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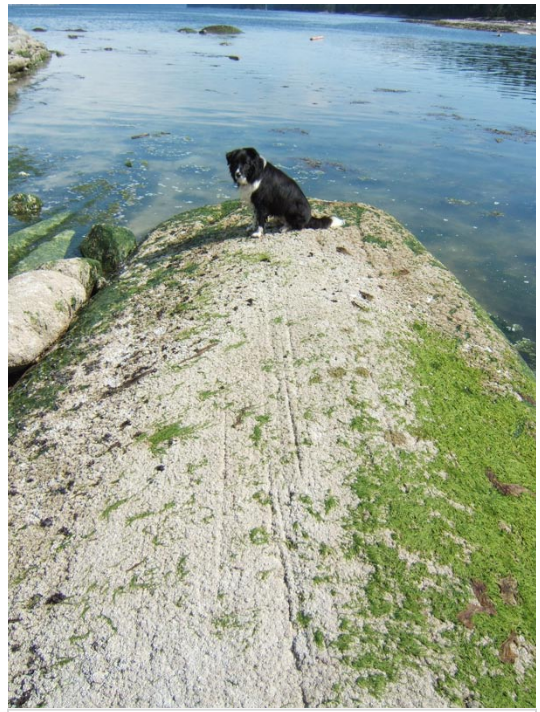
Gabriola's glacial drift—striae and grooves

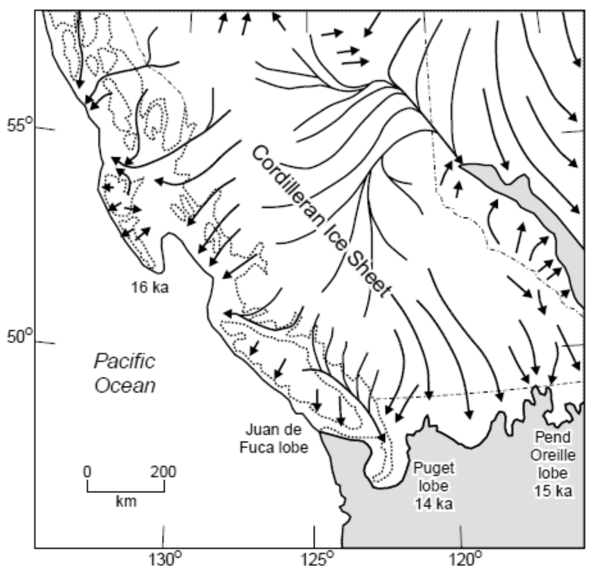
Nick Doe

Geography of the glaciers

At the height of the last ice age (the Vashon Stade of the Fraser Glaciation), ice was flowing from the northwest over Gabriola, following the present line of the Strait of Georgia. This was a huge *valley glacier* with many tributaries flowing in from both the mountains on Vancouver Island and on the mainland. Eventually, the ice became so thick that it spilled over Vancouver Island, and fed from sources in the BC interior, began moving slowly from the northeast across the Strait of Georgia and the mountains of Vancouver Island as if these topographical features were not there.[1] The glacier had changed from being a valley glacier to being a *continental ice cap*.



The ice went this way -- you can tell by the striae pointing down the strait coming from N55°W. Photo taken on Whaleback Rock on the east side of the south end of Mudge.



Southern portion of the Cordilleran ice sheet during the last glaciation. In this view, ice is moving from the NW over Gabriola.

Clague & James, 2002

Despite this change in direction, most of the striae left by gravel embedded in the ice and dragged across the bedrock of Gabriola are parallel to the axis of the strait—the earlier stage of the glaciation.

I'm saying all this as if it were clear to me at the start of the project that this was so; but in fact, it took me a while to figure this out as you will see as you read on. Let's now go back to the beginning.

[1] J.J. Clague & T.S. James, *History and isostatic effects of the last ice sheet in southern British Columbia*, Quaternary Science Reviews, 21, pp.71–87, 2002.

Left: Sometimes, all you need to find striae is a good stiff broom for use after the excavator operator has gone home. This is a set of striae (Site 5 on Gabriola) on sandstone showing flow from the northwest (N55°W).

View is looking northwest.

The orientation of striae

Although rock surfaces in previously glaciated regions always display signs of the passage of ice, for a long while, I was unaware that there were any striae at all on Gabriola.[2] The sandstone bedrock, I reasoned, eroded too fast for them to have endured for ten-thousand years. If petroglyphs can fade away in a decade or two, why not striae? And the answer is …they do; but, like petroglyphs, only if they are exposed and repeatedly wetted by rain and dried-out in the sun.

Wet-dry cycling allows tiny amounts of salt in the rain to accumulate close to the surface, and it is this salt that weathers the sandstone. If the sandstone is buried, the surface is kept out of the sun and kept relatively moist, and the weathering rate is much reduced. Surfaces covered by flowing water hardly weather at all because salt cannot accumulate. To find striae and other evidence of the passage of ice, you have to look for surfaces that have only recently been exposed. You have, in other words, to develop a keen interest in construction sites, and places where men with big machines are moving the earth.

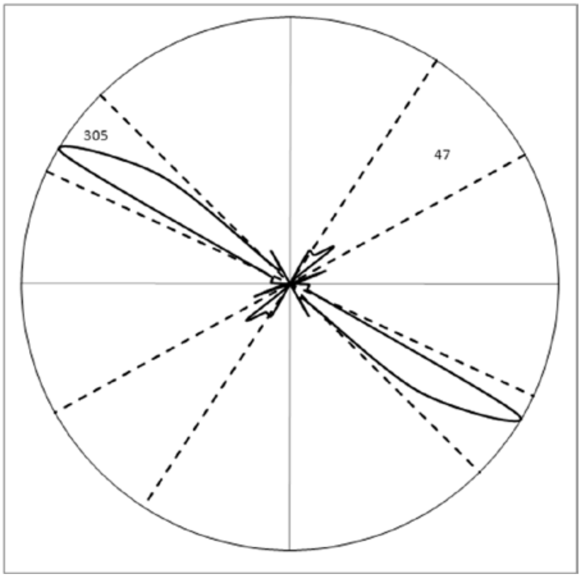
In total, I found a dozen sites on Gabriola where I could measure the orientations of striae. The results are summarized here in polar plots, one for Gabriola, and one for the Harewood Plain, directly west of here in the hills south of Nanaimo. The details are in Appendix 1.

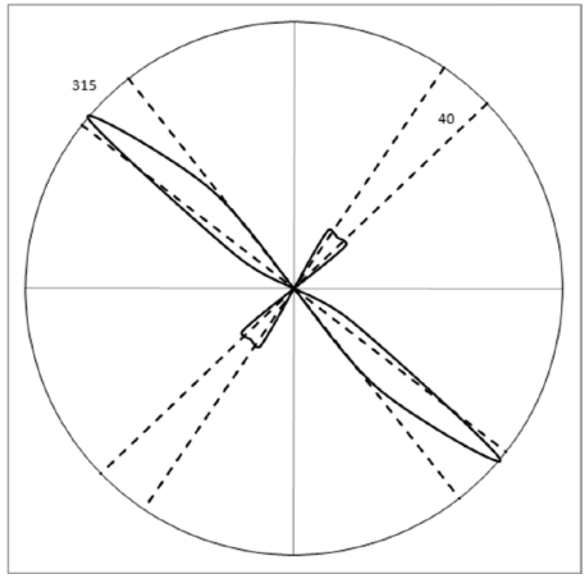
The dominant directions of the sources of ice on Gabriola were northwest (N55°W ±10°) and northeast (N40°E ±14°); and near Nanaimo, N45°W ±7° and N40°E ±6°. These are virtually the same, and curiously close to being 90° apart.

There is also a small but intriguing set from south of west (W21°S) on Gabriola suggesting glaciation originating on Vancouver Island.

Striae from the NW are far more common, and are carved deeper, than those from the NE. They also tend to be longer—some from the NE are mere dashes.

[2] It was Dr. Steven Earle, who, at the time, didn't live on Gabriola, who pointed out to me striae in the bed of the creek that runs down along side the road to what was then the White Hart pub. You can check them out while waiting in the ferry lineup.

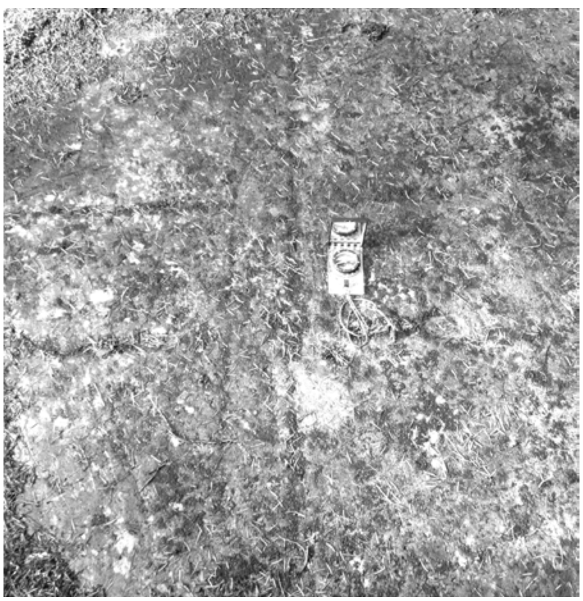




Left: Orientations of striae on Gabriola from ten sites (31 sets).

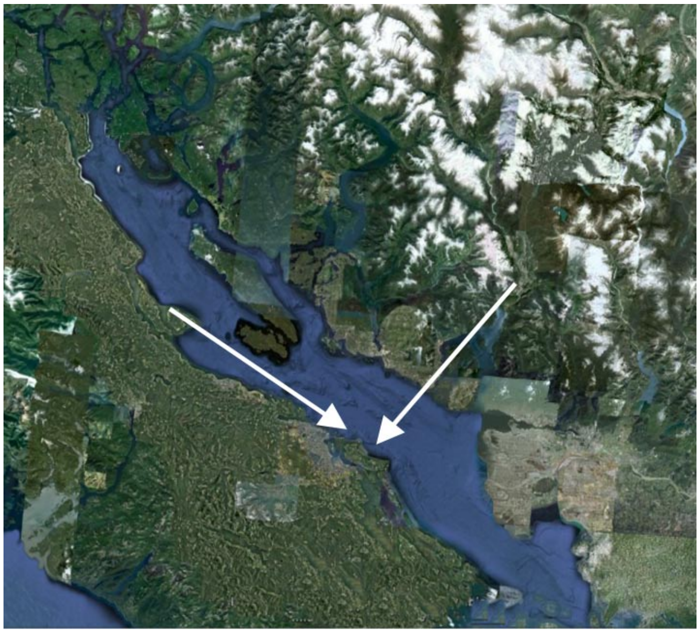
Right: Orientations of striae on Harewood Plains near Nanaimo (200m ASL).

In the graphs, major sets (too many striae to count) have been given twice the weight of sets containing only a few grooves.



Left: Looking northwest along striae at Site 5 (N55°W). Striae crossing the picture horizontally from the right (NE) can also be seen.

Right: Looking northeast along striae at Site 11 (N33°E). A few striae are crossing the picture horizontally from the left (NW).



View of the Strait of Georgia showing the directions from which the ice converged on Gabriola.

The orientation of striae indicate that at different times, ice flowed from the northwest in a valley glacier down the east coast of Vancouver Island where there were undoubtedly eastward-flowing "tributaries" from the Island's central mountains; and from the northeast from the direction of Howe Sound and likely a continental ice cap beyond, which would have included the mountainous area that we now know as Garibaldi Provincial Park.

Striae between NW and NE are not common but do exist at several sites. These were possibly created during the change in direction.

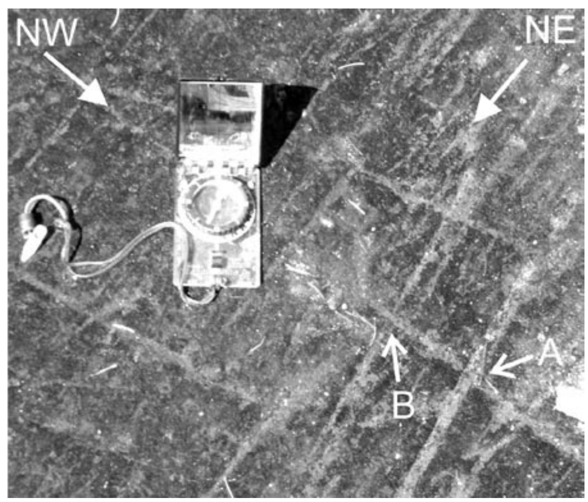
The age of striae

NW-NE which came first?

Dating striae is of course a problem. If it weren't, we would know the age of the petroglyphs.

On the face of it, it ought to be possible to determine which of two sets on intersecting striae is the oldest. It turned out that it isn't so easy. Imagine two intersecting grooves cut by a router with one groove deeper than the other. Then when they are freshly cut, you might be able to tell which groove cut which. But add a few thousand years of weathering to round off the edges, and the task is not so easy.

I looked at a lot of intersections, but the only ones that were useful were grooves equally deep where one groove had scratched the floor of the other. Of the handful I identified this way at different sites, the evidence they provided clearly indicated that the striae from the northwest were older than those from the northeast.



Instances of striae from the NW and NE on the same outcrop are unusual, but have the potential for answering the question, which came first? The evidence is not always clear. Intersection A, for example, looks as though the NE stria is cutting the NW stria. But at intersection B, the opposite appears true. The compass is pointing at true north at Site 11.

In the end, I decided there is little doubt that the NW striae were older. The same conclusion was reached at other sites.

After a lot of thought, I managed to square this observation with published accounts of the history of ice in the region.[3] The striae from the northwest must have been created in the early days of the last ice age when glaciers were growing and the ice was pushing from the northwest down the margin of the Coast Mountains and eastern Vancouver Island toward the junction of Puget Sound and the Juan de Fuca Strait.[4]

At the culmination of the ice build-up, it was so thick that it was no longer confined and was moving directly from the northeast and the interior of the BC mainland, over the Beaufort Range on Vancouver Island and down to the sea. Northeast trending striae I've seen on Vancouver Island are 200 metres above sea level, well above the top of Gabriola in the Pleistocene.

The Cordilleran ice sheet at the glaciation maximum (Vashon stade). This view shows ice moving both from the NE and NW over Gabriola.

Adapted from June Ryder

For crossing sets of striae to exist, the younger set must have been slow-moving, short-lived, and the older set protected by being buried in lodgement till or basal till frozen to the bedrock.

It is unlikely that the from-the-northwest movement was resumed to any extent as the ice thinned during deglaciation. All the evidence is that deglaciation was rapid. Rather than retreating, glaciers simply stopped moving, and wasted away.[5] There are no terminal moraines on the floor of the Strait of Georgia, and there are no iceberg scours either, suggesting that, during deglaciation of the strait, there was no retreating ice shelf.[6]

But how old?

One of the fears of researching striae for the novice is that one always has in the back of one's mind the possibility that the striae are modern artifacts. Just to be absolutely sure this was not the case, I decided to look at petroglyphs on Gabriola and near-by Vancouver Island. The thinking was that if I

[3] Although for a while I was stuck on the idea that the NW trend had to have come after the NE trend as ice continued to flow down the strait even while it was waning. This was the view expressed by J.G. Fyles, *Surficial geology of Horne Lake and Parksville map-areas, Vancouver Island, BC*, GSC Memoir 318, p.68, 1962.

[4] N.F.G. Davis & W.H. Mathews, *Four phases of glaciation with illustrations from southwestern British Columbia*, Journal of Geology, 52, pp.403–413, Nov. 1944.

[5] J.M Ryder, R.J. Fulton, & J.J. Clague, *The Cordilleran ice sheet and the glacial geomorphology of southern and central British Columbia*, Géographie physique et Quaternaire, 45 (3), pp.365–377, September 1991.

[6] J. Vaughn Barrie and K. W. Conway, GSC Current Research 2000-A21, p.6.

One of several petroglyphs at DgRx 009 that are oriented with respect to the numerous striae that surround them. One striation from the NW runs right down the centre of the face, serving as a nose. Striae, some of which are outlined in white on the right, are coming from NW and NE. There is no doubt that the striae existed before the petroglyph was carved and that, by implication, the striae are "very old".

could find a petroglyph that had been cut into the striae, this would at least demonstrate that the striae were older than the petroglyph, and petroglyphs are regarded as being at least a few hundred years old.

The search was a great success. Not only did I find several petroglyphs that were younger than the striae, I found two examples where the striae and their orientations, both northwest and northeast, had been incorporated into their designs.[7]

[7] Beth and Ray Hill, *Indian Petroglyphs of the Pacific Northwest*, pp.114–115, University of Washington Press, 1974. In the sketch on the left side of page 115, one of the figure's three "hairs" is a stria, as is probably at least one of its fingers.

Stone striae

While I'm talking about surprises, I should report another discovery.

One might think that striae were confined to the bedrock. Actually you can easily demonstrate to yourself that this not so. Many of the trails in the forested land of Gabriola, including the 707 Community Park, have stones embedded in the dirt. Apart from sandstone fragments, these stones are igneous rocks brought here by glaciers. The surface soil in these areas is often weathered till, mixed here and there with weathered sandstone from the bedrock.

Some, and in places, many, of these stones have a flat face. They lie trodden into the trail, unsurprisingly enough, with their flat

Some cobbles and boulders have had one side ground flat by being dragged by the ice, have then tumbled, and had another face ground flat. The *granodiorite* erratic boulder down by the Brickyard, *left*, showed signs of having a slickenside—the friction on its left side had been so high that some minerals in the *granodiorite* may have been altered to pinkish *zeolite*. Possibly a rare example of glacial cataclastic metamorphism; however, there is no guarantee that flat faces like these are the result of dragging. It is common for coarse rock fragments (joint-blocks) to have been released from the bedrock by freeze-thaw weathering of existing fractures in the harsh climatic conditions prior to the arrival of the ice. Two faces of the *quartzite* cobble, *right*, Brickyard Beach (from Geoffrey Fm.), are as flat and polished, with minor scratches, as a counter top.

faces horizontal forming the beginnings of a pavement. While there are several reasons why a stone should have a flat face—that the stone was once on the face of a bedrock fracture being the obvious one—[8] a common one here is that the face was ground flat as the stone was dragged along by ice. Every now and then, if you brush the dirt off one of these flat faces, you see striae.

Striae on stones are not usually useful in determining the direction of the movement of the ice for the obvious reason that stones are easily moved around, but, despite this, I did find one site where the striae did appear to be indicating direction. They were on the bottoms of stones in the MoTI gravel pit on South Road. Finding them meant digging out flat stones while preserving as best I could their orientation.

This pit must have been sheltered from the ice moving from the northeast because of the six stones I found with striae, all the striae were orientated within a few degrees of N55°W, as are most of the bedrock striae in the floor of this pit.

Deflection striae

While all of my attention in the early days of the research was directed toward finding and measuring striae on flat, sub-horizontal surfaces—treeless sandstone plains—I

[8] Pebbles can also be flattened by sliding in the surf on a shingle beach. River pebbles on the other hand practically always tumble and are beautifully rounded. Abrasion in the surf long enough to produce a flat face is actually not all that common, and is only noticeable when the ocean has sorted the flat-faced ones out from the others. Sandstone fragments on Gabriola are commonly tabular; however, this has nothing to do with glaciation. These are spall—case-hardened weathering crust that has flaked away from the parent rock.

A layer of till (lodgement or melt-out?) with a high proportion of stones lying on flat faces. The small picture *bottom right* is a key to some of them in the larger picture *top*. Even tabular fragments of fragile siltstone and sandstone are present. Chocolate-coloured iron-and-manganese-rich deposits from meltwater in disintegrating sandstone concretions are abundant.

Some of these imbricated faceted stones have striae, and the striae on all the ones I extracted were oriented fairly precisely northwest-southeast (N55°W). There are small lenses of stone-free medium sand in this patch of till, presumably from meltwater, but the disturbance by flowing water appears to be minimal. There is outwash material in the pit above this layer that may have provided protection over the years, but after all the quarrying it's difficult to be sure.

The strata are tilted upward 7° (120m/km) roughly toward the northeast, which is rather too high to be a result of being deposited while the island was still depressed by the weight of the ice. The greenstone *bottom left* is metamorphic andesitic with traces of *pyrite* internally.

couldn't help noticing at one or two sites some striae on steeply inclined surfaces. These were not very useful for measuring orientations because there were usually only two or three at the most on any one rock face, so you couldn't do any averaging, and also the geometry involved was difficult to understand.

These kinds of striae are called *deflection striae*,[9] because they are created by movements of the ice in response to local topographic irregularities, which is another reason for not paying them too much attention. You don't want to be caught studying the glacial equivalent of a back-eddy while trying to figure out the main flow of a river.

However, like petroglyphs on vertical surfaces, and likely for the same reasons, these striae seem better preserved than the horizontal ones. It was not until I was nearly done with the research that I took another look at these deflection striae, and after I had figured out the geometry of the rock surface and the direction it must have been struck by the ice, they turned out to be very informative. The details are in Appendix 2. At one site a deflection stria gave clear collaborative evidence that movement from the northeast came *after* movement from the northwest. At two other sites there was support for the suggestion that there was at one time movement of ice from south of west, which can only mean from Vancouver Island. I'll discuss those striae shortly.

Glacial grooves

Grooves can be wide, and I'm sure some get counted as being due to an erosional agent other than ice. One impressive groove (near Site 4, Appendix 1) has numerous sinuous striae on both sides of the groove.

While striae are abraded into the bedrock by the gravel and boulders carried along underneath the glacier, it is not so clear what creates grooves, which are much wider.

A glacial groove on Gabriola, six metres wide, worn into sandstone. View is N40°W (there is a compass on the righthand side). Both walls are covered in striae, all trending from the northwest, but, as shown *next page*, curiously sinuous. The fractures in the bedrock slanting upward toward the right are ancient and have nothing to do with glaciation.

Some researchers suggest that grooves and flutes (Nye channels) were created by sediment-laden meltwater moving at high-velocity and high-pressure, and that seems plausible to me. Certainly the nature of the striae accompanying the grooves I have

[9] Deflection striae aren't often studied. The most useful reference I found was: Max Demorest, *Ice flowage as revealed by glacial striae*, The Journal of Geology, 46(5), pp.700–725, Jul.–Aug. 1938.

observed suggest a violent turbulent flow of water rather than the laminar flow of ice. ◊

Unusually sinuous striae on the sides of a glacial groove suggesting they may have been carved by gravel travelling in fast-flowing meltwater under high pressure rather than by ice.

Appendix 1—The orientation of glacial striae

Results of striae orientation of source measurements (Gabriola)								
site	lat.	long.	location	set	major	minor	major	minor
1: Chernoff	49°08.87'N	123°47.30'W	1	1		N85°W		
				2		N77°W		
				3		N69°W		
				4				
				5			N49°E	
				6			N46°E	
				7			N43°E	
2: MoTI	49°08.26'N	123°44.97'W	1	1		N47°W		
				2		N48°W		
				3			N51°E	
			2	1		N58°W		
				2	N48°W			
				3		N48°W		
			3	1			N27°E	
3: Mudge/ Link	49°07.38'N	123°45.93'W	1	1	N55°W			
4: Old man plain	49°08.32'N	123°44.34'W	1	1				W21°S
5: Sunstar plain	49°08.34'N	123°44.60'W	1	1	N55°W			
				2	N57°W			
				3			N31°E	
				4				W20°S
			2	1		N55°W		
6: Secret Garden	49°11.31'N	123°51.97'W	1	1		N50°W		
7: Gallery	49°11.53'N	123°52.39'W	1	1		N48°W		
8: White Hart	49°10.60'N	123°51.39'W	1	1	N56°W			
9: W of W 707	49°10.18'N	123°50.07'W	1	1	N57°W			W20°S/W30°S
10: Church	49°08.14'N	123°44.07'W	1	1		N45°W		
				2		N55°W		
				3		N50°W		
				4		N44°W		
				5	N60°W			
				6			N36°E	
11: Dorby	49°08.76'N	123°43.72'W	1	1	N56°W	N26°W		W16°S
						N37°W		
						N74°W		
12: 707CP W	49°10.17'N	123°50.16'W	1	1	N57°W			
all					N55°W	N54°W	N40°E	W21°S
all					N55°W ±10° 305°		N47°E ±14° 47°	

NOTE: The age sequence is N55°W older than N40°E, ~~N40°E older than W21°S~~.

Results of striae orientation of source measurements (Nanaimo)								
site	lat.	long.	location	set	major	minor	major	minor
11: Harewood Plain	49°07.7’N	123°57.8’W	≈ 5	1	N45°W			
				2	N35°W			
				3	N46°W			
				4		N60°W		
				5			N40°E	
				6			N33°E	
				7			N48°E	
all					N45°W ±7° 315°		N40°E ±6° 40°	
12: Harewood Plain			A	1	N42°W		N39°E	
			B	1			N37°E	W31°S
GEOL-305 independent observations			C	1	N41°W		N43°E	
			D	1			N37°E	W24°S
			E	1	N97°W		N44°E	
			F	1	N38°W		N44°E	
			H	1	N49°W		N37°E	
			A-H all	7	N41°W ±6° 319°		N39°E±6° 39°	W26°S

NOTE: The age sequence is N45°W older than N40°E.

"Locations" are different outcrops at the same site. Having more than one location at a site is highly desirable because continuity in direction over a large area is one indicator that the striae have not been artificially created. Outcrops with more than one "set" of striae were fairly common. "Major sets" were sets where the number of striae was too high to count. "Minor" sets had more than one or two, but less than say ten, but were nevertheless almost certainly glacial in origin. Only striae on horizontal surfaces were included.

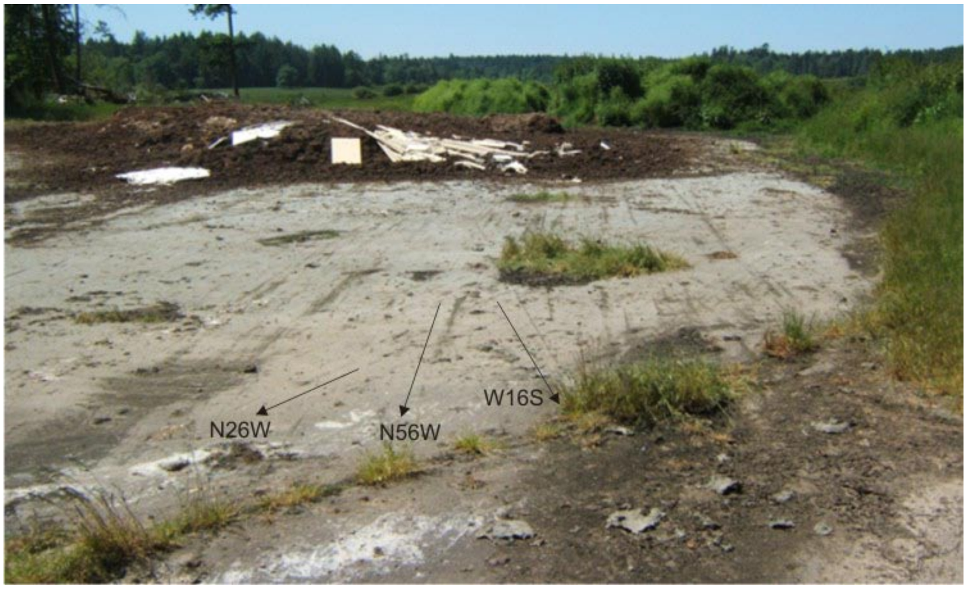
Directions are the direction from which the ice was coming. There is little risk that NW and NE directions are wrong, but W21°S (249°, Vancouver Island) might have been E21°N (69°); if additional evidence had not shown that this is unlikely. All sites in the first table are on Gabriola except for one on Whaleback Rock between Gabriola and Mudge.

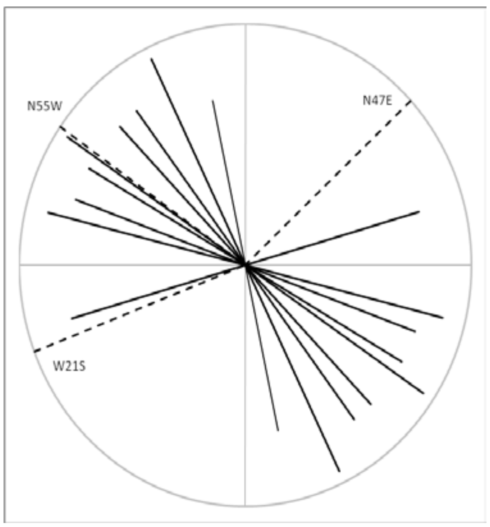
Many of the minor striae lie between N55°W and N47°E and so might have been created when the glacier was changing direction rather than being a local deviation.

The site in the second table was Harewood Plain near Nanaimo, where there are several locations displaying striae that clearly belong to the same sets. These striae were also observed independently by geology students at Vancouver Island University. The summary of their results at the bottom of the table are for a statistical analysis of 640 observations.[10]

The difference in the direction of the source of the NW set on Gabriola N55°W and Harewood N45°W must have something to do with the fact that Mount Benson, 1000 m high, is only 40 kilometres west of Harewood Plain.

[10] Of these, my own analysis identified 67% from the NE, 18% from the NW, and 15% from the SW. However, no evidence was seen at the time to show that striae from W27°S were not in fact from N63°E and possible deviations of the N38°E set. Opinion on this is divided. Students used 20°E magnetic deviation, which I have recalculated using 19°E.



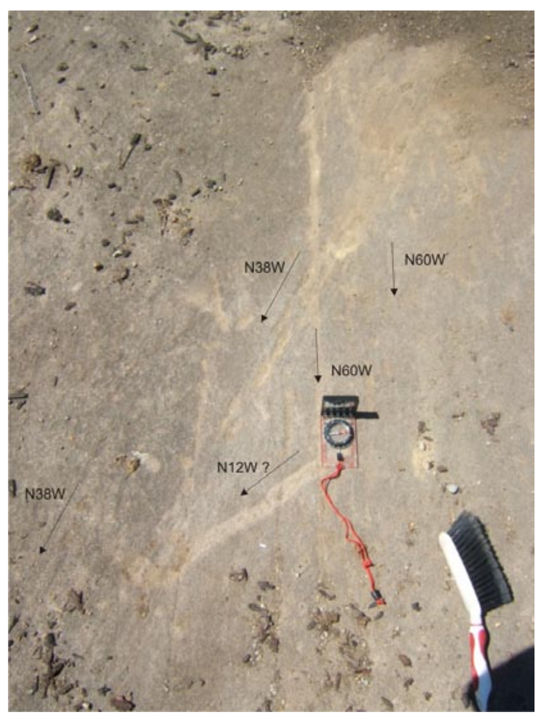


Above: Striae at Site 11 on Gabriola (recently exposed) show an extraordinary range of orientations. Shown are source azimuths and flow directions.

Left: Site 11. The orientations of sets of parallel striae, not the orientations of individual striae.

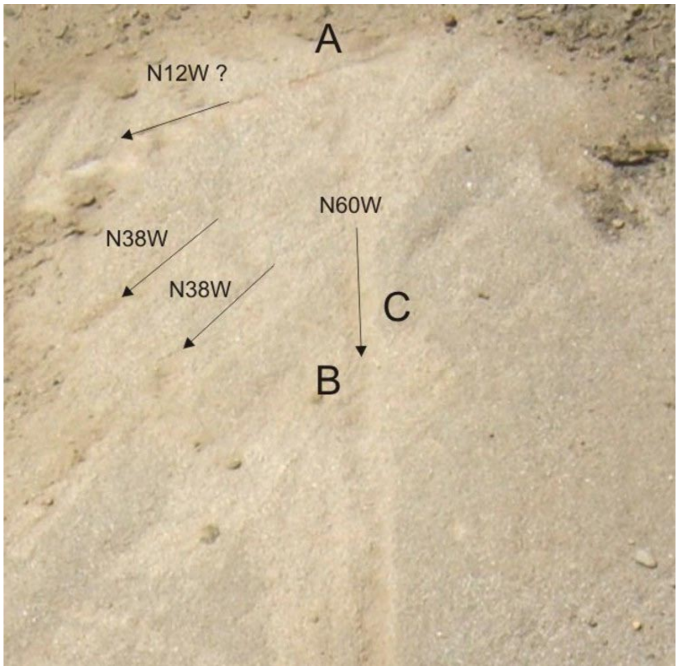
A few striae were seen at all sites that deviated from the general trend, but none appeared to belong to well-populated sub-parallel sets as at this site.

Below: Striae at Site 11. The broad stria marked N12°W is doubtful as not many other striae had this orientation.



At one site, off Dorby Road, the "scatter" was extraordinarily high.

My suspicion is that these are not just deviations due to the local topography, which is relatively flat, but that they represent snapshots of a regional clockwise transition in direction of a major glacier, possibly W21°S (Vancouver Island) to N55°W (Strait of Georgia) to eventually N47°E (Howe Sound).



Left: Site 11. Deciding the relative age of overlapping sets of striae is, in my experience, not easy. In this detailed photo however, it does seem that the more northerly the source, the younger the striae; i.e. the regional directional change was clockwise.

At A, a stria from a shade west of north cuts through all others.

At B, striae from N38°W are scratching the bottom of one from N60°W.

At C, a deep broad stria from N60°W may have plucked by ice moving from N38°W (*not easy to see*).

Shown are source azimuths and flow directions.

On Gabriola, grooves created by excavators were sometimes a problem. Striae tend to be found only on freshly exposed surfaces making it difficult to avoid the risk of mistaken identification. I found it useful at some locations to dig out the edges of a clearing with a trowel to make quite sure that striae continued on underneath the soil that had not been touched by the earthmoving equipment.

Left: Site 1. The compass is recording striae from N50°E, but what about those other striae running diagonally across the picture? Their orientation is odd (E6°N) and not seen at any other site.

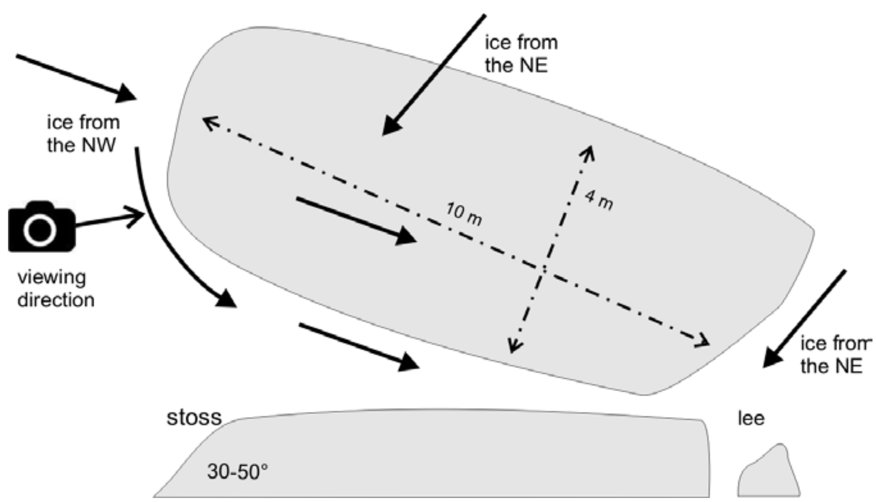
It was only when I came to write-up this article that I noticed the vehicle track in the top lefthand corner. No! that's not a chatter mark, and it runs in exactly the same direction as the mysterious striae. The mysterious striae were created by grit dragged and crushed by the track chains of an excavator.

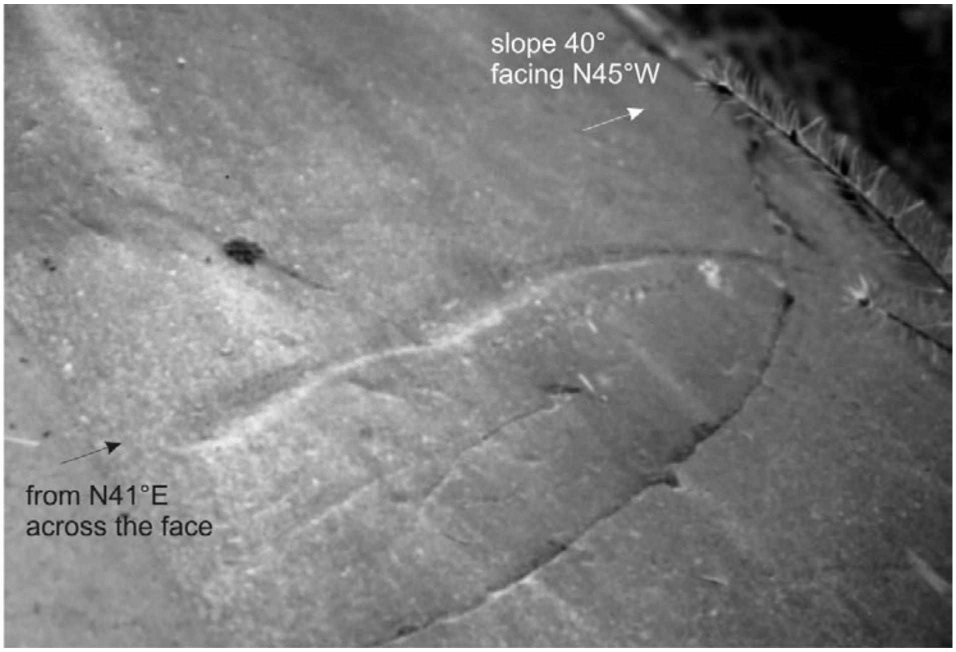
Appendix 2—Deflection striae

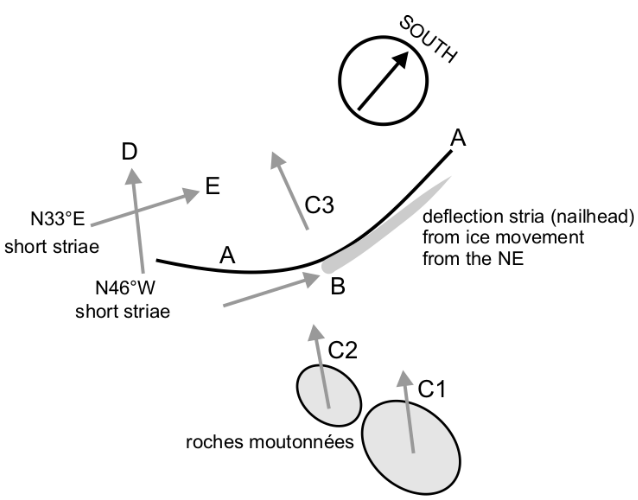
Small sandstone outcrops barely a metre high, like the one on the *right* in the MoTI's borrow pit on Gabriola, ought not to be a noticeable constriction to a glacier over a mile deep, but at some stage in its history, it must have been. Ice not only moved up and over the outcrop shown, clearly visible striae on its polished sides show that ice, moving from the northwest, also moved around it

Ice can move as a solid along multiple shear planes, leaving the bottom layer stagnant, rather like pushing a pack of cards against a small obstruction only a few cards thick, but once the ice is more than around 45 metres thick, the pressure at the bottom is sufficient to make it viscous and it flows more like a fluid than a solid. That is evidently what happened here.

Sandstone is not the easiest rock to polish. At one time I thought that there might have been some metamorphic changes to schist on some surfaces, but a closer look soon dispelled that idea. To the touch, the surfaces are certainly no finer than 220-grit sandpaper (60µ). Not very useful for a counter top without a sealer. ◊







Striae traversing an ice-polished face of an outcrop. In the photograph *above*, the striae appear above a prominent crack in the rock that may or may not be related.

The polished face A-A is the stoss-side C3 of a large *roche moutonnée*. Lower down at the foot of the face are two smaller *roches moutonnées,* C1 and C2. All were formed by ice movement from the northwest. This is confirmed by many minor striae D.

There are also striae E at the top of the face indicating ice movement from the northeast, but these are relatively few and far between.

The large stria in the photograph B appears to have been formed by ice moving from the northeast and striking the face obliquely. It then eased its pressure as it rounded the face and moved away toward the south on the right of the photograph.

If this interpretation is right, it means that ice moving from the northeast came after ice had moved across the island from the northwest.

The photograph *left* shows Buster looking northwest on C2 with C1 in the background.

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GD-521 Introduction
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Sea level changes.