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QUATERNARY GEOLOGY OF RICHMOND, BRITISH COLUMBIA

parts of NTS 092G/02 and 092G/03.

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0 500 1000 2000 3000
Metres

Projection: Universal Transverse Mercator, Zone 10 North.
Datum: North American Datum 1983

Scale 1:20 000 (when printed on 36x60 inch paper)

This map shows geological variation in the Quaternary deposits underlying the City of Richmond, British Columbia, and has been prepared as part of an earthquake hazard mapping project in the city. Richmond is located in one of the most seismically active regions in Canada (Rogers, 1998), and the deltaic sediments on which the city is built can amplify ground motions and are susceptible to earthquake induced liquefaction (e.g. Byrne, 1978; Finn et al., 1989; Byrne and Anderson, 1991; Clague et al., 1992, 1997, 1998b; Watts et al., 1992; Rogers et al., 1998; Harris et al., 1995, 1998; Cassidy et al., 1997; Cassidy and Rogers, 1999; Levson and Monahan, 2004). Because the variation in earthquake hazards is most affected by geological conditions in the upper 20 to 30 metres, this map primarily reflects geological variation in the upper 20 to 30 metres of the Quaternary sequence.

Quaternary Geology Framework

Richmond is located entirely within the Fraser River delta, which is the largest delta in western Canada. The deltaic deposits are entirely Holocene in age and overlie Late Pleistocene glaciogenic sediments (Clague et al., 1983, 1991, 1998a; Luternauer et al., 1994). The thickness of the deltaic deposits underlying Richmond varies from less than 20 metres along the North Arm of the Fraser River to a maximum known thickness of 305 m at Richmond City Hall (Dallimore et al., 1996). Deltaic deposits are generally thicker than 50 m at distances greater than 1 km from the delta margin, and the northern margin is located immediately north of the North Arm of the Fraser River in the southernmost parts of Vancouver and Burnaby. However, a buried ridge of Pleistocene sediments, above which deltaic deposits are locally less than 20 metres thick, trends southeast across the city from the western edge of Mitchell Island, which is located in the North Arm of the Fraser River.

Monahan et al. (1997, 2000a), Clague et al. (1998a), and Monahan (1999) provide descriptions of the stratigraphy of the delta. The deltaic section can be subdivided into topset, foreset, and bottomset units. Topset deposits were deposited on the delta plain in river channel, tidal flat and floodplain environments, and consist of sand, silt and locally peat. The topset forms the uppermost 20 to 35 metres of the deltaic sequence, so that this map primarily reflects geological variation in the topset, which are discussed in more detail below. Foreset deposits underlie the topset sequence and were deposited on the delta slope beyond the river mouth. They are up to 165 metres thick, consist of sands and silt interbedded on a variety of scales, and are characterized by seaward dips that are commonly 7° near the top of the foreset. The modern equivalents of the foreset are currently being deposited on the delta slope offshore of Sand Heads. Bottomset deposits were deposited beyond the delta slope and consist of mainly clayey silt. They occur only in deeper deltaic sections, where they are up to 120 metres thick. Pleistocene deposits underlying the delta generally consist of tills and other sediments that have been overridden by glaciers and are overconsolidated. However, in the deeper deltaic sections, a few metres of normally consolidated Late Pleistocene glaciomarine clay and silt occur between the deltaic sediments and overconsolidated Pleistocene deposits.

Fraser Delta Topset Deposits

In Richmond, the topset deposits thin from 35 metres in eastern Lulu Island, near the apex of the delta, to 20 metres or less at the sea dykes along western Lulu Island (Clague et al., 1983, 1998a; Williams and Roberts, 1989; Monahan et al., 1993, 1997; Monahan, 1999). The westerly thinning of the topset is the result of a relative sea level rise of 13 metres during the Holocene, most of which occurred between 8000 and 4500 years B.P. (Clague et al., 1983; Williams and Roberts, 1989, 1990). The topset forms an overall fining-upward sequence that grades up from a lower sand facies, through an interbedded sand and silt facies, to an upper organic silt facies. The latter is locally overlain by peat.

The topset is dominated by the lower sand facies, which is generally 8 to 30 metres thick. It has an erosional base with several metres of local relief, and is commonly organized into one or more decametre scale fining upward sequences. It has been interpreted to represent a complex of distributary channel deposits (Monahan et al., 1993, 1995, 1997; Hutchinson et al., 1995; Monahan, 1999).

Two subfacies of the sand facies occur in Richmond and with the overlying interbedded sand and silt facies form two distinct facies successions in the topset (Monahan et al., 1993, 1995, 1997; Clague et al., 1998a, Monahan, 1999). In the first facies succession, the sand facies includes shell debris, particularly near the base. The interbedded sand and silt facies is up to 5 m thick, extensively bioturbated, also shell-bearing and contains an intertidal foraminiferal fauna (Williams, 1988). This facies succession is interpreted to represent sands deposited in migrating distributary channels in a tidal flat environment and capped by tidal flat deposits (see Clague et al., 1983). The shell debris was incorporated into the distributary channel sands as channels migrated and eroded earlier tidal flat deposits. In the second facies succession, the sand facies does not contain shell debris and includes sands that are slightly coarser than in the first succession. The overlying interbedded sand and silt facies is generally only a few metres thick, well-bedded and consists of thinly interbedded fine to medium sand and laminated silt. The latter facies succession is interpreted to represent sands deposited in distributary channels in a delta floodplain environment, capped by silts and sands deposited in active bar tops and slough environments during channel abandonment.

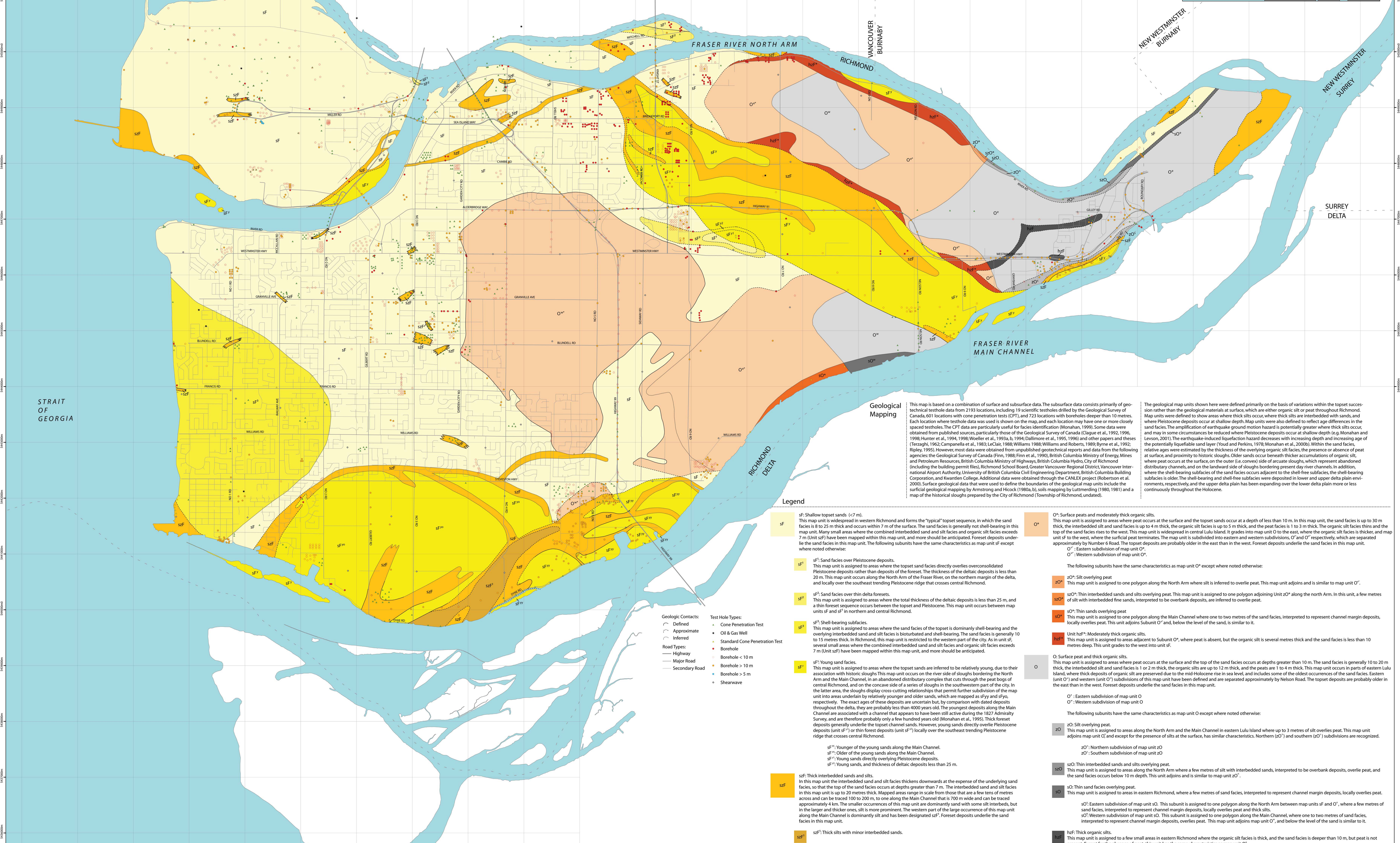
Locally, the interbedded sand and silt facies thickens at the expense of the underlying sand facies to form narrow curvilinear bodies that are up to 20 metres thick. These deposits (represented by map unit szF) are commonly associated with historic sloughs on the delta plain (Township of Richmond, undated) and are interpreted to represent the fill of partially abandoned channels. They range in scale from those that are a few tens of metres across and can be traced 100 to 200 metres, to one along the Main Channel that is 700 metres wide and can be traced approximately 4 kilometres.

The interbedded sand and silt facies is overlain by an organic silt facies consisting of laminated and organic clayey silts deposited in the tidal marsh and floodplain environments. Due to the mid Holocene rise in sea level, the organic silts are up to 12 metres thick in eastern Lulu Island, near the head of the delta, and thin westward to less than 1 metre at the sea dykes on western Lulu Island. The organic silts are in turn overlain by peat in parts of central and eastern Lulu Island (Clague et al., 1983; Williams and Roberts, 1989).

Geological Mapping

This map is based on a combination of surface and subsurface data. The subsurface data consists primarily of geotechnical testhole data from 2193 locations, including 19 scientific testholes drilled by the Geological Survey of Canada, 601 locations with cone penetration tests (CPT), and 723 locations with boreholes deeper than 10 metres. Each location where testhole data was used is shown on the map, and each location may have one or more closely spaced testholes. The CPT data are particularly useful for facies identification (Monahan, 1999). Some data were obtained from published sources, particularly those of the Geological Survey of Canada (Clague et al., 1992, 1996, 1998; Hunter et al., 1994, 1998; Woeller et al., 1993a, b, 1994; Dallimore et al., 1995, 1996) and other papers and theses (Terzaghi, 1962; Campanella et al., 1983; LeClair, 1988; Williams 1988; Williams and Roberts 1989; Byrne et al., 1992; Ripley, 1995). However, most data were obtained from unpublished geotechnical reports and data from the following agencies: the Geological Survey of Canada (Finn, 1988; Finn et al., 1990), British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Ministry of Highways, British Columbia Hydro, City of Richmond (including the building permit files), Richmond School Board, Greater Vancouver Regional District, Vancouver International Airport Authority, University of British Columbia Civil Engineering Department, British Columbia Building Corporation, and Kwantlen College. Additional data were obtained through the CANLEX project (Robertson et al. 2000). Surface geological data that were used to define the boundaries of the geological map units include the surficial geological mapping by Armstrong and Hicock (1980a, b), soils mapping by Luttmerding (1980, 1981) and a map of the historical sloughs prepared by the City of Richmond (Township of Richmond, undated).

The geological map units shown here were defined primarily on the basis of variations within the topset succession rather than the geological materials at surface, which are either organic silt or peat throughout Richmond. Map units were defined to show areas where thick silts occur, where thick silts are interbedded with sands, and where Pleistocene deposits occur at shallow depth. Map units were also defined to reflect age differences in the sand facies. The amplification of earthquake ground motion hazard is potentially greater where thick silts occur, and may in some circumstances be reduced where Pleistocene deposits occur at shallow depth (e.g. Monahan and Levson, 2001). The earthquake-induced liquefaction hazard decreases with increasing depth and increasing age of the potentially liquefiable sand layer (Youd and Perkins, 1978; Monahan et al., 2000b). Within the sand facies, relative ages were estimated by the thickness of the overlying organic silt facies, the presence or absence of peat at surface, and proximity to historic sloughs. Older sands occur beneath thicker accumulations of organic silt, where peat occurs at the surface, on the outer (i.e. convex) side of arcuate sloughs, which represent abandoned distributary channels, and on the landward side of sloughs bordering present day river channels. In addition, where the shell-bearing subfacies of the sand facies occurs adjacent to the shell-free subfacies, the shell-bearing subfacies is older. The shell-bearing and shell-free subfacies were deposited in lower and upper delta plain environments, respectively, and the upper delta plain has been expanding over the lower delta plain more or less continuously throughout the Holocene.



Legend

Geologic Contacts:
- Defined
- Approximate
- Inferred

Road Types:
- Highway
- Major Road
- Secondary Road

Test Hole Types:
- Cone Penetration Test
- Oil & Gas Well
- Standard Cone Penetration Test
- Borehole
- Borehole < 10 m
- Borehole > 10 m
- Borehole > 5 m
- Shearwave

sF

sF: Shallow topset sands (<7 m).
This map unit is widespread in western Richmond and forms the "typical" topset sequence, in which the sand facies is 8 to 25 m thick and occurs within 7 m of the surface. The sand facies is generally not shell-bearing in this map unit. Many small areas where the combined interbedded sand and silt facies and organic silt facies exceeds 7 m (Unit szF) have been mapped within this map unit, and more should be anticipated. Foreset deposits underlie the sand facies in this map unit. The following subunits have the same characteristics as map unit sF except where noted otherwise:

sF^1

sF^1: Sand facies over Pleistocene deposits.
This map unit is assigned to areas where the topset sand facies directly overlies overconsolidated Pleistocene deposits rather than deposits of the foreset. The thickness of the deltaic deposits is less than 20 m. This map unit occurs along the North Arm of the Fraser River, on the northern margin of the delta, and locally over the southeast trending Pleistocene ridge that crosses central Richmond.

sF^2

sF^2: Sand facies over thin delta foresets.
This map unit is assigned to areas where the total thickness of the deltaic deposits is less than 25 m, and a thin foreset sequence occurs between the topset and Pleistocene. This map unit occurs between map units sF and sF^1 in northern and central Richmond.

sF^3

sF^3: Shell-bearing subfacies.
This map unit is assigned to areas where the sand facies of the topset is dominanly shell-bearing and the overlying interbedded sand and silt facies is bioturbated and shell-bearing. The sand facies is generally 10 to 15 metres thick. In Richmond, this map unit is restricted to the western part of the city. As in unit sF, several small areas where the combined interbedded sand and silt facies and organic silt facies exceeds 7 m (Unit szF) have been mapped within this map unit, and more should be anticipated.

sF^y

sF^y: Young sand facies.
This map unit is assigned to areas where the topset sands are inferred to be relatively young, due to their association with historic sloughs This map unit occurs on the river side of sloughs bordering the North Arm and the Main Channel, in an abandoned distributary complex that cuts through the peat bogs of central Richmond, and on the concave side of a series of sloughs in the southwestern part of the city. In the latter area, the sloughs display cross-cutting relationships that permit further subdivision of the map unit into areas underlain by relatively younger and older sands, which are mapped as sFyy and sFyo, respectively. The exact ages of these deposits are uncertain but, by comparison with dated deposits throughout the delta, they are probably less than 4000 years old. The youngest deposits along the Main Channel are associated with a channel that appears to have been still active during the 1827 Admiralty Survey, and are therefore probably only a few hundred years old (Monahan et al., 1995). Thick foreset deposits generally underlie the topset channel sands. However, young sands directly overlie Pleistocene deposits (unit sF^{y1}) or thin forest deposits (unit sF^{y2}) locally over the southeast trending Pleistocene ridge that crosses central Richmond.

sF^{yy}: Younger of the young sands along the Main Channel.
sF^{yo}: Older of the young sands along the Main Channel.
sF^{y1}: Young sands directly overlying Pleistocene deposits.
sF^{y2}: Young sands, and thickness of deltaic deposits less than 25 m.

szF

szF: Thick interbedded sands and silts.
In this map unit the interbedded sand and silt facies thickens downwards at the expense of the underlying sand facies, so that the top of the sand facies occurs at depths greater than 7 m. The interbedded sand and silt facies in this map unit is up to 20 metres thick. Mapped areas range in scale from those that are a few tens of metres across and can be traced 100 to 200 m, to one along the Main Channel that is 700 m wide and can be traced approximately 4 km. The smaller occurrences of this map unit are dominantly sand with some silt interbeds, but in the larger and thicker ones, silt is more prominent. The western part of the large occurrence of this map unit along the Main Channel is dominantly silt and has been designated szF^1. Foreset deposits underlie the sand facies in this map unit.

szF^1

szF^1: Thick silts with minor interbedded sands.

O*

O*: Surface peats and moderately thick organic silts.
This map unit is assigned to areas where peat occurs at the surface and the topset sands occur at a depth of less than 10 m. In this map unit, the sand facies is up to 30 m thick, the interbedded silt and sand facies is up to 4 m thick, the organic silt facies is up to 5 m thick, and the peat facies is 1 to 3 m thick. The organic silt facies thins and the top of the sand facies rises to the west. This map unit is widespread in central Lulu Island. It grades into map unit O to the east, where the organic silt facies is thicker, and map unit sF to the west, where the surficial peat terminates. The map unit is subdivided into eastern and western subdivisions, O^{e*} and O^{w*} respectively, which are separated approximately by Number 6 Road. The topset deposits are probably older in the east than in the west. Foreset deposits underlie the sand facies in this map unit.

O^{e*} : Eastern subdivision of map unit O*.
O^{w*} : Western subdivision of map unit O*.

The following subunits have the same characteristics as map unit O* except where noted otherwise:

zO*

zO*: Silt overlying peat
This map unit is assigned to one polygon along the North Arm where silt is inferred to overlie peat. This map unit adjoins and is similar to map unit O^{e*}.

szO*

szO*: Thin interbedded sands and silts overlying peat. This map unit is assigned to one polygon adjoining Unit zO* along the north Arm. In this unit, a few metres of silt with interbedded fine sands, interpreted to be overbank deposits, are inferred to overlie peat.

sO*

sO*: Thin sands overlying peat
This map unit is assigned to one polygon along the Main Channel where one to two metres of the sand facies, interpreted to represent channel margin deposits, locally overlies peat. This unit adjoins Subunit O^{e*} and, below the level of the sand, is similar to it.

hzF*

Unit hzF*: Moderately thick organic silts.
This map unit is assigned to areas adjacent to Subunit O*, where peat is absent, but the organic silt is several metres thick and the sand facies is less than 10 metres deep. This unit grades to the west into unit sF.

O

O: Surface peat and thick organic silts.
This map unit is assigned to areas where peat occurs at the surface and the top of the sand facies occurs at depths greater than 10 m. The sand facies is generally 10 to 20 m thick, the interbedded silt and sand facies is 1 or 2 m thick, the organic silts are up to 12 m thick, and the peats are 1 to 4 m thick. This map unit occurs in parts of eastern Lulu Island, where thick deposits of organic silt are preserved due to the mid-Holocene rise in sea level, and includes some of the oldest occurrences of the sand facies. Eastern (unit O^e) and western (unit O^w) subdivisions of this map unit have been defined and are separated approximately by Nelson Road. The topset deposits are probably older in the east than in the west. Foreset deposits underlie the sand facies in this map unit.

O^e : Eastern subdivision of map unit O
O^w : Western subdivision of map unit O

The following subunits have the same characteristics as map unit O except where noted otherwise:

zO

zO: Silt overlying peat.
This map unit is assigned to areas along the North Arm and the Main Channel in eastern Lulu Island where up to 3 metres of silt overlies peat. This map unit adjoins map unit O^e, and except for the presence of silts at the surface, has similar characteristics. Northern (zO^n) and southern (zO^s) subdivisions are recognized.

zO^n: Northern subdivision of map unit zO
zO^s: Southern subdivision of map unit zO

szO

szO: Thin interbedded sands and silts overlying peat.
This map unit is assigned to areas along the North Arm where a few metres of silt with interbedded sands, interpreted to be overbank deposits, overlie peat, and the sand facies occurs below 10 m depth. This unit adjoins and is similar to map unit zO^n.

sO

sO: Thin sand facies overlying peat.
This map unit is assigned to areas in eastern Richmond, where a few metres of sand facies, interpreted to represent channel margin deposits, locally overlies peat.

sO^e: Eastern subdivision of map unit sO. This subunit is assigned to one polygon along the North Arm between map units sF and O^e, where a few metres of sand facies, interpreted to represent channel margin deposits, locally overlies peat and thick silts.
sO^w: Western subdivision of map unit sO. This subunit is assigned to one polygon along the Main Channel, where one to two metres of sand facies, interpreted to represent channel margin deposits, overlies peat. This map unit adjoins map unit O^w, and below the level of the sand is similar to it.

hzF

hzF: Thick organic silts.
This map unit is assigned to a few small areas in eastern Richmond where the organic silt facies is thick, and the sand facies is deeper than 10 m, but peat is not present. Except for the absence of peat, this unit has the same characteristics as map unit O^e.

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