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GEOLOGICAL SURVEY OF CANADA | COMMISSION GÉOLOGIQUE DU CANADA

DESCRIPTIVE NOTES

INTRODUCTION

The complex and variable seafloor geology of the Nanaimo area is the result of multiple processes which have been the agents of geological change for the modern Georgia Basin. Today's basin includes three main bodies of water: Juan de Fuca Strait, Puget Sound, and the Strait of Georgia. It is surrounded to the west by Late Cretaceous Nanaimo Group sedimentary rocks (Mustard, 1994; England and Bustin, 1998; Bustin et al., 2000) and to the east by Eocene (England and Bustin, 1998; Bertin et al., 2000), and to the east by deeply buried Tertiary sedimentary rocks of the Chuckanut Formation (Johnson, 1984; Mustard and Rouse, 1994; Bertin et al., 2000). The modern basin structure has developed during 40 Ma as a result of tectonic regime in a series of structural depressions and overdeepening by Tertiary erosion and Quaternary glaciations, and partially infilled by glacial and postglacial sediments.

During the Quaternary Period, several glaciations affected the Pacific margin, including the Strait of Georgia. Most evidence of older glacial episodes has been eroded by the Fraser Glaciation, the most recent glaciation, leaving few remnant outcrops of older glacial deposits on the seafloor. The last glaciation reached its maximum extent by 11 300 BP (^{14}C) and the following deglaciation is known to have been very rapid (Barrie and Conway, 2002; Gulliksell et al., 2003). Consequently, these processes resulted in a stratigraphy comprised of thick diamicton (ice-contact sediments), overlain by a unit of ice-proximal glaciomarine sediments and a thin, discontinuous ice-distal glaciomarine unit (Barrie and Conway, 2002; Barrie et al., 2005). Following deglaciation, relative sea-level fell only slightly below present (Lamers et al., 2000, 2002).

Throughout the Holocene, oceanographic conditions and sedimentation have been controlled by the intense outflow from the Fraser River. A massive delta has been constructed and a thick unit of mud overlies older (pre-Holocene) units (Clague et al., 1983, 1991, 1998; Mosher and Hamilton, 1998). Sponge reefs have developed at a few locations (Conway et al., 2005). Today, most of the bedrock and glacial sediment outcrops found in the southern Strait of Georgia are located on the western side of the strait and are thus common in the Nanaimo area (Barrie and Hill, 2004).

This surficial geology map is the last of three A-series maps for the Nanaimo area, British Columbia. The series includes: Map 2117A, displaying the sun-illuminated seafloor topography along with colour-coded bathymetry derived from multibeam-sonar data (Picard and MacLeod, 2008) and Map 2119A, displaying the backscatter-strength data also derived from multibeam-sonar data (Picard, 2009).

METHODS

Marine survey techniques employed included multibeam sonars EM1002 and EM3000 for bathymetric and backscatter-strength data, high-resolution seismic profiles from Huntec DTS subbottom profiler, Simrad sidescan sonar, as well as seabed videos and still photographs from the remotely-operated platform for ocean sciences (ROPOS) and an in-house ice-hole camera. Figure 8 displays the survey tracklines where collection of geophysical data was accomplished between 1999 and 2004. The interpretation and mapping of the geology as well as the cartography was done using ESRI ArcGIS software.

SURFICIAL GEOLOGY

In this geologically diverse environment of the Strait of Georgia, five main seismostratigraphic units are defined and follow Eyles&Eyles's (1991) complete deglacial sequence (Mosher and Hamilton, 1998). These units consist of: bedrock basement, glacial diamict or ice-contact sediments, ice-proximal glaciomarine sediments, ice-distal glaciomarine sediments, and postglacial sediments. These seismostratigraphic units are exposed at the seafloor on the western edge of the strait, and are shown in cross-sections AN C (Fig. 1).

Upper Cretaceous Nanaimo Group

This bedrock unit outcrops (unit uKN) in many places within the map area (Fig. 2). The unit appears as a succession of bedding planes that are frequently folded and faulted. The most prominent offshore faults, correlating with the extension of onshore faults previously mapped on land (Journeay, 2005), have been symbolized. In addition, the unit is often thinly covered by gravel and sand, and where depressions are present, joints and bedding planes are partially infilled with unconsolidated sediments, mapped mainly as glaciomarine undefined sediments (unit Gmu). The characteristics of the bedrock unit and its juxtaposition with terrestrial mapped outcrops (Barrie et al., 2005) indicate that this unit is formed by sedimentary rocks of the upper Cretaceous, Nanaimo Group (Mustard, 1994; Mustard and Rouse, 1994; England and Bustin, 1998). This unit forms the acoustic basement in the map area. The Nanaimo Group is characterized by thick, sandstone-conglomerate units alternating with mudstone and fine-grained sandstone units, dominantly marine siliciastic sediments that were deposited during the primary phase of the Georgia Basin subsidence in the Late Cretaceous (Mustard, 1994; England and Bustin, 1998). Following the main deposition episode for the Nanaimo Group, periods of uplift and erosion alternating with periods of subsidence and deposition occurred due to variation in plate convergence. During the Eocene the major deformation of Georgia Basin occurred caused by the accretion of the Pacific Rim and Crescent terranes during this time period. The deformation and contraction of the basin continued over the next 40 Ma and today, the main tectonic activity is caused by the subducting Juan de Fuca Plate (England and Bustin, 1998). The basin is now an erosional remnant and its configuration is largely the result of postexpositional deformation.

Glacial sediments

Within the map area, the glacially related sediments predominately occur along the Gulf Islands and the eastern Vancouver Island coast.

The ice-contact sediments (unit ic) present in the strait were described as till by Barrie and Conway (2002). From seismic profiles, the unit is defined by its uniform unstratified character and its high internal backscatter (Mosher and Hamilton, 1998; Picard, 2009). Throughout the strait, the unit varies in thickness from a few metres to 60 m. The unit is lithologically described as massive, poorly sorted gravelly muddy sand with striated and faceted cobbles, up to 10 cm in diameter. Seafloor images, video transects, and grab samples confirm the coarse texture of the unit (Fig. 3). The ice-contact unit may occur as a lag of coarse surficial sediments, including boulders and pebbles, resulting from winnowing processes on the surface of the glacial units. In the surroundings of Nanaimo harbour and east of Gabriola Island, extensive boulder fields overlie ice-contact sediments (Fig. 4).

The glaciomarine ice-proximal sediments (unit Gmp) form a thin unit (less than 10 m) overlying the ice-contact unit (unit Ic) and are acoustically stratified with discontinuous reflectors in seismic profiles. Cores show that these sediments are primarily laminated grey clay with thin silt laminations and low-rafted pebbles, interbedded with well sorted sand layers of variable thickness (Barrie and Conway, 2002). In the southern Strait of Georgia, this unit is, in places, difficult to differentiate seismically from the ice-contact unit. The unit interfingers with the ice-contact unit in a complex fashion, which is most probably due to rapid deglaciation. Therefore, a unit named 'Glaciomarine sediments' (undefined) (unit Gmu) was used to map these complex areas. Figure 5 shows a seafloor photograph representative of this unit.

A thin, discontinuous ice-distal glaciomarine mud (unit Gmd) overlies the ice-proximal sediments or directly overlies the ice-contact sediments. The acoustic signature of the unit is a weakly reflective and well stratified sediment drape that forms sigmoidal beds or lobate forms. In cores, the recovered section shows a bioturbated, somewhat massive unit that contains mostly clay and silt, with sparse sand and ice-rafted gravel (Barrie and Conway, 2002).

Postglacial sediments

The postglacial sediments are mainly derived from the Fraser River and from reworking of older glacial deposits. In addition, limited recent sediments have been incorporated into Holocene sponge reefs, and are also to be found in anthropogenic deposits, such as dredge spoil and dump sites (Fig. 6). The postglacial mud (unit PGm) is characterized by a very low-amplitude reflection on the acoustic records. It is defined as a mixture of silt and clay up to 300 m thick where the Fraser River pro-delta is at its maximum thickness (Hamilton, 1991; Mosher and Hamilton, 1998; Clague et al., 1998). In the northeast corner of the map area, an over 100 m thickness of Holocene mud (unit PGm) is found. The mud is mostly confined to the basins and troughs and has a smooth surface. Disrupting this unit are features such as sidecarks in Departure Bay and surface expression of faults like Porlier Pass Fault (Barrie and Hill, 2004; Barrie et al., 2005).

In the Strait of Georgia, postglacial sand deposits are rare, in part because the relative sea level has never been much lower than present (Lamers et al., 2002). In a few areas, the postglacial sand (unit PGs) is associated with reworking of glaciogenic deposits, and therefore is frequently found inserting the surface of such glacial units and in a transition zone between the bedrock unit and the deep basin mud. The postglacial sand unit is also observed forming the floor of one particular submarine channel found on the northeastern side of Gabriola Island (see legend symbol). The origin of this unit and the mechanisms of formation have not been determined. On acoustic records, these channels show high-angle and clinoconcave reflectors, clear indications of a seafloor disturbance. On the backscatter strength map (Picard, 2009), the strength in the channel is slightly higher than the surrounding environment. It is possible that the channel is associated with turbidity flows, slump deposits, an along-shore current, or a combination of all these processes. A fault, in close proximity and in alignment with this channelized feature, has also been observed on Gabriola Island (Journeay, 2005).

Sponge reefs (unit PGsr) have been discovered in the Strait of Georgia in several areas. The reefs are built by siliceous sponges that anchor on the surface of the ice-contact, or in some cases the glaciomarine units. These reefs then develop through trapping of recent sediments captured from suspension and through sponge recruitment to the reef surface (Conway et al., 2004, 2005). They are found north of Gabriola Island and appear on the seismic records as roughly rounded, interconnected small mounds up to 3 m in height on top of glacial sediments, in water depths between 100 m and 130 m. Although individual siliceous sponges are found extensively on boulders and bedrock outcrops, only sponge reefs form deposits that allow mapping as a surficial unit (Fig. 7).

Anthropogenic deposits (unit PGa) are found in the spoil grounds. These sites are mainly used for disposal of dredged material. The dump site on the northeastern side of Galiano Island has no positive relief on the seafloor, but is apparent as an area of high backscatter strength. Anthropogenic disturbances are also marked on the map as features. Among these, dredged excavation sites, log-boom areas, pipelines, and marina activities are identified. Other features that could not be identified, but were definitively showing anthropogenic shapes were marked as undifferentiated anthropogenic disturbance. These features are abundant in the Nanaimo harbour approaches, including Northumberland Channel.

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Author: K. Picard

Geology by K. Picard, 2004–2008

Digital cartography by R.F. MacLeod, GSC (Pacific)

Any revisions or additional geological information known to the user would be welcomed by the Geological Survey of Canada

MAP 2118A

SURFICIAL GEOLOGY AND SHADED SEAFLOOR RELIEF

NANAIMO

BRITISH COLUMBIA

Scale 1:50 000/Échelle 1/50 000

kilometres 1 0 1 2 3 4 kilometres

Universal Transverse Mercator Projection
North American Datum 1983

Projection transverse universelle de Mercator
Système de référence géodésique nord-américain 1983

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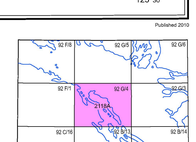
Digital base map from data compiled by Geomatics Canada, modified by GSC (Pacific)

Digital bathymetric contours in metres supplied by the Canadian Hydrographic Service and GSC (Pacific)

Magnetic declination 2010, 17°40'E decreasing 12.0' annually

Depth in metres below mean sea level



NATIONAL TOPOGRAPHIC SYSTEM REFERENCE

Published 2010

LEGEND

QUATERNARY

POSTGLACIAL SEDIMENTS

Geological processes delivering significant sediments to the study area include a large contribution from rivers, especially the Fraser River. Currents rework previously deposited sediments, in particular glaciomarine mud and glacial diamict units, and biogenic carbonate, which accumulates in bedrock and nondepositional areas of low terrigenous input where tidal currents and biological productivity are pronounced. Sponge reefs have developed in deeper water areas where suspended fine sediments are trapped and accumulated by the biological growth of siliceous sponges. In addition to these sources of recent sediments, anthropogenic activities locally contribute sediments as marine dump sites are utilized.

PGa — ***Anthropogenic deposits:*** *the dredged material found at ocean disposal sites consists of mixtures of silt, sand, rock, wood waste, and other approved material. On the map, two disposal sites are visible: Porlier Pass (49°00.75'N, 123°30.50'W) and Five Finger Island (49°13.66'N, 123°54.95'W). These sites are characterized by irregular intermediate to strong backscatter, forming round and linear backscatter features against a low-backscatter background. The spoil sediments overlie Holocene mud and bedrock.*

PGsr — ***Sponge reefs:*** *massive matrix of organic-rich, olive, slightly sandy-silty clay containing siliceous (glass) sponges (Hexactinellida, Hexactinosida) found as in situ whole skeletons and fragments. On seismic records, the unit appears as 1–3 m high transparent mounds overlying glaciogenic deposits. Very low backscatter strength on top of strong acoustic backscatter characterizes this unit.*

PGs — ***Postglacial sand:*** *sand or muddy sand. The unit is mostly found on the surface of some glacial sediments as it originates from the reworking of these sediments. Seismic profiles show that the unit is thin and can, in most cases, be defined as a veneer, with a distinctive low to intermediate backscatter strength. This unit is best represented in a submarine channel found northeast of Gabriola Island, where the unit infills the channel floor. See cross-section B-B'.*

PGm — ***Postglacial mud (Holocene mud):*** *silty clay; sediments originating from the Fraser River and forming the Fraser River pro-delta. The clay/silt ratio in the unit increases distal to the Fraser River mouth. The unit exceeds 300 m in thickness in the deepest basins and acoustic data are masked by interstitial biogenic gas in some areas. This unit has the weakest, but most uniform acoustic backscatter signal and generally does not show much relief. This unit occupies and dominates the deepest areas of the Straight of Georgia.*

GLACIAL SEDIMENTS

Glacial sediments include all sediments deposited during a glacial episode. Glaciomarine sediments were widely deposited in the Pacific region of Canada when glacial processes delivered sediments to the marine environment. A complex interaction between ice-front position, sea level, and rate of ice advance and retreat governed distribution of these sedimentary facies. During the latest phase of the last (Fraser) glaciation, glaciomarine sediments, mainly mud with a sand and ice-rafted gravel component, were deposited in troughs. These glaciogenic deposits all show strong backscatter strength. Ice-contact sediments resulted in glacial diamictons that have acoustically incoherent signatures on seismic-profile data. In some areas of the Strait of Georgia, including the Gulf Island channels, boulder fields overlie these sediments. The ice-contact deposits are common north of Gabriola Island where the geomorphology of the seafloor reflects glacial depositional processes and the presence of glaciogenic sediments.

Gmd — ***Glaciomarine ice-distal sediments:*** *well stratified gravelly sandy mud. On seismic profiles, the unit is represented by weak and continuous reflectors draping underlying units and is also characterized by intermediate to strong backscatter. Rare outcrops occur on the seafloor north of Gabriola Island, where exposed glacial deposits are common. In most cases, the unit fills troughs and is buried under thick postglacial mud.*

Gmp — ***Glaciomarine ice-proximal sediments:*** *texturally variable mixture of sediments including mud, sand, gravel, and boulders. In some areas, the unit is acoustically stratified with discontinuous reflectors, elsewhere more acoustically incoherent and disturbed in appearance. The unit is readily defined when it overlies ice-contact sediments. These deposits are widespread north of Gabriola Island. See cross-section A-A'.*

Gmu — ***Glaciomarine sediments (undefined):*** *stratigraphic relationships, setting, seafloor geomorphology and the backscatter strength of the unit share similarities with other recognized glacial units. This unit includes both ice-contact and glaciomarine ice-proximal sediments; however, these cannot be spatially defined because of the lack of geophysical or sample data available. See cross-section B-B'.*

Ic — ***Ice-contact sediments:*** *glacial diamicton till up to 60 m in thickness. This unit has strong multibeam backscatter strength, similar to the bedrock units, but the glacially derived geomorphology and transparent acoustic signature permit discrimination. See cross-section A-A'.*

PRE-QUATERNARY

Bedrock outcrops east of, and parallel to the Gulf Islands. Where buried, the bedrock surface can be traced on high-resolution seismic profiles, but is best defined using lower frequency subbottom profilers, where it forms the acoustic basement. The bedrock composing the Gulf Islands is sedimentary rocks of Cretaceous age and is part of the Nanaimo Group. Faults, folds, and other structures common on the Gulf Islands are also apparent in the marine environment.

uKN — ***Upper Cretaceous sedimentary Nanaimo Group:*** *dominated by layers of sandstone and conglomerate alternating with fine-grained sandstone and mudstone. The group includes several formations with variable sequences and bed thicknesses (Mustard, 1994; England and Bustin, 1998). Acoustically, the unit shows a discontinuous strong backscatter strength character with alternating low backscatter strength areas, resulting from the sharp and pronounced topography. The unit is most definable using the multibeam-sonar bathymetry and sun-illuminated topography.*

Geological contact (map unit boundaries are interpreted from multibeam-sonar bathymetry and geophysical seismic-profile data and are inferred contacts that may be gradational or conceptual in nature)

Fault; defined, approximate

Normal fault, defined

Oblique thrust fault, defined

Submarine channel

Boulder fields

Pockmarks

Anthropogenic disturbances:

Dredged site — Ad

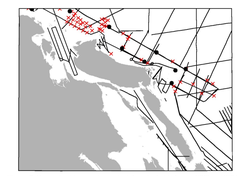
Log boom — Al

Marina pile — Ap

Undifferentiated anthropogenic disturbance — Au

Cable — Ac

Seafloor photograph (see Figures 2–7)


Nanaimo
Gabriola Island
Vancouver Island
Galiano Island
Mudge Island
Valdes Island
Pylades Island
Entrance Island
Round Island
Sandy Island
Five Finger Island
Porlier Pass
Active Pass
Dodd Narrows
Gabriola Passage
Departure Bay
Dorcas Bay
Descanso Bay
Silva Bay
Pilot Bay
Degnen Bay
Horseshoe Bay
Gabriola Reefs
Round Island
Entrance Island
Sandy Island
Five Finger Island
Pylades