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QUATERNARY GEOLOGICAL MAP OF GREATER VICTORIA

TRIM SHEETS (92B.043, 044, 053 & 054)

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Scale 1:25,000 (approximate)

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INTRODUCTION

This map shows the thickness and distribution of the Quaternary stratigraphic units in Greater Victoria. It is intended to provide the geological basis for the assessment of the earthquake hazards shown on companion maps which depict the liquifaction and amplification of ground motion Greater Victoria (Geoscience Maps 2000-3a and 2000-3b Monahan *et al.*, 2000b and c). The geological units shown here are defined in part to reflect these hazards. There are two additional maps relevant to earthquake hazards in Greater Victoria: a map that shows areas susceptible to earthquake-induced slope instability (Geoscience Map 2000-3c; McQuarrie and Bean, 2000) and a composite map that shows areas susceptible to the amplification of ground motion, liquefaction, and earthquake-induced slope instability hazards (Geoscience Map 2000-1; Monahan *et al.*, 2000, a)

This map is intended for regional purposes only and should not be used for site-specific evaluations. For the proper use of this map, the qualifications and limitations section should be carefully read and understood.

SUMMARY OF QUATERNARY GEOLOGY

Quaternary deposits in Greater Victoria overlie an irregular glacially-scoured bedrock surface. The depth to bedrock can vary from zero to as much as 30 metres within the space of a city block (Wuorinen, 1976; Nasmith and Buck, 1998).

The oldest Quaternary deposits include glacial and non-glacial sediments that underlie the Vashon till of the Late Wisconsinan Fraser Glaciation. The pre Vashon sediments occur principally in the central and eastern parts o Saanich Peninsula, where they are up to 60 metres thick and have commonly been sculpted into a series of north-trendin drumlinoid ridges and crag-and-tail features (Clague, 1976). The Vashon till directly overlies bedrock in much of the Greater Victoria area. It is a discontinuous unit and is generally less than a fe metres thick (Nasmith and Buck, 1998). The Vashon till and underlying Pleistocene deposits are grouped together here as "older Pleistocene deposits", because they are overconsolidated and have high shear-wave velocities (Monahan and Levson, 1997).

The Vashon till is overlain by the Capilano sediments, which were deposited at the close o the Fraser Glaciation when sea level was higher than present. The principal units of the Capilano sediments in the Victoria area are the Victoria clay and the Colwood sand and gravel. The Victoria clay is a unit o glaciomarine clayey silt that forms an irregular blanket-like deposit, generally below an elevation of 60 metres, but locally up to about 75 metres. It ranges in thickness from zero over bedrock knolls to 30 metres in depressions on the till or bedrock surface. The Victoria clay has three distinct facies. A lower, soft to firm, grey clay (grey clay facies) is in most places gradationally overlain by a desiccated and oxidized crust of stiff, brown clay (brown clay facies) 2 to 5 metres thick (Crawford and Sutherland, 1971; Nasmith and Buck, 1998). The Victoria clay commonly coarsens slightly upward, and a sand facies occurs locally near the top.

The brown clay facies of the Victoria clay is at the surface in most of the Victoria area. However, in closed depressions and other low-lying areas, the brown cla facies is absent and the Victoria clay is gradationally overlain by up to 6 metres of organic silt and peat that represent lake and bog deposits, referred to here as Holocene organic soils. The upper part of the grey clay facies is slightly overconsolidated where overlain by the brown clay facies, but normally consolidated where overlain by Holocene organic soils (Nasmith and Buck, 1998)

The Colwood sand and gravel is a glaciofluvial outwash and deltaic deposit that occurs at the surface over much o Colwood and Langford (Howes and Nasmith, 1983 Yorath and Nasmith, 1995). The maximum known thickness of the Colwood sand and gravel is 30 metres. The surface of the delta and outwash plain has been incised by late-stage glaciofluvial channels and contains closed depressions interpreted to be kettles. Some of these channels and depressions are still occupied by creeks and lakes, and are in part filled with peat. Sand and grave foreset beds are known from gravel pits, but deposits of silt up to several metres thick interbedded with sand occur on the delta slope on the northeast and southeast sides o the delta and are interpreted to represent distal and lateral foreset deposits (Monahan and Levson, 1997). Similar sediments likely underlie parts of the delta plain.

In shoreline and nearshore settings, the brown clay facies of the Victoria clay extends belo modern sea level, because relative sea level fell below its modern position in the latest Pleistocene and earliest Holocene (Clague *et al.*, 1982; Hutchinson, 1992). In these settings the brown clay facies is overlain by Holocene marine mud deposited during the Holocene rise in sea level (Crawford and Sutherland, 1971 Nasmith and Buck, 1998). Holocene marine muds are locally overlain b prograding shoreline sands. Shoreline sands are in turn locally overlain by peat, and in some places, shoreline peat deposits are overlain by recent beach sands and intertidal sediments (Clague, 1996 Monahan and Levson, 1997).

GEOLOGICAL MAPPING

Subsurface geological data on which this map is based include: over 5000 geotechnical borehole logs obtained from a variety of public and private agencies; several hundred water well logs obtained from the Groundwater Section of the Ministry of the Environment; and nearly 3000 engineering drawings for municipal sewer and water lines, that commonly sho where bedrock was encountered.

Geological map units were defined on the basis of these data and in part coincide with the U.S. National Earthquake Hazard Reduction Program (NEHRP) definitions of site classes for susceptibility to amplification of ground motion (Building Seismic Safety Council, 1994). Map unit boundaries were interpreted on the basis of the subsurface data, airphotos (~1:20,000 black and white dated 1974 and ~1:5000 colour dated 1990) and large-scale topographic maps (1:2000 to 1:5000). Soil maps by Da *et al.* (1959) and Jungen (1985) and seismic microzonation maps of Victoria by Wuorinen (1974, 1976) also provided useful information. Limited field checking was conducted.

In areas of poor subsurface control, the subsurface conditions are largely *inferred* from topographic and geomorphic evidence. For example, scattered bedrock with thin soil cover (unit R2), generally occurs in hilly areas, and thick soft glaciomarine clays (units C2 and O1 generally occur in low-lying areas. In areas of poor subsurface control, map unit C1 was applied to areas of sloping ground between occurrences of units R2 and C2, and in these area represents an uncertain proportion of both these units. To assist the user in determining the accuracy of the subsurface geological mapping, sites where subsurface geological data were available are shown on this map.

QUALIFICATIONS AND LIMITATIONS OF THIS MAP

This map provides the geological basis for the assessment of the amplification of ground motion and liquefaction hazards in Greater Victoria (Monahan *et al.*, in pre a), and the geological map units used here are defined in part to reflect these hazards.

This map is intended for regional purposes only. The map is based in part on interpretations of borehole records, the *approximate* locations of which are shown. Where borehole data are scarce, subsurface conditions had to be *inferred* from topographic and geomorphic evidence. The boundaries of most map units are gradational, particularly in the Victoria area due to the extreme irregularity of the bedrock surface. For these reasons, map unit boundaries are *approximate*, may enclose smaller occurrences of other map units, and are subject to revision as more borehole data become available. Furthermore, geological materials are variable, and deposits of a particular map unit may locally have unusual properties. Finally, only limited field checking was conducted to confirm interpretations.

In addition, this map does not fully address man-made alterations to ground conditions, suc as excavation of problem soils following drilling of the boreholes on which the map is based or the presence of artificial fill. Only the larger fills of which the authors were aware are shown on the map. Other areas of fill are present, and new areas of fill will be developed in the future.

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LEGEND

AREAS WITH ANTHROPOGENIC FILL AT SURFACE

F

UNIT F: FILL

Only the larger and thicker deposits o anthropogenic fill of which the authors are aware are included in this map unit. The principal areas are shoreline settings and reclaimed gravel pits. The thickness of fill can exceed 1 metres. The properties of fill vary widel , from dense engineered fills to loose fills. There are insufficient data to distinguish these regionally.

FC2 — **Unit FC2** is assigned to areas where fill overlies unit C2. In shoreline settings, fill may overlie soft Holocene marine mud that in turn overlies the Victoria clay, in which the brown and grey clay facies are both present.

FC1 — **Unit FC1** is assigned to areas where fill overlies unknown or variabl thicknesses of Victoria clay (unit C1).

FG — **Unit FG** is assigned to large areas of fill in reclaimed gravel pits in Colwood sand and gravel (unit G1).

FT — **Unit FT** is assigned to large areas of fill in reclaimed gravel pits in older Pleistocene deposits (Quadra sand and grave ; part of unit T).

FR2 — **Unit FR2** is assigned to areas where fill overlies bedrock or thin native soils (unit R2).

AREAS WITH HOLOCENE DEPOSITS AT SURFACE

HOLOCENE SANDS

S4 — **UNIT S4; BEACH SANDS:** This unit include modern beach sand . These deposits are up to several metres thick at Ross Bay and the northern part o Cadboro Bay, but elsewhere thicknesses are unknown.

S3 — **UNIT S3; STREAM DEPOSITS:** Sandy alluvial deposits have been mapped only where they are interpreted to be more than a few metres thick or are extensive enough to be mapped. Observations along most streams indicate that they are generally downcutting or have a boulder and cobble gravel bed.

S2 — **UNIT S2; GOLDSTREAM DELTA DEPOSITS:** The Goldstream River has built a small delta at the head of Saanich Inlet. The landward part of the delta plain consists of pebble to cobble gravel alluvial deposits, and the seaward part consists of predominantly sandy tidal flats. The gravel alluvium is interpreted to have prograded over finer deltaic deposits, including tidal flat deposits.

S1 — **UNIT S1; ALLUVIAL FAN AND FAN DELTA DEPOSITS** This unit consists of small alluvial fans and fan deltas. No borehole data are available in this unit, but the fans probably consist of sand and gravel, particularly where they occur along the lower flanks of sandy and gravelly drumlinoid ridges from which they have been derived.

HOLOCENE PEATS

O5 — **UNIT O5; PEAT OVER HOLOCENE BEACH SAND:** This unit is assigned to areas where peat overlie Holocene sand in a shoreline setting. At Cadboro Bay, where borehole data are available, the peat unit is 2 to 6 metres thick and the underlying sand is 3 to 9 metres thick. These deposits in turn overlie over 30 metres of Holocene marine mud and the grey clay facies of the Victoria clay.

O4 — **UNIT O4; HOLOCENE PEAT OVER GLACIOLACUSTRINE DEPOSITS:** This unit consists of peat overlying glaciolacustrine deposits marginal to the Colwood delta a outwash plain (unit G4). The presence of peat is documented in soil surveys (Day *et al.*, 1959 Jungen, 1985), observed in the field, and inferred from the local presence of swamps.

O3 — **UNIT O3; PEAT OVER SAND AND GRAVEL OF THE COLWOOD DELTA AND OUTWASH PLAIN:** This unit consists of peat deposits overlying sand and gravel of the Colwood delta and outwash plain. Peat deposits are generally less than 4 m thick, but locally reach 7 metres. These deposits occur in low-lying areas on the delta and outwash plain, such as late-stage abandoned channels and around the margins of modern lakes like Langford and Glen lakes.

O3a — **Unit O3a** consists of closed depressions, mainly interpreted to be kettles, on the surface of the Colwood delta and outwash plain and in which peat *may* occur.

O2 — **UNIT O2; UPLAND PEAT:** This unit consists of upland peat deposits above 60 metres elevation. The peats in this unit are commonly less than a few metres thick, but locally exceed 5 metres. In boreholes, these deposits have been observed to overlie up to 3 metres of soft clayey silts and sands, that in turn overlie older Pleistocene deposits or bedrock. However, they may also overlie other sediment types, such as colluvial deposits, outwash sand and gravel, and glaciolacustrine sediments.

O1 — **UNIT O1; PEAT OVER SOFT CLAY:** This map unit is defined as Holocene peat and organic soil overlying the Victoria clay. The thickness of peat varies from less than 1 metre to a maximum known thickness of metres immediately northwest of the Saanich Public Works Yard at McKenzie Avenue and Quadra Street. The browncla facies is not present in this map unit. The thickness of the underlyin grey clay facies commonly exceeds 10 metres and has a maximum known thickness of 30 metres. In the absence of borehole data, this map unit is applied to swamps and closed depressions that occur in areas below 60 metres elevation.

AREAS WITH CAPILANO DEPOSITS (LATEST FRASER GLACIATION) AT SURFACE

VICTORIA CLAY

C5 — **UNIT C5; THICK SOFT CLAY OVER THICK OLDER PLEISTOCENE DEPOSITS:** This unit consists of Victoria clay with more than 3 metres of the grey clay facies overlying older Pleistocene deposits thicker than 10 metres. It occupies small low-lying areas on the crest and flanks of the drumlinoid ridge at the University of Victoria

C4 — **UNIT C4; INTERMEDIATE BETWEEN UNITS C3 AND C5, INCLUDING UNDIFFERENTIATED AREAS:** This map unit includes areas with more than 5 metres of Victoria clay but less than 3 metres of the grey clay facies, underlain by more than 10 metres of older Pleistocene deposits, as well as areas of poor subsurface control on gently sloping ground that may include profiles typical of both units C3 and C5. The brown clay facies tends to be thicker (up to 10 metres) where the Victoria clay overlies thick older Pleistocene deposits than where it overlies bedrock, probably because of better drainage through the Quadra sand.

C4a — **Unit C4a** is assigned to the part of unit C4 where subsurface control is sufficient to show that it consists of more than 5 metres of Victoria clay but less than 3 metres of the grey clay facies. The only area assigned to this unit is located in a gentle depression on the top of a Pleistocene drumlinoid ridge in the vicinity of the University of Victoria.

C4b — **Unit C4b** is assigned to areas of sloping ground with poor subsurface control between units C3 and C4. In this map unit, the Victoria clay overlies thick older Pleistocene deposits and may be greater than metres, but the thickness of the grey clay facies is interpreted to be less than 3 metres.

C3 — **UNIT C3; THIN CLAY OVER THICK OLDER PLEISTOCENE DEPOSITS:** This unit occurs in areas with less than 5 metres of Victoria clay overlying older Pleistocene deposits greater than 10 metres thick. It generally occurs on the upper flanks o drumlinoid ridges.

C2 — **UNIT C2; THICK SOFT CLAY:** This unit is assigned to areas with more than 3 metres of the grey clay facies of the Victoria clay. The thickness of the grey clay facies is commonly greater than 10 metres and locally exceeds 20 metres. In this unit, the grey clay facies is overlain by the brown clay facies, which is generally 2 to 5 metres thick. The thickness of older Pleistocene deposits underlying the Victoria clay is generally less than a few metres, but may be greater adjacent to drumlinoid ridges. The unit occupies low-lying and gently sloping ground, and where borehole data are not available, this unit is assigned to such areas below 60 metres elevation.

C2a — **Unit C2a** is assigned to areas where the lower slopes of the Colwood delta are overlain by the Victoria clay. Little is known about the thickness or geotechnical properties of the Victoria clay in these areas. However, the land is low-lying and organic soils locally occur at surface (unit O1), indicating that thicknesses of sof clay greater than 3 metres could be present.

C1 — **UNIT C1; INTERMEDIATE BETWEEN UNITS R2 AND C2, INCLUDING UNDIFFERENTIATED AREAS:** This unit mainly includes areas where soil profiles typical of units R2 and C2 occur together on a scale that is not mappable' with the data available. This unit also includes areas where there is greater than 5 metres of Victoria clay, but where the thickness of the lower grey clay facies is less than 3 metres. In regions of poor subsurface control, the unit is commonly assigned to areas of sloping ground between units R2 and C2, and to small low-lying areas tha cannot be confidently mapped as unit C2. In such cases, use of this map unit indicates uncertainty. However, where borehole data are present, they commonly demonstrate that the subsurface conditions are truly a complex mixture of units R2 and C2. In some areas of sloping ground mapped as unit C1, the absence of reported bedrock may indicate that older Pleistocene deposits underlie the Victoria clay (unit C3). As additional data become available, much of unit C1 could be reassigned to units R2, C2 and possibly C3.

COLWOOD SAND AND GRAVEL

G4 — **UNIT G4; GLACIOLACUSTRINE DEPOSITS MARGINAL TO THE COLWOOD DELTA:** This unit occurs in small valleys adjacent to the Colwood Delta an outwash plain. Borehole control in these areas is poor. Where Highway 1 crosses Millstream Creek, a borehole encountered 14 metres of stiff silt and clay with interbedded compact to dense sand, overlying 3 metres of very dense gravelly till. Downstream, thinly bedded to laminated fine sand and silt were observed in a small exposure. The surface expression of this unit is flat or gently sloping, as in Millstream Creek valley. These areas are interpreted to represent glaciolacustrine deposits margina to the Colwood delta and outwash plain, and may include glaciofluvial and fluvial sediments.

G3 — **UNIT G3; LATE STAGE GLACIOFLUVIAL CHANNEL:** This map unit consists of late-stage channels and associated point bars. These are incised into the upper part of th Colwood delta an outwash plain in the vicinit of Colwood Creek. Where borehole data are available, sediments consist of fine sand and silt a fe metres thick, and elsewhere the deposits are interpreted to be finer than adjacent parts of the delta and outwash plain. Parts o the channels are filled with peat and are assigned to map unit O3.

G2 — **UNIT G2; DISTAL AND LATERAL FORESET SAND AND SILT OF THE COLWOOD DELTA:** This unit consists primarily o interbedded silt and sand that are interpreted to be distal and lateral foreset deposits o the Colwood delta, overlain by a fe metres of the brown clay facies of the Victoria clay. In most areas it forms a regularly sloping surface that descends from the surface of the Colwood delta and outwash plain and represents the final delta slope. Locally it has been assigned to areas where the delta and outwash plain are incised by Holocene stream erosion, exposing older delta foreset deposits. These deposits are commonly 10 to 30 metres thick.

G1 — **UNIT G1; SAND AND GRAVEL OF THE COLWOOD DELTA AND OUTWASH PLAIN:** This unit consists o interbedded sand and gravel of the raised Late Pleistocene delta and outwash plain centred on the City o Colwood and the District of Langford. The delta and outwash plain have a terraced surface between 60 and 90 metres elevation. Fe boreholes penetrate the entire thickness of these deposits, and these are all located in the eastern part of the delta and outwash plain. The maximum known thickness of these deposits is 30 metres, and the thickness is probably greater in much o Colwood and the eastern part o Langford. Silts occur locally in the delta topset in abandoned channel deposits. In the vicinity of Happy Valley Road, outwash sand and gravel are overlain by 1 to 2 metres of silt interpreted to be a late-stage glaciolacustrine deposit marginal to the delta. Deposits of silt up to several metres thick also occur interbedded with sand in lateral and distal parts of the delt foreset. Where these are exposed at the surface they are distinguished as unit G2, but they are likely also present beneath parts of the delta and outwash plain in unit G1. On the margins of the delta, th Colwood sand and gravel overlie bedrock (see unit R2), but in the gravel pits south of Esquimalt Lagoon they overlie older Pleistocene deposits that are locally over 50 metres thick.

AREAS WITH OLDER PLEISTOCENE DEPOSITS AT SURFACE

T — **UNIT T; THICK OLDER PLEISTOCENE DEPOSITS:** This unit occurs where older Pleistocene deposits are greater than 10 metres thick and are exposed at the surface. These deposits are commonly thicker than 30 metres and locally exceed 60 metres, such as along the sea cliffs at Cowichan Head. They occur principally as drumlinoid ridges, several kilometres in length, and as shorter ridges south of prominent bedrock hills (crag-and-tail features) Hilly areas underlain by unit T are typically characterized by smooth topography, in contrast to the irregular topography of areas underlain by shallow bedrock (unit R2). Locally, bedrock knobs reach almost to the surface within this map unit but are rarely detectable with the borehole data available. The surficial deposits are commonly the Vashon till or the Quadra sand but, where th drumlinoid ridges have been subjected to Holocene erosion, older deposits are exposed.

Ta — **Unit Ta** is assigned to areas that have smooth surface topography, comparable to areas with thick older Pleistocene deposits (unit T), but where borehole data indicate that bedrock is locally shallow (<10metres).

T/C3 — **Unit T/C3** is applied to those areas intermediate between units T and C3, typically areas with a discontinuous cover of Victoria clay over older Pleistocene deposits.

AREAS WITH BEDROCK AT OR NEAR SURFACE

R2 — **UNIT R2; THIN SOIL COVER WITH SCATTERED BEDROCK OUTCROP:** This unit generally consist of shallow soils over bedrock. In much of Greater Victoria, this unit includes areas with less than 5 metres of Victoria Clay, mainly the brown clay facies, overlying thin older Pleistocene deposits or bedrock. Scattered outcrops occur throughout the unit, and bedrock is commonly found in the upper fe metres (e.g. in utility line excavations). The thickness of older Pleistocene deposits in most places is less than a few metres, but may locally be up to 10 metres. In areas adjoining the Colwood delta and outwash plain, this unit is assigned to areas where borehole data show that less than 5 metres of the Colwood sand and grave overlies bedrock. In upland regions above 60 metres elevation, the unit is assigned to areas where bedrock is generally overlain by less than a few metres of sediment, commonly older Pleistocene deposits with some colluvium, although locally sediment thicknesses are up to 10 metres. This map unit generally occurs in hilly areas, where the topography is clearly controlled by the irregular bedrock surface. Due to the irregularity of the bedrock surface, the thickness of the sedimentary cover over bedrock can vary by several metres across short distances, such as the length of a building lot.

R2a — **Unit R2a** consists of those areas of unit R2 where thicknesses of older Pleistocene deposits between 5 and 10 metres can be mapped.

R1/2 — **UNIT R1/2; OUTCROP AND THIN SOIL COVER UNDIFFERENTIATED:** This unit includes sparsely developed, mainly rocky, upland areas with little or no subsurface control, and where units R1 (bedrock) and R2 (thin soil cover) could not be readily differentiated on air photos due to extensive tree cover. This unit may include small unmapped upland peat bogs and areas of older Pleistocene deposits.

R1 — **UNIT R1; BEDROCK:** This unit consists of nearly continuous outcrop and generally occurs in hilly and mountainous areas.

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