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**BENTHIC HABITATS OFF  
KAIKOURA -  
Physical characteristics from side-scan  
sonar and depth imagery**

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**NIWA Client Report: WLG2004-50  
July 2004**

**NIWA Project: DOC04403**

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# BENTHIC HABITATS OFF KAIKOURA - Physical characteristics from side-scan sonar and depth imagery

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NIWA Client Report: WLG2004- 50  
July 2004

NIWA Project: DOC04403

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## ABSTRACT

A preliminary assessment of benthic habitats on the continental shelf, between northern Kaikoura Peninsula and Haumuri Bluff, is made using side-scan sonar and single-beam echo-sounding data, supplemented with sediment samples. The datasets vary in detail and type. They include:

1. Echo-soundings at line spacings of 25 m for embayments either side of Kaikoura Peninsula. Side-scan sonar and samples are sparse.
2. Echo-soundings at line spacings of 125 m for the remainder of the peninsula, again with little side-scan sonar and sample verification.
3. Side-scan sonar and single-beam echo-sounding with line spacings of 300-600 m for the shelf between the peninsula and Haumuri Bluffs. Sonar images are verified by seabed samples.
4. Archived data that fills gaps in the better quality datasets noted previously.
5. Multibeam imagery of Kaikoura Canyon, which provided a perspective of this major incision of the continental shelf.

Analysis of the datasets suggest the following habitats (see accompanying charts).

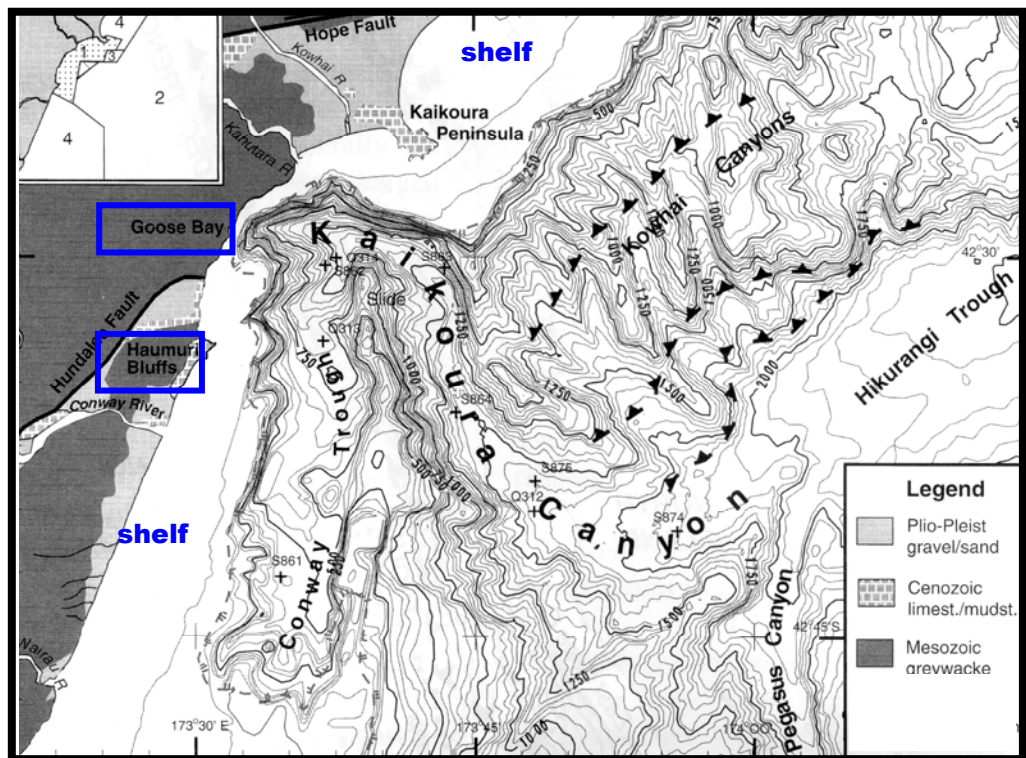
1. **Shore platform** - mainly intertidal, rocky extensions of the coast.
2. **Rocky "reef"** - subtidal extensions of the platforms and coast, often marked and masked by seaweed beds. Exposures are fractured and eroded, with channels/embayments potentially containing coarse sediment.
3. **Boulder-rock aprons** - marginal to "reef" - the probable source of boulders.
4. **Pebble pavement** - marginal to reefs and widespread east of the peninsula.
5. **Megarippled coarse sand** - sediment bearing large ripples formed by swell.
6. **Fine sand cover** - mobile sediment cover above the **megarippled coarse sand** and is well developed off the Kowhai River and on the Oaro-Haumuri Bluffs shelf.
7. **Mud blanket** - occupies the deeper shelf beyond strong current action, and locally provides a habitat for the horse mussel, *Atrina zealandica*.

Habitat identification is preliminary due to incomplete databases, especially "ground-truth" information. To redress deficiencies, multibeam imagery, coupled with seabed sampling and photography, are suggested to provide full coverage in unprecedented accuracy and detail that would be a bench-mark against which future changes could be measured.

## 1. Introduction

This report compiles available depth and side-scan sonar information into a series of charts that provide a preliminary perspective of the physical character of marine habitats on the continental shelf between northern Kaikoura Peninsula and Haumuri Bluffs; an along-shelf distance of about 32 km.

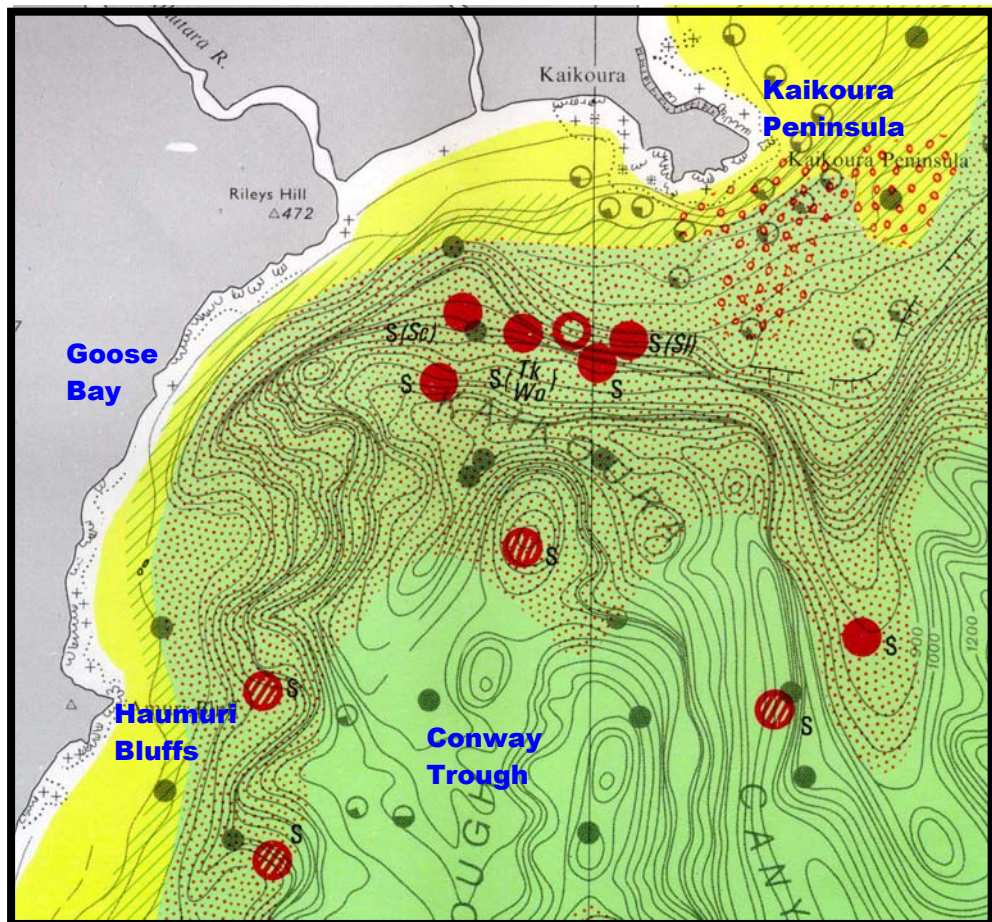
The continental shelf is a low relief surface that extends from shore to the *shelf break*. In the area covered by this report, the shelf dimensions are variable; a feature that results from its interception by Kaikoura Canyon and Conway Trough (Fig. 1.1).



**Figure 1.1.** Regional bathymetry outlining the continental shelf and the offshore deeps of Conway Trough and Kaikoura Canyon with its near-interception of the coast at Goose Bay. Isobath interval is set at 50 m. Modified from Lewis and Barnes (1999).

Due east of Haumuri Bluffs, the shelf is 4 km wide, with the shelf break approximating the 60 m depth contour or *isobath*. Seaward of the shelf break, the seabed descends rapidly to the 800 m-deep floor of Conway Trough (Carter et al., 1982). Moving northeast towards Kaikoura Peninsula, the shelf becomes narrower, reducing to ~ 600 m wide off Goose Bay where the head of Kaikoura Canyon reaches its most landward extent (Lewis et al., 1998). There, the shelf break coincides with the 20 m isobath. The shelf widens northeast of the canyon, and off Kaikoura Peninsula it exceeds 7 km width with the break at 140 m. Thus, the canyon essentially bisects the shelf into northern and southern segments centred on Goose Bay.

Early regional surveys of the seabed (Carter and Herzer, 1986; Carter et al., 1982) suggested a sandy substrate inside the 20 m isobath that became progressively finer grained with water depth, grading into sandy mud on the trough and canyon flanks before becoming almost pure mud in the trough and canyon floors (Fig. 1.2). We use the term "suggested" because sample control is weak, leading to generalized interpolations for the distribution of substrate types.



**Figure 1.2.** Regional perspective of the sediments with yellow = sand; green hatch = muddy sand; green with red dots = sandy mud; green = mud; black dots/circles are various types of sediment samples, and red dots are rock samples. From Carter and Herzer (1986).

Following on from Carter and Herzer (1986), more detailed surveys of the Kaikoura Canyon region were made by Lewis and Barnes (1999) and Lewis et al. (1998). These studies relied primarily on side-scan sonar and bathymetry, supplemented by seabed samples. In addition, a hydrographic survey (detailed depth transects plus a few side-scan sonar tracks) was made of the shelf around Kaikoura Peninsula (Land Information New Zealand - LINZ, 1998) and were compiled into the navigation chart, NZ6216 (LINZ, 1999).

## 2. Databases

### 2.1 Data Sources

The aforementioned datasets, along with information from the NIWA archives, form the basis of the present report.

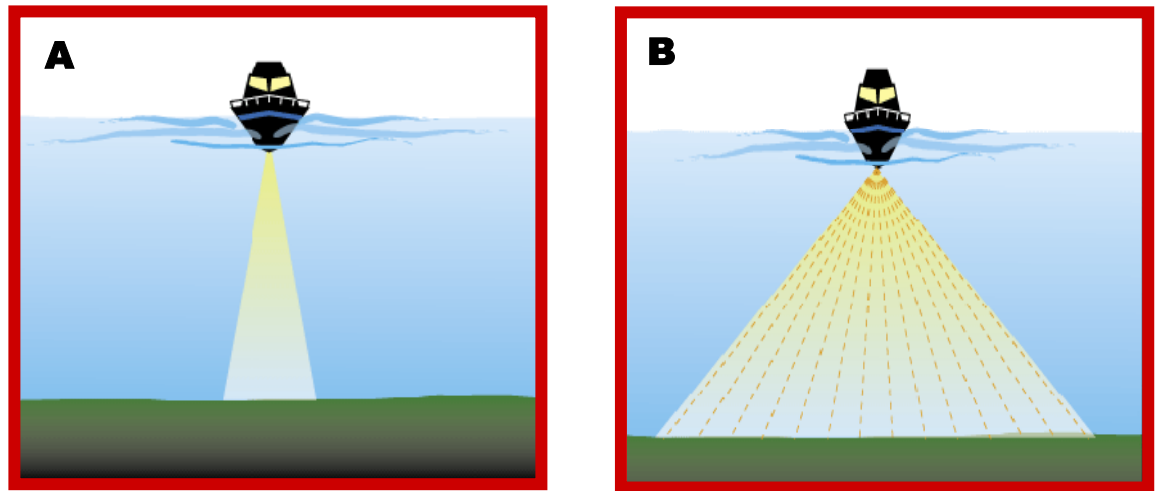
- Side-scan sonar and bathymetric survey of Lewis et al. (1998). A Klein 595 side-scan sonar, operated at a 300 m-wide swath, was run mainly along the shelf to provide near-complete coverage out to the shelf break between Pinnacle Rock and Oaro, and coverage out to between 20 m and 40 m isobaths from Oaro and Haumuri Bluffs (Fig. 2.2). North of Pinnacle Rock to Kaikoura Peninsula, side-scan tracks were spaced 600 m apart. Substrate types portrayed on sonar records were interpreted on the basis of strength of acoustical return, substrate morphology and, where appropriate, by sediment samples collected with a Shipek grab. Sample descriptions are presented in Lewis and Barnes (1999). Bathymetric data were collected concurrently using an Odom *Echotrac DF3200* precision survey echo-sounder (dual frequency, 200 kHz or 24 kHz). All survey lines were positioned by Differential Global Position System, which provided an accuracy of  $\pm 2$  m. Finally, a series of high resolution seismic profiles, generated by an E.G. & G. *Uniboom* system, were run along tracks spaced 600 m to 2000 m apart to give a perspective of sediment structure and thickness beneath the seabed. The seismic data provided additional information on the location of rocky substrates and sediment type as interpreted from the character of the seismic return (e.g., Carter, 1992).
- LINZ hydrographic survey, Kaikoura Peninsula. Single-beam echo-sounding surveys were run at two different scales in 1998. The entire peninsula was surveyed at 1:25,000 using a survey line spacing of 125 metres. These lines were run perpendicular to the general direction of the isobaths. More detailed surveys at 1:5000, were conducted north and south of the peninsula. Sounding lines were spaced 25 m apart and were run perpendicular to the general direction of the isobaths. However, for inshore rocky areas, line spacings

became irregular and extended out to 62.5 m apart. Additional soundings were required to prove or disprove the existence of shoal depths resulting in closer survey line spacings. The survey launch was equipped with an Odom *Echotrac DF3200* precision survey echo sounder (dual frequency, 200 kHz or 24 kHz) with built-in digitizer. Data were corrected for vessel motion using a *TSS 320* Heave Compensation System. Kelp and other seaweed were a problem. The most effected areas appear to be between 6.5 and 10 metres of depth, where prominent kelp beds formed a strong acoustical "curtain" that masked echoes returning from the seabed. A few *Klein 595* side-scan tracks were run off South Bay and towards Kaikoura wharf to help confirm seabed type and morphology.

- Archived data, NIWA. The deep-water sector, outlined by Kaikoura Canyon, was surveyed with a *Simrad EM 12D* multibeam sounder, mounted on the French research vessel, *L'Atalante* (Barnes et al., 1998). Multibeam transects were run in November, 1993 and, while not extending on to the continental shelf (the *12D* multibeam system is designed specifically for deep water), the imagery and depth data characterize Kaikoura Canyon and adjacent deep-water areas to provide a useful "backdrop" for the charts covered by this report.

## 2.2 Data Coverage.

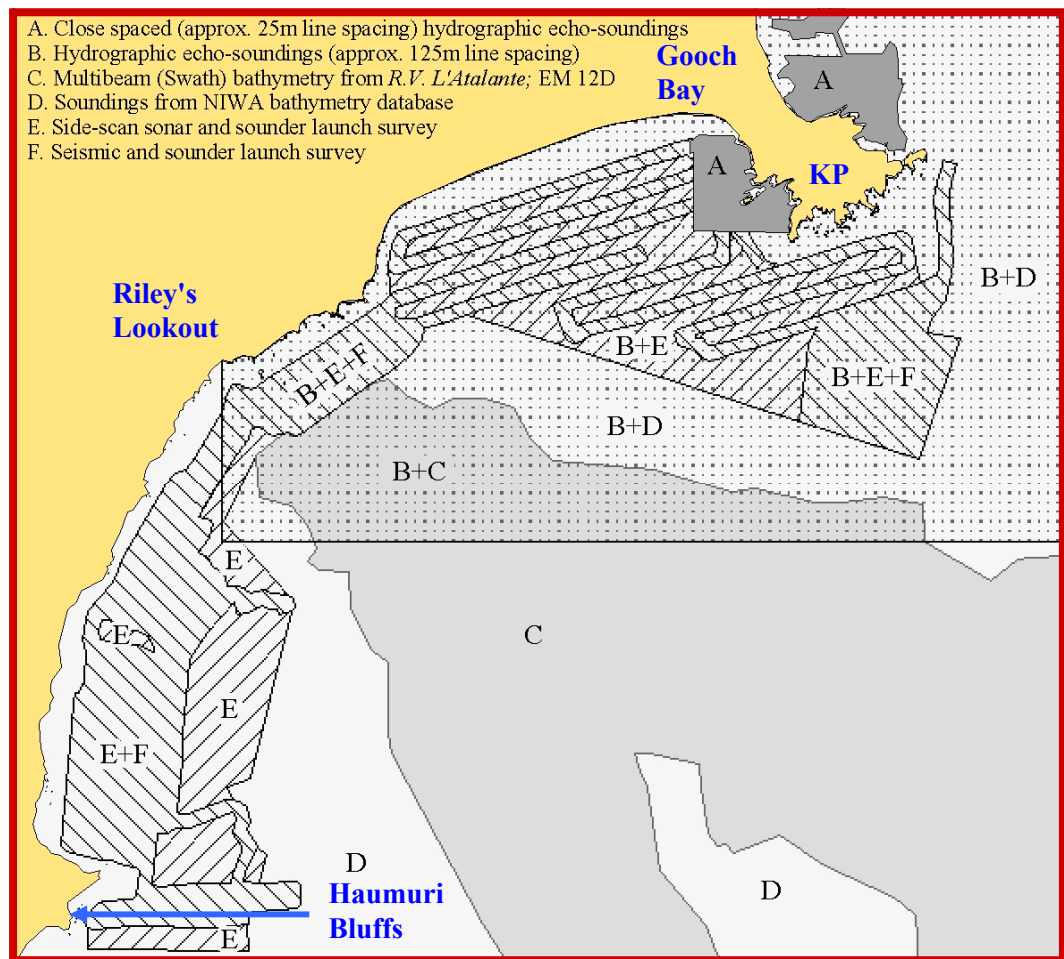
As alluded to in Section 2.1, data coverage is variable, reflecting (i) different requirements for individual surveys and (ii) different surveying equipment, for example, multibeam mapping yields highly detailed depth and backscatter data (i.e., strength of acoustical return from the seabed, which assists substrate identification) for the full width of the swath scanned below the survey vessel; this swath being 100s metres to several kilometres wide, depending on water depth. In contrast, single-beam echo-sounders, such as the Odom *Echotrac*, surveys only a narrow path (few metres) below the survey vessel (Fig. 2.1).



**Figure 2.1.** Acoustical "footprint" of (A) a conventional single-beam sounder and (B) a multibeam sounder which produces wider coverage and data density. As water deepens, the beam widens and at 2000 m depth, systems are scanning the seabed 3-5 km either side of the ship.

For Kaikoura Peninsula-Haumuri Bluffs, coverage is specified for the following areas in Figure 2.2.

- Sector A, located north and south of Kaikoura Peninsula, has single-beam, echo-sounding lines 25 m apart extending out to 62.5 m in areas of very shallow bathymetry, but locally more detailed around shoals. Side-scan sonar tracks are few (LINZ, 1998; 1999).
- Kaikoura Peninsula and the southern shelf to near Riley's Lookout, are covered by single-beam echo-sounding lines, nominally spaced 125 m apart. (Fig. 2.2; sectors B and E) (LINZ, 1998; 1999). While the seabed around the peninsula has only sparse side-scan coverage, the shelf south to Riley's Lookout is about 50% covered by lines spaced 600 m apart and a side-scan swath width of 300 m (Fig. 2.2). In such circumstances, where there are gaps in the sonar records, we have interpolated substrate distribution patterns, using the bordering side-scan and depth information as guides (Lewis et al., 1998).



**Figure 2.2. Reliability diagram for the various surveys around Kaikoura Peninsula (KP) and environs.**

- The shelf between Riley's Lookout and Haumuri Bluffs has 100% side-scan sonar coverage from an inshore line (the closest possible survey line to shore) out to the 20 m isobath or deeper (Sector E, Fig. 2.2). Side-scan and concomitant single-beam echo-sounding tracks were spaced 300 m apart (Lewis et al., 1998). ( Note: while side-scan sonar gave 100% coverage, sounding line data were restricted to immediately below the vessel, resulting in no depth coverage between the survey lines).

- Kaikoura Canyon, from the canyon edge to floor is fully covered by *Simrad EM12D* multibeam bathymetric and backscatter data (Sector C, Fig. 2.2), the former having an accuracy of  $\pm 0.2\%$  of the water depth or  $\pm 2$  m at 1000 m depth within the canyon (Barnes et al., 1998).
- Outside of Kaikoura Canyon and beyond the shelf surveys noted in bullets 1-3, the main data are scattered echo-sounding tracks and other depth data lodged within the NIWA archive (Sector D, Fig. 2.2) and presented on the earlier NIWA chart by Herzer and Carter (1983). That chart and accompanying database have been largely superseded by the more recent data note in previous bullet points 1 to 4 above, but is still valid for areas with no other bathymetric information.

### 2.3 Terrain model.

Echo-sounding lines were processed and merged to create a final binned dataset for the survey area. Line processing involved:

- Extraction of navigation data from the raw files collected in the field.
- Extraction of bathymetry and merging with the navigation data to produce an xyz file of all soundings for a survey line and a binned xyz file of one depth per bin in a regular grid at selected spacing of 10 m for the open shelf and 1 m for the intensely surveyed areas north and south of Kaikoura Peninsula. A median filter was applied to the bathymetry so that where more than one sounding fell within a single 10m x 10m or 1m x 1m grid bin, the median value was selected as that bin depth.
- Binned files were cleaned to remove artefactual spikes using software that allowed the surface to be inspected, artefacts identified, selected and marked as "culls".

- Cleaned binned data for all lines were merged and "culled" soundings removed to produce a final binned dataset for the survey area, which was then converted into an *ArcInfo* Grid. During this conversion process, we used *ArcInfo's* "Topogrid" algorithm to run a spline through the final data set to infill any small holes in the model.

## 2.4 Chart presentation

The terrain model, bathymetric contours and interpreted physical habitats are presented as a series of charts at (1) an over-view scale of 1:40,000 and (2) a more detailed scale of 1:10,000 which is basically a 4 way cut-up of the study region. Small (A4) prints of each chart are appended to the end of this report, and electronic files (PDF format) of the charts are appended on CD-ROM in pockets at the conclusion of this report. Because of the variability in survey detail (see Sections 2.1 and 2.2), the detail displayed in the charts is also variable. For example, the area around Kaikoura Peninsula (Charts 1 and 2; map pocket) has the detailed sectors to the north and south, inset into the less detailed survey. While this makes the charts non-uniform, it preserves the resolution of the detailed surveys - detail that would have been otherwise lost if the data were portrayed at the same scale.

## 3. Habitats

The nature of data available for this report restrict identification of seabed habitats to their physical characteristics, as interpreted from acoustical responses from the seabed, coupled with sediment samples to help verify interpretations.

### 3.1 Habitat Identification- side-scan sonar

The prime source of acoustical data is provided by side-scan sonar images documented by Lewis et al. (1998) and Lewis and Barnes (1999). Long-term, local expertise gained through the interpretation of side-scan sonographs from the New Zealand region (e.g., Arron and Lewis, 1993; Carter et al., 1992; Carter and Lewis, 1995 amongst others), coupled with "ground-truth" seabed samples, allow for a

preliminary assessment of the substrate. From shore to the shelf edge, seven basic physical habitats are proposed.

- **Shore platform** - this is the mainly intertidal, rocky extension from the coast, and it borders much of the study area except within large embayments (e.g., Gooch Bay) where local rivers provide sediment to form a sand cover. As this habitat is usually beyond the innermost survey lines, its location and outline are derived from aerial photographs and hydrographic charts.
- **Rocky "reef"** - typically seaward extensions of the shore platform and are mainly indurated rock with or without a patchy veneer of sediment. The precise outline of the "reef" complex is often masked by large seaweed beds whose air-filled fronds and sacs impede sonar signals. Rarely, rocky reefs occur near canyon heads where incision, possibly aided by localized topographic intensification of currents, yield a rocky substrate.
- **Boulder-rock aprons** - typically occur marginal to "reef" areas and probably represent fragmented platform which may have formed during a time when sealevel was lower (from 18, 000 to 6,500 years before present) and/or formed by modern hydraulic processes, in particular storm-wave action. Whatever the case, the intimate link with the reefs suggest the large fragments have not moved far bearing in mind that there is probably limited mobility under direct wave and current attack of the boulder substrate. Small amounts of finer grained sediment may also be present as mobile or temporary deposits, e.g. veneer of mobile sand. We are cautious in identifying this substrate because of (1) its acoustical similarity and juxtaposition to the rocky "reefs" and (2) the masking of acoustical responses by kelp beds.
- **Pebble pavement** - pebbles, typically between 4 - 64 mm diameter, occur marginal to some gravel aprons, and in a wide patch east of Kaikoura Peninsula. Where marginal to rocky reefs, there is the strong suggestion that **pebble pavement** is derived from either past sea level and/or modern breakdown of the reef and associated boulder apron. The **pebble pavement** off Kaikoura Peninsula is more extensive than elsewhere, which may reflect greater transport from source during the past and/or present current conditions.

- **Megarippled coarse sand** - substrate of coarse sand to fine gravel (0.5 - ~2 mm diameter) occurs as patches marginal to **rocky "reef"** and **boulder-rock apron**, as well as discrete patches on the middle to outer shelf. Typically, the sediment surface is thrown into large ripples or *megaripples* with wavelengths of 0.8- 1.2 m and crests parallel to the isobaths and direction of swell approach.
- **Fine sand cover** - a pervasive habitat that is well developed over much of the continental shelf, southwest of Kaikoura Peninsula, with a more patchy distribution off the peninsula itself. The cover overlies the **megarippled coarse sand** and **pebble pavement** habitats, and patches may even occur on **boulder-rock apron**.
- **Mud blanket** - habitat is dominated by fine sediment and occupies the deeper reaches of the continental shelf and slope including parts of the Kaikoura Canyon walls. In general, the mud blanket produces a weak, featureless acoustical response on sonographs, but mud patches off Haumuri Bluffs, Riley's Lookout and the Gooch Bay shelf have a speckled acoustical signal, which sampling showed to result from colonies of the horse mussel, *Atrina zealandica*.

### 3.2 Habitat Identification - echo-sounding

An attempt was made to differentiate physical habitats around Kaikoura Peninsula mainly on the basis of characteristics of the *Echotrac* sounder data collected during the course the hydrographic survey by LINZ (1998; 1999). This experimental analysis relied primarily upon the strength of the echo-sounding trace, the morphology outlined by the digital terrain model, a few side-scan sonar tracks and samples, and expertise in interpreting such records. The verification of the habitats is inadequate and thus **the results presented here are preliminary.**

Inshore habitats surrounding Kaikoura Peninsula comprise the following (Charts 1 and 2; map pocket):

- **Shore platform.**
- **Rocky "reef"** This is the dominant inshore habitat, forming a wide irregular border, which is locally juxtaposed with **boulder-rocky apron** and possibly other coarse sediment. The entire "reef" complex interfingers with the **fine sand cover** northeast and southwest of the peninsula, whereas "reefs" off the eastern peninsula terminate sharply against pebble pavement. The high resolution terrain model for the detailed dataset shows a fractured rock substrate with a prominent northeast-southwest grain. Presumably, erosion of the fractures has formed channels and embayments that give the reef complex a highly intricate outline. In the absence of samples we surmise that the embayments and channels contain some sediment (e.g., South and Adams, 1976), the grade and quantity of which depends upon (i) the degree of exposure to the wave/swell regime and (ii) the erodability of the source rocks.
- **Boulder-rock apron.** The occurrence of rough seafloor around the margins of the "reefs", suggests the presence of boulders and /or isolated rock exposures which are collectively grouped as **boulder-rock apron**. Again, we emphasize the difficulties in accurately differentiating this habitat from low relief "reef" because of the similar acoustical signatures, and the common problem of sonar masking by kelp and other seaweed beds.

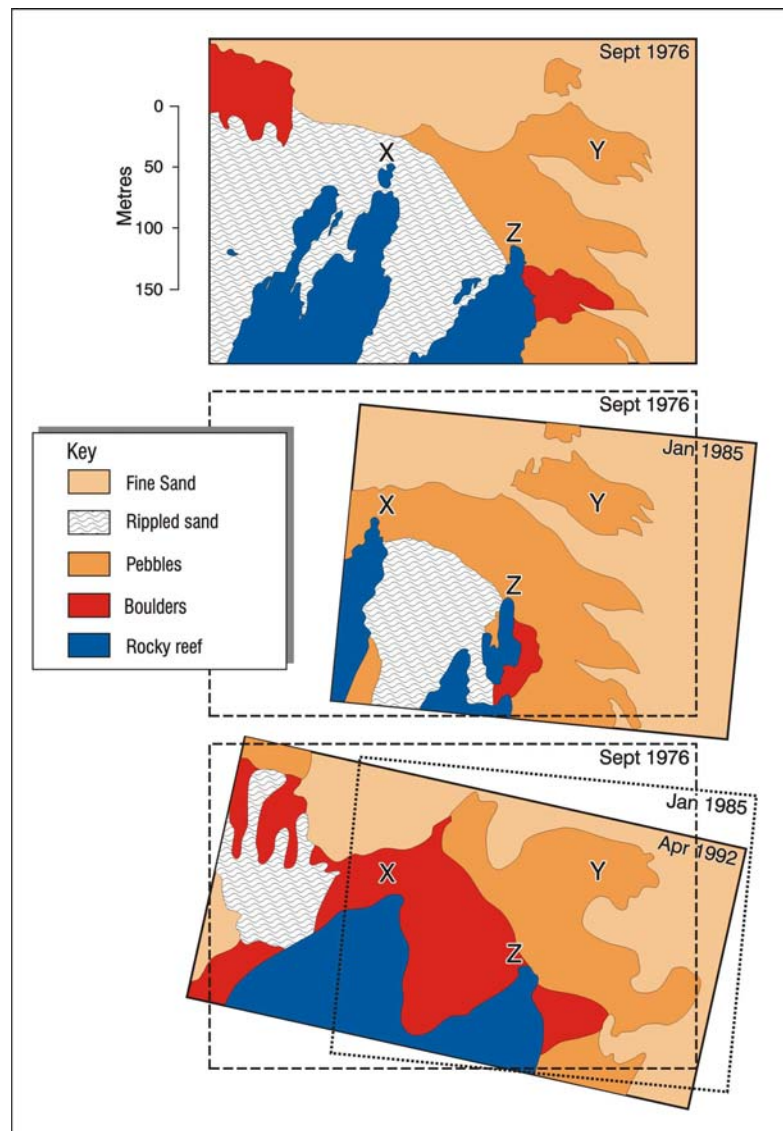
Beyond the reef complex, the substrates are those as described by the side-scan sonar data in Section 3.1.

### 3.3 Habitat Stability

The Canterbury shelf is subject to a vigorous hydraulic regime that is capable of moving sediment, especially in the shallow shelf depths that prevail in the study area (e.g., Carter and Herzer, 1979; Carter and Heath, 1975; Herzer, 1981). **In calm weather**, the regime is dominated by tides, the northeast-flowing Southland Current and deep-sea swell, which collectively affect transport in water depths of 30 m and less. Off Kaikoura Peninsula, we suspect that the tides and Southland Current are intensified by the promontory, and with reinforcement from the swell, result in current speeds that are too rapid to allow sand to settle permanently; hence the prevalence of **pebble pavement** on the adjacent inner shelf (Charts 1 and 2; map pocket). Similar situations have been documented off Otago Peninsula (Carter et al., 1985) and Banks Peninsula (Herzer, 1981).

**Gales and storms** strongly reinforce calm weather water motions to bring about near-continuous sediment movement on the inner shelf (< 30m depth) and episodic transport in deeper water. The prevalence of southerly meteorological disturbances, coupled with the Southland Current, bring about a net northeastward transport of sediment on the shelf.

While we have no direct observations of habitat change in this region, repeated surveys of the south Wellington shelf (Carter and Lewis, 1995) - a setting with swell-dominant climate similar to that of Kaikoura - suggest that habitats may vary with changes in meteorology and sediment supply. The **megarippled coarse sand** and the **fine sand cover** habitats are particularly vulnerable because of their fine grain size and location in high energy environments. (Figure 3.1)



**Figure 3.1.** Interpreted side-scan sonar images of a 30 - 35m-deep section of the continental shelf off Wellington where water motions are dominated by a southerly storm-driven swell regime, similar to that off Kaikoura. Surveys of 1976, 1985, and 1992 highlight the variability of the megarippled coarse sand and overlying fine sand habitats, which Carter and Lewis (1995) attributed to the frequency of southerly storms.

With respect to Kaikoura, estimates of near-seabed current speeds for the Canterbury shelf (Carter and Herzer, 1979) suggest that the **fine sand cover** shifts even in calm or moderate weather conditions, especially off the peninsula. Such mobility, either will bury or expose underlying substrates - a process which is suggested by the patchwork of **megarippled coarse sand** within the **fine sand cover**, south of Pinnacle Rock. North of Pinnacle Rock such windows into the megarippled substrate were not evident

from the Lewis et al. (1998) survey, presumably because there is an ample supply of sand from the nearby Kowhai River. It should be noted that the shelf south of Pinnacle rocks is upstream of the river source, bearing in mind the prevailing northeastward direction of sediment transport. The mobility of the **fine sand cover** is also suggested by the patchiness and embayed outlines of deposits resting on the **pebble pavement** east of the peninsula.

Even the **megarippled coarse sand** is periodically mobile as attested by the well developed megaripples. The crests of these bedforms align with the general direction of swell approach and, along with their near-symmetric profiles, show they were formed by oscillating bottom currents associated with grounding swell. From the coarse sand - fine gravel size of similar deposits, Carter and Lewis (1995) estimated that similar megaripples on the Wellington shelf, formed under swell of 10 second period and 2.25 m height. Waves with those dimensions occur around 2% of time according to the data of Pickrill and Mitchell (1979).

#### 4. Future Work

While the charts presented here provide a broad perspective of the benthic habitats, they have their deficiencies as outlined in Section 2. A paucity of closely spaced echo-sounding lines plus gaps in the side-scan coverage, detract from the surveys to the south of Kaikoura Peninsula, whereas the surveys around the peninsula lack sufficient side-scan sonar and sediment sampling to verify the high quality echo-sounding database.

Ideally, the shelf sector south of the peninsula should be re-surveyed with a shallow-water multibeam system such as the *Simrad EM3000D*, to provide (1) complete, high-resolution depth coverage that was fully geo-referenced and (2) acoustical "backscatter" imagery similar to, but not as detailed as that from a side-scan sonar system. The data collected by Lewis et al. (1998) could be integrated with the multibeam records to provide a bench-mark survey. If the seabed biota were to be included in the survey, quantitative sampling accompanied by seafloor photography, would be required.

With respect to Kaikoura Peninsula, the existing echo-sounding dataset on its north and south sides, is of sufficient accuracy and density to provide a good base but, as noted earlier, requires verification with samples and side-scan sonar surveys. The eastern side of the peninsula could be rerun with multibeam to improve resolution of the seabed morphology, which presently is based on sounding lines 125 m apart.

The undertaking of high quality, bench-mark surveys is, in our opinion, a critical process. Not only would such surveys provide a definitive outline of habitats, but equally important, they would be a base-line against which future changes could be accurately gauged. Such comparisons would provide key information to help answer questions regarding the future of marine environments. How do habitats react to storm events? How are habitats affected by floods? To what extent does bottom-trawling fisheries affect the seabed and biota? These and other questions are becoming increasingly relevant in a world that is undergoing fundamental changes in response to climate change and increased exploitation of its resources.

### **Acknowledgements**

We thank Land Information New Zealand (LINZ) for access to the hydrographic data collected during the course of the survey for navigation chart NZ6212 (LINZ 1998, 1999).

## 5. References

- Arron, E.S., Lewis, K.B., 1993. Wellington South Coast Substrates. *New Zealand Oceanographic Institute*, miscellaneous chart series 1:15,000.
- Barnes, P.M., Mercier de Lapinay, B., Collot, J-Y., Delteil, J., Audru, J-C., and GeodyNZ team, 1998. South Hikurangi Geodynz swath maps, depth, texture and geological interpretation. *National Institute of Water and Atmosphere (NIWA) Chart*, Miscellaneous Series 75.
- Carter, L., 1992. Acoustical characterisation of seafloor sediments and its relationship to active sedimentary processes in Cook Strait, New Zealand. *New Zealand Journal of Geology and Geophysics* 35, 289-300.
- Carter, L., Carter, R.M., Griggs, G.B., 1982: Sedimentation in the Conway Trough, a deep near-shore marine basin at the junction of the Alpine transform and Hikurangi subduction plate boundary, New Zealand. *Sedimentology* 29, 475-497.
- Carter, L., Heath, R.A. 1975. Role of mean circulation, tides, and waves in the transport of bottom sediment on the New Zealand continental shelf. *New Zealand Journal of Marine and Freshwater Research* 9, 423-448.
- Carter, L., Herzer, R.H., 1979. The hydraulic regime and its potential to transport sediment on the Canterbury continental shelf. *New Zealand Oceanographic Institute, Memoir* 83, 33 p.
- Carter, L., Herzer, R.H., 1986. Pegasus sediments (2nd edition). *New Zealand Oceanographic Institute Chart*, Coastal Series 1:200,000.
- Carter, L., Lewis, K.B., 1995. Variability of the modern sand cover on a tide and storm driven inner shelf, south Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics* 38, 451-470.
- Carter, L., Wright, I.C., Collins, N., Mitchell, J.S., Win, G., 1991. Seafloor stability along the Cook Strait power cable corridor. Pp 565-570 in "Coastal Engineering - Climate for Change". Proceedings of the 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, 2-6 December 1991.
- Carter, R. M., Carter, L., Williams, J. J., Landis, C. A., 1985. Modern and relict sedimentation on the South Otago continental shelf, New Zealand. *New Zealand Oceanographic Institute Memoir* 93, 43 p.

- Herzer, R.H., 1981. Late Quaternary stratigraphy and sedimentation of the Canterbury continental shelf, New Zealand. *New Zealand Oceanographic Institute, Memoir* 89, 1-71.
- Herzer, R.H., Carter, L., 1983. Pegasus bathymetry (2nd edition). *New Zealand Oceanographic Institute Chart, Coastal Series* 1:200,000.
- Lewis, K.B. and Barnes, P.M., 1999. Kaikoura Canyon, New Zealand: active conduit from near-shore sediment zones to trench-axis channel. *Marine Geology* 162, 39-69.
- Lewis, K.B., Garlick, R.D., Dawson, S.M., 1998. Kaikoura Canyon; depths, shelf texture and whale dives. *National Institute of Water and Atmosphere (NIWA) Chart, Miscellaneous Series* 78.
- LINZ (Land Information New Zealand). 1998. Kaikoura Hydrographic Survey. Project 97/98-3HS. NIWA contract report WLG98/16.
- LINZ (Land Information New Zealand). 1999. Plans on the northeast coast of the South Island. *Hydrographic Chart NZ6212*; scales 1:10,000 to 1:35,000.
- Pickrill, R.A., Mitchell, J.S., 1979. Ocean wave characteristics around New Zealand. *N.Z. Journal of Marine and Freshwater Research* 13, 501-520.
- South, G.R., Adams, N.M., 1976. Marine algae of the Kaikoura coast. National Museum of New Zealand Miscellaneous Series 1. 6p.