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Hexactinellid Sponge Reefs on the British Columbia Continental Shelf: Geological and Biological Structure with a Perspective on their Role in the Shelf Ecosystem

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Abstract

Globally unique sponge reefs dominated by species of hexactinellid sponges occur in the deep shelf troughs on the western Canadian continental shelf. Submersible dives reveal these reefs to consist of dense populations of hexactinosan sponges that cover bioconstructions that are up to 18 m high and many kilometres wide. The non-living portion of the reef, in the subsurface, is composed of a framework of sponge skeletons encased in a matrix of modern clay trapped by the sponges. Three species of hexactinosan sponge form this skeletal framework through the biological fixing and deposition of opaline silica, which fuses the spicules of the skeleton of the individual sponges. This structure also allows inter- and con-specific attachment of young sponges onto skeletons of deceased hexactinosan sponges, which permits the multi-generational habitation of reef sites. The mounds (bioherms) and sheet-like accumulations (biostromes) cover a low angle, non-depositional, iceberg scoured seafloor, relict since the deglaciation of the region, about 13 thousand years ago. The base of the oldest sponge reefs date from approximately 9000 years BP. The reefs discontinuously cover about 700 km^2 of seafloor in Queen Charlotte Sound and Hecate Strait at depths between 165 and 230 metres.

The sponge reefs have been subject to damage by seafloor trawling in the past decade. Sidescan sonar data indicate that intensive trawling has impacted one of the four hexactinellid sponge reef complexes. Repeat sidescan sonar surveys accomplished in 1988 and 1999, indicate that seafloor scouring by trawling has occurred at a sponge reef complex in southern Queen Charlotte Sound. Trawl marks identified with sidescan sonar record the passage of trawl doors across many sponge biohermal structures in water depths of 210 to 220 metres. The importance of the sponge reefs to the ecology of the continental shelf is largely unknown. Qualitative submersible observations suggest that species of crab, shrimp, prawns and rockfish utilize interstices within and between the sponges as refugia. A cyclicity of habitation by sponges followed by sediment coverage of mound surfaces is inferred from core and photographic data.

The sponge reefs, as geological features, are most closely related to Upper Jurassic siliceous sponge reefs, which stretched in a belt 7000 kilometres wide across the northern Tethys and Atlantic Ocean margins. The analogue, which the modern sponge reefs provide for the extinct reef belt, represents a unique opportunity to gain insight into what was the largest bioconstruction in Earth History. In view of the globally unique and fragile nature of the sponge reefs, and the unknown contribution that these reefs make to the shelf ecosystem, recommendations for habitat management include (1) restriction of mobile fishing gear deployment and other types of seafloor dragging in the sponge reef complexes; (2) further biological, biophysical and environmental studies of the sponge reefs to define ecological relationships and the critical physical environmental conditions of reef formation and growth; and (3) further surveys to allow assessment of reef "health" and the nature and extent of impacts sustained to date.

Résumé

Des récifs d'éponges uniques au monde, dominés par des spongiaires hexactinellides, se rencontrent dans des fossés profonds du plateau continental de la côte ouest du Canada. Des examens par submersible ont montré qu'ils étaient formés de populations denses d'éponges hexactines recouvrant des bioconstructions dont la hauteur peut atteindre 18 m s'étendre sur plusieurs kilomètres. La partie non vivante du récif, sous la surface, est composée d'une infrastructure de squelettes d'éponges noyée dans une matrice d'argile récente capturée par les éponges. Trois espèces d'éponges hexactines sont à l'origine de cette infrastructure de par la fixation et le dépôt biologiques de silice opaline qui fusionne les spicules du squelette des éponges individuelles. Cette structure permet la fixation de jeunes éponges, de même espèce ou d'espèce différente, sur les éponges hexactines mortes, ce qui permet à plusieurs générations d'habiter les sites des récifs. Les monticules (biohermes) et les accumulations stratiformes (biostromes) couvrent un fond de faible pente, sans dépôt et raclé par les icebergs qui date de la déglaciation de la région, il y a environ 13 mille ans. La base du récif le plus vieux date de 9 000 ans environ. Les récifs couvrent, de façon discontinue, près de 700 km^2 de fonds océaniques dans le détroit de la Reine-Charlotte et le détroit d'Hecate, à des profondeurs variant entre 165 et 230 mètres.

Les récifs d'éponges ont été endommagés par des chalutages au fond réalisés au cours de la dernière décennie. Les données du sonar latéral indiquent que le chalutage intensif a altéré l'un des quatre complexes de récifs d'éponges hexactinellides. La répétition des relevés au sonar latéral en 1988 et 1999 a montré que le chalutage avait donné lieu à un raclage du fond où se trouvait un complexe de récifs d'éponges dans la partie sud du détroit de la Reine-Charlotte. Les marques de chalutage décelées au sonar latéral indiquaient le passage de panneaux de chalut au travers de plusieurs structures biohermes à des profondeurs de 210 à 220 mètres. L'importance des récifs d'éponges pour l'écologie du plateau continental demeure largement inconnue. Des observations qualitatives faites par submersible portent à croire que les interstices présents tant au sein qu'entre les éponges servent de refuges à diverses espèces de crabes, de crevettes et de sébastes. Les carottes et les photos permettent de déduire l'existence d'un cycle, les surfaces des monticules étant habitées par des éponges qui seraient ensuite recouvertes de sédiments.

En tant que structure géologique, les récifs d'éponges s'apparentent le plus aux récifs d'éponges silicieuses du Jurassique supérieur, qui formaient une bande de 7 000 kilomètres de longueur couvrant le nord de la mer Téthys et de l'Atlantique. Le récif d'éponges moderne, qui est l'analogue de cette bande disparue, constitue une occasion unique de mieux comprendre ce qui était la plus importante bioconstruction de l'histoire de la planète. Étant donné le caractère unique à l'échelle du globe et la fragilité de ces récifs d'éponges et leur apport encore inconnu à l'écosystème du plateau continental, les recommandations ci-après ont été formulées pour la gestion de cet habitat : 1) limitation de l'utilisation d'engins de pêche mobiles et d'autres types d'appareils raclant le fond dans la zone des complexes de récifs d'éponges ; 2) réalisation d'autres études

biologiques, biophysiques et environnementales visant à définir les rapports écologiques et les conditions environnementales physiques critiques de la formation et de la croissance des récifs et 3) réalisation d'autres relevés pour évaluer la « santé » des récifs de même que la nature et l'étendue des perturbations jusqu'à ce jour.

Introduction

Globally unique Hexactinellid sponge reefs have been investigated on the continental shelf of western Canada. The reefs were first discovered in 1987-1988 with towed high-resolution geophysical instruments and by seafloor sampling (Conway et. al, 1991). Submersible exploration of these features during the summer of 1999 has revealed several seafloor areas densely colonized by at least six species of siliceous sponges. Healthy sponge populations to more than one metre in height form the seafloor and sponge skeletons also form the sub-seafloor over the reef areas. The sponge reefs are constructed by the frame-building growth and expansion of Hexactinellid sponges of the Order Hexactinosa and by the trapping of sediment by the sponges. The sponge reefs cover more than 700 km^2 in troughs which cross the shelf, with reef complexes displaying biohermal (mound form) and biostromal (sheet form) morphologies. The biohermal structures reach heights of 18 m in Hecate Strait where the focusing of tidal currents is strongest and trough bathymetry is most pronounced. Analysis of cores collected on the reefs indicate that growth of the mounds was initiated shortly after deglaciation in the early Holocene, 8500 to 9000 years ago (Conway et al., 1991).

The surficial marine geology of the western Canadian continental shelf has been mapped by the Geological Survey of Canada and presented as 1:250,000 scale compilations (Barrie et. al, 1990a, 1990b, 1990c and Luternauer et. al, 1990a and 1990b). Seafloor morphology and surficial sediment distribution are to a large extent controlled by the recent (late Quaternary) glacial and sealevel history. The last glacial advance deposited thick till in the major troughs of the shelf (Luternauer et. al, 1989a, Barrie and Bornhold, 1984). Grounded icebergs moved with tidal currents (Luternauer and Murray, 1983) as the ice receded from the shelf thereby furrowing the till. The shelf areas, more shoal than 100 m on the inner shelf (Luternauer et.al, 1989b) and 150 m on the outer shelf (Josenhans et. al, 1997; Barrie and Conway, 1999), have been subject to erosion by eustatic and glacio-isostatic lowering of sea levels at the close of the last glaciation. As a result the iceberg furrowed till was not buried by subsequent deposits on the inner shelf. In outer shelf areas the late Quaternary transgression eroded the seafloor to a greater depth on the outer shelf (150 m), mobilizing bank edge sediments and covering the ice berg furrowed till surface. Post-glacial deposition is restricted to the inner portion of the Goose Island Trough and the deepest portion of Moresby Trough, where a variable thickness of mud is deposited (Luternauer et. al, 1989a).

The sponge reefs are most similar to fossilized Jurassic siliceous sponge reefs, which are widespread in rock formations in southern Europe, from Portugal to Romania, and in some areas of North America (Conway and Barrie, 1990; Krautter, 1997). The distribution of the sponge reef facies culminated in the Late Jurassic. On the northern shelf of the Tethys and the adjacent North Atlantic basins, siliceous sponges formed a discontinuous deeper water reef belt extending over more than 7000 km . Outcrops are known from the Caucasian Mountains, from Romania, Poland, Germany, Switzerland, France, Spain, Portugal, off Newfoundland and Oklahoma (among others: Jansa et al. 1982; Leinfelder et al 1993; Werner et al. 1994; Krautter 1995, 1997; Gaillard 1983; Oppliger 1926; Schrammen 1936; Flügel & Steiger 1981; Pisera 1997; Trammer 1982, 1989; Herrmann 1996). This sponge reef belt was the largest bioconstruction ever built on earth. Further Late Jurassic siliceous sponge reefs are known from the Oxfordian of Neuquen Basin/Argentina (Legarreta, 1991) and from the Atlantic Ocean off the Moroccan coast (Steiger & Jansa, 1984).

The comparison of these modern reefs to the geological record is an area of active research in an ongoing, joint scientific project between the Geological Survey of Canada – Pacific, and researchers at the University of Stuttgart, which is largely being funded by the Deutche Forshungsgemeinshaft (DFG). Funding of this project allowed the use of the submersible Delta in the field portion of the program during July 1999, which provided the first ever videotape of the sponge reefs. The potential of these modern reefs as an analogue or a reference point in understanding what was the largest bioconstruction in Earth history provides a great scientific opportunity (Conway and Barrie, 1997). One of the central tenets of geology is that the present is the key to the past and, at present, the only known analogue to the vast Jurassic sponge reef belt exists within the troughs of the British Columbia continental shelf.

The purpose of this document is to provide an up–to-date overview of geological and biological aspects of the Hexactinellid sponge reefs found on the continental shelf. Most data (see Methods, below) are still being compiled from the July 1999 research cruise and have yet to be analyzed, so that the information presented here is preliminary. Combined with earlier knowledge, however, this information should facilitate discussion regarding the sustainable use of the seafloor in areas where the sponge reefs are found.

Methods

Cruise PGC99-01 (CCGS JOHN P. TULLY) collected data at known sponge reef sites during a research cruise from July 9-25, 1999. The cruise was a multi-parameter survey utilizing different geological, geophysical and oceanographic methods to examine the sponge reefs and their physical and oceanographic environment. Underway-geophysical surveying was accomplished using a Simrad dual frequency sidescan sonar system collecting digital data at frequencies of 120 kHz and 330 kHz. Two areas of seafloor in Hecate Strait were surveyed with a close line spacing to allow the construction of sidescan sonar mosaics. Huntec Deep-Tow seismic data were collected simultaneously to provide acoustic penetration of the sponge sediments which allows determination of the thickness of the sponge reefs.

The submersible Delta, a commercially operated two person scientific submersible, was utilized to facilitate direct observation, sampling, videotaping and still photography of the reefs. Methodology of dive site selection included examination of underway-geophysical data to determine the most appropriate dive sites. Dives of one to three hours duration provided transects of reef areas identified from acoustic data. A total of eighteen dives of a planned 40 dives, were completed, because of adverse weather. Dr. W. Austin, Director, Cowichan Marine Station provided taxonomic expertise during the cruise; he participated as an observer on several of the dives. Data reduction of video and still photography is ongoing and will include the transfer of observations of biota and environmental data to a GIS format.

Piston cores to 6 m were collected at two sites and Shipek grab samples were recovered from six stations. Drift camera stations were occupied at seven sites using a still camera equipped with a bottom contact switch. A large bucket type sampler (IKU Sampler) was used in order to recover large volume (0.75 cubic metre) samples of the reef surface and subsurface. Foraminifera and clay mineralogy samples were collected from core and grab samples and from submersible slurp gun samples. Six oceanographic water-sampling stations were occupied adjacent to reef areas. Nutrient and density measurements have been completed on these water samples.

Results

Biota associated with sponge reefs

Assessment of the biota associated with the sponge reefs is ongoing, in cooperation with Dr. W Austin, the director of the Cowichan Marine Station. This work will include the transcription of 40 hours of videotapes of species identified during the dive transects, additional species will be identified from nearly two thousand 35 mm slides collected on the reefs. Important spatial relationships will be established by placing these biological observations together with environmental data into a GIS framework. The following description does not represent an exhaustive list of reef organisms, it is included here to provide information about the salient character of the biota found on, within and adjacent to the sponge reefs.

The sponge species found on the surface of the sponge reefs (Figure 4) were also abundant in the subsurface. Identification of sponge species was accomplished by using material obtained by grab sampling, coring (Conway, et al., 1991) and submersible sampling. Visual identification of sponge species was possible in many cases during submersible transects. Three main species form the framework of sponge skeletons of the reef; they include the hexactinellid Hexactinosan species *Chonelasma calyx, Aphrocallistes vastus* and *Farrea occa.* Sponges that were often abundant on but are not considered the main reef forming species included the hexactinellid Rosselid species *Rhabdocalyptus dawsoni, Acanthascus platei* and *Staurocalyptus dowlingi.* In some areas the reef surface has a dense coverage of one or two of the Hexactinosan species over many square metres. *Chonelasma calyx*, with very prominent tubes, form large mono-specific clusters.

Other taxa identified to date include several species of annelid worms, bryozoans, bivalves and gastropods. Several species of rockfish occur in some areas of the reefs utilizing openings in and between the sponges. Species of spider crab and box crab, shrimp and prawns are locally abundant. Many different species of echinoderms, notably seastars and urchins, were common on some parts of the sponge reefs. Ophiuroids were locally very abundant both on and off the sponge reefs.

Physical environment of sponge reefs

Seafloor at reef sites:

The surface of the sponge reefs consists of a sandy mud matrix with abundant biogenic detritus and sponges and sponge skeletons on and within the seafloor. Many worm tubes, plates of echinoderms, foraminifera, filamentous strands of a spider-web-like consistency, which may have a bacterial composition, cover the areas of the mound where sponges do not occur. The areas of the sponge reef that do contain populations of living sponges are often completely covered in living or dead sponges. Although dead sponges appear to sediment over, they do not lose the structure of the living organism but become buried in place with little apparent change in the morphology of the skeleton of the sponge. Particle size analysis reveals the reef sediments to be predominately clay with some silt and sand fractions that are mostly biogenic in origin (Conway et al., 1991).

Figure 2 shows the details of the southernmost sponge reef complex. This reef complex is composed of biohermal and biostromal accumulations of sponge rich sediment. The sidescan sonar images (Fig.3) allow differentiation of the sponge reef sediments from the more reflective glacial sediments. Sponge reef patches appear to begin with a small nucleous of sponges, growing typically on a boulder at the edge of an iceberg furrow (Fig. 5). These small mounds grow over time and coalesce to form larger irregular structures as seen in Figure 2. In the subsurface, the reef sediments are an unconsolidated matrix of clay-rich mud enclosing in situ, intact sponge skeletons. The skeletons recovered are often attached to skeletons of other sponge species. Whole skeletons are difficult to extract from the clay matrix due to their fragility. The stiffness of the reef sediments increases with depth from watery and soft near the surface, to firm below about 1 m depth into the seafloor. Cores show the sponge reef sediments to be unconsolidated to the base of the reef, with some dewatering of the sediments apparent.

Seafloor at adjacent, off reef sites:

Seafloor areas unmantled by reef sediment are a boulder rich, sandy muddy gravel bottom, variably blanketed by 0-10 cm of sandy mud. Boulders to one metre diameter occur as isolated clasts on the seafloor. Where iceberg furrows cross the seafloor, concentrations of boulders of varying width are observed. Large isolated sponges such as *Chonelasm calyx* and *Mycale bellebellensis* and groups of the sponge *Iophon chelifer* occupy larger boulders. Boulders are frequently covered with various coelenterate species notably anemones. Raised burrow openings to a few centimetres in height, associated with infauna feeding or habitation structures, were common off the sponge reefs. These structures were not observed on the reefs suggesting that infauna is probably more common in the off-reef setting. Seawhips were common off the reefs and absent on the reefs. There was a scarcity of flatfish such as halibut over reef sediments. The thickness of the glacial till unit, which forms the seafloor, is up to 40 m (Figure 3).

Discussion

Chronology of sponge reef development

Figure 1 shows the known distribution of sponge reefs on the continental shelf of British Columbia. The areas of sponge reef growth correspond with areas of seafloor with abundant iceberg furrows preserved at the seafloor. (Barrie et al., 1989). The reefs are found between 165 and 230 m depth in the three main troughs, which cross the shelf in Hecate Strait and Queen Charlotte Sound (Conway et al., 1991). The late Wisconsin deglaciation resulted in the iceberg scouring of some shelf areas (Luternauer and Murray, 1981; Barrie and Bornhold, 1988). The margin of iceberg furrows are much more coarse than the surrounding seafloor and the edges of the furrow are often raised (Woodward-Lynas et al., 1991). The ploughing action of the icebergs concentrates coarse gravel at seafloor and these form good attachment sites for benthic organisms. The correlation of sponge reefs with the distribution of iceberg furrows is thought to be the product of this relationship of substratum to benthos distribution. Figure 5 shows the growth of sponge mounds along the relict iceberg furrows. The formation of the seafloor scours occurred during deglaciation about 15-13 thousand years ago (Luternauer et al., 1989).

Subsequent to the glaciation of the continental shelf much of the present shelf area was sub-aerial due to eustatic drawdown of sealevel and due to a glacio-isostatic forebulge which uplifted the outer part of the continental shelf (Josenhans et al., 1995; Barrie and Conway, 1999). The emergent banks in Queen Charlotte Sound and Hecate Strait were eroded and sand and mud was deposited into the outer parts of the shelf troughs as erosion of the banks took place during the lowstand of sea level and the transgression of the sea during late Pleistocene to early Holocene time (13,000 – 10,000 years ago). The outer shelf portion of the troughs (Luternauer et. al, 1989a) was therefore rendered unsuitable for development of sponge reefs. Relative sea level lowering was not as great for the inner shelf areas (Barrie and Conway, 1999) and the emergent central shelf banks provided some protection from sediment transport of fine sediments into the inner shelf trough areas thus allowing the iceberg scours to be colonized by sponges. While some non-sedimented iceberg furrowed areas have been identified in Dixon Entrance, no sponge reefs have been observed there (Barrie and Conway, 1999).

Formative seafloor processes

Figure 6 shows the nature of near seafloor currents where sponge reefs are found. The currents, which are focused by the bathymetry, deliver sediment in suspension to the reefs. The sediment trapped by the sponges protects the sponge skeletons from dissolution by seawater (Conway et al., 1991). The sediment accumulates only at sites of sponge reef growth and is trapped by the baffling action of the sponges in the current. Sediment is likely trapped by the sponges when seawater is filtered. The seafloor adjacent to the sponge reefs is unsedimented or relict, showing iceberg furrows, and thus is an area of non-deposition of modern sediments. Over large areas of the continental shelf the sponge reef sediments are the only significant Holocene (postglacial) deposition. Hexactinosan sponges are thought to grow on the order of about a cm per year (Levings and McDaniel, 1974).

Attachment of Hexactinosan sponges to skeletons of dead sponges was observed in large volume samples collected from reef areas. None of the Hexactinosan sponges described here are known to attach to muddy or sandy seafloor sediments (Conway et al., 1991). A framebuilding process is thus responsible for the multi-generational habitation of the reefs by sponges. This use of skeletal remains as an attachment substratum is a similar process to that of coral reefs construction.

This is the first documented study showing framework construction by modern hexactinellid sponges. The sponge complexes are truly reefs, and are to be differentiated from other sponge build-ups, or sponge spicule mats on this basis.

Evidence of mechanical destruction of sponge reefs by trawling

Figures 7a and 7b show sidescan sonar images of sponge reef areas in southern Queen Charlotte Sound (southernmost sponge reef area Figure 1), which have been subject to bottom trawling by fishing vessels. The parallel tracks visible on the images correspond to the path made by trawler net doors. The tracks are usually 70-100 m apart and traverse many kilometres of seafloor. Data collected in 1988 over the same areas did not display these abundant trawl marks (Figure 2).

In northern and southern Hecate Strait, areas of sponges lying broken off at the seafloor were observed. In some areas, broken projections of sponges (“stumps”) and sponges with abraded distal edges were seen during dives. In undisturbed settings, the sponge skeletons remain in place after death though becoming blanketed with sediment (Figure 3). At one site in Hecate Strait a linear ridge or berm of sponge skeletal debris to approximately 40 cm in height was observed. This debris ridge possibly represents a ploughed reef surface where the skeletal remains of sponges have been piled by mobile fishing gear. We infer that the mechanical damage to the sponges observed in these areas was due to fishing (trawling) gear. The timeframe of recovery of a destroyed sponge reef, based on what we know about the growth rates of hexactinellid sponges, is suspected to be on the order of 100 - 200 years.

Summary

Globally unique hexactinellid sponge reefs occur in the iceberg scoured troughs of the continental shelf in both Hecate Strait and Queen Charlotte Sound in water depths between 165 and 230 metres. The sponge reefs form mounds to 18 m in height and are extensive, forming reef complexes up to 300 km^2. The surface of the reefs in some of these areas is estimated to be 100 -150 years old, based on sponge growth rates and longevity. The sponge reefs have continuously occupied the oldest sites since the end of the last glaciation. Sponge reef formation occurs through a fine balance between sediment input and sponge growth. The sponges, especially members of the Order Hexactinosa, form a framework of sponge skeletons which trap sediments entrained in currents.

Recommendations

1. The sponge reef complexes should be protected immediately from bottom trawling and other forms of anthropogenic activity. The southern Queen Charlotte Sound sponge reef complex appears to have been subject to serious impacts through bottom trawling. The opportunity for study of the sponge reefs, both in terms of their modern ecology, and the linkages that these reefs have with extinct Mesozoic reefs, will not exist in the future without protection.

2. The role played by the sponge reefs in the continental shelf ecosystem is unknown. Observations suggest the variable morphology of the sponge reefs, and their resultant physical complexity provide benthic habitat for a diverse group of organisms including species of rockfish, shrimp and crabs. Further biological study of these reefs will be required to determine relationships between these organisms and the sponge taxa.

3. Further surveys to determine the extent of healthy sponge reefs and to establish the nature and extent of impacts to date should be undertaken. Significant diving information was collected at only two (the Hecate Strait sites) of the four main sponge reef complexes. Remote sea floor photography suggests that even in the southern Queen Charlotte Sound complex, which appears to have been subject to the most frequent trawling, some areas of healthy sponge reef remain.

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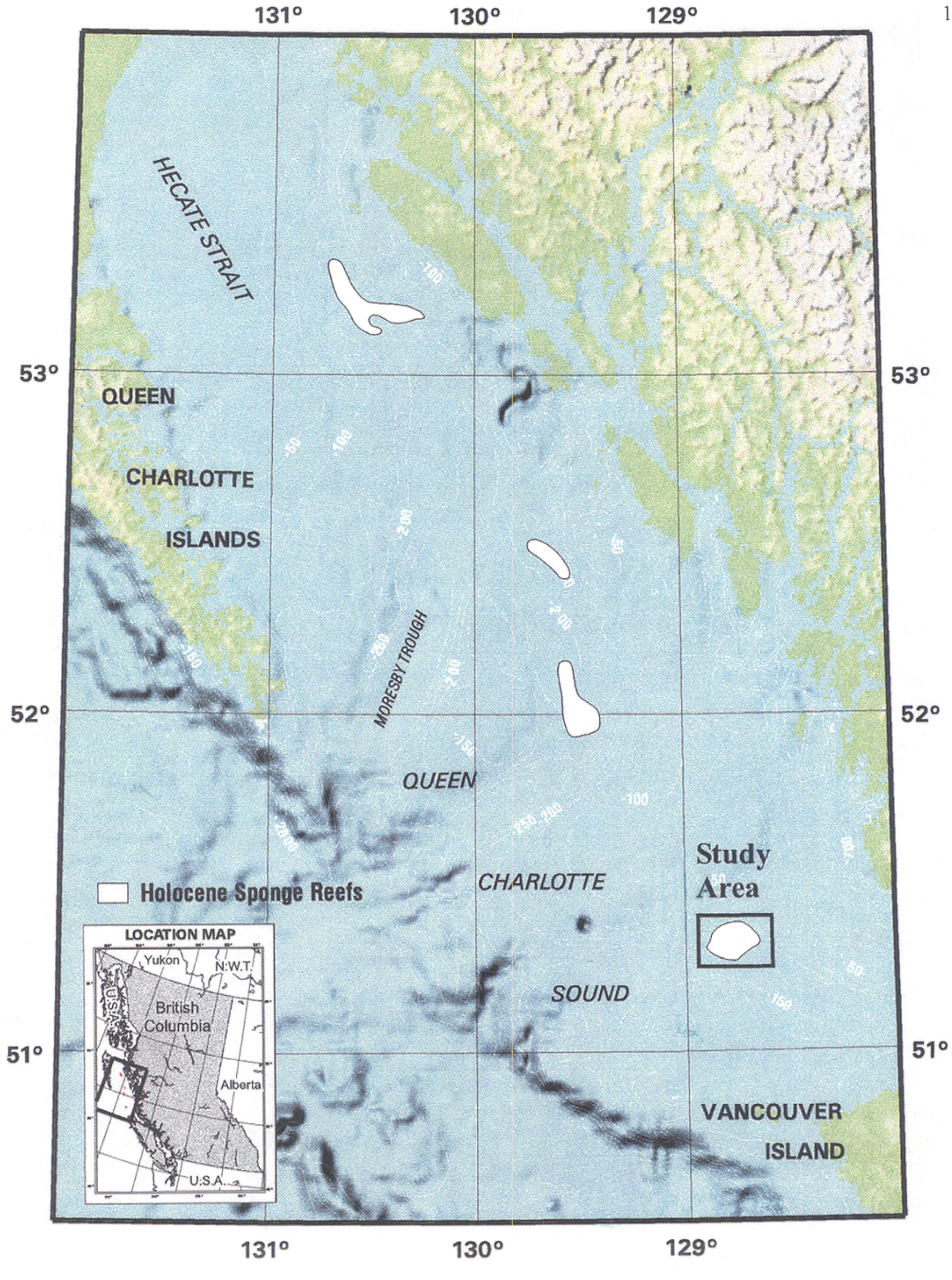


Figure 1. Location of sponge reefs in Hecate Strait and Queen Charlotte Sound. Distribution of sponge reefs was mapped from sidescan sonar and seismic data from cruises compiled for the Frontier Geoscience Program of the Geological Survey of Canada (Barrie et al., 1991)

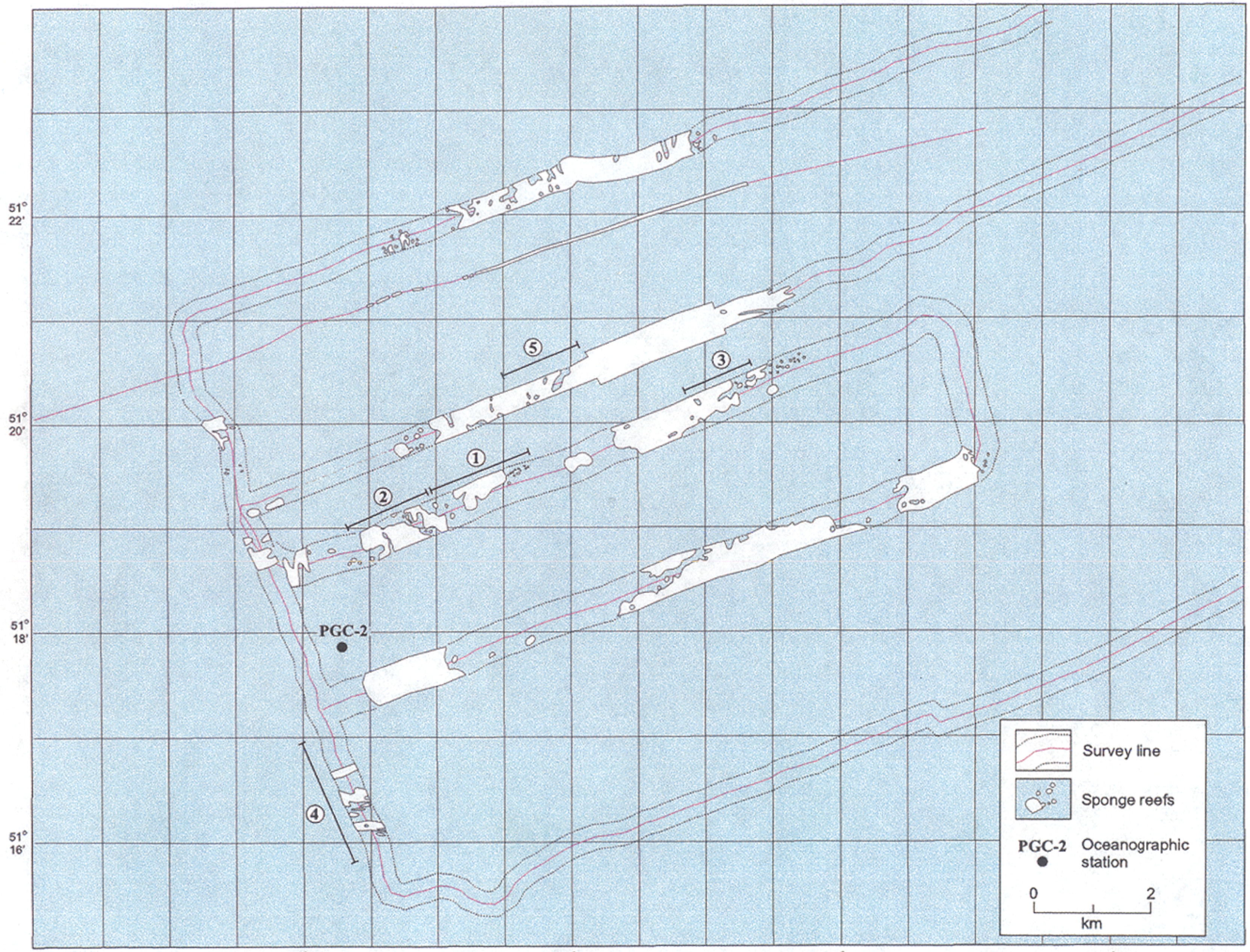


Figure 2. Sponge reef complex in southern Queen Charlotte Sound. Pecked lines parallel to solid line indicates sidescan sonar area surveyed in 1988; white areas correspond to sponge reef.

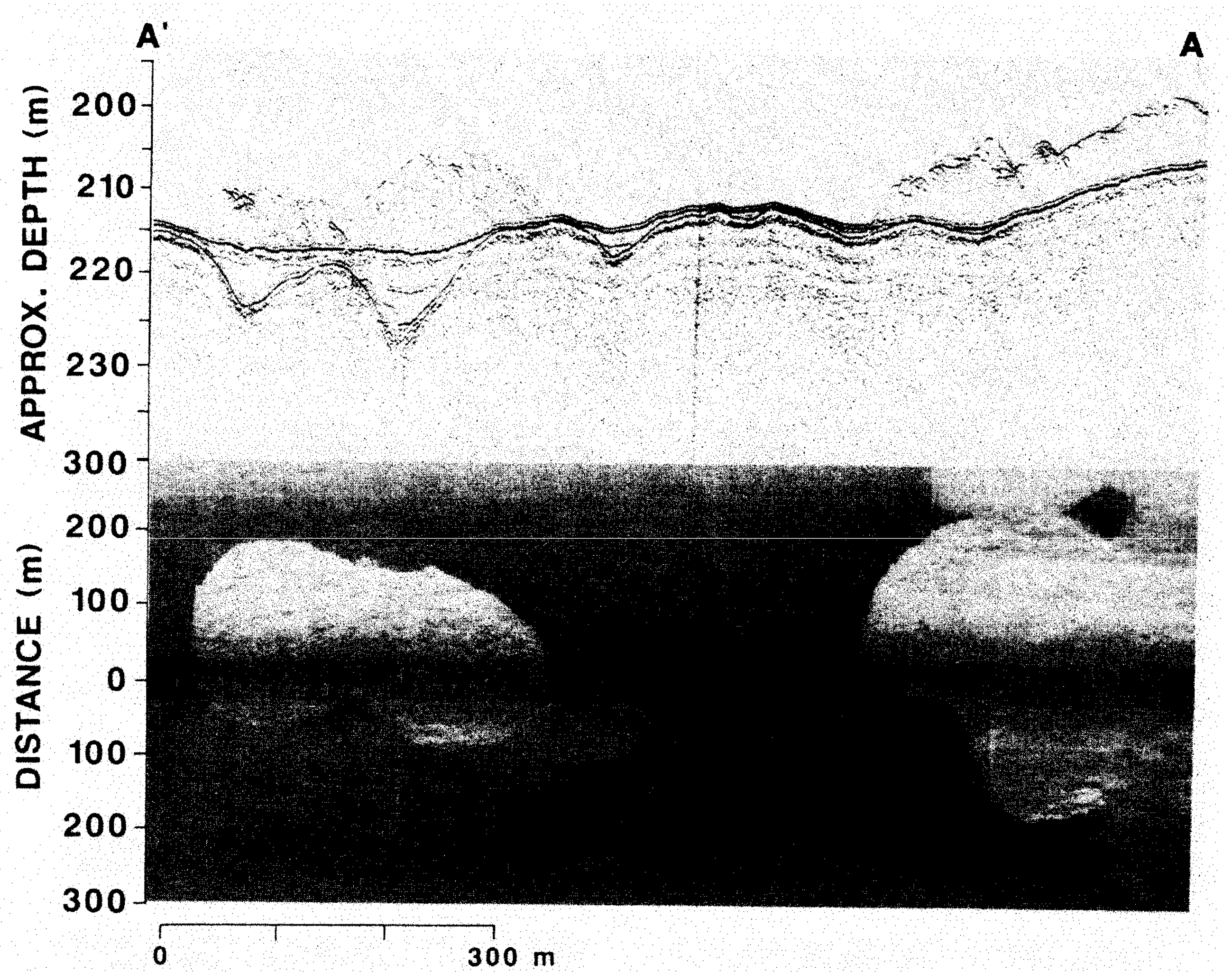


Figure 3. Example of Huntec Deep-Tow Seismic image (above) and coincident EG&G Sidescan sonar image (below) of sponge reefs in southern Queen Charlotte Sound. Sidescan sonar responds to the lack of a significant acoustic return from the very soft surface of the sponge reef sediments (light) compared to the reflective nature (dark) o the glacial sediments.

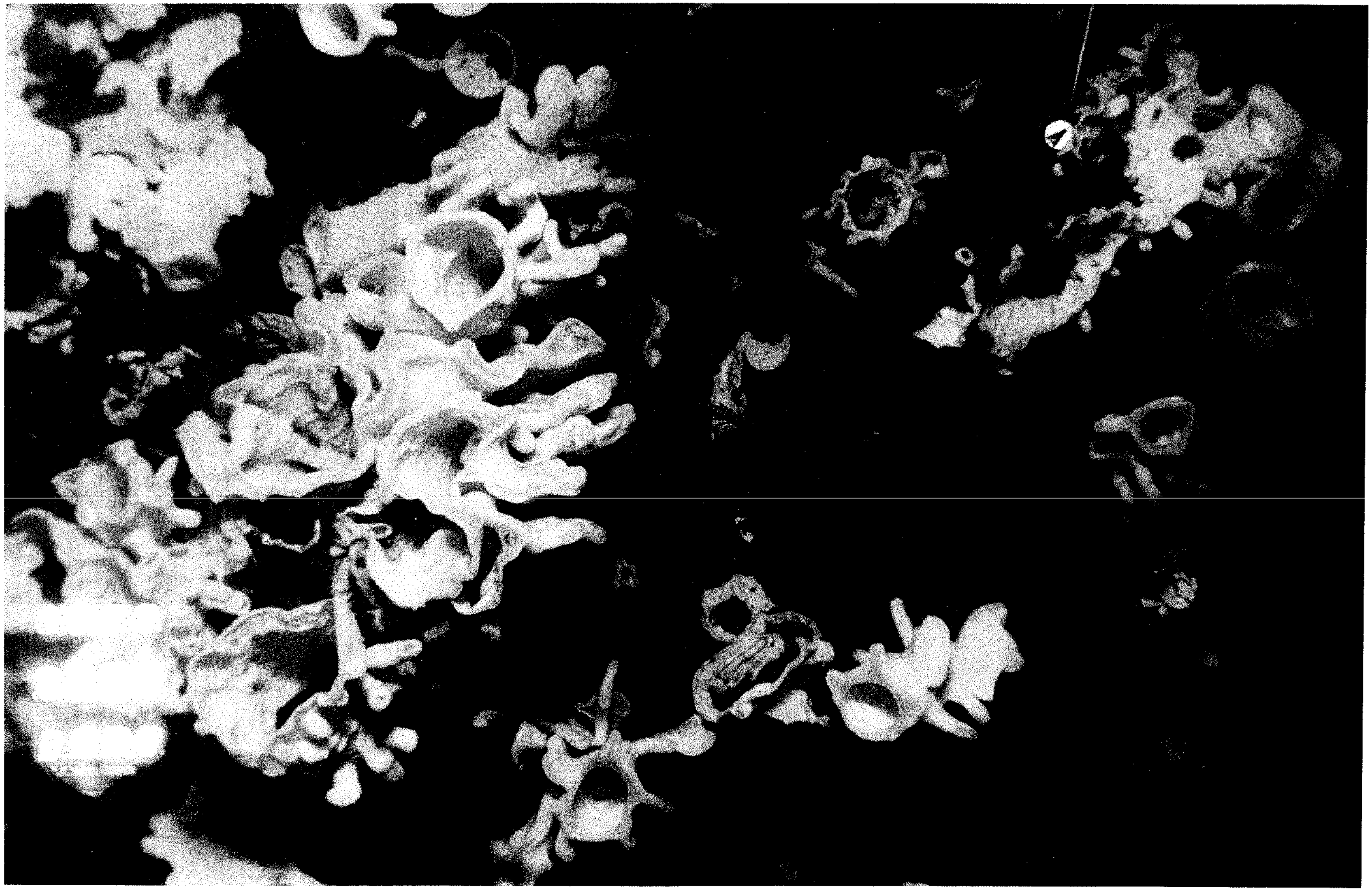
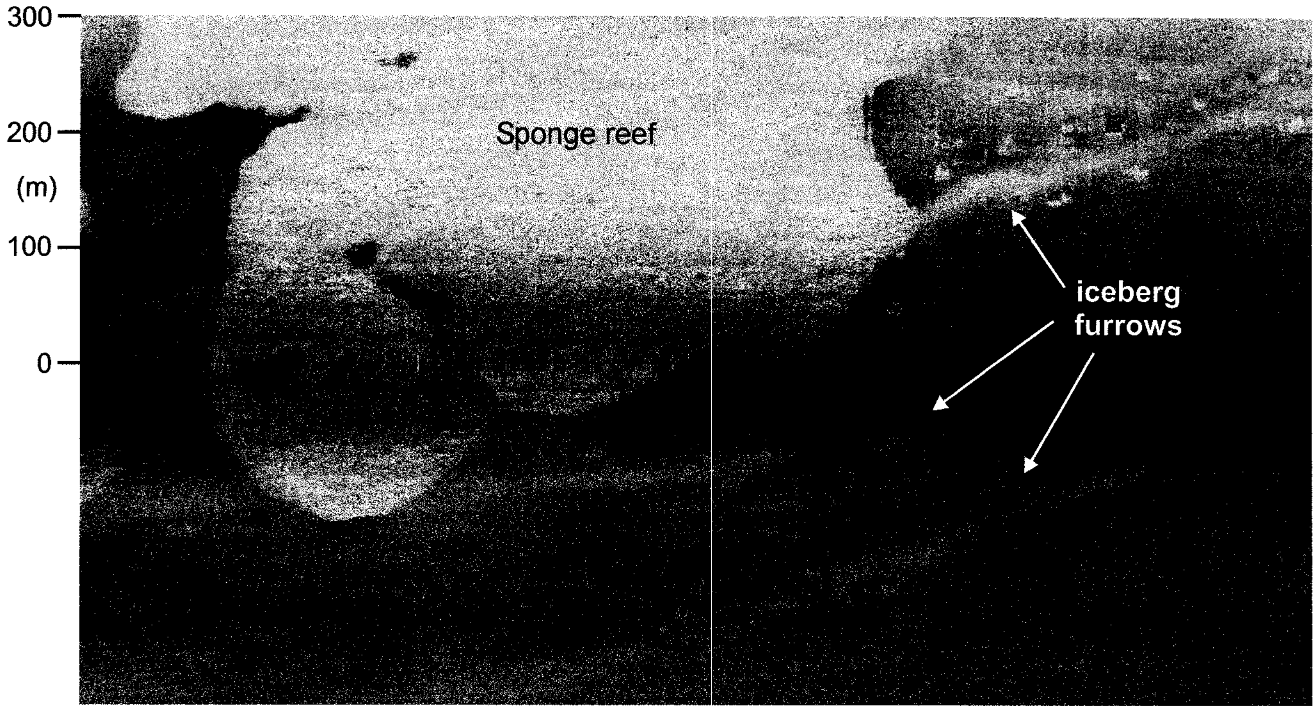


Figure 4. Surface of sponge reef in Hecate Strait. Note the abundant sponge skeletons which are intact though covered with fine sediment. Species in photo are almost entirely *Chonelasma calyx*.



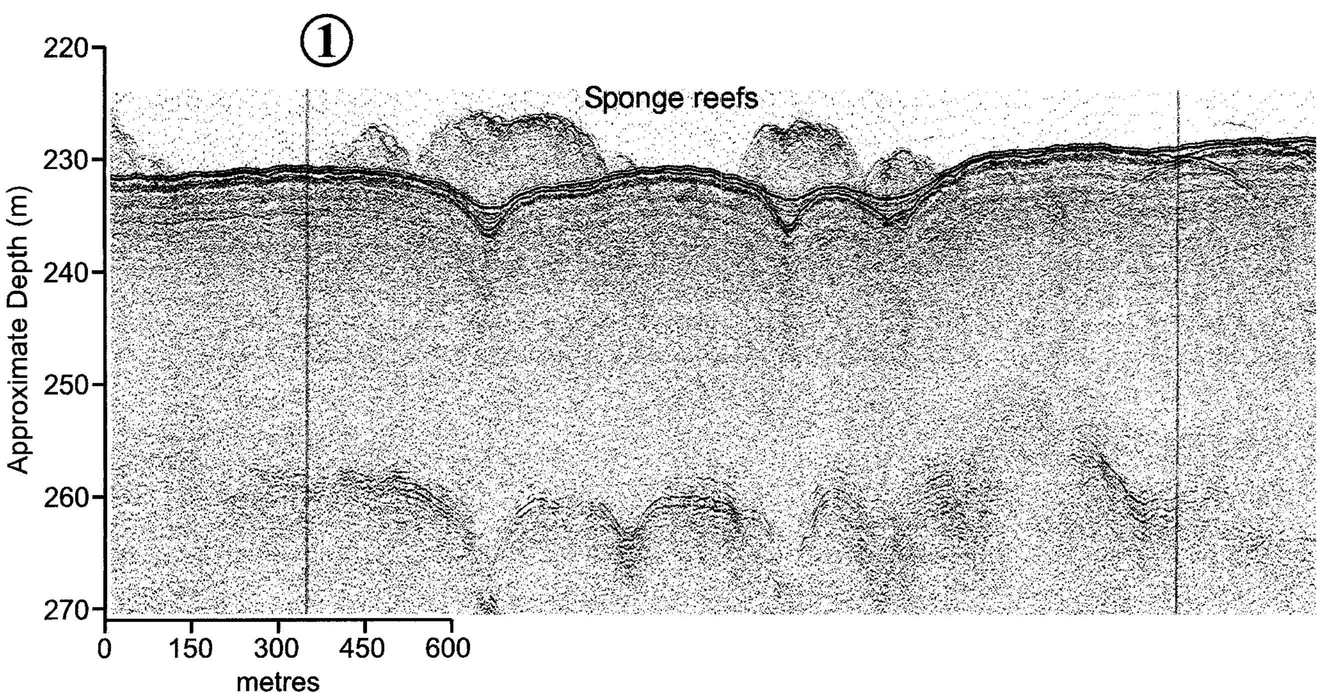


Figure 5. Sidescan sonar image (upper) and Huntec Deep-Tow Seismic record (lower) showing ice berg furrows and developing sponge mounds in southern Queen Charlotte Sound. Note line of small sponge bioherms, seen on sidescan sonar image as non-reflective circular white shapes, along trace of relict iceberg furrow. Location in Figure 2.

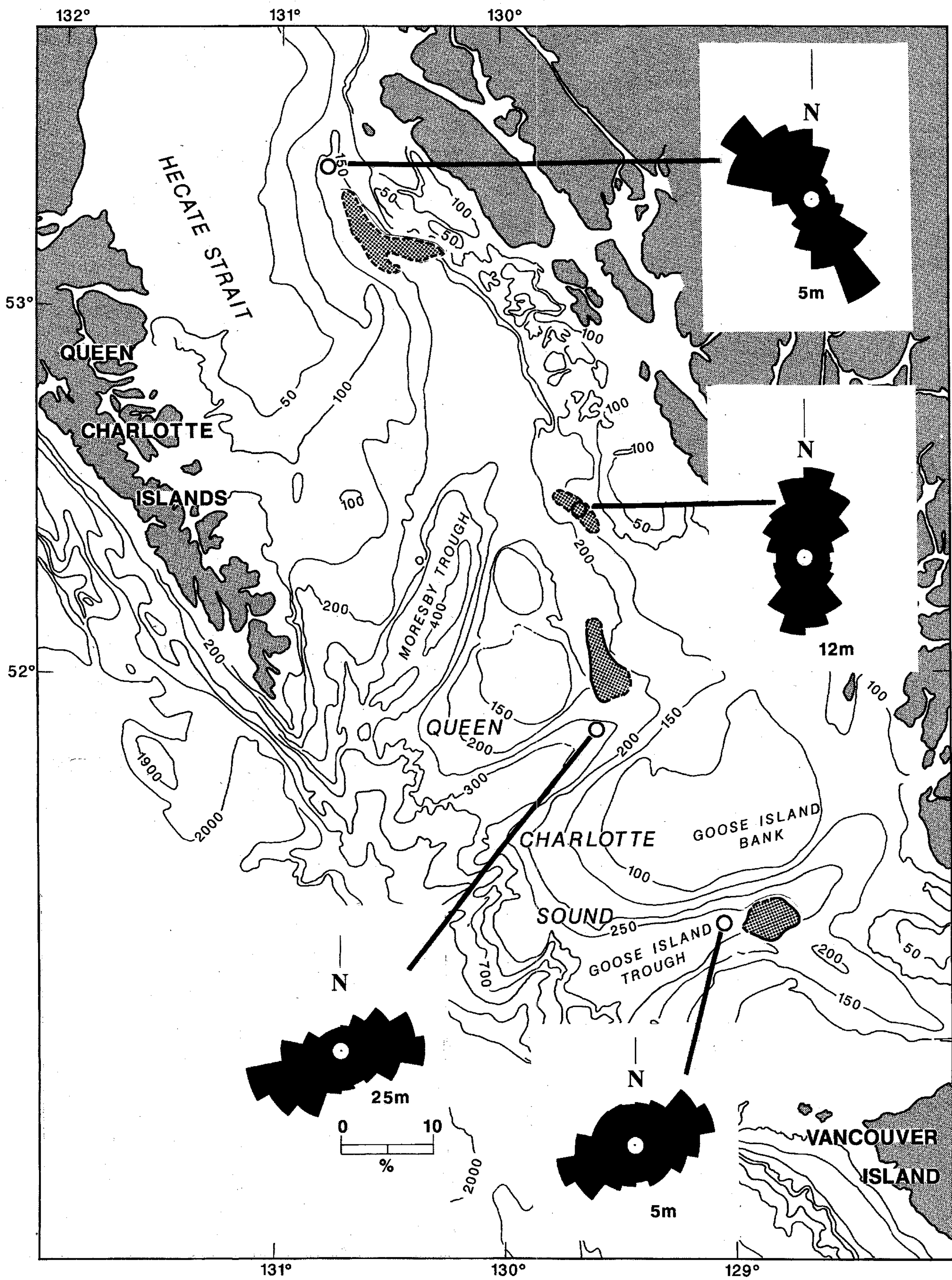


Figure 6. Current regime proximal to reef complexes. Current rose represents proportion of time currents are in the direction indicated. Current velocities at all four stations can exceed 60 cm/sec.

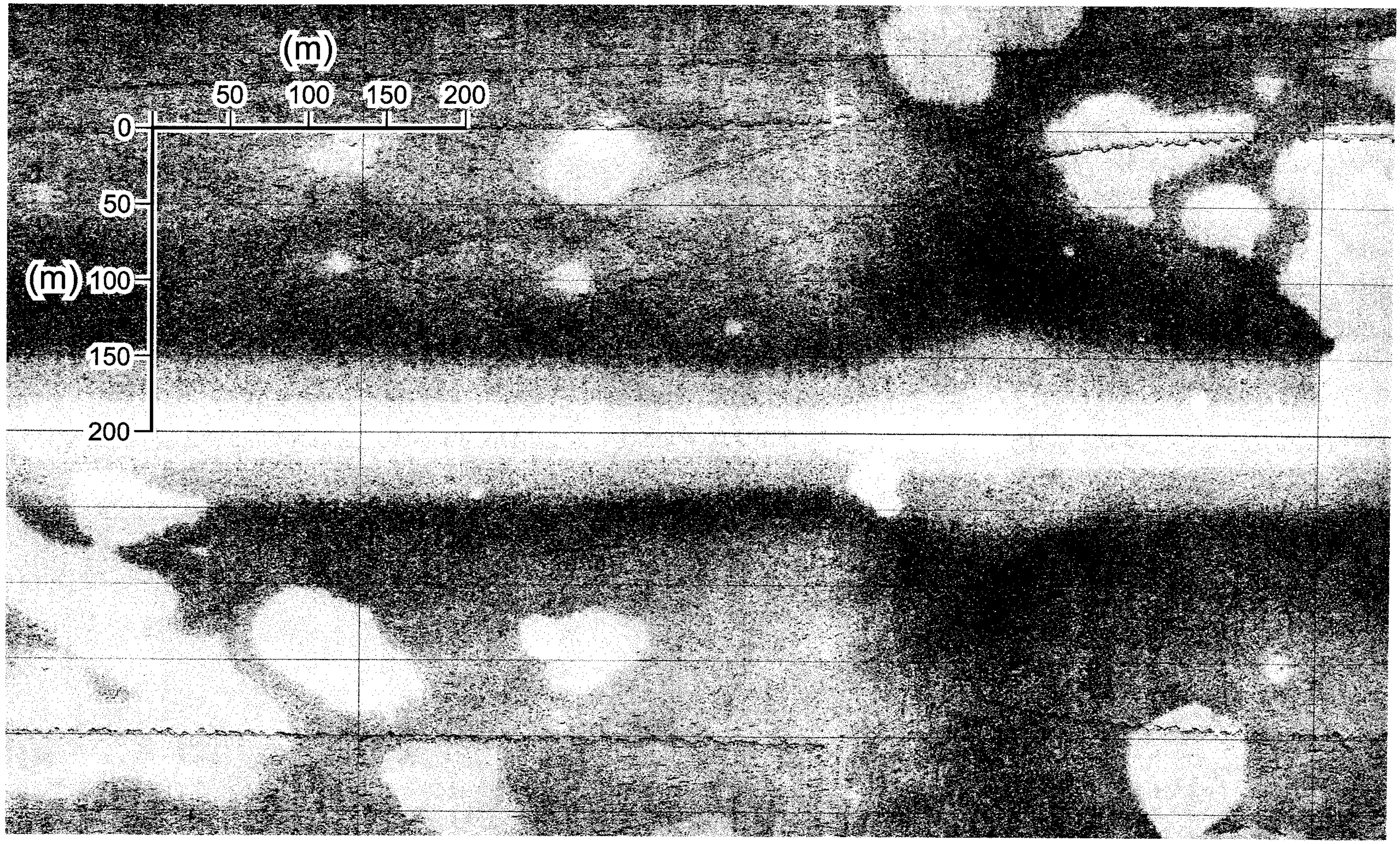


Figure 7a. Trawl marks across sponge reef area - southern Queen charlotte Sound. Trawl marks in this sidescan sonar image are the parallel dark tracks. Sponge reefs are circular to irregular shaped, white areas.

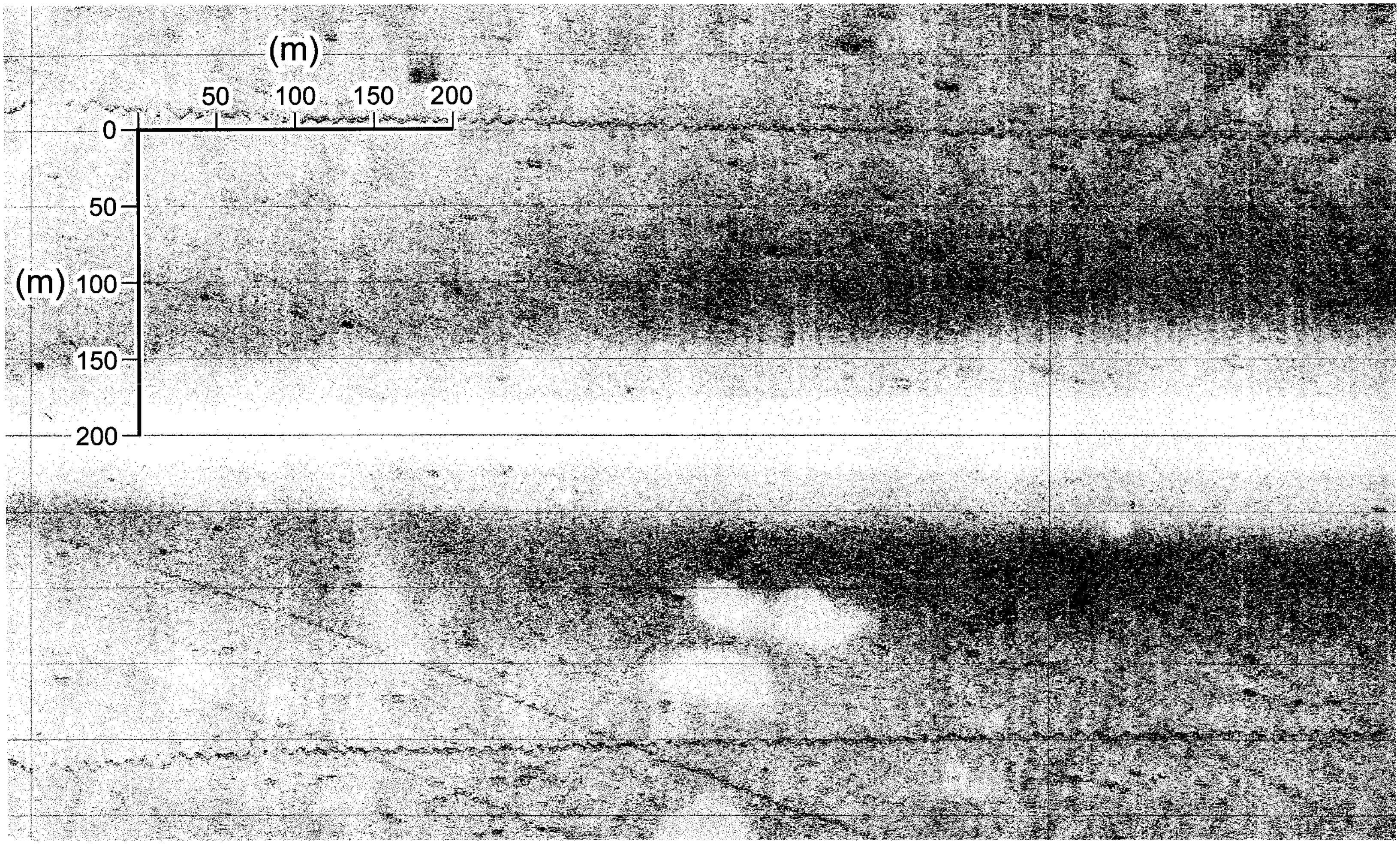


Figure 7b. Trawl Marks across sponge reef area - southern Queen Charlotte Sound. Trawl marks in this sidescan sonar image are the parallel dark tracks. Sponge reefs are circular to irregular shaped, white areas.