Douglas Channel (Fig. 1) is part of the Kitimat fiord system that dissects the Coast Range of northern British Columbia, Canada (Macdonald et al., 1983). This map encompasses not only the fiord system but also parts of the adjacent (> 50 m) occur at the heads of the fiords, in the Kitimat area. Maximum thicknesses (up to ~ 90 m) are found in a series continental shelf (Hecate Strait).

RECENT GEOLOGICAL HISTORY About 15,000 to 14,000 years ago the region was covered by glacial ice that flowed to the southwest in Hecate Strait and thence into Moresby Trough (Barrie and Conway, 1999; Clague and James, 2002). Streamlined landforms developed under the grounded ice on the continental shelf, just outside the fiords. As deglaciation progressed, meltwater Safety Geoscience Program. Robert Kung created and managed the ArcGIS project that contained multibeam plumes deposited a blanket of glaciomarine silt outside the fiords. Icebergs impacted this unit, creating furrows and pits.

As the ice retreated inland, thick deposits of glaciomarine mud formed in fiord basins. Transverse moraines formed

less so than farther offshore, near the transform Queen Charlotte Fault (Rohr and Tryon, 2010). Several recent publications describe the extent to which mass transport processes have conditioned the seafloor (e.g. Conway et al., 2012, 2013). The preliminary evaluation of the evidence suggests that mass transport has occurred throughout the Barrie, J.V. and Conway, K.W., 1999. Late Quaternary glaciation and postglacial stratigraphy of the Northern Pacific postglacial period, and continued to the modern day, as evidenced by the 1970s slope failures at Kitimat (Prior et al., Strong bottom currents impact the fiord floors in some areas, creating alternating areas of scour and high Bornhold, B.D., 1983. Sedimentation in Douglas Channel and Kitimat Arm; in Macdonald, R.W. (ed.), Proceedings sedimentation rate (Bornhold, 1983). Large deltas are found at the head of the fiord system, at Kitimat and Kitkiata, while numerous smaller, fan deltas (Prior and Bornhold, 1989, 1990) are found through the area, preferentially located in

places, notably at the south end of Squally Channel and at Kitkiata.

The area was mapped by the Canadian Hydrographic Service using Kongsberg Maritime multibeam sonar systems that provide high-resolution bathymetry of the sea floor as well as "backscatter strength", a derived attribute that correlates loosely with sediment type at the seafloor. Figure 2 shows the distribution of backscatter strength in the fiord system. Other information used for mapping was derived from sub-bottom profiles, grab samples, piston cores, and bottom The approach is similar to that of "seascape mapping" (e.g. Shaw et al., 2012) in which it assumed that the seafloor can be mapped in terms of units, each unit having a distinct combination of morphology, texture, and biota. However, it was felt that there were insufficient bottom photographs to adopt the exact same approach in the Douglas Channel region, so the seascape map units described here are essentially geomorphology and texture.

have developed on 'hard' glacial substrates, as elsewhere in the fiords of the Pacific Northwest (see Stone et al., 2014).

fiords. Outside the fiords bedrock is commonly exposed. Streamlined landforms were formed parallel to ice-flow direction. Moraines record temporary halts in the incremental retreat of grounded ice, and were formed normal to ice turbated by icebergs. Deposits of postglacial mud/sandy mud are found in areas of low current activity, while areas of winnowed/scoured seafloor, probably underlain by glaciomarine sediment, occur where currents are relatively strong.

Thirteen seascape classes are designated for the fiords. Fiord sidewalls consist of either bedrock or unconsolidated sediment, the latter consisting of a blanket of glaciomarine mud, with or without a cover of postglacial mud. Fiord floors

Rohr, K.M.M. and Tryon, A.J., 2010. Pacific-North America plate boundary reorganization in response to a change in relative are divided into either banks of postglacial mud up to 90 m thick, gas-charged in places, or areas of scour and winnowing, where underlying glaciomarine sediments are exposed at the sea floor under surface gravel lags. Figure 3 shows the differing acoustic character of these two seascapes at the south end of Douglas Channel. Moraines are located transverse to fiord axes, and consist of thick deposits of glacial diamict capped by glaciomarine mud. Deltas are grouped into two types: 1) large deltas at Kitimat and Kildala; and 2) the numerous fan deltas that form cone-shaped deposits banked against fiord sidewalls. Mass transport deposits are grouped as: 1) large, complex failures of probable Late Glacial age on the rear slopes of moraines; 2) debris flows and translational slides; 3) bedrock slump/rockavalanche; and 4) bedrock creep (i.e. sackung, Ambrosi and Crosta, 2006). One area of bioherms was mapped, and an area of anthropogenic disturbance. The map also shows the distribution of pockmarks and gas masking. Figure 4 is a coloured, shaded relief image of an area at the south end of Devastation Channel (location on main map) showing several of the seascape types within the fiords. Figure 5 shows backscatter strength for the same

of depocentres in the Whale Channel/southern Douglas Channel area. Figure 3 shows how the depocentres are commonly located in close proximity to scoured areas. This work was part of a project managed by Dr. Gwyn Lintern under the aegis of Natural Resources Canada's Public

bathymetry, backscatter strength, and other data sets. Scott Hayward processed GIS data in Dartmouth. Brian J. Todd during halts in glacier retreat. Following further retreat, glaciomarine silt on top of these moraines failed in several reviewed the map and provided valuable advice. The Kitimat fiord system is subject to high precipitation and high rates of snowpack melt. It is seismically active, although

Ambrosi, C. and Crosta, G.B., 2006. Large sackung along major tectonic features in the Central Italian Alps; Engineering

Margin of Canada; Quaternary Research, v. 51, p. 113–123.

of a workshop on the Kitimat marine environment; Canadian Technical Report of Hydrography and Ocean Sciences, The recent surveys have located reefs composed on glass sponges (Hexactinellida) within the fiord system. They

Clague, J.J. and James, T.S., 2002. History and isostatic effects of the last ice sheet in southern British Columbia; Quaternary Science Reviews, v. 21, p. 71–87. Conway, K.W., Barrie, J.V., and Thompson, R.E., 2012. Submarine slope failures and tsunami hazard in coastal British Columbia: Douglas channel and Kitimat Arm; Geological Survey of Canada, Current Research 2012-10, 17 p.

> Conway, K.W., Kung, R.B., Barrie, J.V., Hill, P.R., and Lintern, D.G., 2013. A preliminary assessment of the occurrence of submarine slope failures in coastal British Columbia by analysis of swath multibeam bathymetric data collected 2001–2011; Geological Survey of Canada, Open File 7348, 38 p. doi:10.4095/292370 Macdonald, R.W., Bornhold, B.D., and Webster, I., 1983. The Kitimat fiord system: an introduction; in Macdonald, R.W.

(ed.), Proceedings of a workshop on the Kitimat marine environment; Canadian Technical Report of Hydrography and The seascapes are divided into two classes: those on the inner continental shelf outside the fiords, and those within the

Prior, D.B. and Bornhold, B.D., 1989. Submarine sedimentation on a developing Holocene fan delta; Sedimentology,

flow direction. Glaciomarine sediments were deposited by fallout from meltwater plumes, and were subsequently Prior, D.B. and Bornhold, B.D., 1990. The underwater development of Holocene fan deltas; Special publication of the International Association of Sedimentologists, v. 10, p. 75–90. Prior, D.B., Bornhold, B.D., and Coleman, J.M., 1983. Geomorphology of a submarine landslide, Kitimat Arm, British Columbia; Geological Survey of Canada, Open File 961. doi:10.4095/129784

> plate motion: offshore Canada; Geochemistry Geophysics Geosystems, n. 11, no. 6. doi:10.1029/2009GC003019 Shaw, J., Todd, B.J., and Li, M.Z., 2012. Seascapes, Bay of Fundy, offshore Nova Scotia/New Brunswick; Geological Survey of Canada, Open File 7028, scale 1: 350 000. doi:10.4095/292047

Stone, R.P., Conway, K.W., Csepp, D.J., and Barrie, J.V., 2013. The boundary reefs: glass sponge (Porifera: Hexactinellida) reefs on the international border between Canada and the United States; U.S. Department of Commerce, NOAA Technical Memoir NMFS-AFSC-264, 31 p.

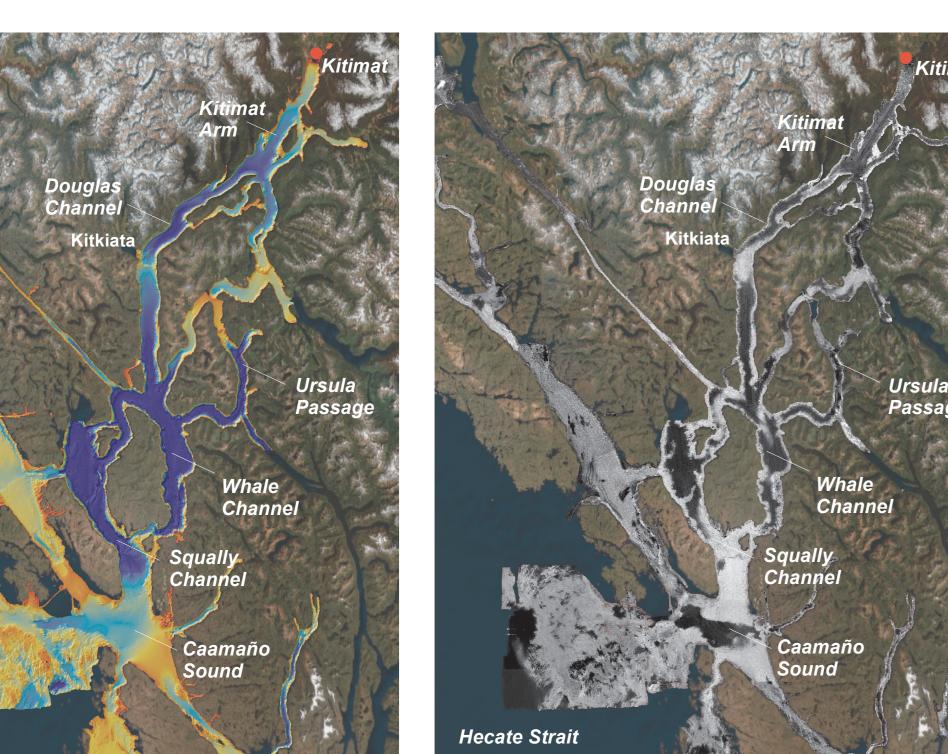


Figure 1. Coloured, shaded-relief image of the Kitimat fiord system and adjacent continental shelf (Hecate Strait), derived

Figure 2. Backscatter strength—a derivative from multibeam sonar surveys—serves as proxy for sediment texture. In from multibeam bathymetry surveys by the Canadian Hydrographic Service. The fiord basins attain a maximum depth of this image sand and mud have low backscatter (dark tone) while all other types of terrain (gravel, bedrock) have high

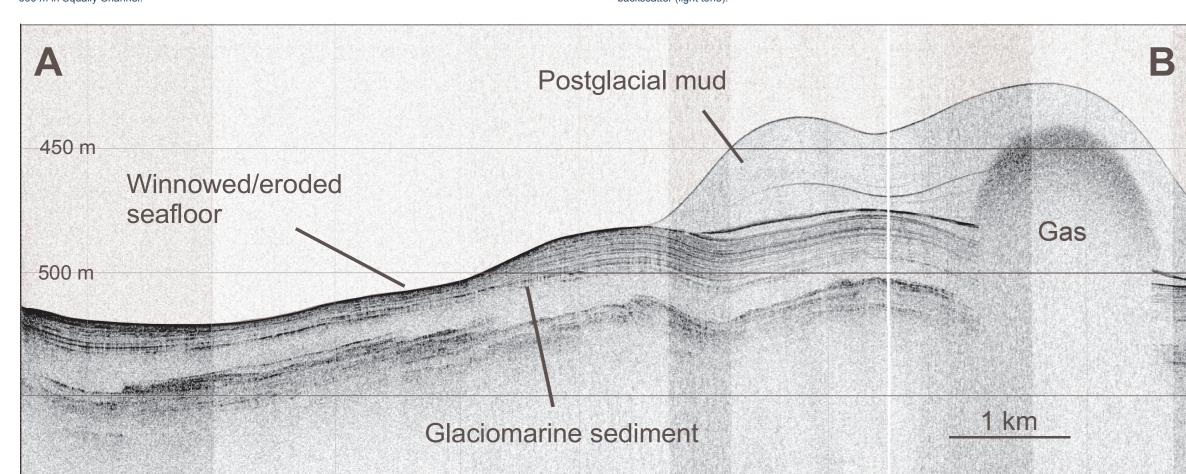
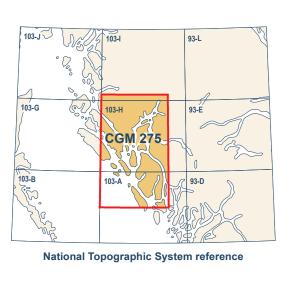


Figure 3. 3.5 kHz seismic reflection profile showing acoustically transparent postglacial mud adjacent to an area of seafloor winnowing and erosion in which acoustically stratified glaciomarine sediments are exposed at the sea floor. Location indicated on the principal map.

This map depicts the geomorphology of the Kitimat fiord system, British Columbia, and is based on bathymetry and backscatter data from multibeam sonar surveys, complemented by 3.5 kHz sub-bottom profiler data, grab samples, cores, and bottom photographs. The coverage extends from the head of Kitimat Arm to Hecate Strait, and includes Douglas Channel. The seafloor is divided into classes based on morphology and texture. The classes include glacial landforms that record the advance and retreat of grounded ice, and a wide range of submarine slope failures. The map also shows that postglacial sediment distribution on the fiord floors is highly variable: large areas are current- reliefs glaciaires qui témoignent de l'avancée et du recul scoured, so that underlying glaciomarine sediments are de la glace ancrée, ainsi qu'une vaste gamme de exposed. More than a hundred submarine fans deltas are present within the fiords.

Cette carte illustre la géomorphologie du système de fjords de Kitimat, en Colombie-Britannique, et elle est fondée sur des données bathymétriques et des données de rétrodiffusion acquises lors de levés au sonar multifaisceaux, auxquelles s'aioutent des données recueillies à l'aide d'un sondeur de sédiments à fréquence d'émission de 3,5 kHz, des échantillons prélevés par benne, des carottes et des photographies du fond marin. La zone couverte s'étend du fond du bras Kitimat au détroit d'Hecate et comprend le chenal Douglas. Le fond marin est divisé en classes selon la morphologie et la texture. Les classes englobent des ruptures sous-marines de versant. La carte illustre également la répartition très variable des sédiments postglaciaires sur le fond des fjords : de vastes zones ont été érodées par les courants, ce qui a permis d'exposer les sédiments glaciomarins sous jacents. Plus d'une centaine d'éventails deltaïques sous-marins sont présents dans les fjords.



Catalogue No. M183-1/275-2016E-PDF ISBN 978-1-100-22030-7 doi:10.4095/297482

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CANADIAN GEOSCIENCE MAP 275 MARINE GEOLOGY **GEOMORPHOLOGY OF THE**

Natural Resources Ressources naturelles du Canada

KITIMAT FIORD SYSTEM parts of NTS 103-A, NTS 103-H, and NTS 103-I



Preliminary Geological Survey of Canada Canadian Geoscience Maps

Geological compilation by J. Shaw Map projection Universal Transverse Mercator, zone 9. North American Datum 1983

Figure 6. Postglacial sediment thickness based on analysis of 3.5 kHz sub-bottom profile data and multibeam

bathymetry. The maximum thickness is slightly over 90 m at the south end of Whale Channel.

Canada, with modifications.

Illumination: azimuth 345°, altitude 45°, vertical factor 10x

MARINE GEOLOGY GEOMORPHOLOGY OF THE KITIMAT FIORD SYSTEM **British Columbia**

Mean magnetic declination 2016, 18°22'E, decreasing 12.8' annually. Readings vary from 18°37'E in the NW corner to 18°06'E in the SE This map is not to be used for navigational purposes.

The Geological Survey of Canada welcomes corrections or additional

Mt1 Mass transport complex

on exposed rock and infauna in depressions; high—gullies, depositional zones, and residual 'mesas' composed of high backscatter on outcrops, low backscatter in depressions. acoustically stratified glaciomarine sediments; surficial sediment is muddy sandy gravel; high backscatter but low backscatter for small areas of post-failure sedimentation; Lobate ridges 100 m wide and 5-10 m high; linear ridges 7 km created by failure of glaciomarine sediments draped over long and 30 m high; composed of acoustically incoherent Slopes > 10°, smooth surfaces or incised by gullies up to 10 m moraines, in the Late Glacial period. The area at Kitkiata may glacial diamict; bouldery gravel at the seafloor; high deep; consists of glaciomarine sediment with surface lag or a include failures but was more likely conditioned by an outburst backscatter; formed at the margins of grounded glacial ice.

veneer of postglacial mud; generally gravelly sandy mud at the seabed (high backscatter) but also sandy mud (low flood.

Mt2 Debris flows / translational slide Submarine slide deposits of differing ages, including finegrained material and ranging up to boulders tens of metres in diamict; bouldery gravel at the seabed; high backscatter;

size; high backscatter except low backscatter where slides formed parallel to the flow of grounded glacial ice. are buried by postglacial mud; the Kitimat slide (ca. 1970s)

Bedrock slump / rock avalanche

irregular bedrock blocks mantled by sand.

Mt4 Bedrock creep

Slump is a convex mass extending ~ 1 km away from foot of

gullies in places; high backscatter; formed by bedrock creep.

Ridges located on top of glacial deposits with relief commonly

5-10 m; acoustically transparent with low backscatter;

composed on glass sponges (Hexactinellida); also includes

Gentle relief (slopes <10°) deposits of postglacial mud and sandy mud; commonly located in banks to either side of channel thalwegs; acoustically transparent or with moderate has complex morphology including remoulded debris, pressure ridges, depositional lobes, longitudinal shears, outrunner blocks; sand and muddy sand with some gravel; Areas of low relief imprinted by iceberg furrows and pits; high backscatter; formed by failure of sediment on fiord surface lag of sandy muddy gravel overlies draped, sidewalls or delta fronts.

internal reflections; low backscatter; formed primarily by

deposition of fluvial sediments, but also by reworking of glacigenic sediments. F2 Fiord floor – winnowed/scoured Low-relief (<2°) areas of non-deposition or erosion with glaciomarine mud exposed at the seafloor; some areas have a scalloped appearance with relief 0.5 to 2.0 m; surficial lag of

muddy sandy gravel overlies acoustically stratified

glaciomarine sediments; high backscatter; formed where bottom currents are relatively strong. M Moraine High-relief (>100 m) transverse ridges; gullied in places; Blocks up to 5 km long, detached from fiord sidewalls; rate of Low relief, smooth seafloor; gravel lags; high backscatter;

Fiord sidewall – bedrock

backscattter).

S2 Fiord sidewall – unconsolidated

F1 Fiord floor – postglacial mud

acoustically incoherent glacial diamict draped by acoustically movement uncertain; may be equivalent to sackung (sagging found where deposition of postglacial sediment is inhibited by stratified glaciomarine mud; surface veneer of muddy gravel; bedrock on land); veneered by Quaternary sediments with currents. high backscatter; formed at former ice margins during the retreat of grounded ice.

Located where major rivers enter the fiords; stepped, concave profiles; slopes up to 15°; steeply-dipping internal reflections on acoustic records; chutes up to 15 m deep; generally gravel to sand at the seafloor; high backscatter; formed by deposition of delta foresets and bottomsets.

Fan delta Fan-shaped deposits extending from sea level to depths of 300 m; slopes of 10° to 30°; chutes up to 1 m deep with transverse steps; generally coarse sediments (bouldery gravel to sand); high backscatter; small fan deltas may be separated from the coast by an area of bedrock (sediment bypassing); created by fluvial deposition where small to

death assemblage of the giant acorn barnacle (Balanus O Station photographs nubilus) in Devastation Channel; classified as bioherms (reefs of fossilized biological remains with some sediment).

Area of the Kitimat delta impacted by harbour activities; rectilinear dredge pits up to 6 m deep; anchor drag marks.

Steeply sloping (> 40°) with bedrock outcrops separated by Large areas of seabed failure, with failure volume >1 km³ in Bedrock ridges and knoll with relief up to 30 m, separated by depressions containing gravelly sandy mud; attached fauna Squally Channel; irregular relief including escarpments, depressions containing glacial and postglacial sediments;

Streamlined ridge

Glaciomarine sediment

Ridges up to 10 m high and 3 km long, tapering to the

southwest; composed of acoustically incoherent glacial

acoustically stratified, gravelly sandy mud; high backscatter;

Narrow ridges with relief of up to 5 m, with low backscatter

strength, located on top of glacial deposits, are tentatively

identified as glass sponge (*Hexactinellida*) reefs.

formed by deposition from glacial meltwater plumes.

Postglacial mud / sandy mud

O6 Winnowed / scoured seafloor

bedrock slope; irregular surface with relief ~ 10 m; total Low-relief banks with weak acoustic stratification in a semi-

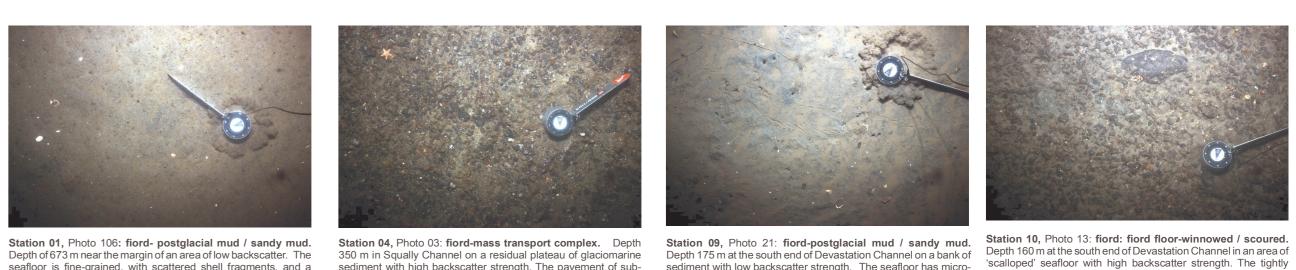
volume 0.3 km³; veneered by Quaternary sediments with high ponded style; mud and sandy mud; low backscatter; formed

backscatter (muddy sandy gravel); rock avalanche includes by deposition of reworked glacial sediments and fluvial

KITIMAT FIORD SYSTEM British Columbia parts of NTS 103-A, NTS 103-H, and NTS 103-I

MARINE GEOLOGY

medium rivers enter the fiords. light tone) include the bank of postglacial mud (A) and the postglacial mud (B) north of the large moraine. The high backscatter strength of the scoured seafloor (C) is due to the presence of gravel lag overlying glaciomarine sediment. Note: the backscatter scale is the opposite of that on Figure 2. Figure 4. Coloured shaded relief image of an area at the south end of Devastation Channel showing elements found throughout much of the map area. These are moraines (A), bedrock fiord sidewall (B), unconsolidated sidewall (C), debris flows (D), bank of postglacial mud (E), winnowed/scoured seafloor (F), fan delta (G), rockfall (H), and bioherms (J).

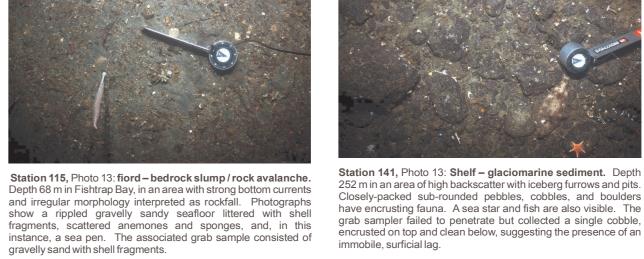






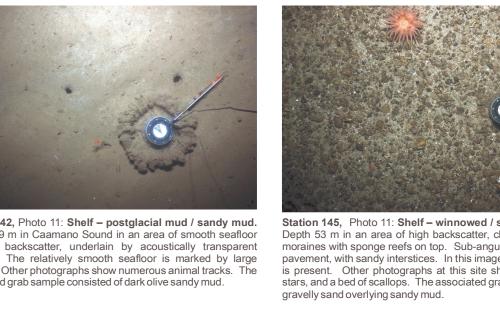
gravelly sand with shell fragments.



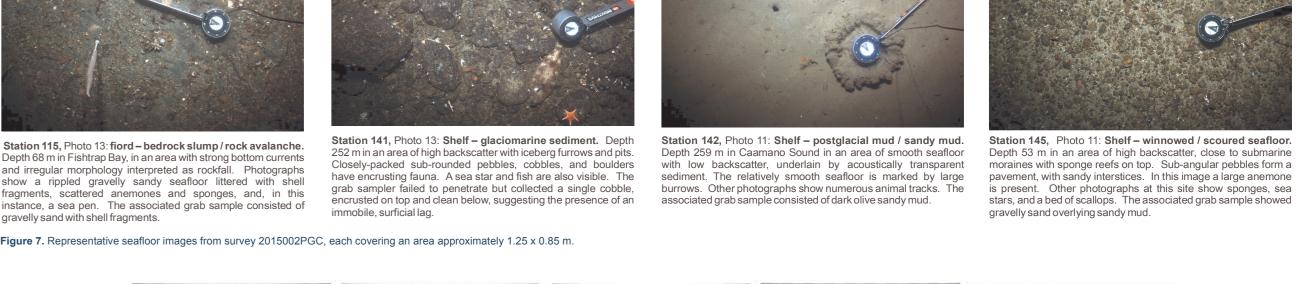






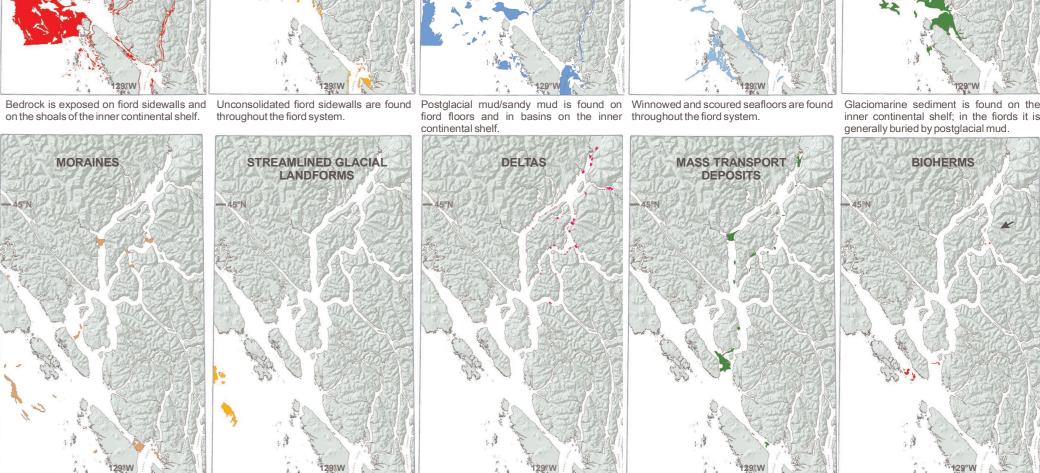


encrusted on top and clean below, suggesting the presence of an associated grab sample consisted of dark olive sandy mud. Figure 7. Representative seafloor images from survey 2015002PGC, each covering an area approximately 1.25 x 0.85 m.



background the seafloor is fine-grained sediment. Other

inner continental shelf; in the fiords it is



Submarine moraine crests are located Streamlined glacial landforms are located Deltas are found mostly in the inner fiords. Mass transport deposits occur throughout Bioherms have been mapped in several areas, but only those in Devastation the fiord system. Channel (arrowed) have been confirmed by

transverse to fiord axes; on the inner on the inner continental shelf. continental shelf they trend NW to SE. Figure 8. Distribution of seascape units. For this figure, distributions of bedrock inside and outside the fiord have been amalgamated, as have the distributions of postglacial mud

> Shaw, J. and Lintern, D.G., 2016. Marine geology, Geomorphology of the Kitimat fiord system, British Columbia, parts of NTS 103-A, NTS 103-H, and NTS 103-I; Geological Survey of Canada, Canadian Geoscience Map 275 (preliminary), scale 1:200 000. doi:10.4095/297482

Preliminary publications in this series have not been

CANADIAN GEOSCIENCE MAP 275 GEOMORPHOLOGY OF THE scientifically edited.

Authors: J. Shaw and D.G. Lintern

Postglacial sediment thickness (m)

> Base map at the scale of 1:250 000 from Natural Resources Shaded relief image derived from the Canadian Digital Elevation Data

Parts of NTS 103-A, NTS 103-H, and NTS 103-I

CANADIAN GEOSCIENCE MAP 275

Title photograph: Snow covered hills near Douglas Channel, British Columbia. Photograph by J. Shaw. 2016-001

Data may include additional observations not portrayed on this map. This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

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