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The statement that wetlands on Gabriola maintain surface water only when fed by springs is misleading. The wetlands are invarably underlain by layers of completely impervious clay (gleysol) and the water may be just collected rainwater and rainwater fed into the area in the wet season by intermittent creeks. In a few wetlands I have monitored, the drop in water level in the dry season was consistent with there being no inflow (no springs) and the only water loss being evapotranspiration.

Later references:

N/A

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Author:

Nick Doe, 1787 El Verano Drive, Gabriola, BC, Canada V0R 1X6
Phone: 250-247-7858, FAX: 250-247-7859
E-mail: nickdoe@island.net

The geology of Gabriola Island's diatomaceous earth

by Nick Doe

Diatomaceous earth is fairly common in wetlands and former lake beds on Gabriola. It contains *diatomite*,[1] which is the indurated fossil remains of types of pond algae called "diatoms". Diatoms use silica (SiO_2) for the walls of their cells rather than the more common *calcite* ($CaCO_3$). If the algae had been of a type that used *calcite*, we would be calling their skeletal remains "chalk". Diatoms are microscopic—you can't see individual fossils in diatomite without a good microscope.

When you dig down into an old lake bed or swamp in the dry season, diatomaceous earth appears in white or greyish-white bands, a few inches to a foot or more thick, often interspersed with black bands of peat or peat-laden clay. People who haven't come across diatomaceous earth before are always surprised how soft it is, and how little it weighs compared to regular soil.[2]

Although in some places in the world, deposits of diatomaceous earth were formed from marine algae and are millions of years old, ours are all freshwater deposits formed some time since the end of the last ice age about ten thousand years ago. The same types of diatoms that formed these fossils still live on the island. They're found as slime in ponds and mires, and are related to the unwelcome brown coating that sometimes appears on the gravel and glass in small aquariums.

Diatomaceous earth, a few inches thick, on the Commons Land. The modern surface is just above the top of the picture about 400 mm (16 in.) higher. Below the diatomaceous earth is a bit of pale clay with some diatomite, and below that 570 mm (nearly two feet) of massive clay (gleysol) sitting on sandstone bedrock. The dark material above the diatomaceous earth is black peaty loam capped with a thin layer of brown topsoil and grassroots. The profile of the soil in this area is variable. Sometimes there are one or more bands of diatomaceous earth—some dirty, some not—other places, there are none. There's no sign of a marine deposit.

[1] The terms "diatomaceous earth" and "diatomite" are very widely regarded as being interchangeable, but my preference would be to use the term "diatomite" to mean "diatomaceous earth" without any extraneous minerals, soil, and organic matter. Diatomite is sometimes called "fossil flour".

[2] Be very careful when handling it. Diatomite dust is a known cause of silicosis (Am. J. Respir. Crit. Care Med., 158, 3, Sept. 1998, pp. 807–814).

Deep mudcracks during the summer in land adjacent to wetlands containing diatomite strongly suggest the presence of a smectite, a common class of clays that readily expands and shrinks as its water content varies.

Although "pure" diatomite—along with glass, opal, and coal—fails to qualify technically as a mineral, the diatomaceous earth from Gabriola showed up in an X-ray diffraction analysis as containing *cristobalite*.[3] *Cristobalite* is a particular crystalline form of silica, as is *quartz*, and both *cristobalite* and *quartz* conform to the modern definition of a mineral.

Wetland geology

The bedrock of Gabriola is late-Cretaceous sandstone, conglomerate, and shale. It is too fractured to hold surface water for more than a few weeks,[4] and so wetlands on the island depend for their existence on beds rich in clay. Even then, because evaporation is so high in summer, and precipitation so low, natural ponds and lakes only keep surface water year-round if they are fed by springs. The largest natural lake on the island, Hoggan Lake, for example, is fed by three springs from east, north, and west. Most ponded wetlands, including those on the Commons Land and in Coats Marsh, have been deepened below the summer watertable by an earlier generation of farmers using horse-drawn scrapers. Possibly this activity led to the discovery of the diatomite that was briefly exploited commercially on Gabriola in the late-1930s.

The commonest type of clay in wetlands is a smectite known as *montmorillonite*.[5] It appears in waterlogged, oxygen-depleted environments as greenish-grey clay (Munsell 5GY 6/1), though it is whitish when dry. *Montmorillonite* is usually the principal clay mineral in "fuller's earth".

The colour of the wet clay is due to microbes that convert traces of iron within it from its ferric (Fe^{3+}) to ferrous (Fe^{2+}) state. In doing so, they are using iron as an energy-generating electron-receptor in the same way that aerobic microbes use oxygen.

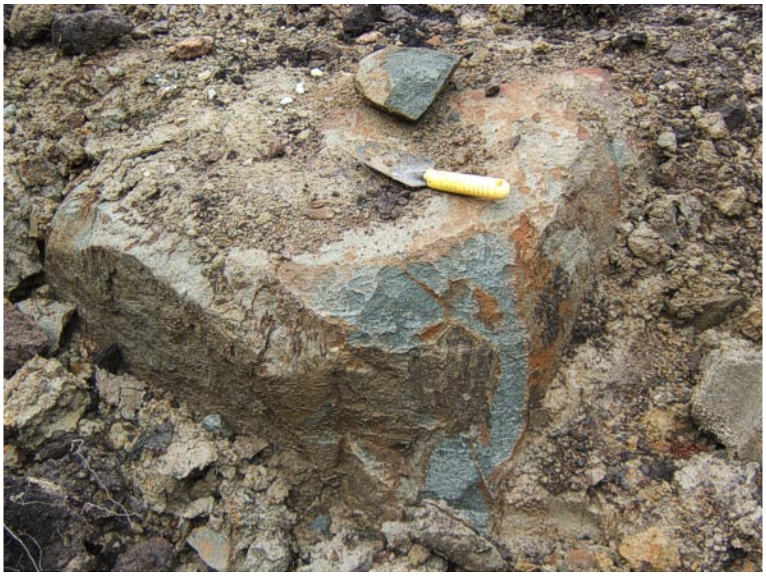
Ferrous compounds are green; the clay however nearly always has orange streaks and mottles in it, some of which may be quite bright. These are where air has penetrated the clay and re-oxidized the iron to its rusty-coloured ferric state.[6] Rotted

3 Sample 26, Teckcominco V04-0062R: XRD showed *quartz* significant; *cristobalite* significant; *albite* possible and if present moderate.

4 On average, it's only about 700 times slower to drain than your kitchen sink.

5 Sample 23, Teckcominco V04-0042R: XRD showed *montmorillonite* moderate; *albite* moderate; *quartz* moderate; *kaolinite* minor–very minor.

6 Possibly *lepidocrocite* (FeO.OH). If the clay also contains silt and sand, oxygen-rich water percolates slowly down and turns the entire top of the deposit



Bottom of a hole excavated through four feet of gleysol in the Commons wetland down to bedrock. The coarse fragments are sandstone including the boulder the trowel is resting on.

rootlets and burrows make passageways for the air.[7] Anaerobic deposits of clay like this are known as "gleysol" or "gley soil".

Clay origins

Layers of clay and *montmorillonite*-rich silty clay, a metre or so thick, exist in depressions and swales all over Gabriola, both above and below late-Pleistocene (ice age) sea levels. They lie directly on bedrock or, more rarely, and at lower elevations, over marine deposits of bluish-grey, quartz-rich fine sand and silt containing seashells. The gleysol is massive (structureless), and contains modern roots, but no dateable organic material that is reliably of the same age. All that is certain is that it is not slowly-accumulated gyttja (organic-rich sludge). Exactly when and how the clay layers were generated is puzzling and still being researched.

When in direct contact with the bedrock, the regolith immediately above the bedrock within the clay contains coarse sand and fragments of rotting sandstone. In places, the clay is topped by, sometimes-thick, glacial-fluvial (meltwater) outwash deposits of sand and gravel. Within the clay however, there is usually little sand and no gravel except for an occasional dropstone.[8]

Water pooled in the clay is acidic (pH ≈ 6–7) in contrast to the alkaline water in the obviously marine deposits (pH ≈ 7–9). The feldspar associated with the clay, *albite*, is identical to that in the bedrock, while a test on a marine deposit showed a slightly different feldspar, *andesine*.[9] Marine deposits contain no smectite, and though lodgement till on the island contains clay-sized particles, none are detectably clay minerals other than in isolated thin laminae that are seepage paths for groundwater. Marine deposits of clay also commonly contain *chlorite*, which is absent here.

It appears that the clay was formed by weathering in temperate, fairly dry conditions not favouring production of *kaolinite*. Perhaps it was originally glacial flour deposited in pools beneath stagnant

orange. The sharp colour difference between the aerobic and anaerobic clay easily creates the impression that they are different geological strata.

[7] The roots of horsetails (*Equisetum* spp.) particularly go deep in sandy soil.

[8] Dropstones are isolated pebbles within very fine lacustrine sediment. They may have fallen from melting icebergs, or, more rarely, have been rafted onto the lake in the roots of trees. The dropstones described here were mainly igneous—volcanic (basalt, rhyolite) and intrusive (granodiorite)—but with some sandstone.

[9] Sample 31, Teckcominco V08-0790R: XRD showed *quartz* abundant; *andesine* moderate abundance; *hornblende* minor; *muscovite* or *phlogopite* minor; *kaolinite* very minor.

Map (80m and 90m AMSL contours) shows the Commons was likely once part of Hoggan Lake—the two are separated by a sandstone ridge. Early settlers lowered Hoggan Lake "considerably" by excavating an outlet to the sea, but the lake was dammed in the early 1900s as part of a hydroelectric project. There is diatomite on the Commons Land and in wetlands around Hoggan Lake.

ice. When this sludge dried out in the warm and light-rainfall climate of the early-Holocene, *plagioclase* and Mg-biotite may have chemically weathered preferentially to *montmorillonite*. If so, local Nanaimo-group sandstone is a likely parent material.

Chemistry

One of the initially puzzling questions about the diatomaceous earth on Gabriola was: where did the diatoms get their silica?

Silica can exist in several forms including crystals of *quartz*, which are abundant in sand; glass; opal; a gel; and a white powder. *Quartz* however is practically insoluble. It is always the last mineral to be weathered in granite, and can persist for many millions of years. The source of silica (as orthosilicic acid) has therefore to be something more readily available to the diatoms.

One interesting suggestion at the time this research started (2004) was that the source might be associated with Mazama ash from the Crater Lake explosion in Oregon about 5677 BC (6800 ^{14}C BP).

Volcanic ash is a silica fertilizer and that may lead to a diatom bloom. Examples of this are found in the BC interior; however, diatomitic layers associated with the Mount Mazama eruption have not been seen on Vancouver Island where the layer is very thin. The ash idea was firmly put to bed when it was discovered that the diatomaceous earth on the Commons Land is in layers, the uppermost being just inches from the modern surface.

A more likely source of the silica, and one that accords with the geology of the island, is the weathering of sandstone, the same weathering that might have created the clay. The Nanaimo-group sandstone contains a high proportion of feldspars, especially *plagioclase*, and is, on account of this, sometimes known as "feldspathic wacke".

A chemical and charge "accounting" of the weathering of *albite*, the common variety of *plagioclase* in Gabriola's sandstone, is:

$6NaAlSi_3O_8$ (*albite*, Na-feldspar) + Mg^{2+} + $6H^+$ + X^+ $\Rightarrow$ $(Si_2O_5)_3.Al_5Mg^-(OH)_6.(Si_2O_5)_3.X^+$ (*montmorillonite*) + $6SiO_2$ + $6Na^+$ + Al^{3+}

where X^+ can be ½Ca^{2+}, ½Mg^{2+}, Na^+, etc.

On the righthand side of this complicated-looking, but basically simple, equation is a possible source for biogenic silica.

Montmorillonite is represented here in its sandwich structure, the "bread" being the two layers of silicate tetrahedral sheets $2 \times (Si_2O_5)^{2-}$, and the "meat" being the predominately gibbsite-like octahedral sheet $(Al_2(OH)_2)^{4+}$. This is a comparatively complicated structure compared to *kaolinite*, which accords with its early position in the sequence of weathering reactions that break down feldspars, with a 3-dimensional framework crystal structure, into clays, with a 2-dimensional sheet crystal structure, and then eventually, after a very long time, into end-products silica and *gibbsite* ($Al(OH)_3$).

Montmorillonite distinguishes itself from other smectites by having small amounts of Mg^{2+} substituting for Al^{3+} together with loosely-bound exchangeable cations, represented here by X^+, to make up for the reduced charge.

The presence of magnesium is easily accounted for. Magnesium does not occur in feldspars; yet, is plentiful in Gabriola groundwater. It comes from ferromagnesian minerals in the sedimentary rock, *hornblende* and magnesium-rich biotite (mica) *phlogopite*. Both minerals are easily weathered in acidic environments. Acidic environments also eliminate diatomite weathering by hydroxyl ions that would otherwise be present:

$$SiO_2 + OH^- + H_2O \Rightarrow H_3SiO_4^-$$

After calcination, some diatomite on Gabriola is tinged apricot-peach (Munsell 7.5YR 8/3, #FBCEB1, close to what Crayola used to call "flesh"). A guess is that this is due to traces of *hematite* (Fe_2O_3), although the tint it imparts is usually pinker.

Age?

Determining the age of the diatomaceous earth directly is a bit of a challenge as silica is not dateable. The "good news" is that the deposits are often associated with clay blackened with traces of vegetable matter. The "bad news" is that dating clay and silt that is not much more than "sooty" is expensive. Despite this, I have obtained one radiocarbon date from the Commons Land on Gabriola.

Sampling site. The bottom of the 36-inch scale rests on top of grit-free gleysol, which extends 30 in. down to bedrock. From the surface down, there is 1-inch of topsoil/roots, 5-inches of bands (¾ in. each) of diatomaceous earth and organic matter, 12-inches of mainly peat, another thin band of diatomaceous earth and peat, then the clay. The stone lying on the grass left of the scale is an especially large "dropstone" from within the clay. The sample, peaty clay, was taken from the surface of the gleysol at the bottom of the scale.

It was about 450 mm below the modern surface, immediately above a 760 mm band of gleysol—anaerobic, clay with some silt but no gravel except for an occasional pebble-sized dropstone—with a pH of 5.9.

The dropstones were, more often than usual, coarse sandstone with a weathering rind.

Sample 12 (DGRWOO4-OO12):

5870 ± 40 BP ^{14}C conventional, which the BARDL interpreted as:[10]

4720 BC, 4700–4790 BC (1-sigma).

(49°10.25'N, 123°50.40'W).

Although one has to be cautious about interpreting a single date from a single location, this date for the earliest diatomaceous earth deposits, roughly midway through the Holocene (the geological epoch since the end of the ice age) rather neatly accords with broad-scale patterns of climate change in western Canada over the past ten thousand years.[11]

Following the abrupt ending of the Younger Dryas cold interval *circa* 9450 BC (10000 ^{14}C BP), the climate became warmer and drier than it is now.[12] There were no rainforests on Gabriola—no cedar and no hemlock—and judging from soil profiles beneath shell middens, very little soil development. Lakes, if they existed, would have frequently dried out completely in summer, and the supply of nutrients for diatoms would have been sparse on account of the lack of surface runoff.[13]

This warm arid period lasted until around 5800 BC (7000 ^{14}C BP) when still warm, but wetter, conditions began to prevail. More moisture brought more trees to the island, and with them more beavers, and with them more ponds. Beavers, although fewer in numbers than they used to be, are still active in several of the island's wetlands.[14] The warm weather would have kept water shallow, which would have benefited algae that thrive in bright sunlight.

By 3100 BC (4500 ^{14}C BP), temperatures and precipitation were close to modern values, and the coastal forests would have begun to look familiar. Shell middens first became common in the Gulf Islands from about this time.

The date obtained from the Commons Land for the earliest diatomaceous earth/organic matter layer above the thick clay thus falls into the timeframe of the warm-but-wet phase of the paleoclimate, and this makes perfect sense.

The formation of bands of diatomaceous earth has several possible explanations from being the result of cycles of climate change, which have time scales ranging from decades (El Niños and Pacific decadal oscillations) to centuries, and being simply due to changes in lake level as the result of activity by beavers or the vagaries of the weather. Only dating more samples in more locations could resolve this.

Small though they are, study of deposits of "fossil pond slime" can still add something to our knowledge of more than one aspect of the history of the island over the past ten thousand years. ◊

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[10] Beta Analytic Radiocarbon Dating Laboratory. Laboratory number: Beta-269982. Reckoned using the INTCAL04 database.

[11] The following account is a much simplified reporting of on-going research, notably by Richard Hebda at the Royal BC Museum, John Clague at SFU, and Ian Hutchinson at SFU.

[12] Sea level, which was very high during the Pleistocene, had by ten thousand years ago dropped below the present level, and was just starting its asymptotic rise to its current level.

[13] J.R. Bennett et al., *Diatom, pollen, and chemical evidence of postglacial climatic change at Big Lake, south-central BC, Canada*, Quaternary Research 55, pp.332–43, 2001.

[14] While it may be of no significance, while augering down in the Good Earth Market Garden close to South Road, I came across abundant rotted wood about four to five feet down—perhaps the work of beavers if not the road builders. Finding wood deep in wetland auger holes is not uncommon.