Pahaua Canyons do not narrow progressively towards the shelf, but show a distinct expansion at the headward end. This tendency is greatly magnified in the Madden Canyon, which expands at its upper end into the wide Madden Depression, and which has a shape quite unlike that of most other submarine canyons.

Other conspicuous and unusual features of the Madden Canyon are the abrupt constriction between the North and South Madden Banks, the 15-mile zone where the axis runs almost horizontally at slightly below 1,100 fathoms, and the wide, shallow depression defined by the 1,200- and 1,300-fathom isobaths (the Akitio Depression).

The South Honeycomb Canyon does not reach the shelf, but all the other canyons indent the shelf edge, and in these cases the axis of indentation is directed not at right angles to the shelf but in a somewhat more southerly direction. In their uppermost reaches the axes of these canyons are thus convex towards the north. Away from the shelf the axes of the Poverty Canyons are consistently convex towards the north, whereas the southern canyons are slightly sinuous and show no obviously consistent direction of curvature.

The Pahaua and Madden Canyons can be traced down to 1,400 fathoms and 1,300 fathoms respectively (these being the limits of the available information), but the Honeycomb Canyons are seen to fade out at about 1,000 fathoms and the Poverty Canyons at 600–800 fathoms, long before reaching the foot of the continental slope in either case.

As far as can be ascertained from the available soundings the wall topography of the central and lower parts of the Madden, Honeycomb, and Pahaua Canyons is smooth, and the outer limits of the canyons are not well defined, as the walls grade laterally into the general continental slope. Near the heads of these canyons, however, the wall topography becomes markedly irregular, with numerous smaller gullies converging on the main canyons. A conspicuous break in slope also appears near the upper end of each of these canyons, extending around the canyon head and linking up with the indented shelf edge in the case of the Pahaua, North Honeycomb, and Madden Canyons. The greatest relative extent of this break in slope is seen alongside the North Honeycomb Canyon, where the break continues downward for about two-fifths of the total length of the canyon.

There is an overall tendency for the walls of the Madden, Honeycomb, and Pahaua Canyons to become steeper as they approach the shelf edge, but in each case the variation in gradient is more or less irregular. The wall gradient of the Madden Canyon is extremely variable, being steep near the head of the Madden Depression and near the Banks, but comparatively gentle elsewhere. The headward expansion which occurs in the Pahaua and Honeycomb Canyons is accompanied by a locally diminished wall gradient.

In the Poverty Canyons the wall topography is mainly irregular and the walls are relatively steep, except at the lower extremities of the canyons where they flatten out on reaching the 600–800-fathom zone. The outer limits of these canyons are defined in many places by a rapid change in gradient at the junction of the canyon walls with the adjacent continental slope.

Sea Valleys: In addition to the canyons there are a series of minor submarine valleys which lack some of the distinctive characteristics of the canyons. Sea valleys of this type occur south-east of the Whareama River, south of Cape Turnagain, just outside the Lachlan Ridge, south-east of the

Poverty Canyons and east of Gisborne. The Whareama, Turnagain, and Hawke Sea Valleys, which lie on the upper part of the slope, are markedly sinuous in plan and run obliquely to the general trend of the slope. The Poverty and Gisborne Sea Valleys lie at a much greater depth than the nearby canyons and appear to be relatively straight, although their shape is only approximate due to the comparatively wide spacing of the echo-sounding lines in the vicinity.

Slope Depressions: This term is proposed for a series of features with negative relief whose origin appears to be, at least in part, fundamentally different from that of the submarine canyons and sea valleys. The major features belonging to this category are divided here into three groups corresponding to the sectors in which they occur, and are as follows:

Castlepoint Group—
Uruti Depression
Pukeroro Depression
Aorangi Depression

Madden Group—
Madden Depression
Motukura Depression
Paoanui Depression
Omakere Depression
Akitio Depression

Mahia-Gisborne Group—
Mahia Depression
Paritu Depression

The depressions of the Castlepoint and Madden Groups vary from 10 to 15 miles in width and range up to 50 miles in length. The majority exhibit a pronounced NE-SW elongation and run approximately parallel to the general trend of the slope. They have a more rounded cross section than the canyons, and there is frequently a wide flat zone in the centre. The depressions of the Mahia-Gisborne Group are less regular in morphology and trend than those in the area further south.

Slope Highs: This term is proposed for the numerous slope features with positive relief. The major examples have been divided into groups corresponding to the same three sectors as were used for the slope depressions.

Castlepoint Group—
Kaiwhata Bank
Uruti High
Pukeroro High
Aorangi High
Honeycomb High

Madden Group—
Motukura Bank
North Madden Bank
South Madden Bank

Omakere High
Porangahau High
Akitio High

Mahia-Gisborne Group—
Ritchie Banks
Te Kapu High
Gable High
Tuaheni High

Many of the highs are markedly asymmetric in cross section, and there is a distinct tendency in the Castlepoint and Madden Groups for the seaward-facing gradients to be steeper than the landward-facing gradients. There is also evidence that the highs, particularly those on the upper part of the slope, have a more irregular relief than the associated depressions, although the available information is not conclusive in this respect.

The Ritchie Banks (fig. 8) and the Gable High show a NE-SW elongation, but the other highs of the Mahia-Gisborne Group are not greatly elongated and are generally smaller than the highs further south. The relief in the Mahia-Gisborne Group varies from about 100 to 400 fathoms.

The highs of the Castlepoint and Madden Groups are markedly elongated and show a conspicuous NE-SW alignment, running parallel to the associated slope depressions. They range from 3 to 10 miles in width and from 6 to 40 miles in length. Their relief, as compared with the surrounding general level, varies from 70 fathoms (Motukura Bank) to 600 fathoms (Madden Banks).

Hikurangi Trench

Very few of the *Lachlan* sounding lines extend into the area of the Hikurangi Trench and the shape of the Trench can only be delineated on a broad scale. (The same lack of detail, unfortunately, extends to the lower part of the slope.) The profiles indicate that the floor of the trench is virtually flat over large areas, any depressions and elevations being very broad and gentle. Pronounced irregularities like those on the slope appear to be absent.

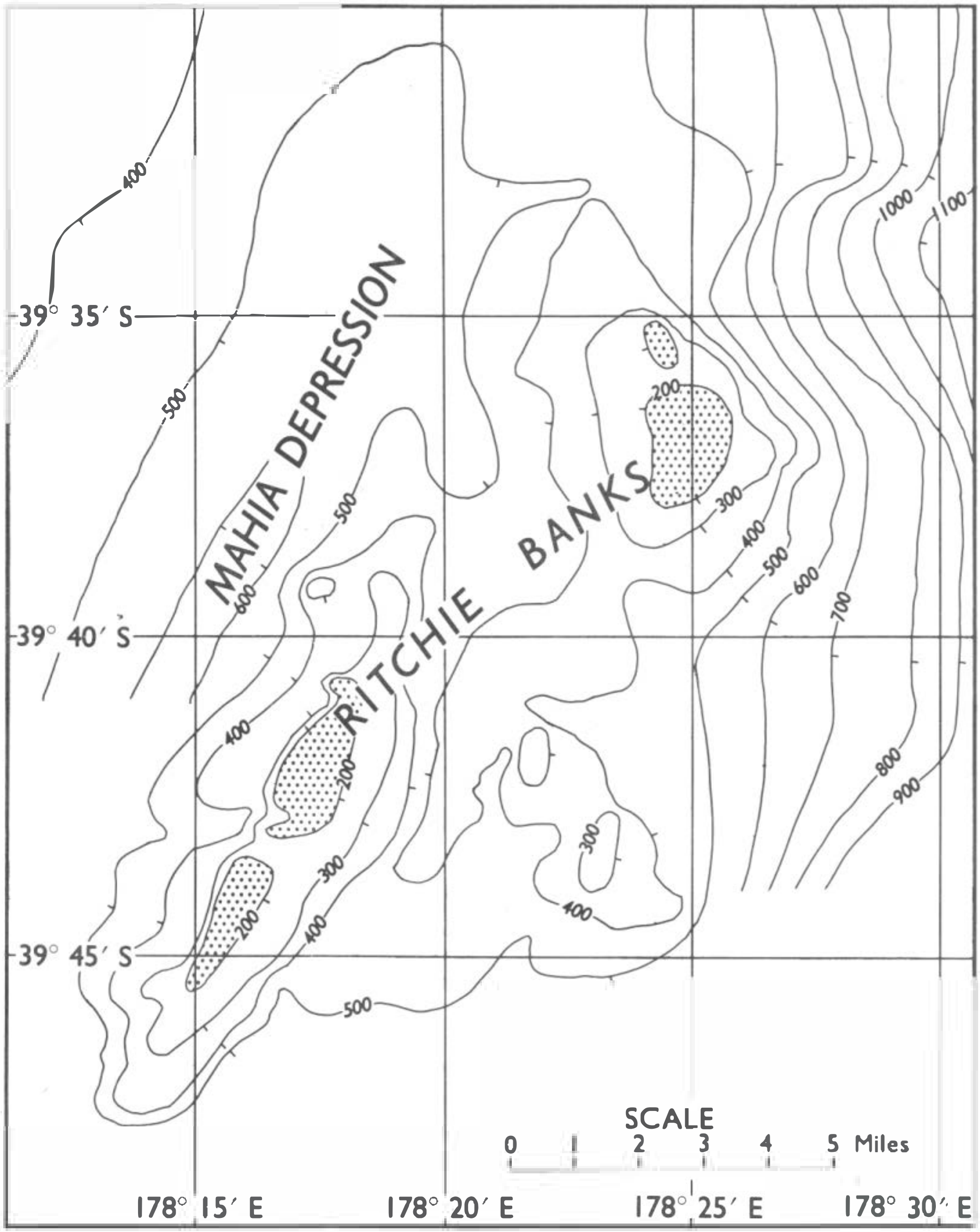

Fig. 8. Ritchie Banks. Depths less than 200 fathoms shown stippled.

Sig. 4

DISCUSSION

The Shelf

General Morphology: Although the surface of the shelf is virtually planar, it lies immediately alongside a land mass which has suffered a considerable degree of folding and faulting. The structures now seen are the accumulated result of tectonic activity that persisted throughout most of the Tertiary and continued into the Quaternary; it is still in progress at the present day. There can be little doubt that similar folding and faulting has affected the rocks underlying the shelf, and such a process would tend to produce a well developed ridge-and-valley morphology, provided that no other factors intervened. The actual morphology of the shelf, however, shows clearly that the effects of marine erosion and sedimentation have been dominant in late geological times and have almost entirely prevented the development of a ridge-and-valley morphology. The only remaining evidence of tectonic features in the shelf area is the presence of banks like the Lachlan Ridge and the Ariel Bank. The isolation and irregular surfaces of these banks indicate that they are erosional relicts derived from older and more extensive elevations. It is noteworthy that both the Lachlan Ridge and the Ariel Bank are elongated in directions which fall within the spread of major fold axes on the nearby land. This upholds the view that these two banks, at any rate, are derived from features of tectonic origin.

The tectonic environment shows that some of the shelf at least must have been produced by marine planation of zones of comparatively resistant Tertiary rocks. Such rocks would not suffer significant erosion below about 10 fathoms, and it is therefore clear that the outer part of the shelf has been cut during periods of low relative sea level. Glacially controlled eustatic lowering of sea level offers an explanation for the general depth of the outer shelf, but does not account for the varying depth of the shelf edge from one part of the area to another. Differences in the lithology of the underlying rocks might give rise to corresponding differences in the depth of the shelf edge, but variations due to lithology would probably be more irregular, abrupt, and localised than is actually the case. Moreover, the levels of elevated marine platforms and terraces are frequently seen to be virtually unaffected by the underlying lithology. It is therefore probable that the observed variations in the depth of the shelf edge are due to tectonic warping during and after the cutting of the shelf.

The width of the shelf must be controlled partly by the resistance of the country rocks to marine erosion and partly by tectonic movements in the shelf area. The general southward narrowing of the shelf is in keeping with the simultaneous increase in the proportion of older and more resistant rocks in the nearby land mass, and can thus be explained in terms of lithological control, whereas in the Hawke Bay area marine erosion has been greatly assisted by tectonic subsidence, causing a large re-entrant in the coastline and a considerable local increase in the width of the shelf. A similar situation, though on a smaller scale, is found in the embayment between Poverty Bay and Mahia.

Benches and Banks: Three factors must be considered with respect to the various benches on the shelf: (1) differential lithological control; (2) intermediate stands of sea level; and (3) tectonic warping of the shelf. The location of benches would be determined mainly by (1) and (3), whereas their hypsometric level would be determined mainly by (2) and (3). Lithological control has clearly been responsible for the survival of the isolated banks on the shelf, which presumably consist of material that proved more resistant to erosion than the rocks on either side. This indicates that lithology had little effect in determining the location of the Hawke Bay benches or the 40–50 fathom bench in the Kidnappers-Porangahau sector, as these occur in zones of smooth topography and show no topographical correlation with the shelf banks. Tectonic warping of the shelf provides the most satisfactory explanation of these particular benches. There is also strong evidence of shelf warping in the case of the wide bench outside Poverty Bay. The Ariel Bank and another group of banks to the south form a conspicuous rim to this bench, suggesting lithological control, but the bench contains a basin of very low relief but considerable width (fig. 9), and is evidently a zone of subsidence. The 20–30-fathom bench in the Te Kaukau - Honeycomb Rock sector lies in a zone of irregular topography and has probably been subjected to some degree of lithological control; however, the variable depth of the shelf edge in this sector indicates that the shelf has been affected by tectonic warping, and hence this bench also may be tectonic in origin.

On the assumption that the main benches in the area are due to tectonic deformation of the shelf, zones of relative uplift and subsidence are indicated on fig. 10. The axes of deformation are not well defined, but tend to run NE-SW. Basining might have been expected in the subsiding zones, but its absence, except in the case of the Poverty Bay bench, is no doubt due to sedimentation.

The possible effect of intermediate stands of sea level may be gauged by reference to the morphology of the shelf banks. Erosion during stationary or slowly changing sea levels would be expected to give rise to concordant summit levels on the banks, although these levels would be progressively modified and their concordance obscured by later tectonic movements. Over a limited area, however, there should be some degree of hypsometric correlation between the summits of banks and any erosional benches in the vicinity.

No such correlation is evident between the main benches on the shelf and the summit levels of the banks, either on a local or on a regional scale. The summit levels show a wide range of variation, but although there appear to be preferred levels around 14, 36, 50, 67, and 78 fathoms, these show no hypsometric correlation with the benches in question. This supports the view that these benches are tectonic, since the hypsometric levels of tectonic benches would be determined by their location on the shelf, and would thus be independent of sea level.

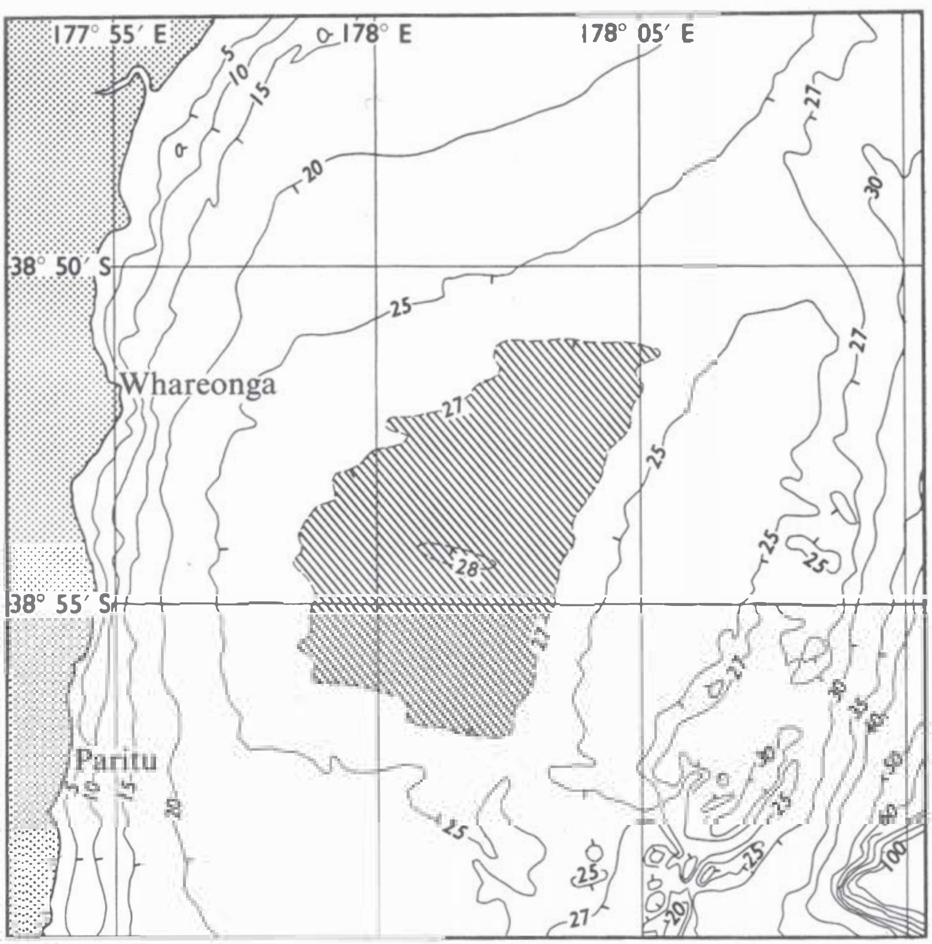

Fig. 9. A shallow enclosed basin on the shelf off Whareonga in Poverty Bay. The general depth below sill is 1 fathom with a maximum in the centre of 2 fathoms.

The small 65-fathom bench west of the Pahaua Canyon may have been produced by erosion at an intermediate stand of sea level, but any other benches which were formed in this way have apparently been obscured by sedimentation, or else are insignificant in width. The small bench east of the Ariel Bank probably owes its existence to local variations in lithology, as its northward inclination (25-45 fathoms) cannot be readily explained in terms of tectonic warping and is not consistent with erosion at a particular stand of sea level.

Sinuous Portions of the Shelf Edge: The sinuosity of the shelf edge in the Castlepoint-Porangahau sector is probably also due to tectonic warping. The convexity opposite Castlepoint gradually dies out towards the shore, but that opposite Cape Turnagain persists all the way across the shelf, and in both cases there are banks lying along the line of greatest convexity. These features indicate that the shelf has undergone warping on broad axes running NW-SE at Cape Turnagain and WNW-ESE at Castlepoint. The convex parts of the shelf, surmounted by banks, correspond to zones of upwarp, with zones of downwarp in between. Morphological considerations indicate that Porangahau Beach is a zone of relative subsidence, and the shelf downwarp opposite Porangahau has therefore been drawn to include the beach area. The demonstrated fault running along the back of the beach (Lillie, 1953, map for Porangahau S.D.) may mark the north-western limit of the downwarp. There is little doubt that Porangahau Beach has suffered a small degree of late uplift (Lillie, *op. cit.*, p. 94), but the whole coastline north and south of Porangahau is emergent (King, 1932, p. 79) and evidently shared this uplift.

The convexity of the shelf edge near the Lachlan Ridge is probably due to upwarping along an axis running through Mahia Peninsula, the banks around Portland Island, and the Lachlan Ridge itself (fig. 10).

Faulting: The terrain behind Castlepoint and Cape Turnagain shows no evidence of warping on NW-SE axes comparable with that on the nearby shelf. This suggests the presence of a fault running parallel to the coast, allowing the shelf and nearby land mass to undergo independent tectonic movement. The suggested fault has been drawn to coincide with the demonstrated faults (Ongley, 1935, map) separating the rocks of Castlepoint and Cape Turnagain from those of the mainland.

Between the Mohaka River and Napier there is a pronounced uplift of the post-Nukumaruan marine peneplain of northern Hawke's Bay, the uplifted area reaching the coast in high cliffs around Matangimomoe. The nearby submarine morphology, on the other hand, shows no evidence of this uplift below the 10-fathom isobath, while 20-fathom and lower isobaths are convex towards the coast and indicate mild subsidence. The abrupt change from uplift to subsidence in the region of the coast suggests the existence of an off-shore fault running parallel to the coast. Cotton (1956, p. 687) recognised the possible existence of such a fault, but preferred the hypothesis of a monoclinal flexure on the grounds that the fault hypothesis was not supported by collateral evidence. It seems to the present writer, however, that the abrupt termination of the uplift is best explained by a fault.

Another fault on the shelf is indicated by the abrupt change in direction of the shelf across the line of banks running ENE from Flat Point.

The Slope

Introduction: The significance of the continental slope as a world-wide feature is still a matter of considerable discussion. It may be said first of all that given the existence of continents and ocean basins the continental slope is a geometrical necessity. As there are two main preferred levels on the earth's surface, there *must* be a zone of maximum gradient leading from one to the other, and any explanation for the existence of continents and ocean basins automatically covers the continental slope. Due to its tectonic environment, the slope is often a zone of flexure or faulting, but these movements merely modify the form and gradient of the slope: they are not the basic reason for its existence. In the present area the unusual steepness of the slope as compared with the rest of New Zealand (except for the region west of Fiordland) is undoubtedly due to the tectonic movements (principally Tertiary and Lower Quaternary) which resulted in the uplift of the eastern part of the North Island and the subsidence of the Hikurangi Trench.

The Submarine Canyons: The general problems concerning the origin of submarine canyons in various parts of the world are also a prolific subject for discussion. A great deal of evidence has been collected and the problem has been discussed at length by a number of workers. The canyons are clearly the result of erosion by some gravity-operated process and the weight of evidence in particular cases usually supports one or other of two possible modes of origin: (1) erosion by rivers, followed by submergence; and (2) erosion by turbidity currents (Kuenen, 1953).

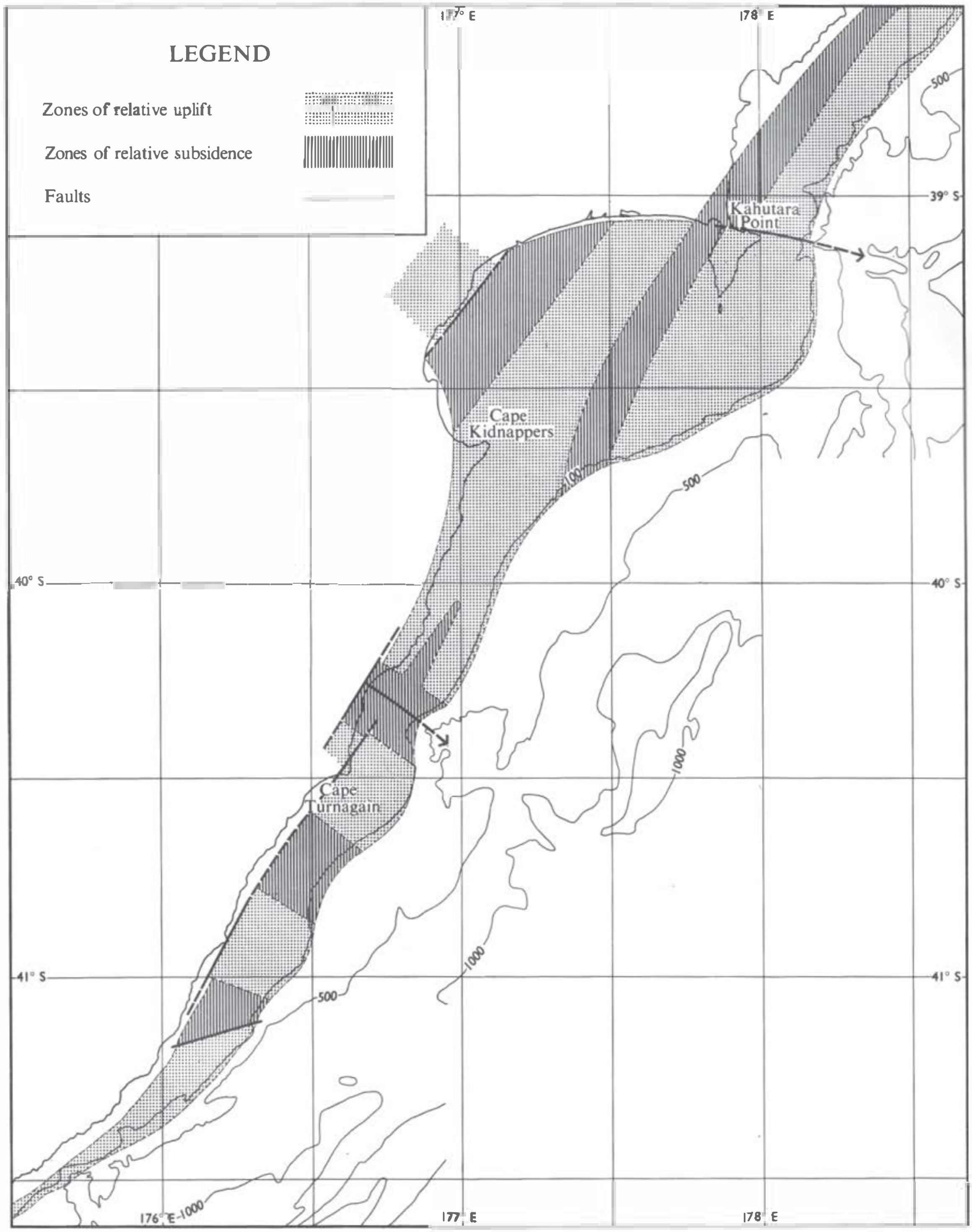

Fig. 10. Zones of relative uplift and subsidence on the east coast shelf.

The morphology of the canyons in the present area indicates that both these factors have played a part. One important characteristic of turbidity currents is that below a certain critical velocity a current with a given sediment content will slow down and deposit sediment, whereas above that velocity it will speed up and erode sediment. It would therefore be expected that with turbidity currents passing down a submarine canyon, deposition would take place on the edges and erosion in the centre. This would cause a fairly sharp break in gradient to develop along the edges of the canyon. In contrast, marine erosion during the submergence of a river valley would tend to flatten the sides of the valley, particularly if the country rocks were susceptible to mechanical erosion. The walls of the eventual submarine canyon would thus grade into the general slope on either side. Although the valley would be partly or even wholly infilled by sedimentation during submergence, the sedimentary fill would be much less resistant than the bedrock, and the buried topography might easily be resurrected by turbidity currents (compare Daly, 1936, p. 419).

This indicates that the central and lower portions of the Pahaua, Honeycomb, and Madden Canyons represent submerged river valleys, as in these portions the wall topography is smooth and the walls grade outwards into the general continental slope. The smooth wall topography may be due in part to the blanketing effect of recent sedimentation, but this effect would probably not be sufficient to obliterate a well defined break in gradient along the canyon margins, if such a feature had once been present.

The irregular topography at the heads of the Pahaua, Honeycomb, and Madden Canyons, and in the Poverty Canyons, shows that turbidity currents have been active in these localities during recent geological time. This irregular topography has probably been produced by turbidity current erosion below sea level; a terrestrial landscape of similar complexity would be unlikely to survive the effects of marine erosion during submergence unless the bedrock was very resistant and the submergence rapid. In any case, even if some of the gullies are terrestrial in origin, they must have been scoured or kept open by turbidity currents.

The hypothesis of turbidity current erosion is supported by the northward convexity of the canyons in the zones of irregular topography. Currents of this type might occur as a result of earthquakes, but could also be generated by muddy water churned up in the shelf area by storms, particularly during times of low eustatic sea level. The heaviest storms along the present stretch of coast are produced by strong southerly winds, which would produce a north-easterly wind drift parallel to the coast in the upper layers of sea water. Muddy water in the shelf area would thus start with a north-easterly velocity component due to wind drift, but as turbidity flow down the shelf and slope became operative the wind-drift component would gradually be replaced by a south-easterly gravitational component. Turbidity currents generated in this way would thus follow a curved track, convex towards the north, and canyon heads eroded by them would be expected to show the same convexity.

The Sea Valleys: The origin of the Whareama, Turnagain and Hawke Sea Valleys cannot be readily explained in terms of erosion by turbidity currents, as all three are situated on relatively uniform parts of the continental slope and any turbidity currents would be expected to flow more or less at right angles to the general contours. The oblique and sinuous courses of these sea valleys are therefore inconsistent with turbidity current erosion, but can be easily explained on the assumption that these sea valleys represent portions of winding river valleys which have been largely obliterated by erosion and sedimentation during submergence and are no longer visible elsewhere.

The location of the Poverty Sea Valleys appears to be associated with faulting (see below), but the available information is not sufficient to determine their mode of origin. Likewise the precise origin of the Gisborne Sea Valley cannot be determined from the available soundings, but it may correspond to a zone of subsidence.

The Slope Highs and Depressions: The persistent NE-SW trend of the slope highs and depressions, and with their parallelism to the dominant strike on the mainland, show clearly that these features are fundamentally tectonic. Their form and orientation cannot be explained in terms of gravity-operated erosion alone. The width of the slope highs and depressions and the cross-strike intervals between them are of the same order as in the main tectonic structures on land (see geological map, fig. 2), and it is therefore considered here that these slope features correspond to the axial zones of folds or fault blocks, and not merely to alternating outcrops of harder and softer units within a series of tilted beds. The slope highs evidently correspond to zones of uplift, and the slope depressions to zones of subsidence. This interpretation is consistent even if the morphology has been modified at some stage by erosion, since the rocks of the area tend to become more resistant

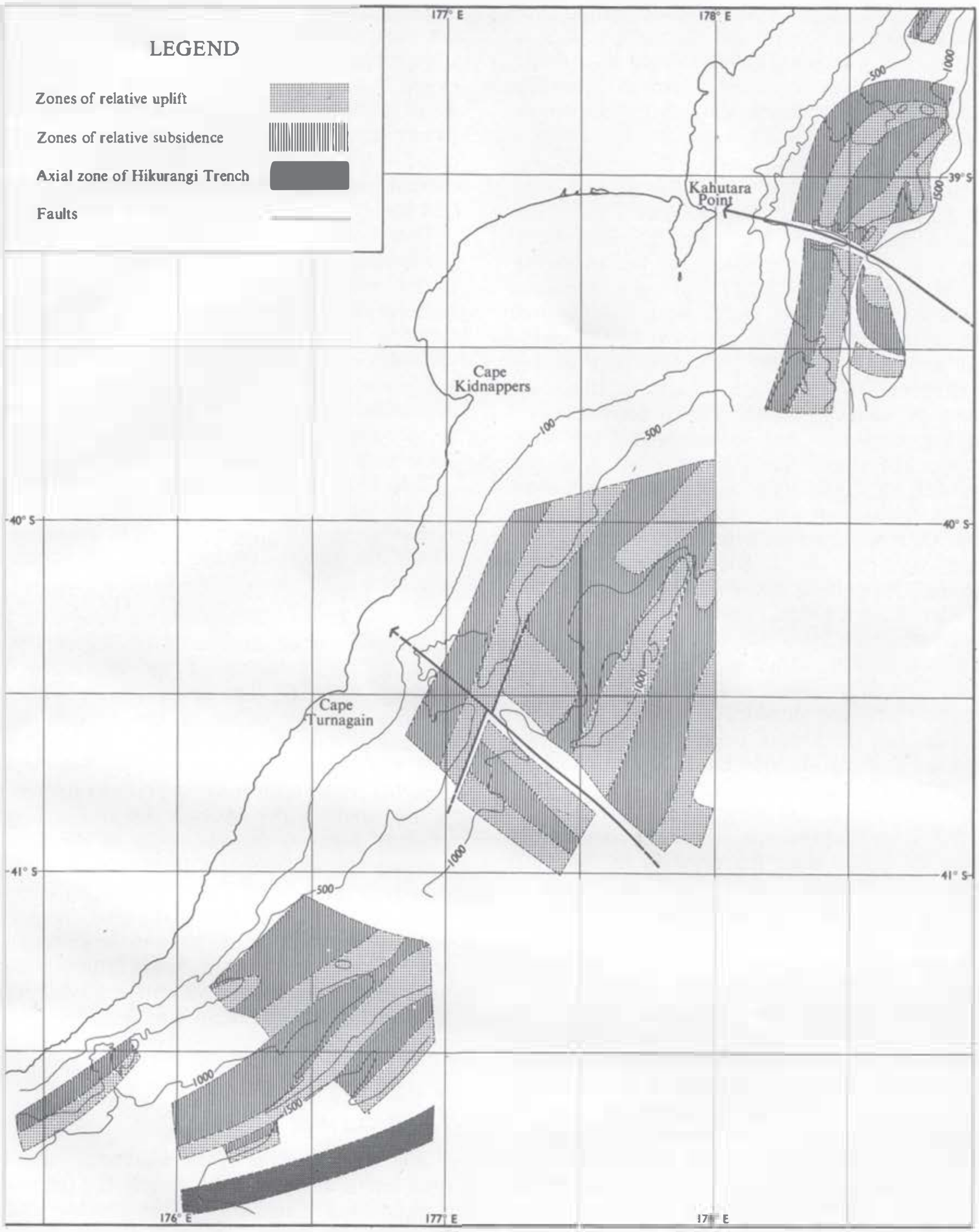

Fig. 11. Zones of relative uplift and subsidence on the continental slope off the east coast, North Island.

with increasing age: zones of uplift would thus contain more resistant rocks than zones of subsidence, and primary features formed as a direct result of crustal movements would generally coincide with secondary features developed by erosion.

These slope structures on NE-SW axes (fig. 11) are presumably more or less coeval with the parallel structures on land, but in most places there is no conclusive evidence, as yet, to decide whether the zones of uplift and subsidence are bounded by flexures or faults. Both faulting and folding are widespread in the rocks of the mainland and both probably played a part in the development of the slope structures (fig. 12). There are, however, certain positive indications of faulting. Between Cape Palliser and Cape Kidnappers the major tectonic units on land are bounded by faults with a NE-SW trend, and similar faults may account for the long and relatively straight scarps which bound some of the slope highs in the Castlepoint and Madden Groups. Supporting evidence is found in the Madden Canyon area, where a zone of broad features running NW-SE dies out abruptly along the south-eastern margin of the Madden Banks. These features probably correspond to zones of tectonic uplift and subsidence formed on a NW-SE axis, and the abrupt termination of this axis indicates that the Madden Banks are bounded by a fault on the south-eastern side.

The slope depressions are more continuous along the strike than the slope highs, and this requires explanation, as there is no reason to suppose that the zones of tectonic subsidence would be more extensive and continuous than the complementary zones of elevation. If the lower portions of the larger canyons are really submerged river valleys, the whole area must at one time have been subjected to terrestrial and coastal erosion, which would have the effect of reducing and splitting up any topographical elevations. Such an effect is difficult to explain in terms of purely submarine processes. It may be, therefore, that the slope highs owe their limited extension parallel to the strike to erosion at or above sea level. If so, some of the tectonic relief represented by the slope highs and depressions must have developed while the area was still above sea level, although continued deformation no doubt accentuated the relief after submergence had taken place. Submergence must have been rapid, or the topographic highs would have been planed off by marine erosion in the same way as the rocks underlying the shelf.

Sedimentation is evidently responsible for the flat central areas, which occur in many of the slope depressions, and for the general lack of closed basins, but this process has conspicuously failed to obliterate the major features on the slope. In any case, the effects of sedimentation would be offset in some localities by slumping and turbidity currents, which would tend to resurrect features that had been previously buried by sediment.

The headward expansions of the Pahaua, Honeycomb, and Madden Canyons evidently correspond to the intersections of the canyons with zones of tectonic subsidence, the widening of the canyons being partly due to the erosion of relatively soft formations filling these zones, and partly the direct result of subsidence. The degree of erosion around the Madden Depression seems to be quite exceptional, and the widespread occurrence of bentonitic beds on the mainland (Lillie, 1953, p. 111) suggests that the unusual size of the depression may be due to the self-perpetuating disintegration and slumping of bentonitic material, either before or after submergence.

Cross Faults: East of the Mahia Peninsula there is a conspicuous alignment of features which indicate the presence of an important fault running NW-SE. The most obvious of these features are the offset of the margin of the Hikurangi Trench, the offset of the shelf edge, and the presence of the Poverty Sea Valleys. Another major fault running in the same direction is indicated by the obvious differences in morphology between the two sides of the Madden Canyon. Faults with this orientation are comparatively rare inland, but become progressively more common near the coast, and there is no reason to doubt their existence in the rocks underlying the slope. The term "cross faults" could be used to emphasise their orientation with respect to the main tectonic trend (see fig. 11).

The Hikurangi Trench

The western border of the Hikurangi Trench has been included in the chart mainly for the sake of completeness. The margin of the trench is sinuous, following the depressions and elevations on the nearby slope, but the floor is almost flat, presumably due to the levelling-out effect of sedimentation. The difference in profile between the Hikurangi Trench and the much deeper Kermadec Trench to the north is probably a consequence of heavy sedimentation near the New Zealand land mass (Brodie and Hatherton, 1958, p. 26).

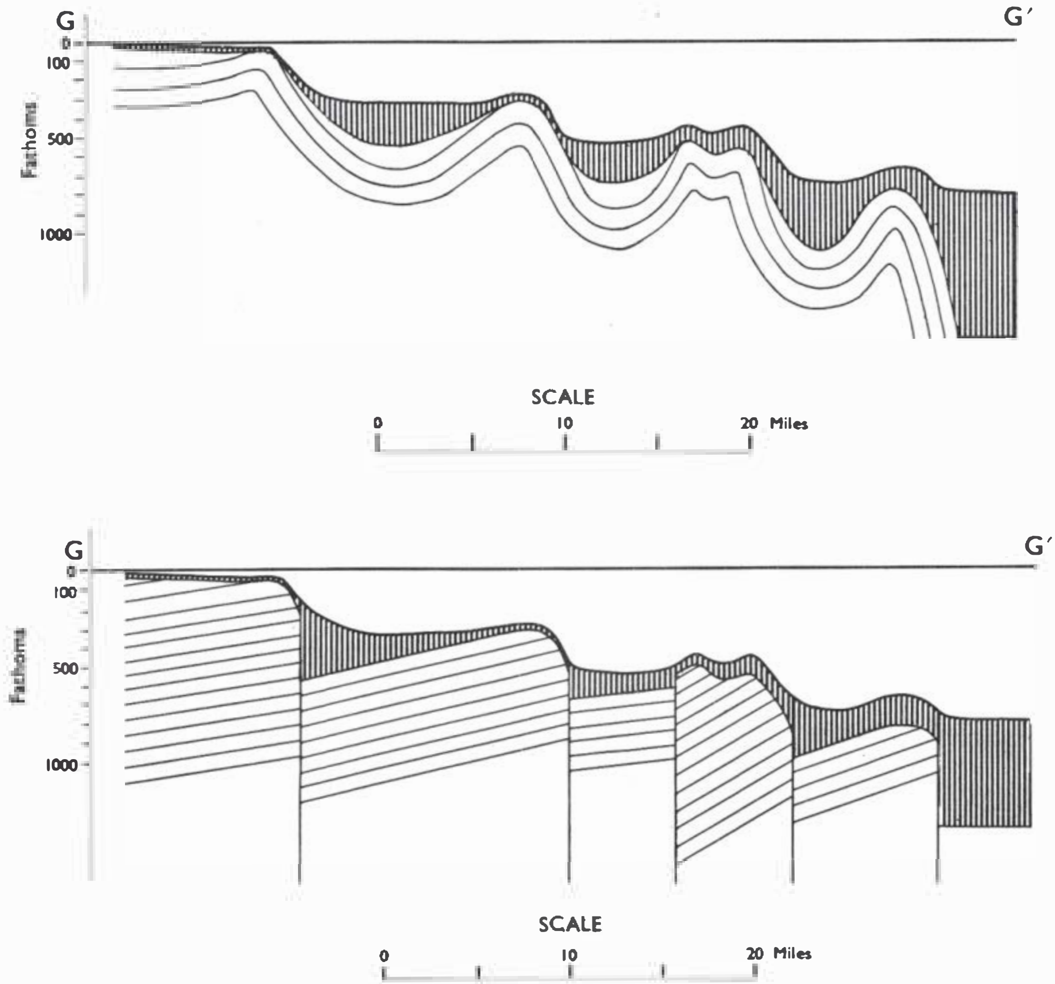

Fig. 12. Alternative hypotheses to account for the morphology along section GG′ (figs. 4 and 5). Faulting (upper), folding (lower figure). Sediment cover shown hatched.

COMPARISON WITH SOUTHERN CALIFORNIA

The morphology of the area described in the present account and its relationship to the coastal geology correspond in some ways to the situation found along the coast of southern California, where a range of geologically very young mountains (the Coast Range) is bounded on the seaward side by a narrow shelf which gives way in turn to the well known "continental borderland" with its ridge-and-basin morphology. In the Santa Barbara - San Diego sector, where this morphology is best developed, the vertical relief reaches 1,400 fathoms, with basins and ridges 20–30 miles across. The continental borderland terminates on its western side in a scarp leading down to the Pacific floor at about 2,000 fathoms (Shepard and Emery, 1941).

The ridges and basins of the continental borderland are clearly tectonic, this being demonstrated by their persistent NW-SE elongation and their parallelism to the major structures in the Coast Range (Shepard and Emery, 1941, p. 19), and in this respect the morphology of the borderland resembles that of the slope east of the North Island of New Zealand. However, there are several points of difference. The features off California are two to three times as large as those off the North Island, in both horizontal and vertical dimensions, while off California the ridges are more continuous and closed basins are much more numerous than off the North Island. Furthermore, the average level of the California borderland is fairly constant, with abrupt changes in gradient up to the shelf and down to the Pacific floor, whereas off the North Island the general level of the slope descends from the shelf to the trench (the latter feature being absent off California). Again, a number of submarine canyons cut the steep slope on the east side of the California borderland but do not run out across the borderland itself, whereas off the North Island the more southerly canyons continue for a considerable distance down the slope, although with diminishing vertical relief.

It thus appears that although the features described from off California and off the North Island are fundamentally tectonic in both cases, there are numerous differences in the size of tectonic units, in the rate and amount of crustal displacement, and in the degree to which the various tectonic features have been modified by subaerial or submarine erosion. The discontinuous ridges and the relative lack of closed basins on the slope off the North Island could be explained on the assumption that in this area the features have been modified by erosion and sedimentation to a greater extent than is the case off southern California.

ACKNOWLEDGMENTS

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INDEX

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TURNAGAIN

(SCALE 1:200,000 AT LAT. 41°)

BATHYMETRY
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Bathymetry by H. M. Pantin, from surveys by H.M.N.Z.S. Lachlan 1955-56.

From data supplied by the Hydrographic Branch, Navy Department.

Assistance with compilation by F.C. Spence and A. G. York.

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Depths in fathoms

Vertical Interval

Spot Depths

Down-slope direction

Heights in feet — Projection: Mercator

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BATHYMETRY

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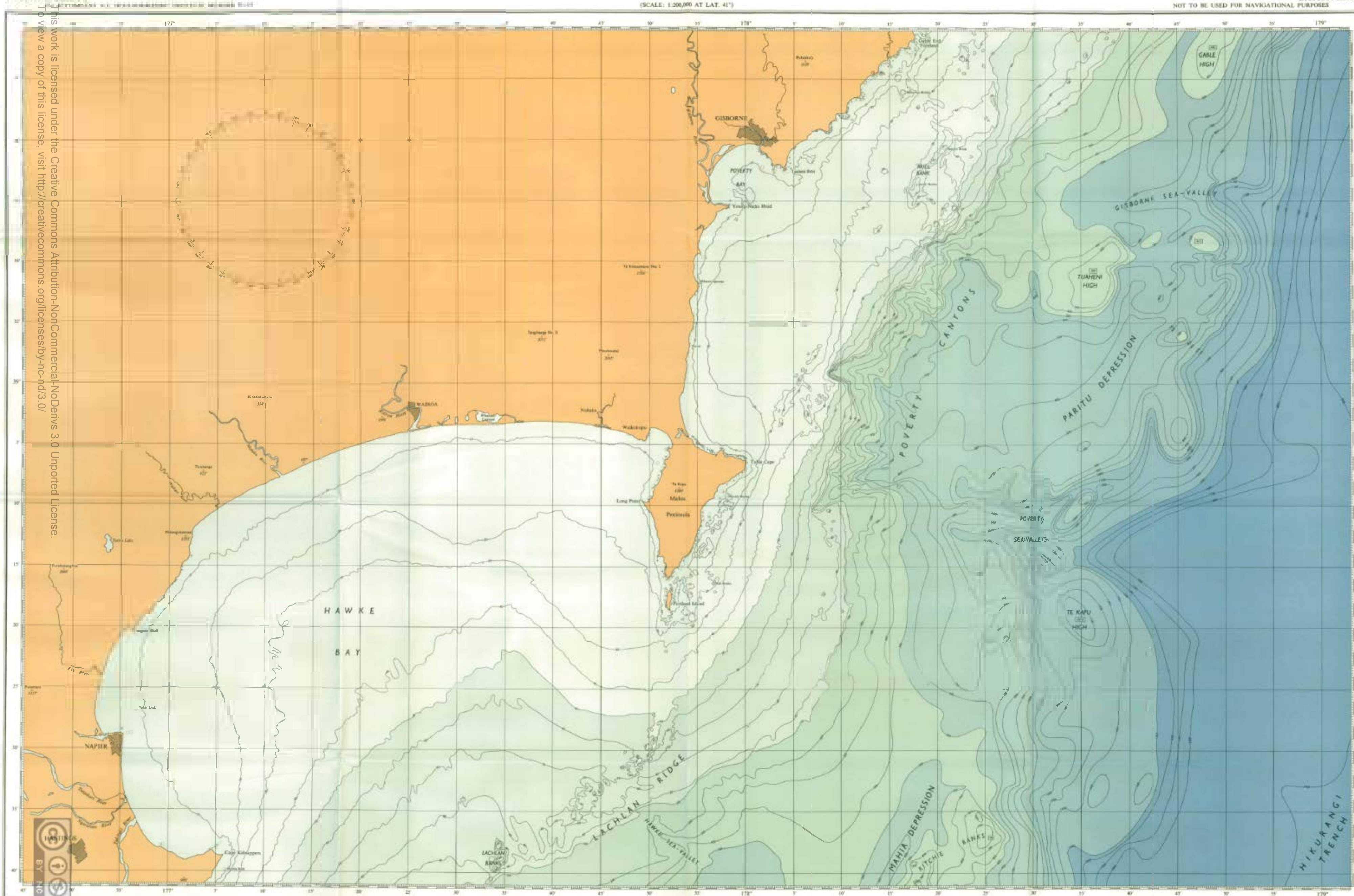

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This chart is not to be used for navigational purposes.

REFERENCES

Depths in fathoms

Vertical Interval

Spot Depths

Down-slope direction

Isobaths drawn thus:

Heights in feet

Projection: Mercator

ADJOINING SHEETS

INDEX TO PLOTTING AREAS

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A: Lines of Soundings up to one mile apart.

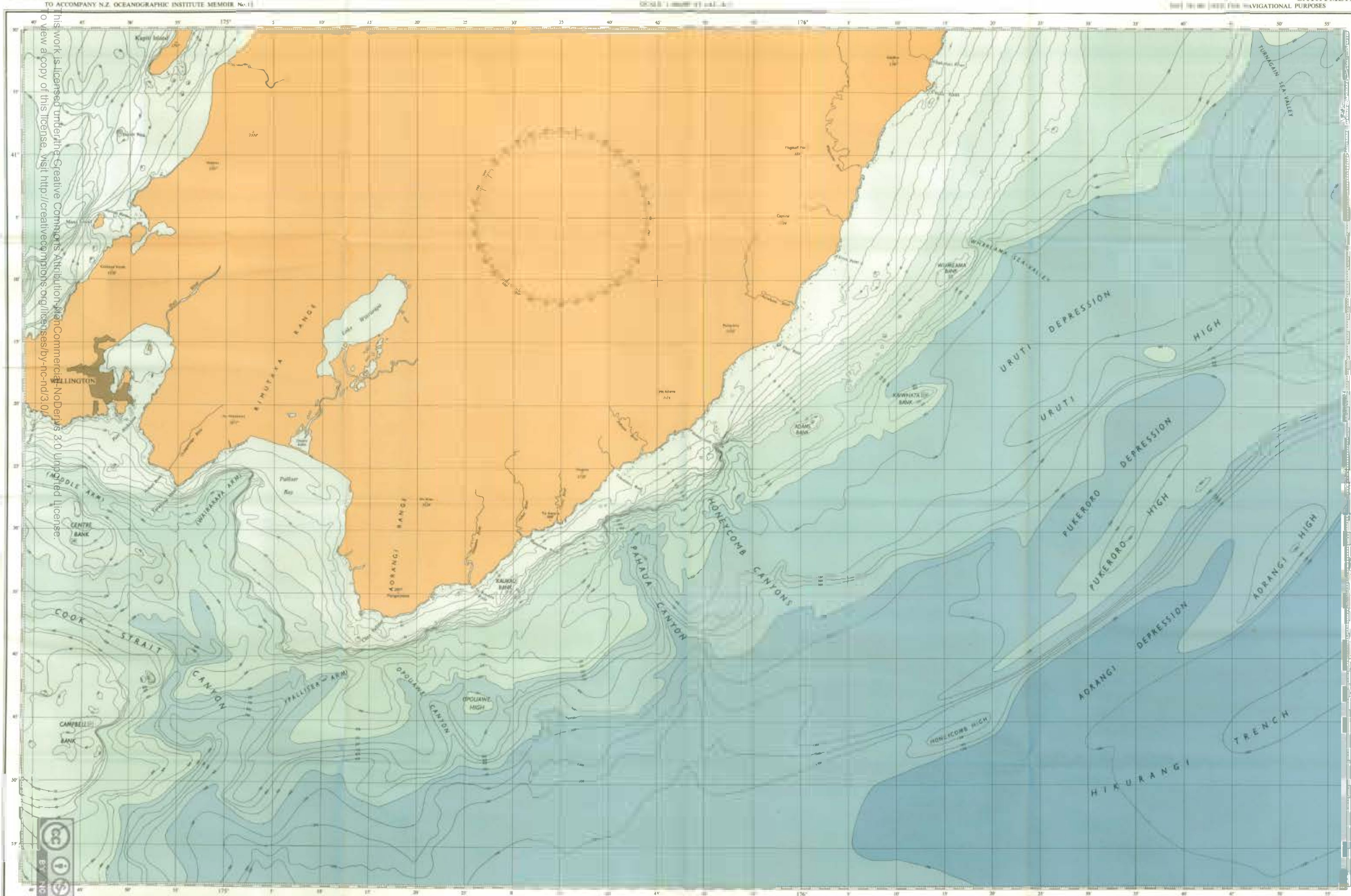
B: Lines of soundings two to ten miles apart.

FATHOMS

COASTAL SERIES
TO ACCOMPANY N.Z. OCEANOGRAPHIC INSTITUTE MEMOIR No. 11

PALLISER

BATHYMETRY



REFERENCES

Depths in fathoms
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