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Abstract: The reef-forming scleractinian coral, *Lophelia pertusa* has been recovered in bottom samples and observed as a dense debris field during remote-operated vehicle transects on a terrace on the flank of a steep-sided seamount-like knoll in the central Strait of Georgia, British Columbia. The coral debris has a minimum thickness of 33 cm and extends over several hectares in water depths of 225 to 255 m, suggesting that the coral community dominated this site for several centuries. *Lophelia pertusa* forms extensive reefs in many regions of the world, suggesting that a cold-water coral reef existed at this site in the recent past. This site and a sample from the west coast of Vancouver Island represent the first recognized British Columbia occurrences of *Lophelia pertusa*. In addition, regional multibeam surveys have revealed the presence of small (< 1 km^2) Hexactinellid sponge reefs in waters 100 to 140 m deep along the eastern approaches to the Gulf Islands in the southern Strait of Georgia in areas of low-relief glacial deposits. The surfaces of these reefs are covered with large Hexactinosidan sponges, predominately *Heterochone calyx* and *Aphrocallistes vastus*, or mantled with broken sponges where anthropogenic impacts, including trawling, have occurred. Mapping of these and other sensitive habitats will allow effective ocean management measures to be undertaken by the responsible agencies.

Résumé: Le corail scléractiniaire constructeur de récifs *Lophelia pertusa* a été identifié dans des échantillons remontés à la surface et observé sur le fond marin dans un champ de débris denses défini par les transects d'un appareil téléguidé. Ce champ de débris, situé dans la partie centrale du détroit de Georgia, en Colombie-Britannique, occupe une terrasse perchée sur la paroi d'un dôme à flancs raides s'apparentant aux monts sous-marins. Les débris de coraux forment une couche d'au moins 33 cm d'épaisseur et s'étendent sur plusieurs hectares par des profondeurs d'eau de 225 à 255 m, ce qui porte à croire qu'une communauté corallienne a dominé cet endroit pendant plusieurs siècles. Le corail *Lophelia pertusa* forme des récifs de grande étendue dans plusieurs régions du globe, ce qui laisse croire qu'un récif corallien d'eau froide a existé à cet endroit jusqu'à un passé tout récent. Ce site, ainsi qu'un échantillon provenant de la côte ouest de l'île de Vancouver attestent des premières occurrences reconnues de *Lophelia pertusa* en Colombie-Britannique. Dans les approches des îles Gulf, dans la partie méridionale du détroit de Georgia, des levés multifaisceaux effectués à l'échelle régionale révèlent en outre la présence de petits (< 1 km^2) récifs de spongiaires hexactinellides par des profondeurs d'eau de 100 à 140 m, dans des secteurs où les dépôts glaciaires présentent un faible relief. Les surfaces de ces récifs sont couvertes de grands spongiaires des Hexactinosida, où dominent *Heterochone calyx* et *Aphrocallistes vastus*, ou encore de fragments de ces spongiaires là où les récifs ont subi des impacts d'origine anthropique, du chalutage entre autres. La cartographie de ces habitats et d'autres milieux sensibles permettra l'adoption de mesures efficaces de gestion des océans par les organismes responsables.

INTRODUCTION

Scleractinian, or stony, corals are well known to form reefs in warm tropical shallow seas. It is less well understood that corals form extensive reefs in deep-sea settings. Cold-water coral reefs have been well documented on the European margin in many settings from the Mediterranean Sea to Norway (Freiwald et al., 2002; Fosså et al., 2002; Taviani et al., 2005). The coral *Lophelia pertusa* is the most well known deep-sea reef-forming coral globally, but other species including *Occulina varicosa* (Reed et al., 2005), *Solenosmilia variabilis* (Burgess and Babcock, 2005), and *Madrepora oculata* are also known to form reefs in cold- and deep-water settings. These coral habitats are thought to play an important role in benthic ecosystems by providing complex seabed structures and morphology (Costello et al., 2005; Freiwald et al., 2002). *Lophelia pertusa* reefs are known to be important habitat elements in deeper shelf and slope waters in the northeast Atlantic region where they have been shown to support over 1300 species of associated fauna (Waller, 2005). These reefs are susceptible to damage from anthropogenic impacts, particularly from mobile fishing gear.

Hexactinellid sponge reefs occur on the British Columbia shelf, in the Georgia and Queen Charlotte Basins (Conway et al., 2001; 2005; Krautter et al., 2001), and these provide habitat for fish species, especially young rockfish (Cook, 2005) and invertebrate species. Many of these sponge reefs have been extensively damaged or destroyed by mobile fishing gear or trawling (Conway et al., 2001; Jamieson and Chew, 2002). Sponge reefs, unlike deep-sea coral reefs, have only been reported from the British Columbia margin.

The purpose of this paper is to report the occurrence of *Lophelia pertusa* in British Columbia waters, recognized for the first time, and to describe the setting of a dense *Lophelia* community or reef that existed until recently. In addition, several newly discovered small sponge reef sites are described and the known sponge reef distribution in the Strait of Georgia is presented.

METHODS

Geological and morphological features described in this report were initially defined from the multibeam swath bathymetric dataset of the Strait of Georgia. This dataset provides a 5 m resolution map of the seabed (Barrie et al., 2005). The research remote-operated vehicle (ROV) ROPOS (Remote Operated Platform for Ocean Science) based at the Institute of Ocean Sciences in Sidney, British Columbia, was operated in November 2004 and October 2005 from the CCGS *Vector* to survey selected seafloor areas.

ROPOS Dive sites 928 and 929, located on a very steep knoll rising from 400 m to 150 m water depth (49°22´N, 123°53´W, Fig. 1), were selected based on the recovery of a large volume of the scleractinian (stony) coral species in a Shipek grab sample (VEC01A073) collected during cruise VEC01A in 2001 aboard the CCGS *Vector*. ROPOS Dives 928 and 929 were undertaken in the same location on Oct. 20, 2005 to examine the coral site in detail and further sampling of the corals was accomplished using the ROPOS ROV. Using the ROPOS coring system two short (40 cm) cores of the coral debris field were collected to establish a chronology and recent geological history for the site. The cores were subsequently split, described, and photographed.

Two new sites were interpreted to be sponge reefs, where multibeam and geophysical surveying recorded chevron-shaped anomalies. The distribution of sponge reefs, including previously reported reefs and new discoveries, is shown in Figure 1. These were described and photographed during ROPOS Dives 930 and 931.

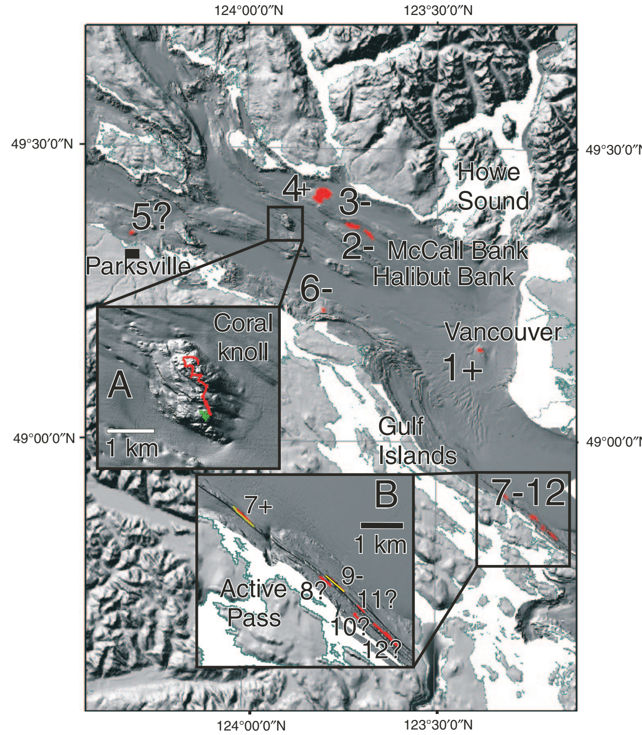

Figure 1. Location of known sponge reefs (numbers) and location of *Lophelia pertusa* coral occurrence in Georgia Basin (Inset A). Status of sponge reefs is indicated by a + symbol when the reef is known to be healthy; a – symbol where largely or completely dead and a ? symbol where the status of the reef is unknown. For further information on site 1 (Fraser Ridge) *see* Conway et al., 2004; for sites 2 to 4, including McCall and Halibut Bank reefs, *see* Conway et al., 2005. Sites 5 to 12 are newly discovered reefs first reported here. Inset A shows ROPOS remove-operated vehicle transects (shown in red) over the coral knoll site and the location of the *Lophelia pertusa* debris field (shown in green). Inset B shows reefs adjacent to Active Pass where ROPOS transects (shown in yellow) revealed a healthy reef (7) and a largely dead reef (9).

RESULTS

Scleractinian coral site

During Dive 929 (Fig. 2), the ROPOS encountered a steep wall at 300 m depth to the east of the coral-rich grab-sample site (VEC01073) and after climbing this slope, identified coral debris at the shoulder of the knoll at 255 m water depth. In transects oriented west-northwest to east-southeast, the debris field was mapped using the ROPOS video system. The dense accumulation of coral fragments, covering an area roughly 200 by 150 m, was noted to consist of branching fragments measuring a maximum of 12 cm in length (Fig. 3). The video survey will enable biota distribution and sediment type to be accurately mapped. Scoop samples were obtained at three sites to sample the coral debris, which was noted to extend into the subsurface. Silty-clay sediments thinly cover the coral branches in some areas, and in the subsurface the muddy sediments form a cavity-infilling matrix in which the coral is enclosed. The coral branches recovered are typically of uniform dimension, 5 to 8 cm in length, 0.5 to 1 cm in width, and appear to have formed from breakage of the branch at the point of attachment to the stem of the colony (Fig. 3). The scleractinian corals were subsequently identified as *Lophelia pertusa* (S. Cairns, written communication, 2006). Coral branches at the sediment-water interface were typically stained with a thin brown or black oxide coating. Video of the debris area also indicates that many of the surface corals are oxide stained. The boundary or contact of the debris field with adjacent seabed is very sharp, indicating that the coral community was locally dominant and not widely distributed as part of a more diverse seabed community. The samples contain few other organisms, but are completely dominated by the single coral species in a mud matrix. Coral branches found lying on the seabed are stained black or brown by iron, manganese, or magnesium oxides indicating very low sedimentation rate, and further indicating that the seabed has been undisturbed for at least several decades. The cores were taken from a massive, unstratified bed of unencrusted and unstained and relatively intact *Lophelia pertusa* branches in a siliciclastic silty-clay matrix.

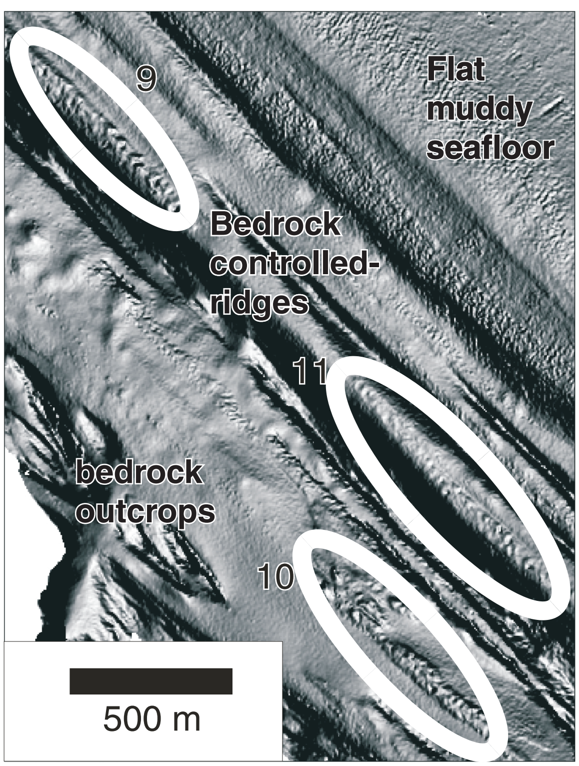

Figure 2. Chevron-shaped seafloor features indicating the presence of sponge reefs near Active Pass (*see* Fig. 1 for location).

Sponge reefs

ROPOS Dive 930 site, on the top of Galiano Ridge (Fig. 2), in 95 to 105 m water depth, was to the north of Active Pass and revealed a healthy sponge reef measuring up to 4 m in height composed of the species *Heterochone calyx* and *Aphrocallistes vastus*. This reef was noted to host several species of rockfish (Fig. 4). The reef was somewhat discontinuous and restricted to glacial substrate. Adjacent bedrock slopes did not develop sponge reefs, though isolated sponges were observed on these bedrock slopes.

ROPOS Dive 931 site, south of Active Pass (Fig. 2), in 140 m of water, transected a largely dead reef with few living sponges covering a small portion of the reef. Living, but broken, sponges and dead and broken sponge debris were common at this site. Waveform mounds to 4 m in height are the common reef shape here. Mud deposition seems to be ongoing and smothering the reef, with mud accumulating over sponge debris in several areas along the transect. Shrimp were very common along this survey line, while rockfish were infrequently observed, associated with the few remaining living sponges.

DISCUSSION

Scleractinian coral site

The coral field, which is composed of masses of well-preserved branches, indicates that a community of deep-sea corals dominated the site for a period of centuries. *Lophelia pertusa* and other deep-water corals are normally slow growing; averaging a few millimetres per year (Freiwald et al., 2002) and some fragments were recovered which measured up to 12 cm long (Fig. 2, 3). Coral branches in a mud matrix extend to a minimum depth of 33 cm below the seabed. The branches found buried within the muddy matrix sediment were white and unstained. Corals in recovered cores showed similar results, with oxide stains on surface corals while those buried by the clay-rich mud were unstained. It is possible that this

Figure 3a) Seafloor covered in *Lophelia pertusa* branches *in situ* at the coral knoll site. **3b)** *Lophelia pertusa* branches recovered from site.

coral community died in place as the result of an environmental change, such as an increase in sedimentation rate or some other oceanographic event. The surface oxide staining of the coral fragments on the seabed would indicate that the demise of the coral community did not happen recently and so is unlikely to be related to anthropogenic impacts such as trawling. In addition, the surface distribution of some branches of coral suggests coral colonies collapsing in place, with no evidence of their being transported by sedimentary processes such as gravitational debris flows or slides. The skeletal density of the corals is relatively low compared to living *Lophelia pertusa* from another site, suggesting some surface dissolution of the coral skeletons may have occurred. Though the fragile branching structures are in many cases intact, some of the corals samples appear somewhat worn (S. Cairns, written communication, 2006) again suggesting some dissolution of the aragonite corals may have occurred. The fine texture of the cored sediments, and lack of sedimentary structures related to emplacement of the corals by sliding or tractive transport, is strongly suggestive of coral colonies being smothered in place by fine sediments. The muddy sediments could perhaps have infiltrated the generally open framework of the corals to result in the eventual death of the coral thicket. Lophelia reefs elsewhere are known to be sensitive to sedimentation rate and a balance between sediment input and coral growth is inferred in some coral reef settings (De Mol et al., 2005).

The topographic setting of the dead coral community on a seamount-like feature is notable. Concentrations of deep-sea coral reefs constructed by *Lophelia pertusa* are frequently found on the margins of seamounts and banks in the northeast Atlantic, where hydrodynamic and oceanographic processes locally enhance the coral habitat by increasing the availability of nutrients and seafloor currents preventing smothering by sediment accumulation (White et al., 2005). Small coral reefs have been found on sills of two fjords in British Columbia. Although samples were originally identified as *Solenosmilia variabilis* by J. Wells (Austin, 1985) another sample has recently been identified as *Lophelia pertusa* (S. Cairns, written communication, 2006).

Sponge reefs

The chevron-shaped features observed on multibeam data do correspond to the presence of sponge reefs on the seabed, indicating that remote mapping of even narrow, elongate, and discontinuous sponge reefs is readily done using multibeam data sets. Dive 930 (Fig 1 at 7 in Inset B) is a very good video record of a reef on the Galiano Ridge. The reef is healthy and undamaged and has probably been a reef site for several centuries at least, estimating by the size of the bioherms encountered. Future mapping of substrate types will assist delineation of those required environmental conditions favourable for, or required for, the development of sponge reefs. Bernard (1978) reported the distribution of various benthic communities, including one dominated in part by *Aphrocallistes vastus*, in the Strait of Georgia. With respect to the eastern approaches to the Gulf Islands, Bernard's mapped distribution of the *A. vastus* community corresponds reasonably well to the distribution of the reefs identified using multibeam surveying. Further north, few reefs are found and the *A. vastus* sponge community mapped by Bernard is probably present as individuals as opposed to sponge reefs.

It is suspected that trawling has caused the damage to the reef surveyed during Dive 931. Evidence for this includes the living but broken sponges and dead and broken sponge debris that is very common at this site. Trawling activity may accentuate the shape of the waveform chevron shaped features by dragging and piling sponge debris at the crests of the features. The proximity of the sites surveyed by these two dives makes them particularly useful as a comparison of pristine versus impacted sponge reefs. The near absence of rockfish at the damaged site compared to the Galiano Ridge reef, where rockfish were quite common, was noteworthy. Many sponge reefs have been trawled in Queen Charlotte Basin (Jamieson and Chew, 2002) and Georgia Basin (Conway et al., 2005). Many small chevron-shaped reefs in the vicinity of Active Pass are noted on multibeam data in deeper water (Fig. 4), but these are yet to be examined by video transects.

There appears to be a correlation between steep and inaccessible sites and the health of sponge reefs that occur there. Rough and steep glacial slopes or areas protected by rough bedrock slopes are where healthy sponge reefs are found, probably due to problematic access to trawl-equipped fishing vessels. It is possible, therefore, that the small reefs identified on the multibeam data in steeper topography remain healthy while deeper, low-slope-angle seabed areas have been trawled (Fig.4).

Sponge reefs within the Georgia Basin are of considerable interest to the scientific community. They form accessible sites that can be reached from laboratories in southern British Columbia, unlike the much more extensive, but remote, Queen Charlotte Basin (QCB) reef complexes. For example, there is a proposal being developed that would see the Fraser Ridge sponge reef complex (Conway et al., 2004) studied by a seabed observatory with instrument arrays supported by the VENUS program (http://www.venus.uvic.ca/). Mapping sponge reefs and other sensitive habitats is a critical first step in providing effective ocean management and further science opportunities.

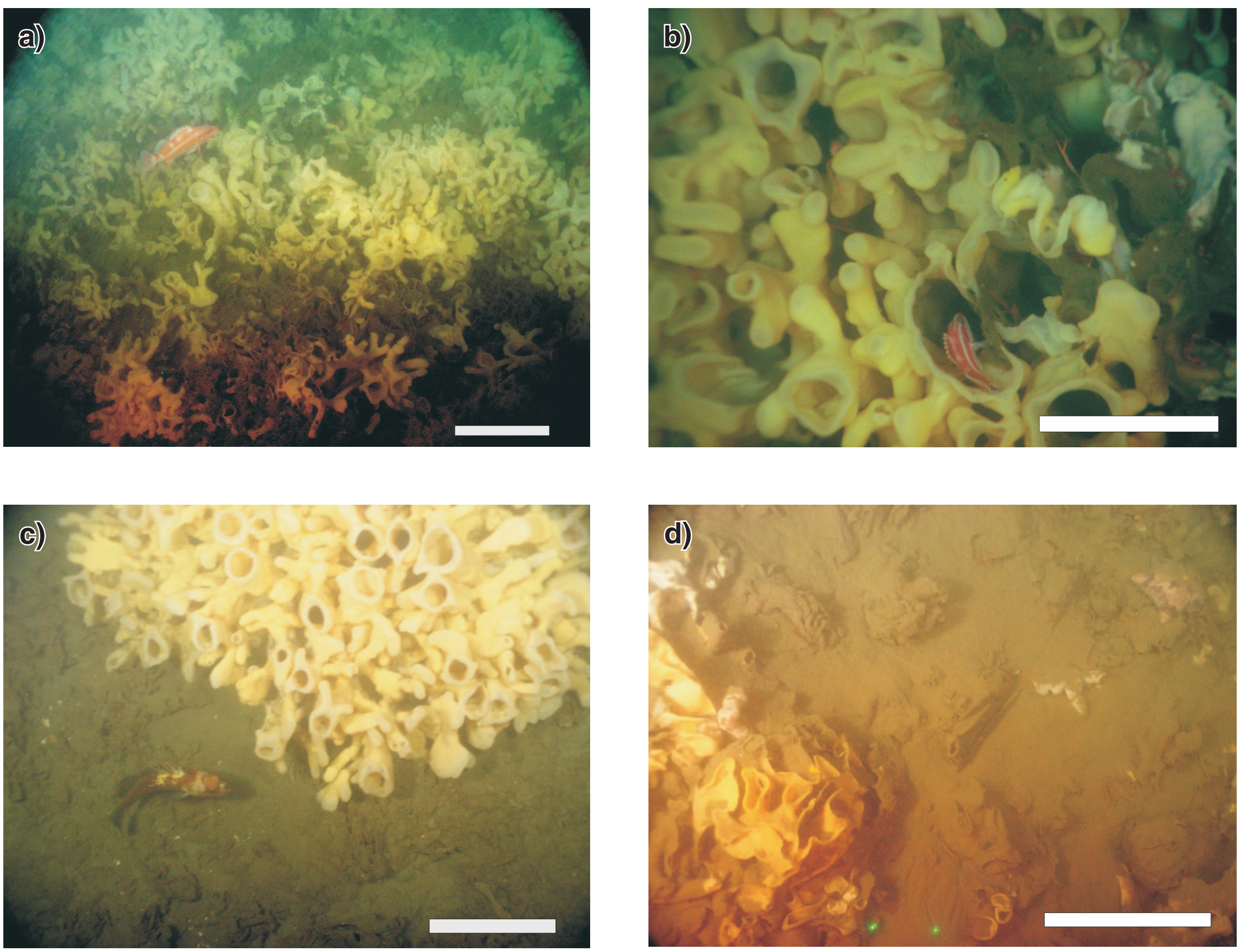

Figure 4a) A young Yelloweye (?) rockfish in dense sponges. **b)** A young rockfish inside *Aphrocallistes vastus* **c)** Quillback rockfish beside *Aphrocallistes vastus* at reef north of Active Pass (a, b and c located at reef 7 in Fig 1). **d)** Mechanically damaged sponges at reef south of Active Pass (located at reef 9 in Fig. 1 and 2). Scale bar in images is 30 cm long.

CONCLUSIONS

Abundant remains of the scleractinian coral species *Lophelia pertusa* have been encountered at one site during surveys in the Strait of Georgia. This reef-forming coral has not been previously reported in British Columbia waters.

The dense coral debris at the site probably represents the remains of a reef that grew over a period of centuries in water depths of 225 to 255 m. An undetermined oceanographic process or processes caused the reef to die in place. In view of this discovery it seems probable that living scleractinian coral reefs will be found in the deeper waters off British Columbia in the future.

Small sponge reefs occur on the eastern approaches to the Gulf Islands at several locations. The condition of the reefs varies from apparently healthy and pristine to mechanically damaged, sediment covered, and largely 'dead'.

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