MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

ISSN 1175-1584

Classification of acoustic fish marks for the 2001 Mid-East Coast orange roughy survey

A. Hart
I. J. Doonan
R. F. Coombs

New Zealand Fisheries Assessment Report 2003/18
May 2003

Classification of acoustic fish marks for the 2001 Mid-East Coast orange roughy survey

A. Hart
I. J. Doonan
R. F. Coombs

NIWA
Private Bag 14901
Wellington

New Zealand Fisheries Assessment Report 2003/18
May 2003

Published by Ministry of Fisheries
Wellington
2003

ISSN 1175-1584

Citation:
Hart, A.; Doonan, I.J.; Coombs, R.F. (2003).
Classification of acoustic fish marks for the
2001 Mid-East Coast orange roughy survey.
New Zealand Fisheries Assessment Report 2003/18. 24 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Hart, A.; Doonan, I.J.; Coombs, R.F. (2003). Classification of acoustic fish marks for the 2001 Mid-East Coast orange roughy survey.
***New Zealand Fisheries Assessment Report 2003/18.* 24 p.**

An acoustic survey of the Mid-East Coast orange roughy fishery was carried out in June-July 2001 using *Tangaroa* to gather acoustic and trawl data and *Tasman Viking* to trawl. The survey was focused on spawning roughy around Ritchie Hill in management area 2A South. The species composition of acoustic fish marks in echograms was predicted by assigning each mark to one of 7 mark-types. Each type was characterised by the shape and acoustic intensity (encoded as colour) of marks in echograms, mainly those from biomass survey transects. The species composition was estimated by trawling on the different mark-types and matching the catches and the echograms collected while trawling with those from transects.

The trawl data available were limited which in turn limited the number of mark-types it was practical to define. To enable survey biomass variance to be estimated, adequate numbers of trawl samples for the main types were required. It was also necessary to limit categories so that assignment of marks was reasonably clear-cut and not confused by gradations in shape and colour from one type to the next. The mark-types derived here were reasonable for most areas, but were somewhat uncertain in the Rock Garden.

1. INTRODUCTION

This report describes a method to predict the species composition of different acoustic 'marks' in echograms from acoustic survey transects. The approach was developed for the Mid-East Coast (MEC) orange roughy fishery and specifically for the acoustic survey carried out in the area in June-July 2001 (Doonan et al. 2003). The acoustic and trawl data for the work came primarily from the part of the Mid-East Coast covered by area ORH 2A South with the focus on spawning fish near Ritchie Hill (Figure 1).

Acoustic surveys of orange roughy both in New Zealand and elsewhere have all used the echo-integration method (e.g., Do & Coombs 1989, Doonan et al. 1999) in which acoustic signals backscattered by fish and other targets are measured. To convert backscatter into biomass it is necessary to apportion it amongst the different species present in the survey area, and this is typically accomplished by classifying it into different types or classes of 'marks.'

Orange roughy typically form large spawning aggregations, mostly on the tops of underwater hills but occasionally as "plumes" on flat bottoms. These appear as distinctive marks on echograms. Figure 2a shows plumes from the "spawning box" on the North Chatham Rise (from Doonan et al. 1999). There are usually also orange roughy outside these distinctive marks, widely distributed in more or less uniform layers surrounding the aggregations and hills. There are thus normally only two types of mark to be considered (ORANGE ROUGHY and BACKGROUND) and these are clearly defined with no ambiguities about assignment. The latter is usually effected visually from echograms and the image is enhanced by selecting an appropriate colour-coding scheme and applying a threshold to eliminate low-level signals. Figure 2a shows an orange roughy and background marks in an echogram with colour coding and a threshold of –80dB. Figure 2b shows the same echogram with no colour settings or thresholding in which the roughy school is hard to pick out. Figure 2c shows the same school with a threshold applied and the roughy now appear as small 'blobs.' The two mark-types are sampled by random trawling to estimate their average species composition and this is then applied to the acoustic data.

In the early years of the fishery, such aggregations were seen on Ritchie Hill, but they are now gone and spawning takes place in smaller scattered schools in the vicinity of the hill. Whilst the acoustic marks produced by some of these schools are clear-cut, especially if they are on hills, others are not and may be confused with marks from other species. The clear-cut orange roughy marks in the area are now usually quite small and typically have a length (as seen on a thresholded echogram) of about 100 m in contrast to the 3 km length of the spawning box mark in Figure 2a. A significant proportion of spawning orange roughy are now to be found in a variety of other types of marks.

It was clear that a more complex classification scheme was needed to analyse the 2001 MEC survey data and ideally this should employ an objective scheme of the sort used for oreos (Doonan & McMillan 2000). However, before the survey, no matched trawl and acoustic data were available for the fishery in its present state. The survey faced strict time constraints and two vessels were used to accommodate this. Acoustic data were consequently collected with two different echosounders. To cope with this, a somewhat ad hoc approach was taken in which a rough classification was made as the survey progressed and trawls targeted at the different types of marks seen. After the survey the scheme was revisited and the categories were revised.

2. METHODS

As far as possible, characterisation of marks was based on objective physical characteristics such as intensity, length and height, depth in the water column, its 'texture', whether attached

to the bottom, and so on. Quantitative measurements of all of these parameters were possible with *Tangaroa*'s echosounders, but not *Tasman Viking*'s. Consequently there is a substantial degree of subjectivity in both the definitions of the mark-types and allocating any particular mark to a type.

2.1 Acoustic survey

The MEC acoustic survey was carried out using NIWA's 70 m research vessel *Tangaroa* and the 37 m trawler *Tasman Viking*, chartered from Donker Marine Limited, between 22 June and 9 July 2001. The survey was documented by Doonan et al. (2003).

A stratified random design was used for the acoustic part of the survey together with the standard fisheries acoustics method of echo-integration. Strata were allocated to reflect expected fish density and divided into two groups: 'main' strata around the Ritchie Hill area and 'background' strata which covered most of the orange roughy depths in the ORH 2A (Figure 1). South part of MEC that were not included in the main strata. There were three repeat surveys (snapshots) of the main strata and one of the background.

The main strata covered the area around Ritchie Hill and the Rock Garden (Figure 3). In each main stratum, a number of systematically positioned acoustic transects were defined usually in the east-west direction. The position of the first transect was randomly assigned. For the background, transects were aligned to run across depth contours. Point-strata (e.g., hills) were surveyed using a star pattern (Doonan et al. 2003). Trawling for species composition was targetted at the various types of marks seen on the echosounders of both ships.

2.2 Acoustic data

On *Tangaroa*, the acoustics data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs 1994) and stored in a digital form for later analysis. The data were from both towed and hull-mounted systems operating at 38 kHz (see Doonan et al. 2003). Both types of data were available for transects, but only hull data from trawls. The systems were calibrated, but the data were mostly used qualitatively for classifying marks.

Tasman Viking had a Furuno FCV-140 colour fishing sounder, with a conventional hull-mounted transducer operating at 28 kHz. Data from this system could not be stored digitally and were recorded by photographing the sounder's video display.

The echo-sounders on the two vessels operated at different frequencies with different transducer beam angles and different pulse lengths. This meant that both the horizontal and vertical resolution of the two systems were different. The scattering properties of roughy and other species are also known to differ at these two frequencies. The systems also used different colour schemes to encode echo intensity. As a consequence, for similar mark-types, *Tasman Viking*'s echo-sounder displayed a different set of colours and in some instances, shapes, from *Tangaroa* as shown in Figures 4–10. In *CREST* echograms the colours were predominantly combinations of shades of grey, red, and white with light grey corresponding to low backscatter intensity and white high. Colours on the *Tasman Viking* sounder were, from low intensity to high, no colour, green, yellow, red, and white. These colours were translated into *CREST* colours for the analysis. With only photographs to work from this translation was an approximation.

2.2.1 Working categories

Initially, working categories were assigned as the survey progressed and new marks were seen. There were four broad types: DISTINCT, LAYER, FUZZ, and BACKGROUND, where DISTINCT were any distinct, but short, marks which were variously described as a blob, plume, or pillar. A LAYER was longer than a DISTINCT mark and FUZZ was any low intensity mark or layer. BACKGROUND marks appeared as light grey marks or widely spaced flecks on *CREST* but did not show on *Tasman Viking*'s echosounder. In practice, each category encompassed many diverse mark-types (shape and intensity) and there were some indeterminate areas between each category. Selections were hampered somewhat by the different colours, intensities, and shapes seen on the echosounders of the two vessels. Other restrictions were that only verbal descriptions of marks could be given over the radio between *Tangaroa* and *Tasman Viking* (i.e., no exchange of echograms via fax or email was possible) and the time-lag between reporting a mark seen on a transect by *Tangaroa* and the time it was fished. A further factor was the reluctance of *Tasman Viking*'s skipper to trawl on LAYER or FUZZ marks and on "possible roughy marks" that he considered did not contain orange roughy.

The working categories were selected to be as simple as possible for the conditions of the survey and to allow for the limited number of tows possible since the full range of marks could not be sampled in adequate numbers to differentiate them all in an analysis. As noted earlier, in other areas, orange roughy form a large fraction of the catch from trawls on short distinct marks (plumes) and blobs on hills in the depth range 700 to 1200 m. They occasionally also occur as layers hard down on the bottom. With the *CREST* standard colour scheme, orange roughy marks are mainly red, sometimes with a little green. However, other species, or species mixes, can occur in similar looking marks. Intense marks (white) are known to be deepsea cardinalfish or other schooling species with large swimbladders. These are usually shallower than 700 m, but they can occur in roughy depths. Layers may contain orange roughy, but only as one of many species, and so they need to be separated from the shorter marks.

2.3 Classification

The working categories (DISTINCT, LAYER, FUZZ, BACKGROUND) formed the initial classification and trawls were assigned to these by comparing the echograms or echogram photographs (where available) and drawings and descriptions available at the time, including the opinions of *Tasman Viking*'s fishing staff. During this phase, it became clear that in some cases, it was difficult to translate a sounder photograph to a *CREST* echogram and the categories were so broad that they seemed inadequate. This led to an approach where the working categories were first divided into many preliminary mark-types based on those seen in the survey transect echograms and these were later amalgamated into a smaller number of types.

Expanding the working categories into a number of preliminary mark-types was based on mark shape, colour, and texture. Types considered were a distinct mark, layer, flecked, or dispersed. The expanded categories were defined primarily using *CREST* echograms, but some were identified from *Tasman Viking* photographs. The aim was to get types with concrete features that avoided gradations of shape and colour.

Trawls were assigned to mark-classes by either the shape and colour of the echogram or, for some *Tasman Viking* trawls, by plotting the position over transect tracks that had been colour-coded by mark-type. Provisional *Tasman Viking* trawl assignments were checked by comparing echogram photographs with the marks seen in the area on *CREST* transect echograms. This process showed up mismatches and the assignment was revised. Checking was repeated until there was a good match between *Tasman Viking* and *CREST* echogram shapes and colours.

The mark-types, geographical distribution of mark-types, and trawling results were cross-checked by two other NIWA staff members (D. Tracey and A. Hicks) to ensure consistency and some allocations and definitions were changed as a result. These mark-types were then further checked by *Tasman Viking* fishing skippers and other fishing industry representatives before being finalised.

3. RESULTS

There were 58 useable trawls (Table 1); 24 from the *Tasman Viking* (out of 29 attempts) and 34 from *Tangaroa* (35 attempts). There was more than 1 t of fish in 12 of the usable trawls, indicating a commercially significant mark, and 11 of these caught mainly orange roughy (65–100% with a median of 96%). The other large catch was of deepsea cardinalfish. Thus, the only species in commercial quantities were orange roughy and deepsea cardinalfish. The latter generated very intense marks (white on both sounders which is at the saturation level for the colour coding used) and were usually at depths shallower than 700 m.

The number of survey transects was 83 and there were 161 transects recorded with the *CREST* hull system. The extra hull transects were generally from searches carried out before each snapshot in the main survey strata (Table 1) (Doonan et al. 2003).

Table 1. All strata, all snapshots: number of transects and useable trawls.

	Transects		
Area	Hull	Tow body	Trawls
Ritchie			
Hull search	27	-	-
North Hill	6	2	1
South Ritchi Hill	3	3	-
RA	22	22	13
814 hill	5	3	2
RB	16	16	12
Rock Garden			
Search	20	-	-
Survey	17	11	6
	-		
Tolega Knoll			
	7	-	-
Background			
Madden	7	6	4
Portland	13	13	10
Tolaga	7	7	3
Wairapapa	11	-	7

3.1 Classification

There were 16 preliminary mark-types identified from the trawl and transect echograms. These were given descriptive names indicating position, shape, colour and texture. They are:

MARK
RED MARKS
GREY MARK RED FLECKS
GREY LAYER RED FLECKS
GREY LAYER
GREY LAYER RED FLECKS LOW
GREY FLECKS
RED LAYER
RED LAYER OFF
NOTHING
INTENSE MARK (high threshold distinct marks)
LAYER INTERSECTS BOTTOM (mid-water layers meeting the bottom: called feed-layers by fishers)
PENCIL MARKS (intense high but narrow plume)
HARD DOWN LAYER MARKS
CARDINAL MARK
RED FLECKS (based on the distinctive flecked high mark seen covering Ritchie hill)

These were then grouped into seven final types as follows. MARK and RED MARKS were almost exclusively orange roughy and were grouped as ORANGE ROUGHY. Most of the layer categories were grouped into a single type, GREY LAYER RED FLECKS, because there was a continuum between a grey layer and a red layer. LAYER INTERSECTS BOTTOM and RED MARKS GREY LAYER were considered distinct and retained. PENCIL MARK was discarded because this mark yielded no catch after several trawls and in consultation with the *Tasman Viking* skipper it was thought to be a freshwater spout. Also discarded was CARDINAL MARK because all marks of this type were shallower than 700 m.

The final mark-types were:

1. ORANGE ROUGHY – distinctive red coloured mark not attached to layers (Figure 4)
2. RED MARKS GREY LAYER – red layer hard down (less than 50 m) or red distinct mark attached to layer mark (Figure 5)
3. GREY LAYER RED FLECKS – layer mark mostly grey or may have red flecks throughout (Figure 6)
4. RED FLECKS – extensive(about 100 m+) red flecked mark, may extend off hill (Figure 8)
5. INTENSE – generally green, pink or white (Figure 9)
6. LAYER INTERSECTS BOTTOM – extensive (about 100 m thick) midwater layer that meets the bottom on slope (Figure 10)
7. BACKGROUND – absence of layer or other mark, may have flecks (Figure 7)

The mean percentage by weight of orange roughy in the catch for each mark-type was: 83% for ORANGE ROUGHY, 71% for RED MARK GREY LAYER, 22% for GREY LAYER RED FLECKS, 5% for LAYER INTERSECTS BOTTOM, 35% for BACKGROUND, 3% for RED FLECKS and 0.3% for INTENSE. The number of tows in each mark-type is given in Table 2 and a list of all trawl data used is given in Appendix 1.

4. DISCUSSION

The catches of trawls assigned to mark-types were surprisingly distinct (Table 2) with different fractions of orange roughy in each type and also different species compositions. Four-rayed rattail (CSU) appear to be numerous, but non-commercial, part of the ecosystem. Large catches came from only three mark-types. Of the 12 trawls that caught more than 1 t, 8 were in ORANGE ROUGHY (catches mainly orange roughy), 3 were in RED MARK GREY LAYER (mainly orange roughy), and 1 was from INTENSE (mainly deepsea cardinalfish). Thus, the mark-types appear to have successfully separated commercial from non-commercial fish marks and also marks from the two commercial species present in the area. For orange roughy, only spawning fish appear in commercial quantities. Very few spawning roughy are in the layers, but non-spawning roughy are present in the BACKGROUND mark-type in relatively high densities. Interestingly, the layers in GREY LAYER RED FLECKS have fewer roughy than BACKGROUND even though they are extensive in the main strata RA and RB (see Table 1).

Table 2: Mark-types: proportion (%) by numbers of spawning orange roughy (ORH) and the next two main species. Species codes are: nORH, non spawning orange roughy; BYS, deepsea cardinalfish; CSU, four-rayed rattail; CYP, *Centroscymnus crepidater*; HJO, Johnson's cod; SND, shovelnose spiny dogfish; and SOR, spiky oreo.

Mark-type	ORH	Species other than spawning ORH			
	proportion	*Species*	*Proportion*	*Species*	*Proportion*
ORANGE ROUGHY	92	nORH	3	CSU	2
RED MARKS GREY LAYER	30	CSU	60	nORH	2
GREY LAYER RED FLECKS	3	CSU	71	nORH	5
RED FLECKS	2	HJO	48	SOR	17
INTENSE	1	BYS	94	CYP	1
LAYER INTERSECTS BOTTOM	1	SND	27	CSU	26
BACKGROUND	9	CSU	21	nORH	15

Examples of applying the mark-types to transects are shown in Figures 11 to 12. These echograms are from the towed system and were used to estimate the biomass from the survey. Figure 11 shows ORANGE ROUGHY, GREY LAYER RED FLECKS, and RED FLECKS. The RED FLECKS mark is on the side of Ritchie Hill in about the same place that the major spawning plume occupied in the 1980s and early 1990s. It was initially taken to be orange roughy, but trawling and target strength data from the area showed that it was mainly Johnson's cod (a species with a large swimbladder so that a low density of fish shows as an orange roughy school.) The ORANGE ROUGHY mark is on the ridge of which Hill 814 is part this is known to be an orange roughy spawning site.

Red marks and grey layer types are shown in Figure 12. The rightmost RED MARKS GREY LAYER looks little different from the GREY LAYER RED FLECKS on the left and also the one in Figure 11, showing that the application of the classification can, at times, be subjective. ORANGE ROUGHY, INTENSE, and LAYER INTERSECTING BOTTOM are shown in Figure 13 from a transect on the Rock Garden. The INTENSE mark looks more like ORANGE ROUGHY in the reproduction here, but it does have some green in it. On a video screen, this mark is pink and green and is clearly differentiated from the nearby ORANGE ROUGHY. Colours are often slightly different between a video screen and printer and it is hard to reproduce them in print. As a black and white figure, BACKGROUND and other marks all look similar and are hard to differentiate, hence the colour codes, and to a lesser extent, thresholds used are an important part of viewing echograms.

As noted above, RED MARKS GREY LAYER and GREY LAYER RED FLECKS are quite similar with the main difference being the amount of red in the mark. It is easy to envisage marks that fall between these two which would be hard to assign to either type (see Figure 11). With only four trawls, RED MARKS GREY LAYER is possibly over-fitted given that it has similar proportions of four-rayed rattails to GREY LAYER RED FLECKS (Table 3). However, most catches in the former were more substantial at over 1 t and contained much more spawning orange roughy than the latter. Given that the interest was in orange roughy, we were prepared to accept the possible bias arising for the time being. Clearly more work is needed to separate these two types.

Other problems with the analysis are the small sample size in some mark-types (Table 3) and mark identification in the Rock Garden. Of types with small sample sizes, RED MARKS GREY LAYER has substantial amounts of roughy and the numbers may be too few for the bootstrapping required for the abundance variance calculations. The other three with few trawls were RED FLECKS, INTENSE, and LAYER INTERSECTS BOTTOM. These had very few spawning orange roughy and bootstrapping for biomass is not a problem. The small sample size potentially has an effect on mark classification. INTENSE and LAYER INTERSECTS BOTTOM are distinctive types and fishers do not associate them with roughy. However, RED FLECKS can be mistaken for a roughy mark and the trawls for this type are all at one site (Ritchie Hill) and so the catches may not generalise well to other sites (e.g., there is a Rock Garden mark classified as RED FLECKS).

Table 3: Mark-types, the main species in the catches and the number of trawls in each class, 'ORH' - orange roughy.

Mark-type	Main species	Number of tows
ORANGE ROUGHY	mostly ORH	14
RED MARKS GREY LAYER	mostly ORH	4
GREY LAYER RED FLECKS	mostly rattail species, some ORH	22
RED FLECKS	mostly Johnson's cod	4
INTENSE	alfonsino, cardinals	1
LAYER INTERSECTS BOTTOM	Mixed species, but few ORH	2
BACKGROUND	Mixed species, some ORH	10

There were a number of difficult allocation choices made in the Rock Garden with respect to INTENSE marks, some of which were in roughy depths. Decisions were based on an assessment of the way the proportion of roughy changed with depth down the Rock Garden slope. The number of trawls was too low for any detailed analysis and so this was somewhat subjective. However, the geographical distribution of the marks as assigned did correspond to the catch composition in the small number of trawls carried out. The uncertainty of mark assignments is highest in this area and further work is needed.

Other uncertainties stem from the chance of trawling missing the targeted mark and the subjective nature of the classification. Marks were supposed to be classified on elements of the echogram, but some marks were treated differently because the analyst cannot forget that a good orange roughy catch was made there. ORANGE ROUGHY marks came from a limited number of sites: DB in stratum RB, Hill 814, North Hill, and in the Rock Garden. These sites were small in area and although marks moved around somewhat within them, our impression is that the ORANGE ROUGHY type could have been recast in terms of sites rather than in terms of echogram shape and colour. In the survey transects, ORANGE ROUGHY assignments were made outside these areas, but in all but two instances, they were on the ridge of which Hill

814 is part, suggesting that the Hill 814 stratum should be extended to include the whole ridge. The two exceptions were small and were located in RA stratum, one close to this ridge and the other out in the open.

5. ACKNOWLEDGMENTS

This work was carried out for the Ministry of Fisheries under project ORH2000/01. We thank Gavin Macaulay for comments on the manuscript, A. Hicks and D. Tracey for assistance with the analysis, Steve Donker (Donker Marine Ltd) for providing the vessel *Tasman Viking*, and Donker Marine skippers Matthew Hardyment and Chris Whelan for assistance with mark classification.

6. REFERENCES

Coombs, R.F. (1994). An adaptable acoustic data acquisition system for fish stock assessment. International Conference on Underwater Acoustics, 5–7 December 1994, University of New South Wales, Sydney, Australian Acoustical Society.

Do, M.A.; Coombs, R.F. (1989). Acoustic measurements of the population of orange roughy (*Hoplostethus atlanticus*) on the north Chatham Rise, New Zealand, in winter 1996. *New Zealand Journal of Marine and Freshwater Research 23*: 225–237.

Doonan, I.J.; Bull, B.; Coombs, R.F.: (2003). Star acoustic surveys of localized fish aggregations. *ICES Journal of Marine Science 60*: 132–146.

Doonan, I.J., Coombs; R.F.; Barr, R.; McClatchie, S.; Grimes, P.; Hart, A.; Tracey, D.; McMillan, P.J. (1999). Estimation of the absolute abundance of orange roughy on the Chatham Rise. Final Research Report for Ministry of Fisheries Research Project *ORH9701*. (Unpublished report held by Ministry of Fisheries, Wellington.)

Doonan, I.; McMillan, P.J. (2000). Objective classification of acoustic fish marks for the 1998 south Chatham Rise (OEO 4) oreo survey (TAN9812). *In* Coombs, R.F., Final Research Report for Ministry of Fisheries Research Project OEO9801, Objective 1, November 2000. (Unpublished report held by Ministry of Fisheries, Wellington.)

Doonan, I.J.; Hicks, A.; Coombs, R.F.; Hart, A.C.; Tracey, D. (2003). Acoustic estimates of the abundance of orange roughy in the Mid-East Coast fishery, June-July 2001. *New Zealand Fisheries Assessment Report 2003/4*. 22 p.

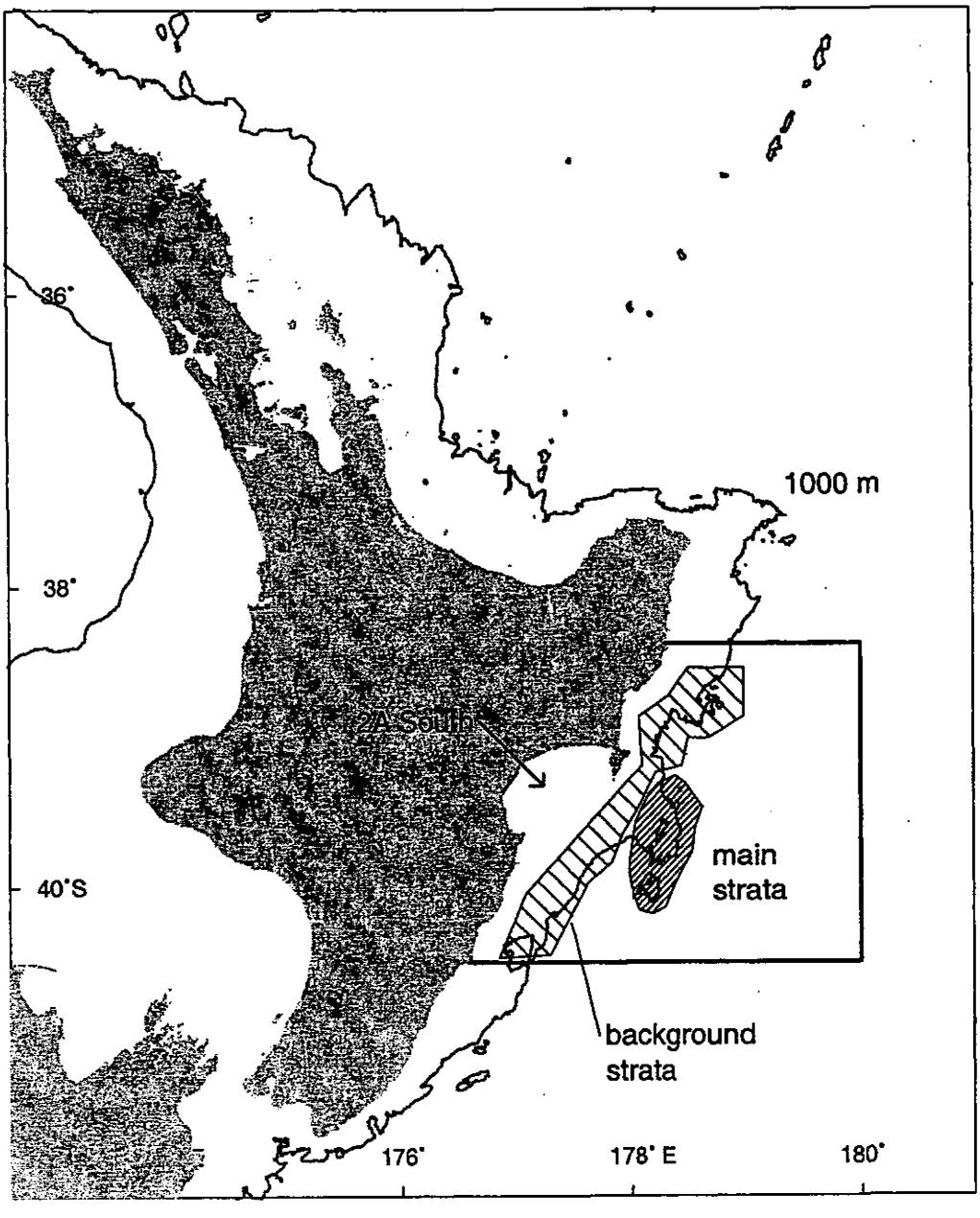
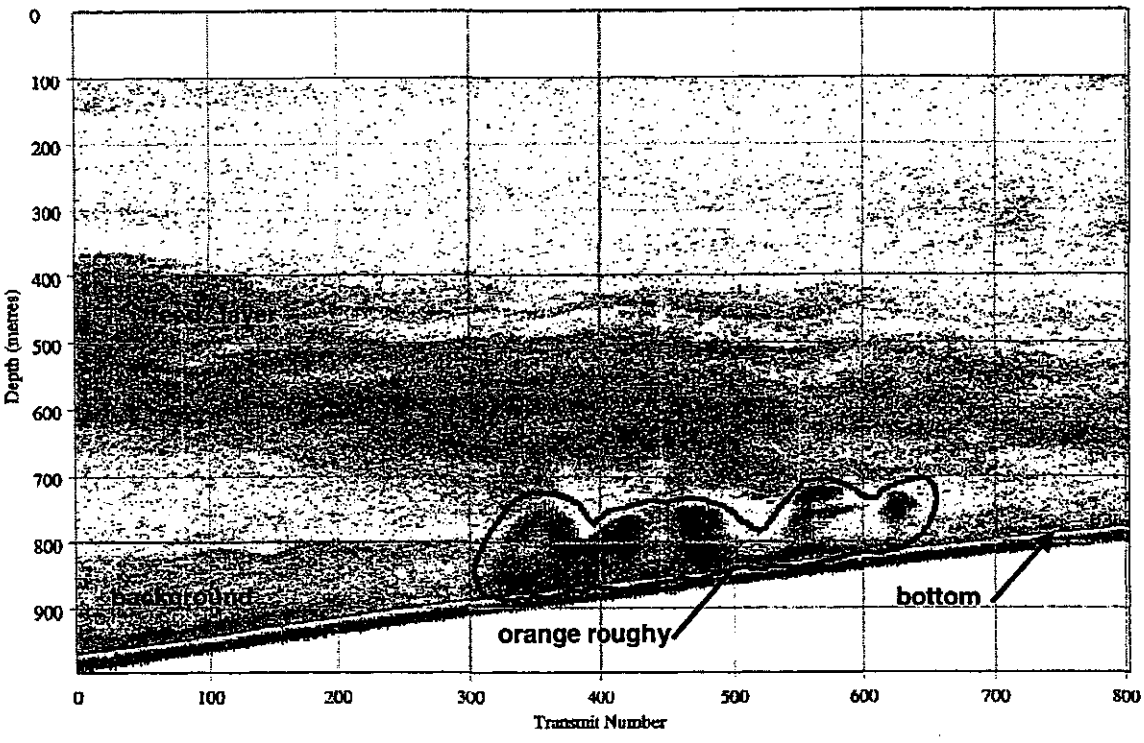
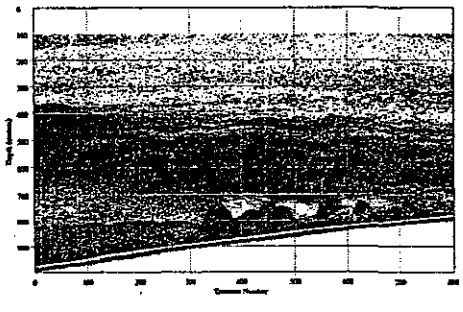
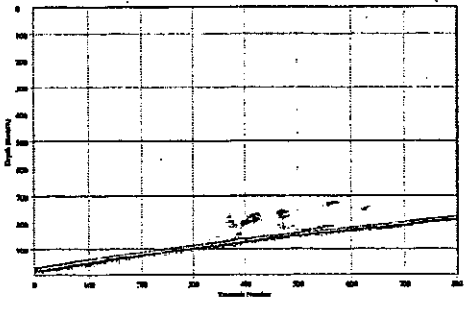


Figure 1: **Areas surveyed in the ORH 2A South section of the Mid-East Coast fishery for spawning orange roughy in 2001. The main strata surround Ritchie Hill and contain the only known spawning schools in this area.**



a





b c

Figure 2: Acoustic echogram of a transect on the spawning orange roughy plume in the Spawning Box on the north Chatham Rise in 2000. The transect length is 7.8 km. (a) shows the marks encountered. The feed layer contains little orange roughy and is composed of salps and small fish species. Background marks have 40 to 60% orange roughy by weight, but only 5 to 10% by number. The orange roughy mark is 3 km long and is about 98% orange roughy, by weight. The threshold is –80 dB. (b) shows a grey-scale echogram with no thresholding. (c) shows a grey scale echogram with a threshold of –65 dB.

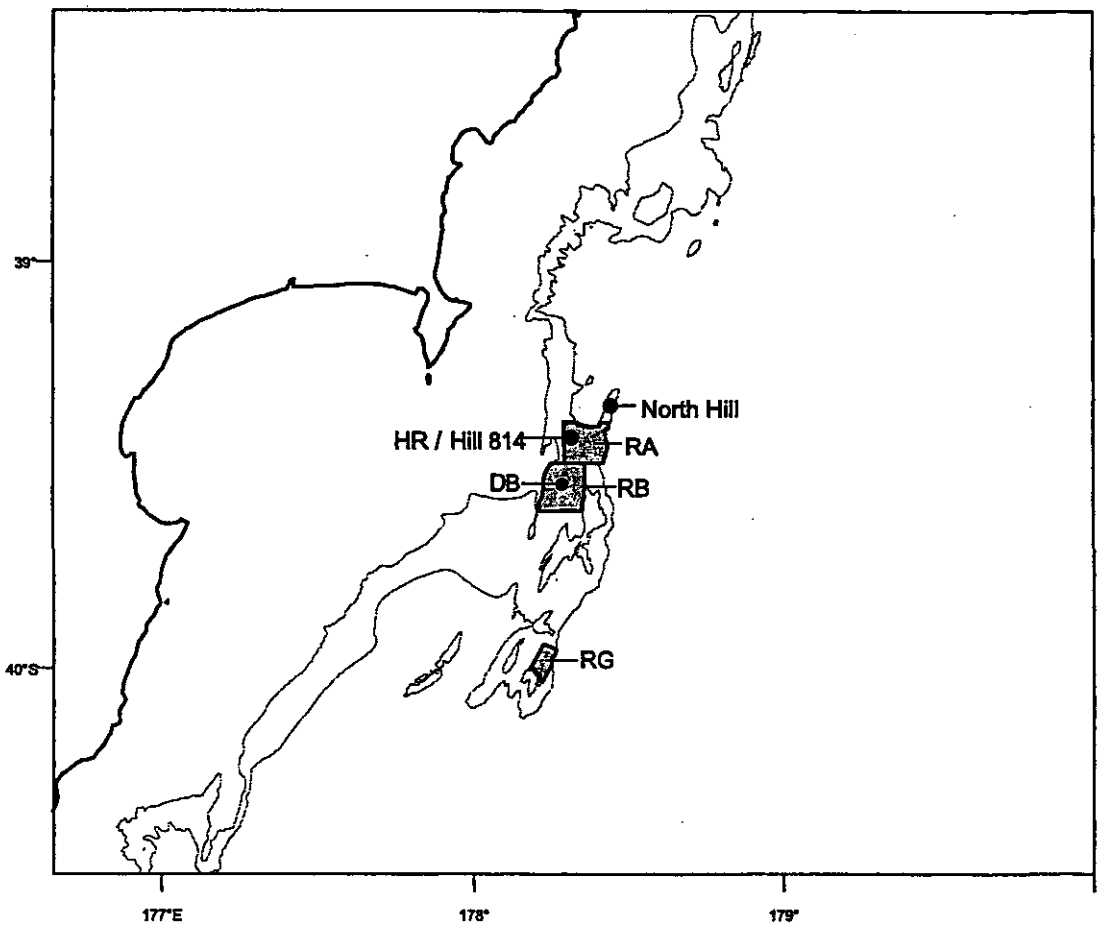


Figure 3: **Map of the strata over the main area (RA, RB, RG (on the Rock Garden), positions of point-strata (North Hill, Hill 814), and the position where a small spawning plume was found (DB).**

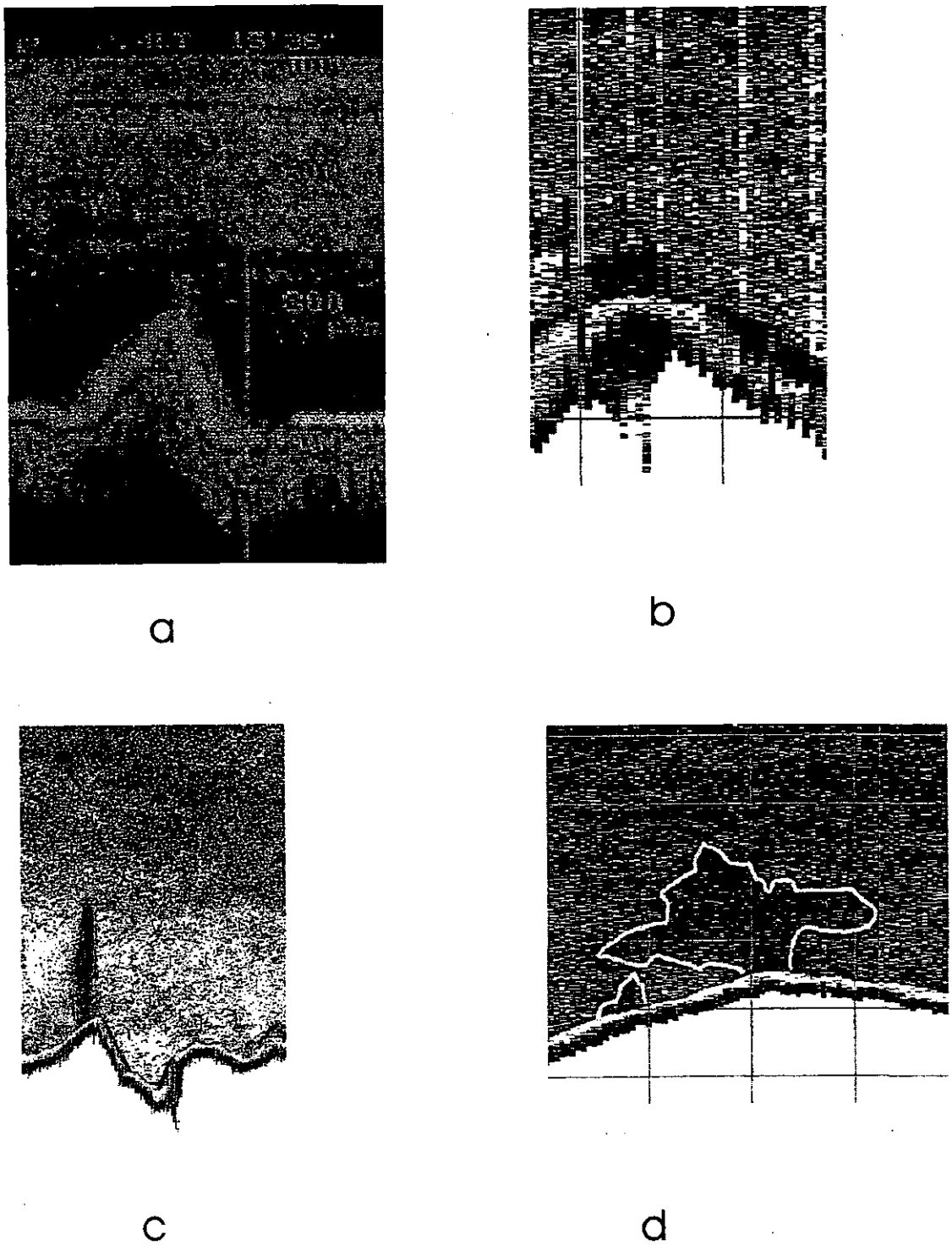


Figure 4: ORANGE ROUGHY mark-type. (a) *Tasman Viking* sounder photo of a spawning school on Hill 814 (height 50 m). (b) A spawning school on Hill 814 (height 40 m, width 48 m) from the *CREST* hull system. (c) Echograms of orange roughy in stratum RB at the position DB, towed system, height 150 m, width 80 m. (d) at the Rock Garden, hull system, height 147 m, width 200m, mark outlined by a white line to distinguish it from the background if viewed as a black and white image.

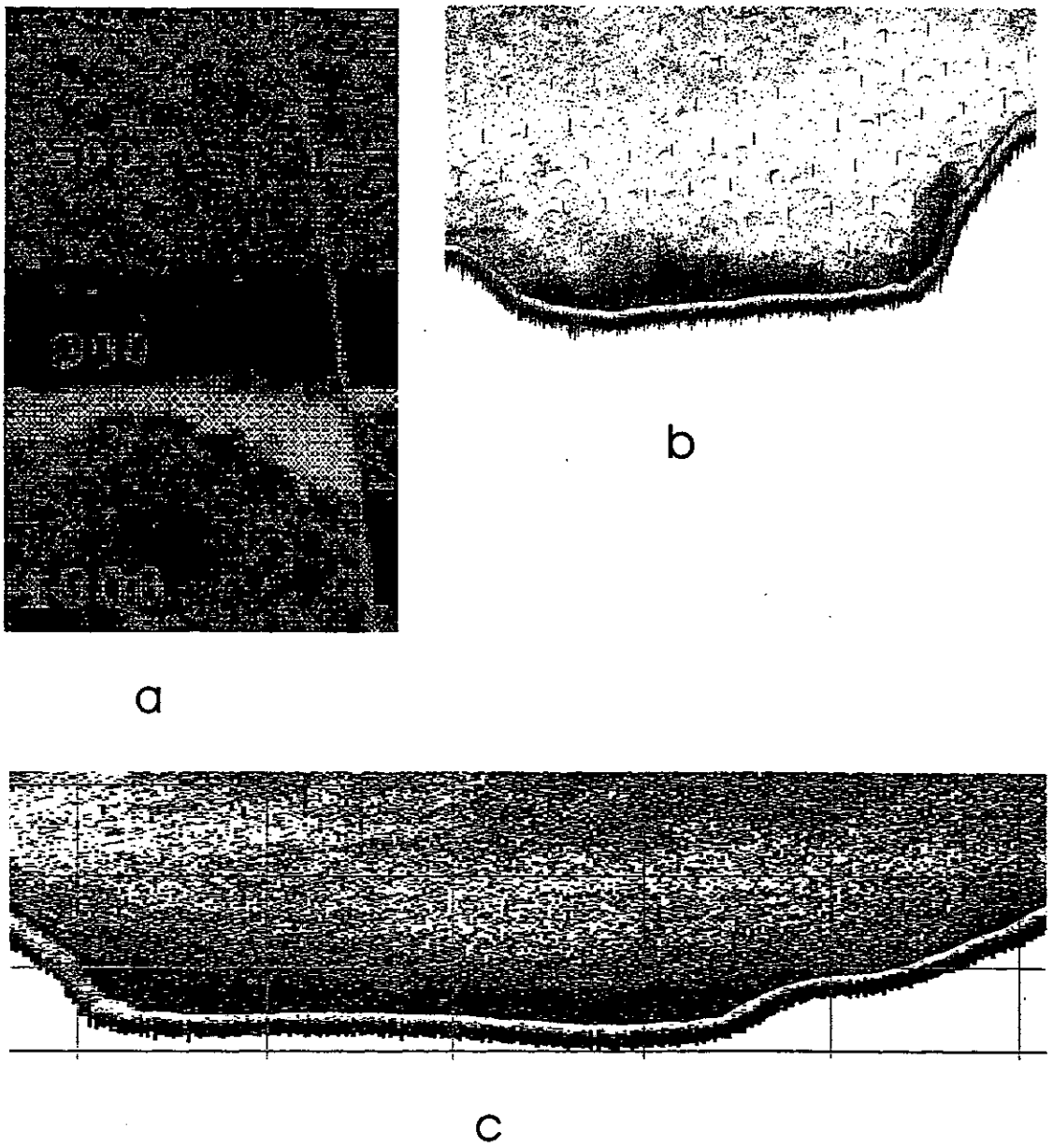


Figure 5: RED MARK GREY LAYER mark-type. *Tasman Viking* echo sounder photographs (a) spawning fish near DB of an ORANGE ROUGHY mark-type after a trawl on it (not quite the same thing as those seen by the *Tangaroa*, but the only one available from the *Tasman Viking*). The sloping white line divides the screen so that two echograms can be viewed, usually an earlier one which has been saved from the first pass over the mark as well as that for the trawl. (b, c) Echograms from *CREST* (b, towed system; c, hull system, no thresholding).

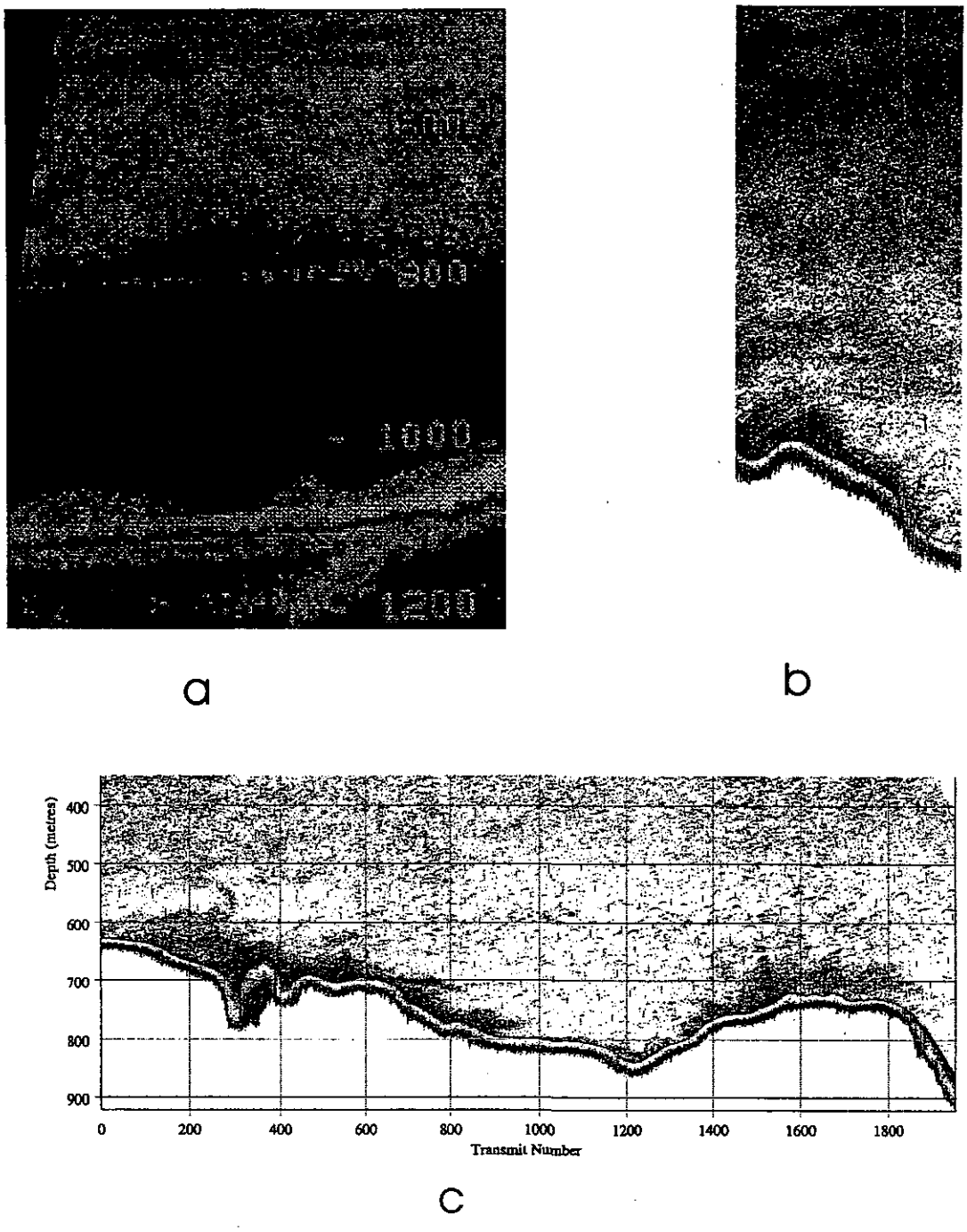
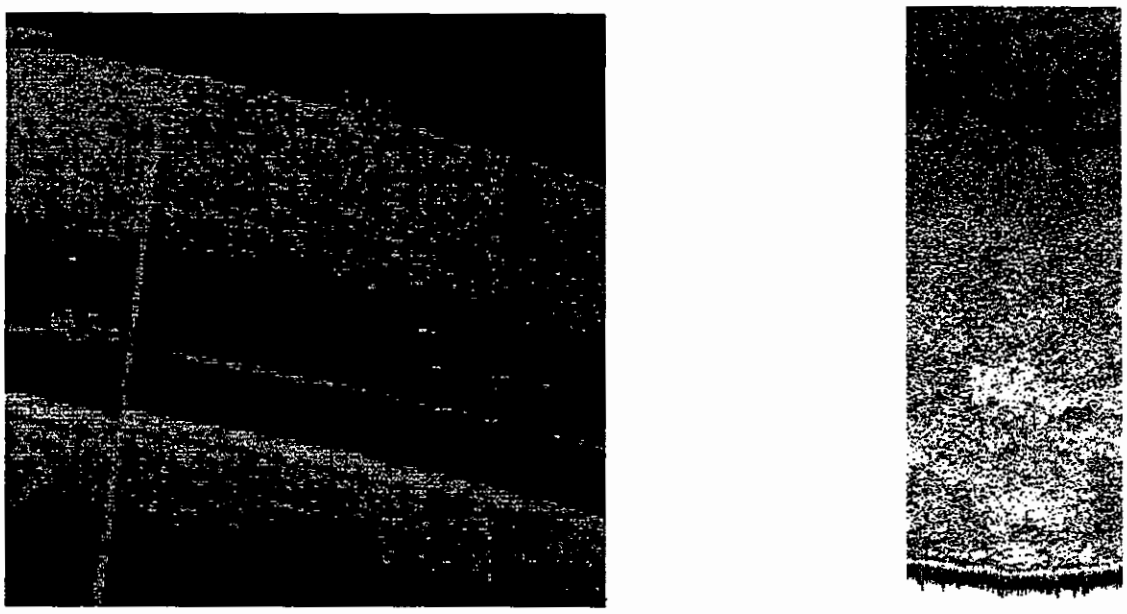
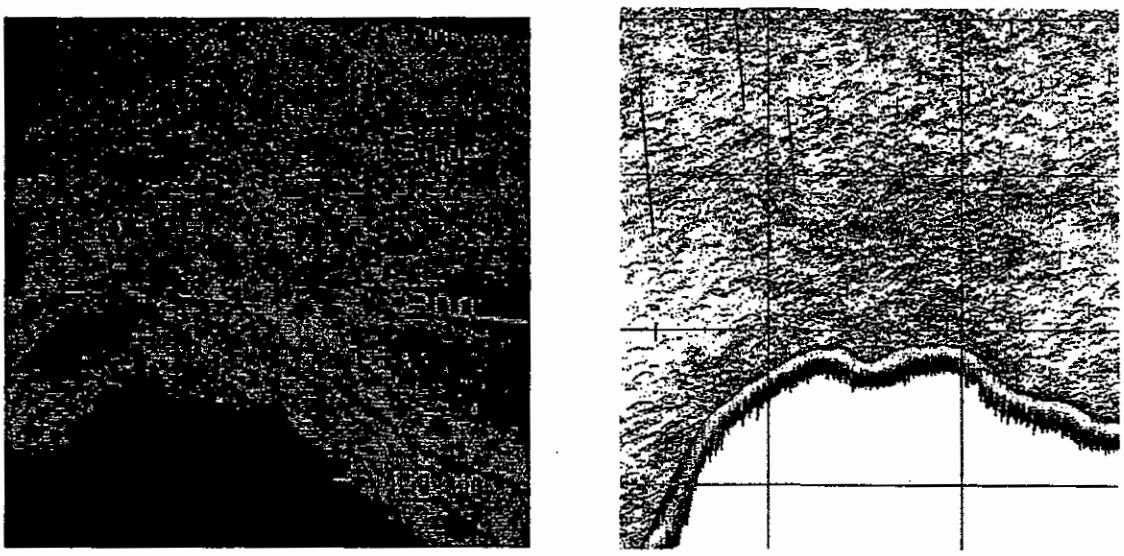


Figure 6: **GREY LAYER RED FLECKS mark-type. *Tasman Viking* sounder photo (a) on their 'Stromboli' tow line; (b, c) Echograms from the towed *CREST* system (no thresholding).**



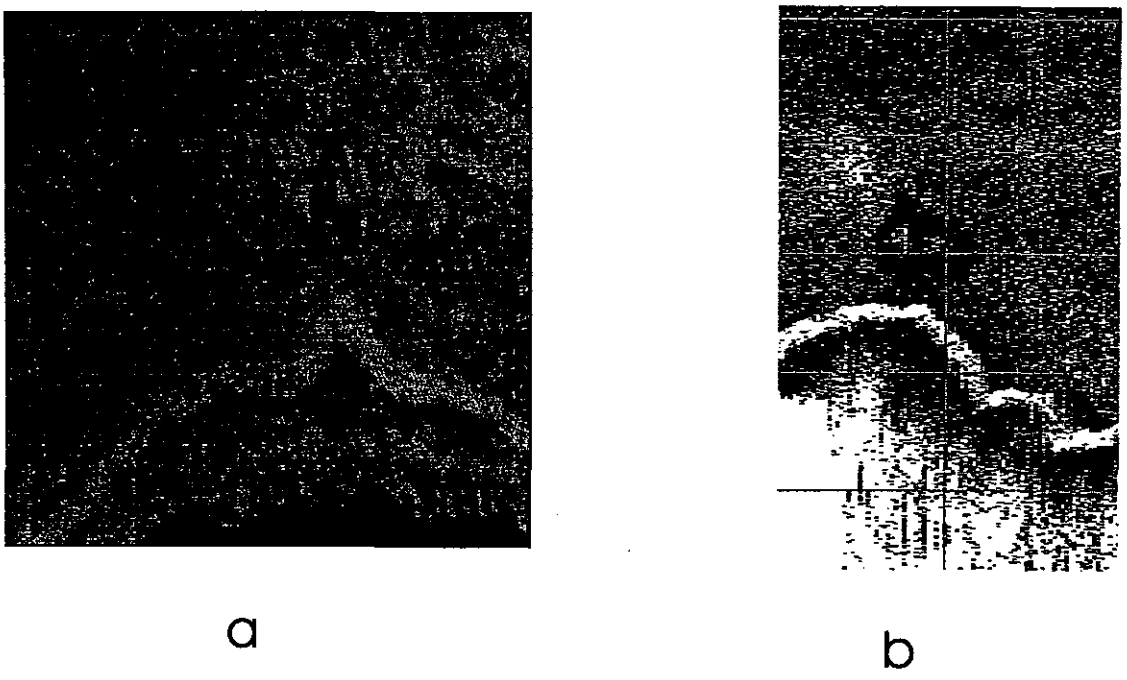
a b

Figure 7: BACKGROUND mark-type. (a) *Tasman Viking* sounder photo which shows nothing because the sounder controls were set not to show low backscatter; (b) fragment from *CREST* towed system (no thresholding); the light speckles disappear on thresholding at –77 dB.



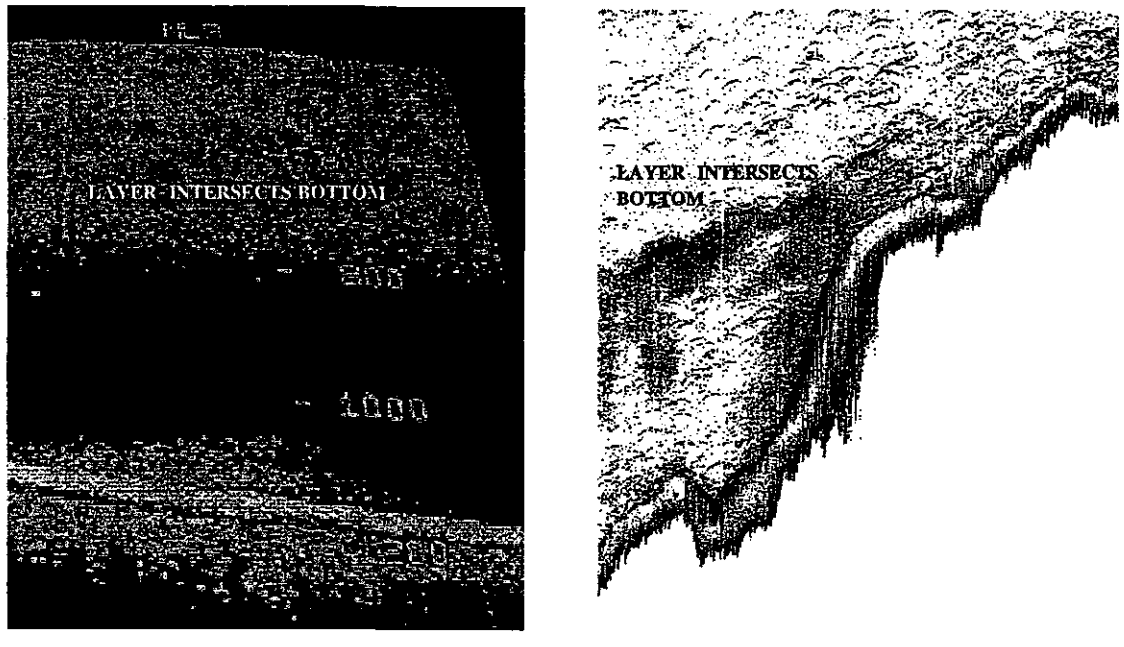
a b

Figure 8: RED FLECKS mark-type. (a) *Tasman Viking* sounder photo. (b) Fragment from *CREST* towed system (no thresholding).



a b

Figure 9: INTENSE mark-type. (a) *Tasman Viking* sounder photo. (b) Fragment from *CREST* towed system (no thresholding).



a b

Figure 10: LAYER INTERSECTS BOTTOM mark-type. (a) *Tasman Viking* sounder photo. (b) Fragment from *CREST* towed system (no thresholding).

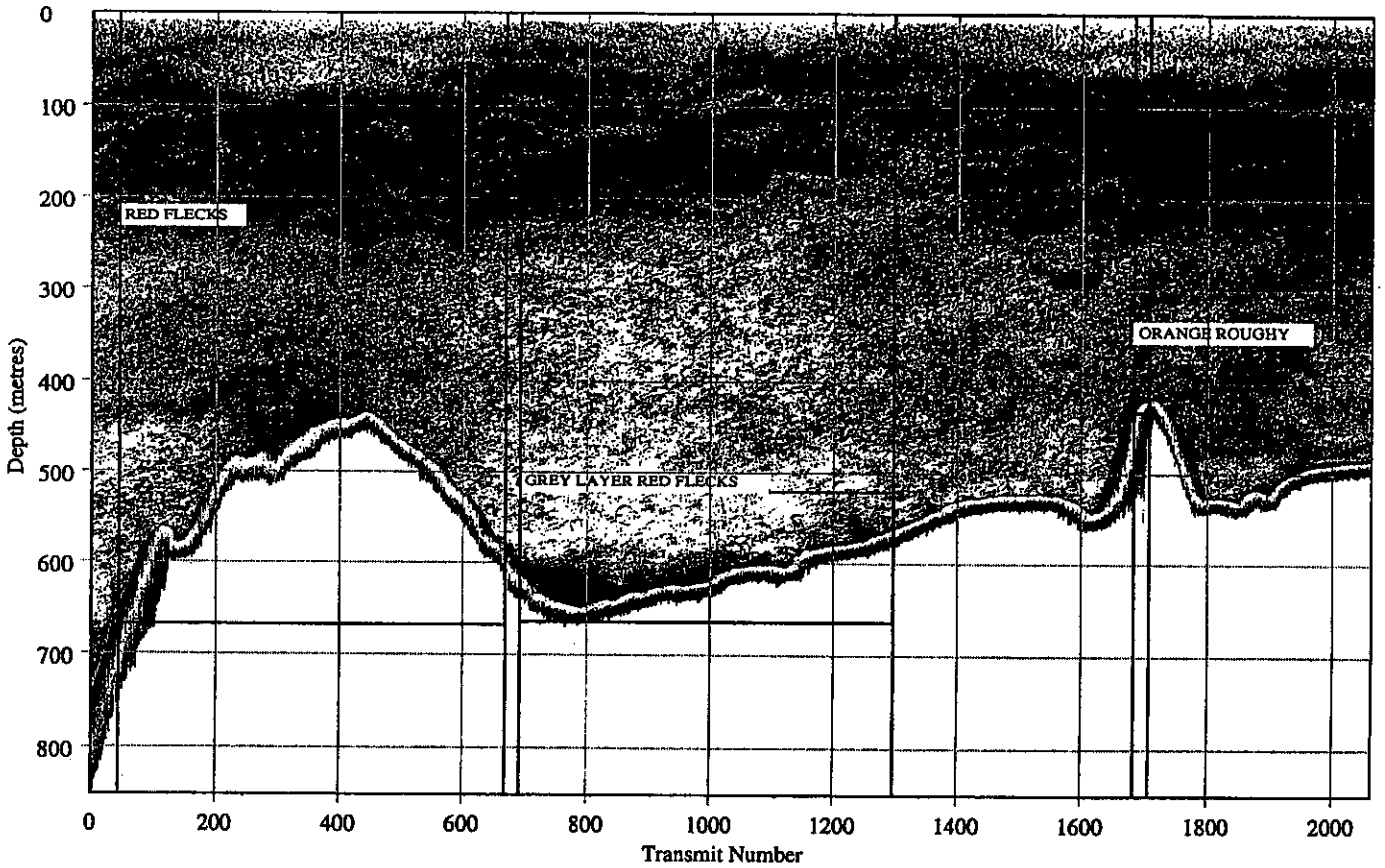


Figure 11: Partition of the echogram from transect 6 in stratum RA in snapshot 1. Ritchie Hill is on the left and the ridge that Hill 814 is on is to the right. Areas not marked are in the background mark class.

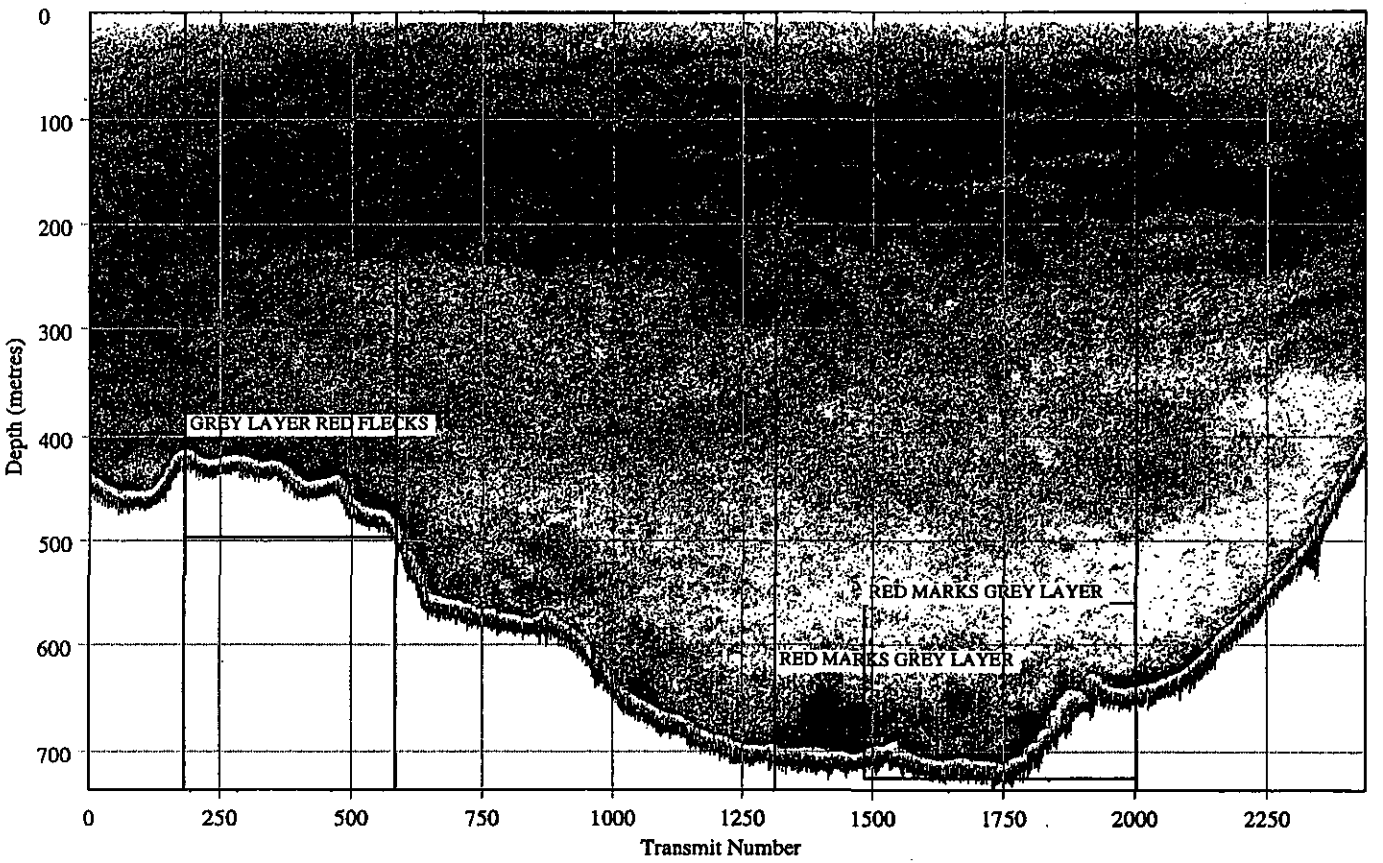


Figure 12: Partition of the echogram from transect 4 in stratum RB in snapshot 1. Areas not marked are in the background mark class.

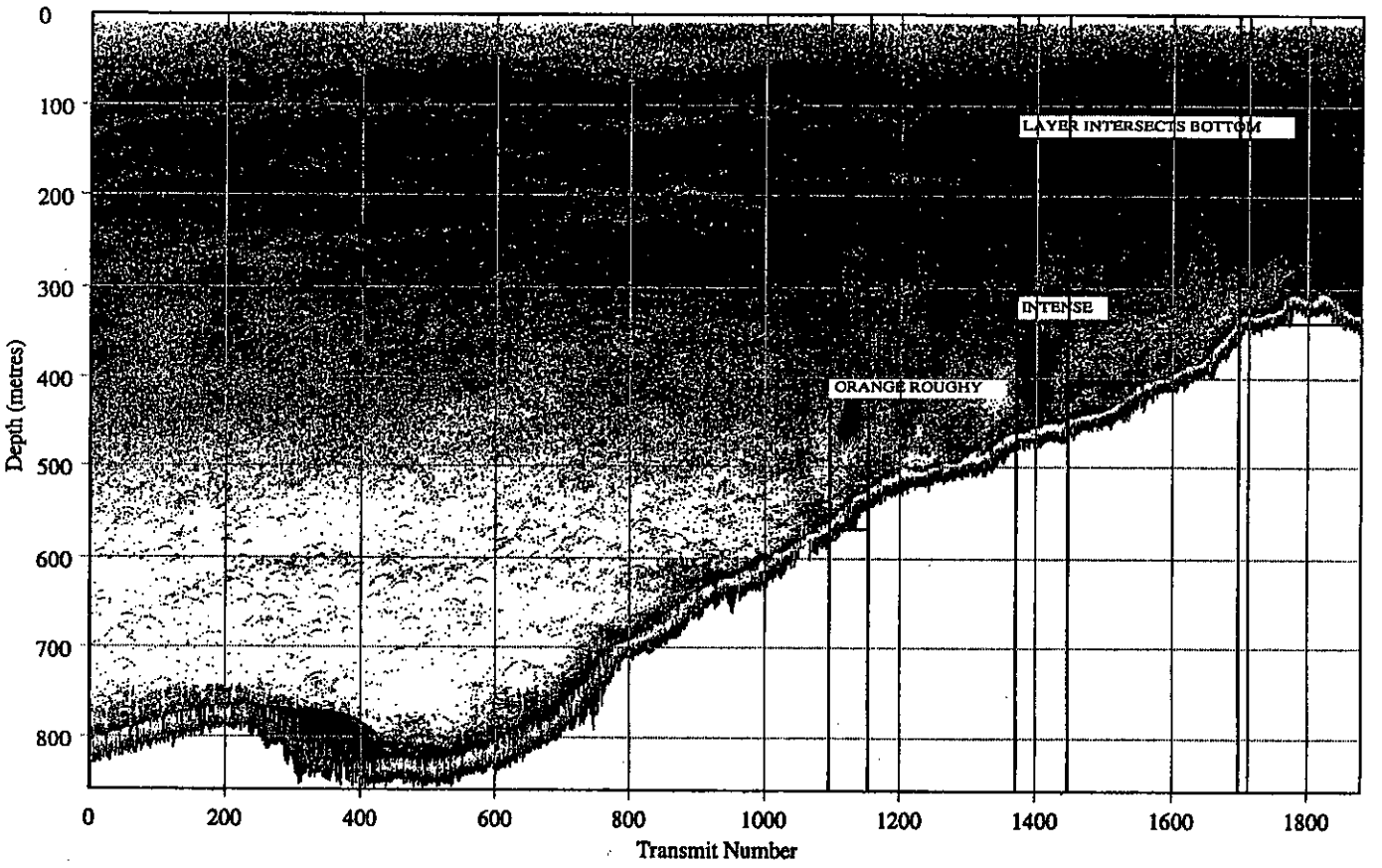


Figure 13: **Partition of the echogram from transect 4 in stratum Rockgarden in snapshot 1. Areas not marked are in the background mark class.**

APPENDIX 1: Trawl data used in analysis

The trawl data and the final mark-class assignment are given in the following table. Stratum codes are: "RA" and "RB" are strata in the main spawning area; "ROCK", Rock garden; "H814", Hill 814; "RBDB", the plume at the site marked DB in stratum RB; RNOR, North Hill; numbers refer to background strata.

Station number	Stratum	Mark-type	Orange roughy (kg)	Orange roughy Proportion of catch (%)	Total catch (kg)
Tasman Viking					
1	10	ORANGE ROUGHY	3 277	68	4 828
2	10	ORANGE ROUGHY	235	63	375
3	10	BACKGROUND	260	61	424
4	2	BACKGROUND	47	11	409
5	RA	GREY LAYER RED FLECKS	24	11	214
6	RNOR	ORANGE ROUGHY	20 790	100	20 847
9	RA	ORANGE ROUGHY	3 130	89	3 504
11	RA	GREY LAYER RED FLECKS	41	15	268
13	H814	ORANGE ROUGHY	1 199	98	1 227
14	RBDB	ORANGE ROUGHY	3 300	99	3 344
15	RB	RED MARKS GREY LAYER	43	51	85
16	RB	RED MARKS GREY LAYER	100	55	184
17	ROCK	INTENSE	6	0	1 777
19	ROCK	RED FLECKS	6	1	398
20	ROCK	ORANGE ROUGHY	11 059	96	11 535
21	RB	GREY LAYER RED FLECKS	17	30	56
22	RA	RED FLECKS	2	5	48
23	RA	ORANGE ROUGHY	72	38	186
24	RA	ORANGE ROUGHY	860	88	980
25	RA	GREY LAYER RED FLECKS	16	8	190
26	RA	RED FLECKS	20	6	333
27	RA	GREY LAYER RED FLECKS	47	27	177
28	H814	BACKGROUND	10	20	48
29	RBDB	ORANGE ROUGHY	6 913	100	6 934
Tangaroa					
1	RA	GREY LAYER RED FLECKS	16	10	152
3	ROCK	ORANGE ROUGHY	111	77	144
4	ROCK	GREY LAYER RED FLECKS	21	16	131
5	ROCK	BACKGROUND	1	3	32
6	RBDB	ORANGE ROUGHY	8 851	99	8 945
7	RB	RED MARKS GREY LAYER	0	0	0
8	RB	RED MARKS GREY LAYER	309	83	374
9	RB	GREY LAYER RED FLECKS	12	8	152
10	RA	RED FLECKS	0	0	30
11	RA	GREY LAYER RED FLECKS	7	8	85
12	RB	GREY LAYER RED FLECKS	11	7	168
13	RA	GREY LAYER RED FLECKS	9	4	231
14	RB	LAYER INTERSECTS BOTTOM	20	9	215
15	RB	RED MARKS GREY LAYER	543	95	573
16	5	GREY LAYER RED FLECKS	109	59	185
17	6	GREY LAYER RED FLECKS	302	78	388
18	6	LAYER INTERSECTS BOTTOM	2	1	318
19	6	GREY LAYER RED FLECKS	18	12	149
20	5	GREY LAYER RED FLECKS	199	52	385

21	5	GREY LAYER RED FLECKS	290	41	714
22	5	GREY LAYER RED FLECKS	21	12	171
23	4	GREY LAYER RED FLECKS	63	24	265
24	4	GREY LAYER RED FLECKS	5	4	115
25	4	BACKGROUND	65	39	168
26	1	GREY LAYER RED FLECKS	16	10	152
27	10	BACKGROUND	93	35	262
28	10	ORANGE ROUGHY	908	86	1 052
29	10	BACKGROUND	1 461	68	2 159
30	10	ORANGE ROUGHY	1 132	65	1 740
31	2	BACKGROUND	23	20	110
32	2	GREY LAYER RED FLECKS	217	33	664
33	8	BACKGROUND	237	67	354
34	7	GREY LAYER RED FLECKS	36	11	321
35	7	BACKGROUND	39	26	153