AN ANALYSIS OF SEA-BED IMAGES COMPARING LINEAR AND CHEVRON ROUTE SURVEYS

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1. INTRODUCTION

The Mine Countermeasures (MCM) Group of the Defence Research Establishment Pacific (DREP) is researching an imaging route survey concept as an essential mine hunting adjunct. The concept consists of conducting two surveys, a peacetime pre-mining survey and a mine hunting survey during hostilities. At an analysis facility archival images are compared to newly acquired images, and checked for new objects (possible mines) on the sea-bed. To resolve mine-sized objects requires an areal resolution of better than 0.3 by 0.3 m. Images are generated using a side-scan sonar. Since this is an active sensor, images of the same area of sea-bed will have characteristics dependent on the position and attitude of the sensor. Beam bearing, sensor altitude and range to a specific object on the sea-bed are the major determining factors which affect an objects appearance in side-scan sonar images.

General sea-bed characteristics such as the presence of gravel, sand or mud can also be gleaned from the side-scan images. In many cases the sea-bed appears "textured", as in the case of sand ripples. It is desirable that the general characteristics assigned to a particular area not depend on the aspect at which the images are obtained. Also, the effect of varying aspect angle on shadows and backscatter may seriously impinge on the ability of an operator to compare images and detect MLOs.

In order to better understand the problem of comparing images with varying characteristics, a detailed route survey was conducted in an area off the southern tip of Vancouver Island. This report outlines the results of surveying a ~2 km^2 area using towfish paths at nominal headings of 0^o, 30^o and 60^o. The result is that the area was surveyed a number of times with sonar beam bearings at 90^o, 120^o, 150^o, 270^o, 300^o and 330^o. The major intent of the survey was to consider the effects of beam bearing; thus sonar altitude and range were kept as constant as was practical.

2. SURVEY AREA

The area discussed is a 500 m wide 4 km long route. Sea-bed images were obtained with a Mesotech 972 side-scan sonar, using the 330 Khz transducers and a range setting of 100 m. Towfish altitude was 16±3 m. With a nominal towing speed of 2 m/s and a ping rate of 6.1 hz, the sonar produces an image raster line 200 m long (port and starboard transducers) every ~0.33 m along the towfish path. The geographic position and the attitude of the towfish were measured using a variety of systems. An overview of the equipment used is given by Poeckert *et al* [1].

The first survey was a *linear* survey, wherein the towfish track was parallel to the route axis. Since the route is 500 m wide and a single traversal over the route provides a survey width of only 200 m, several parallel tracks were made. The images from adjacent tracks overlapped providing complete coverage of the route. The second survey consisted of a *chevron* survey, wherein the towfish track criss-crossed the route at $\pm 30^o$ to the route axis. Figure 1 shows the towfish tracks for both surveys.

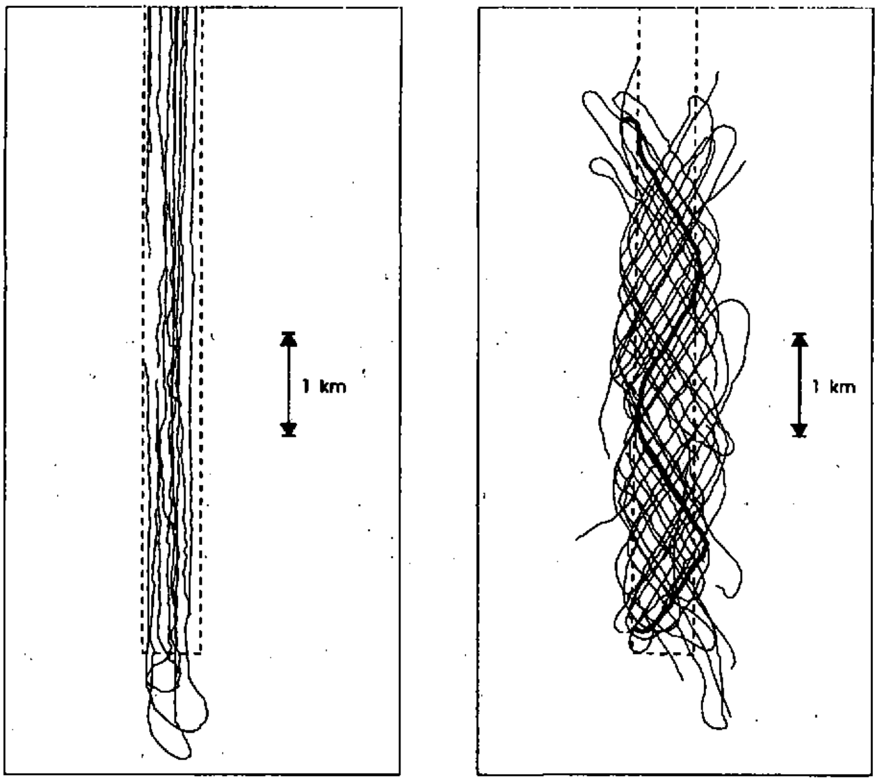

Figure 1. Towfish tracks; (a) *linear* survey, (b) *chevron* survey. The bold line shows an example of a single chevron traversal of the survey region. The dashed line denotes the intended survey area.

Towfish position was estimated by combining the ship position as determined by a Racal MicroFix (microwave radio ranging system), the towfish layback and bearing as determined by a Trackpoint II system (ultra-short baseline acoustic system) and a towfish depth sensor. Towfish attitude, heading, roll and pitch were measured with an on-board sensor package. A tracking algorithm [2] was used to provide an optimal estimate of towfish position and attitude for each side-scan image raster.

The survey plan called for towfish tracks that were straight, parallel and spaced every 75 m. Figure 1 shows that in practice this was not achieved. The intent of the chevron survey was to provide four different aspects of the entire survey area. Preliminary analysis [1] indicated that 78% of the area was surveyed at least four times. It was erroneously reported that the coverage was at four aspects. In fact less than 50% of the survey area has coverage at four <u>different</u> aspects lowering the true four-aspect coverage rate to ~0.07 km^2/hr. This is indicative of the difficulty of carrying out a comprehensive *chevron* survey. It should be noted that the survey area had tidal currents up to 4 kts, which exacerbated the ship's ability to follow the planned survey tracks.

The Mesotech 972 processor applies a time varying gain (TVG) to the sonar data to correct for range dependent signal strength decrease. Sonar images were produced by digitising the analogue output from the Mesotech system. An angle dependent TVG was applied after digitisation to correct for the sonar's vertical beam pattern. This second TVG was derived from analysis of a number of side-scan sonar images. In applying this TVG it was assumed that the sea-bed was flat and the towfish had zero roll. Both TVGs were fixed for all of the image data so that direct comparison of image intensity is possible across the entire route survey data set.

The DREP Sonar Image Processing System (SIPS [3]) was used to combine the side-scan sonar images and the towfish track and attitude estimates to produce geo-coded sea-bed images. For analysis purposes, the sonar data were divided into six groups, one for each of the nominal beam bearings. SIPS was used to mosaic images to provide a broader view of the survey area at a given beam bearing.

Images of the survey area show a variety of patterns. For the remainder of this report the sea-bed characteristics as seen in the images will be denoted as:

- textured: changes in acoustic backscatter strength on a scale of 0.5 to 10 m, covering an area >1000 m^2.
- structured: features on a scale > 10 m covering an area >1000 m^2.
- cluttered: areas with mine-sized objects (a dimension of between 0.5 to 5 m) of densities >100 per km^2,
- featureless: no identifiable structures, textures or clutter.
- bright or dark: areas with high or low signal strength.
- shadow: areas behind objects (as seen from the sonar) which are shaded from the acoustic beam and consequently appear dark.

The images also have artifacts. Slant range correction, a part of the geo-coding process, produces a "zipper" effect along the towfish path. Immediately paralleling this path are effects due to the vertical beam pattern of the sonar not being adequately corrected by the TVG. These effects are most obvious in images with both port and starboard data and especially where there are significant elevation changes (e.g. Figure 5).

3. MINE-SIZED OBJECTS

The surveyed area contains numerous mine-sized objects, but these are all well separated and no area would be considered "cluttered". Detection of these objects is not aspect dependent, that is, any object detected in the more intensive *chevron* survey was also found in the *linear* survey (except for gaps in coverage).

Over twenty mine-sized objects have been examined, each at a minimum of three different beam bearings. All are presumed to be boulders. An object exhibiting a straight highlight and a "squarish" shadow is considered mine-like. It was found that 50% of the boulders would be classified as mine-like based on a single aspect. This reduces to 25% with two different aspects. An example of a mine-sized boulder is shown in Figure 2.

(a) (b) (c)

Figure 2. Scene (20X20 m) showing a mine-sized object at beam bearings of (a) ~120^{o}, (b) ~300^{o} and (c) ~250^{o}. This object lies in an area of small ripples. Note the asymmetrical shadows and uneven highlight.

Four concrete cylinders (MLOs) were deployed in the survey area. Figure 3 shows two of these. The objects exhibit either straight edges, or corners indicating a length to width ratio of ~2:1. The shadows are "squarish" at some aspects, but are somewhat indistinct due to a dark background. The corner highlight and square shadow is indicative of a cylindrical MLO. However, these objects can easily be mistaken for boulders at certain aspects. It is noteworthy that none of the mine-sized boulders exhibited cylinder-like corners.

(a) (b) (c)

Figure 3. Scene (30X30 m) showing two MLOs at beam bearings of (a) 155^o, (b) 300^o and (c) 330^o. The dark patterns in the scene are due to "snake-skin" dunes (see the discussion below).

4. SEA-BED TEXTURES AND STRUCTURES

Two areas in the survey show structure due primarily to elevation variations. Dramatic changes in elevation, up to 4 m over a distance of 10 m, result in bright up-slope areas adjacent to dark down-slope areas, as seen by the sonar. There are also bright areas which are apparently associated with rough patches. The alignment between the beam bearing and the ridge patterns has a marked effect on the appearance of these areas in the sonar images.

Figure 4 shows a section of a dune field as seen at a beam bearing of 150^o. The dunes lie in a nominally east-west direction and the dune crests are ~3 m high. Ripples are evident on and between the dunes and are roughly parallel to the dunes, although the ripple pattern is complex. The beam bearing and ridge lines are approximately perpendicular, resulting in shadows which add significant contrast to the scene. This makes classification of this area as a region of sand dunes and ripples unambiguous. Figure 5 shows the same area seen at beam bearings of 90^o and 270^o. The dunes and ripples are less evident when the beam bearing parallels the ridges because no shadows are formed. In some areas the ripples are not visible at all. A beam bearing of 120^o (or 300^o, the *linear* survey) shows the dunes and ripples clearly (shadows are present) indicating that the low contrast in Figure 5 is limited to a relatively small range (~15^o) in beam bearing. In all images of the dunes the featureless area to the south-east is brighter than the dunes themselves. This suggests that the dunes are composed of a finer material than the adjacent area. Note that the dunes are brighter than flat sandy areas seen in other parts of the survey.

A "snake-skin" pattern also owes its origin to elevation changes. The structure is quasi-circular with "saw-tooth" elevation changes, with the steeper slope facing west. Figure 6 shows a portion of the snake-skin area as seen at beam bearings of ~90^o and ~270^o. The quasi-circular structure is apparent at both bearings, but the presence of shadows at the 270^o bearing makes the the "scales" more dramatic.

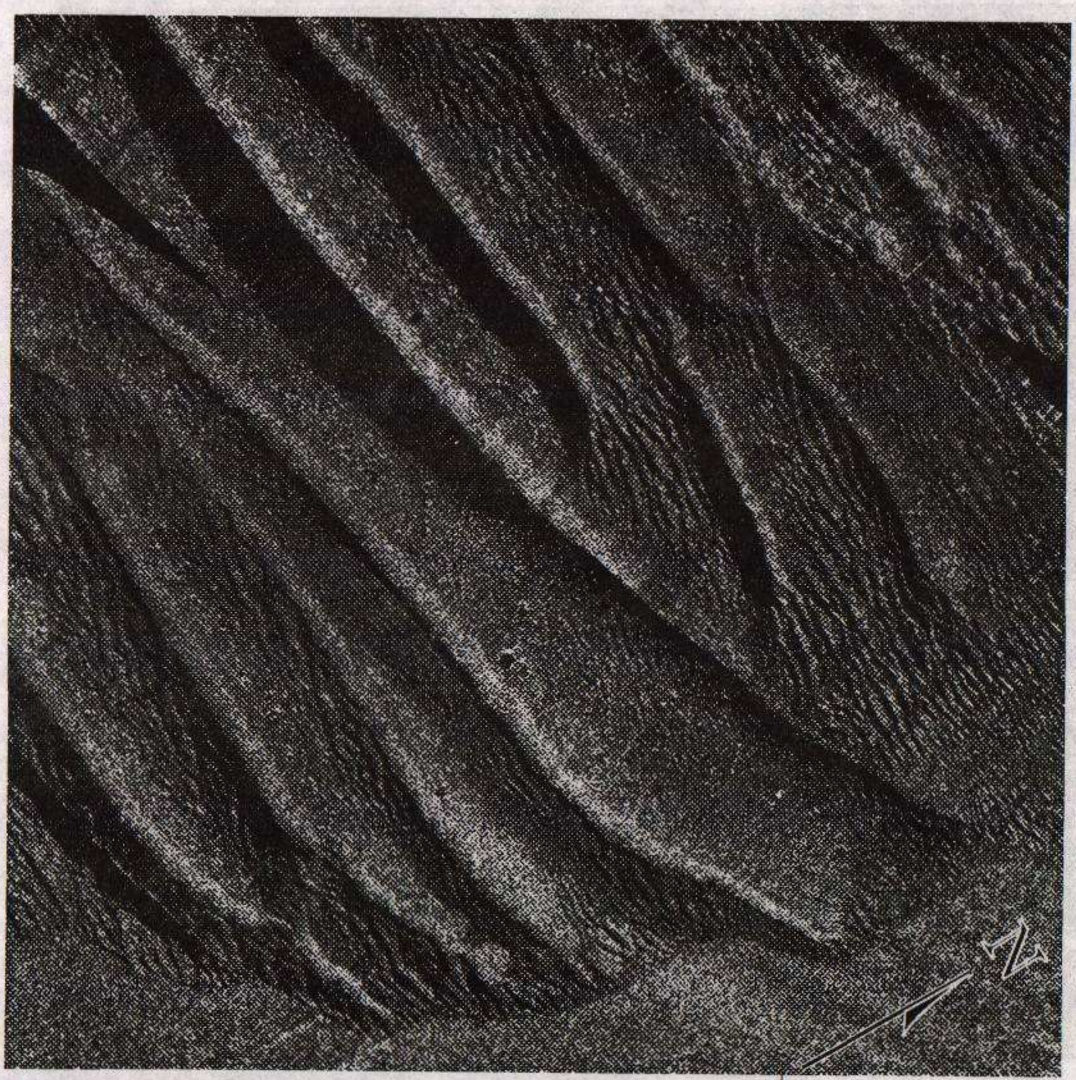

Figure 4. Mosaic of four overlapping runs showing a 200X200 m portion of the dune area. The scene is aligned with the surveyed route, the arrow indicates north. The beam bearing is ~150^{o}.

The snake-skin pattern extends over 1.5 km of the route. At the southern end the "scales" are ~30 m in diameter and the ridges are up to 4 m high. The scales are progressively smaller towards the north, decreasing to ~3 m diameter before petering out. The elevation variations decrease commensurably with scale size. Where the scales are <5 m in diameter their appearance is virtually independent of beam bearing as the effect of shadows is lost. The snake-skin area is much darker than the large dunes (cf. Figure 4), and this relative darkness is apparent at all beam bearings. This suggests that the snake-skin area is composed of even finer material or is less rippled than the large dunes.

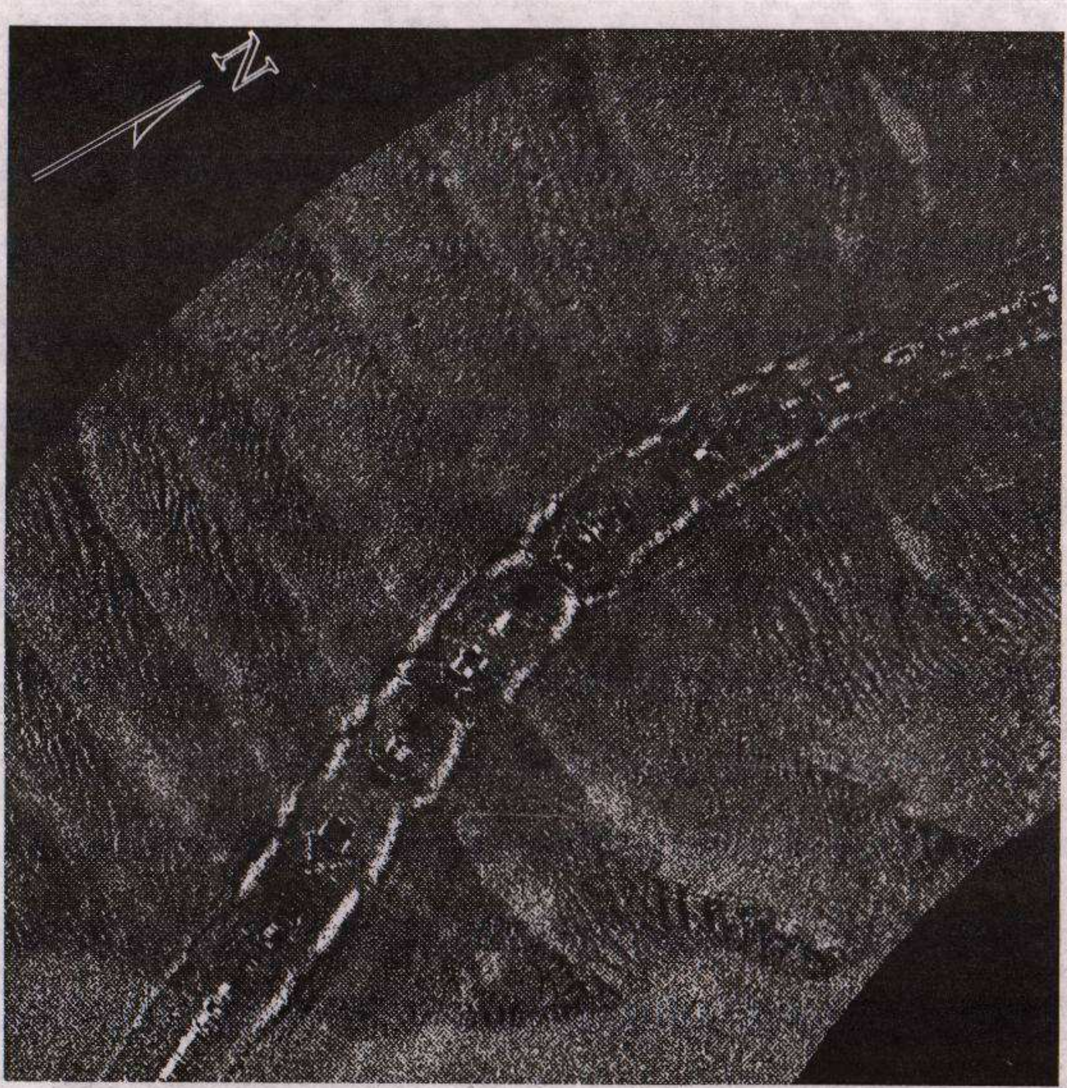

Figure 5. A single run showing the same 200X200 m area as depicted in Figure 4. The arrow indicates north. The towfish track is evident through the middle of the image ("zipper-like" pixels). The beam bearing is ~90^{o} to the right of the track and ~270^{o} to the left.

Parts of the survey region exhibit structure which is not the result of significant variations in elevation. Figure 7 shows a region of bright stripes on a darker background. Elevation variations are <0.2 m across the bright/dark pattern, insufficient to produce shadows or changes in brightness. This pattern has the same contrast at all beam bearings. Presumably the bright areas are rough material (gravel or rock) while the dark areas are smooth sand or mud. There are a number of linear features in the scene which give the appearance of having shadows, but these features present the same contrast and arrangement at all beam bearings.

It appears that there are thin sand layers arranged in broad stripes overlying coarser material. This area borders the snake-skin pattern which also shows evidence of an underlying coarse stratum. It is likely that the type of dune structure depends on the availability of sand with a thicker sand layer producing the snake-skin pattern.

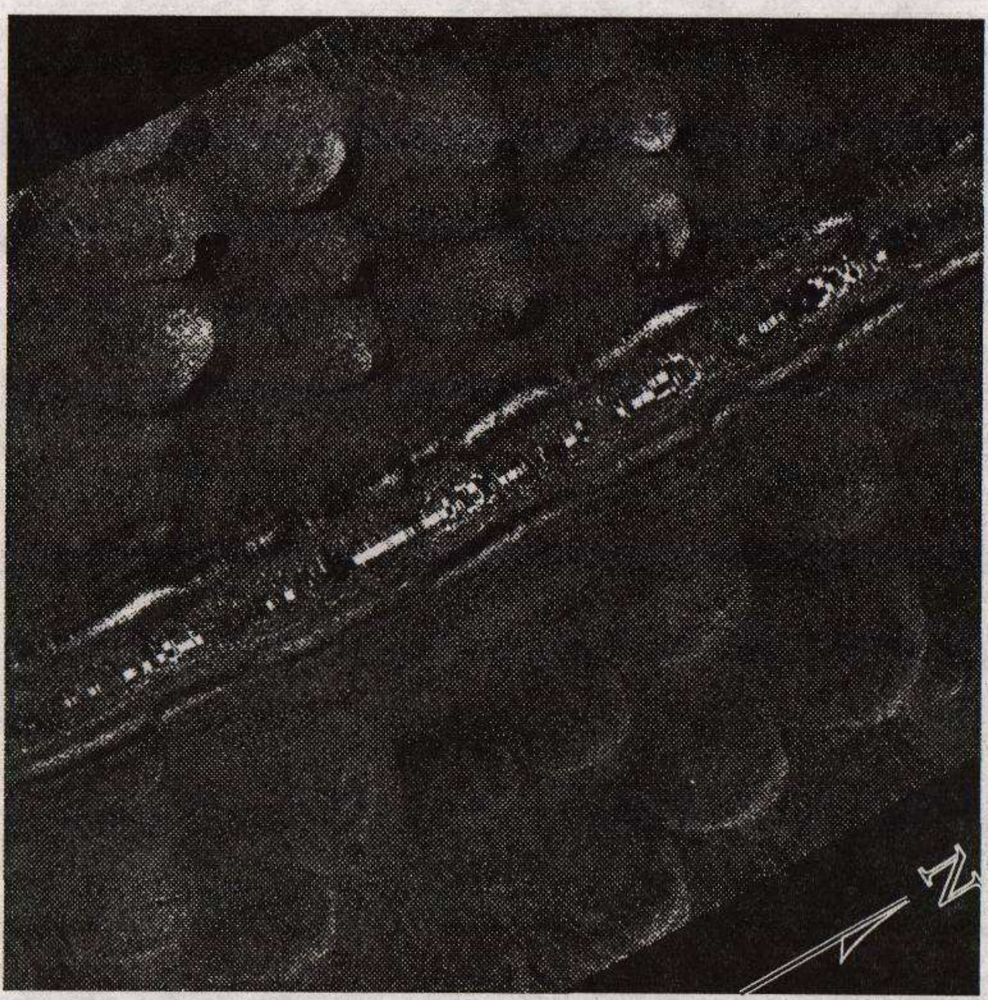

Figure 6. A single run showing a 200X200 m portion of the snake-skin pattern at its southern end. There are bright patches in the bottom of some "scales" suggesting that coarse material underlies the sand.

5. CONCLUSIONS

The *linear* and *chevron* surveys had comparable detection performance for mine-sized objects. The less efficient *chevron* survey [1] is not warranted for simple detection. However, such a survey is extremely useful for object classification. A 75% correct classification of non-MLOs can be achieved with just two different aspects. The small number of objects in the survey was insufficient for determining whether more than two aspects could improve this number.

The appearance of texture and structure due to elevation variations is aspect dependent. Linear features may escape detection at an unlucky aspect angle. However, elevation variations should be evident directly beneath the sonar and large ripples or dunes can be inferred from this data. Classification schemes based solely on pattern recognition (textures) will not provide unambiguous results unless the aspect dependence of contrast is in some way taken into account or multi-aspect data is available.

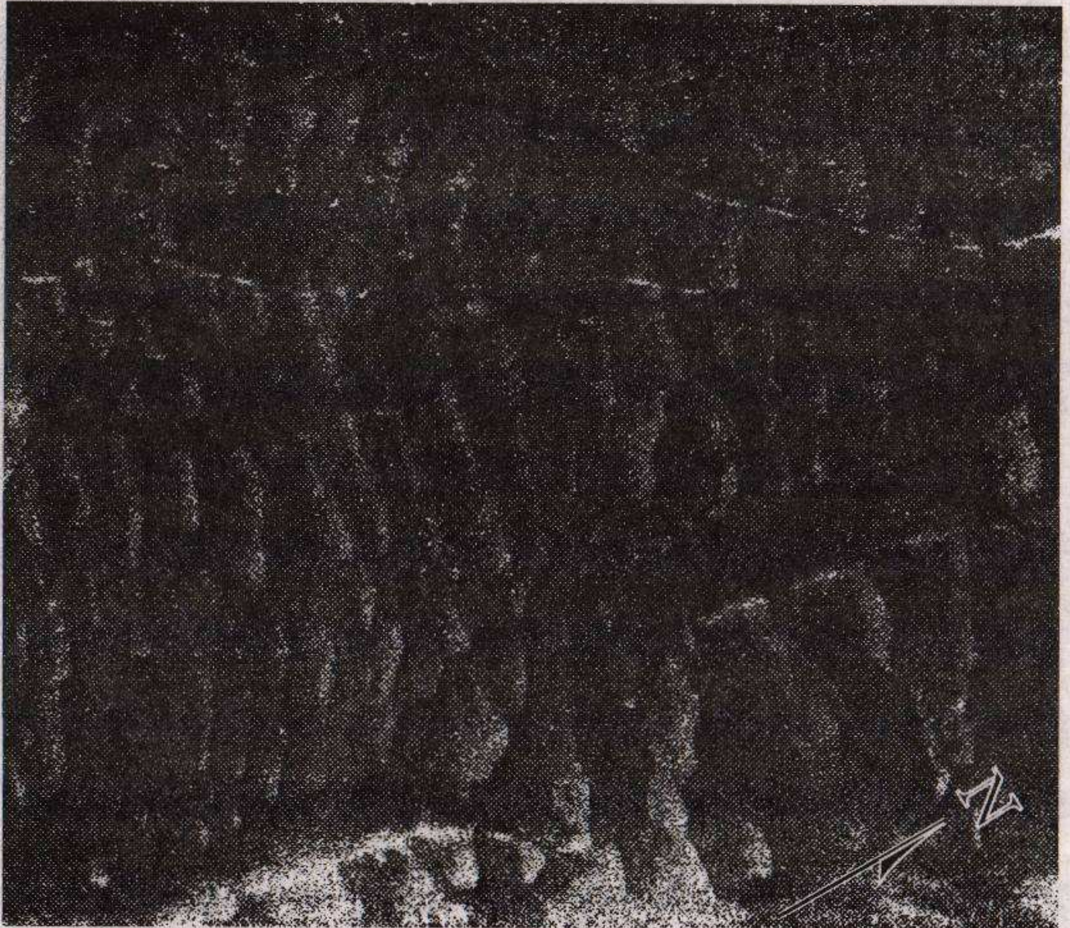

Figure 7. Mosaic of three overlapping runs showing a 200X220 m area with bright stripes. Beam bearing over the entire scene is ~300^{o}.

In the case of this particular route survey the *linear* survey crossed all ripple patterns at a favourable angle and was adequate to classify all areas. The *chevron* survey provided little additional information.

6. REFERENCES

[1] Poeckert, R.H., Kuwahara, R.H., Preston, J.M., Vogel, W.H., and Don, W., 1992, "An Analysis of Route Survey Procedures for the May/June 1991 MCM Trial", DREP Technical Memorandum 92-03.

[2] Poeckert, R.H., 1993, "Estimating Towfish Position Using Dead Reckoning", DREP Technical Memorandum 93-03.

[3] Desandoli, M., and Taylor, J., 1989, "Sonar Image Processing System II, High Level Design, Functional Specifications", MacDonald Dettwiler and Associates, Contractor's Report (limited circulation).