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Errors and omissions:
Some of the captions on pages 48–51 were truncated in the printed version. This version is correct.

The original printed version did not contain a list of references at the end of the article. These have been added in this version.

Later references:
There is a note on the possible structural relationship of Gabriola's North-End fault (Leboeuf-Cox Bay) and Gabriola's South-End fault (Maples-Dragon's Lane) in:
Doe, N.A., Gabriola's nose and tail, *SHALE* 22, pp.34–35, January 2010.

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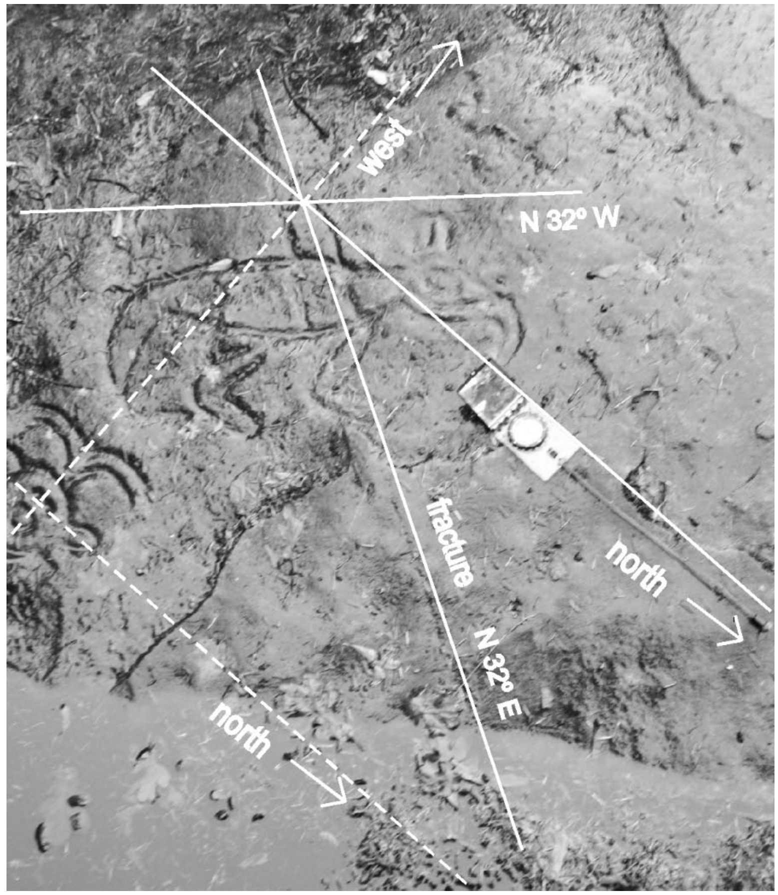
Author:
Nick Doe, 1787 El Verano Drive, Gabriola, BC, Canada V0R 1X6
Phone: 250-247-7858, FAX: 250-247-7859
E-mail: nickdoe@island.net

The orientation of fractures on Gabriola

by Nick Doe

On casual inspection of Gabriola's beaches—as if anyone would otherwise inspect a beach—it would seem that the long, linear fractures that one sees in the sandstone run in no particular direction. But, as anyone who spends an hour or two with a compass will find out, this is not so. The petroglyph carvers of long ago knew this too, and they incorporated the orientation of the fractures in their designs. A typical example is shown on the right.



Petroglyphs at the Church site illustrate a typical use of fractures in their layout and orientation.

The fractures here run N32º E (A-set fractures, common all over the island)—there is one running directly through the body of the glyph in the centre parallel to its waist-bands. The axis of this glyph runs close to N32º W, so a line oriented exactly half way between the axis of the glyph and the fracture runs, within a couple of degrees, north-south. There is another glyph, seen here on the far left, which has deeply carved eyes on an axis accurately oriented north-south. Such arrangements involving geographic, fracture, and glyph orientations are common at south-central sites on Gabriola.

The pattern of the orientations however is not simple, nor is there always a simple relationship between the fractures and the morphology of the island. Some patterns can't be explained (at least by me), or, as used to be said of bad BC wines, are "of local interest only". But what makes trying to figure them out rewarding (the fractures that is) is that their complexity may be concealing clues as to the way the Gulf Islands and eastern coastline of Vancouver Island has evolved over the past fifty million years or so. They may, on the other hand, be just meaningless random variations.

The purpose of this article is to describe measurements of the orientation of hundreds of the fractures, present the results, and make a preliminary stab at reducing the data to something that might make sense.

Measuring

The orientations were measured by walking along with Silva® magnetic compass[1] and notebook in hand. All fractures that ran in long straight lines and that were not just local "flaws" were included.[2] No observations were made of the dip of the fractures; it was just assumed that they were all bedding-plane-perpendicular fractures.

Very prominent fractures that ran from the sea to the back of the beach in a definite straight line were counted as two fractures, even though they might physically have been only one. About 20% of the fractures measured qualified for this extra weighting. Similarly, sets of parallel minor fractures were sometimes deliberately under-counted so as not to unduly skew the data.

In some cases, where sets of minor fractures (joints) ran at right angles to each other, a subjective judgement was made as to how many of each set to include, the aim being to try and have the numerical data reflect the apparent relative regional importance of the two sets. These counting procedures, although *ad hoc*, were applied reasonably consistently at all locations.

In all, I measured the orientation of almost nine hundred fractures, and I am very grateful to Dan Mackie, who allowed me to include in this article data that he collected for his M.Sc. Thesis completed in 2002.[3]

The total number of weighted observations used for this article was thus brought up to just shy of fourteen hundred.

Processing

The results were processed by first assigning each measured fracture orientation to one of 36 bins, each of which was five degrees wide: …–5º±2.5º, 0º±2.5º; 5º±2.5º, 10º±2.5º…. Orientations ranged between N 90º W (–90º, or due west), through N 0º (due north), to N 85º E (just north of east, or +85º).[4]

The counts per bin displayed in the following graphs were determined by a second stage of processing, which consisted of applying a low-pass filter designed to reduce quantization noise. The processed bin count N(x) was calculated as

$$N(x) = 0.25.[n(x-5) + 2.n(x) + n(x+5)]$$

where n(x) was the unprocessed first-stage count for the bin for orientations of xº.

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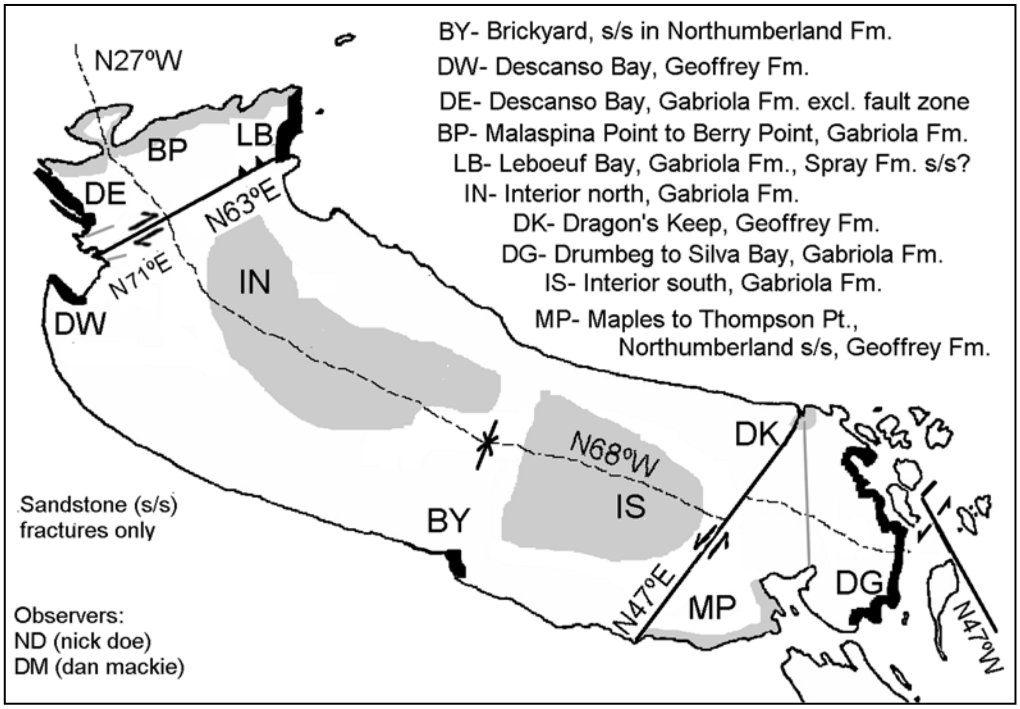
[1] The compass was set for a magnetic north at N 19.5º E, January 2004. The compass could be read with a precision of one degree, but the accuracy was probably no better than about ±2º.

[2] Excluded were short and sinuous joints, fractures that were splayed, anastomosed, pinnate, or appeared to be due to inhomogeneous bedrock or purely local stress.

[3] Dan also measured dip. I did not include Dan's measurements of fractures associated with faults that were obviously not bedding-plane-perpendicular. Comparisons between his and my observations were made by computing the cross-correlation functions of the observations at the various sites and checking that they peaked at zero ±5º offset. There was only one location (Brickyard beach, DM-00-017) where there was an apparent non-zero offset. Dan's set appeared to be rotated 10º clockwise compared to mine. This difference was far too consistent to be attributed to statistical variation, but on checking and re-checking my own measurements at the site, I could find no flaw in my own determinations, nor could I see any reason for bearings to be ambiguous. Apart from that, the two sets of observations were pleasingly consistent, the main variations being due to my more subjective counting of fractures and Dan's evident inclusion of rather more shorter joints than me.

[4] Orientation of each fracture line was always taken to be the more northerly of the two possibilities—for example, a line running S 45º E (southeast) to N 45º W (northwest) was taken to be N 45º W (northwest). This is an arbitrary choice. Lines running exactly east (N 90º E) to west (N 90º W) were taken to be west (N 90º W).



Locations surveyed. All coastal observations were made on the beach.
The three "regions" were NW of the Leboeuf-Cox's Bay fault running N63–71ºE; Central between the faults; and SE of the Maples-Dragon's Keep fault running N47ºE.

Identifying fracture sets

The task of splitting the processed observations into sets of fractures, each with a specific orientation, was tackled by postulating an "ideal" set of fractures, the members of which had a tightly clustered "bell-shaped" spread about a precise orientation. Sets were then identified by computing the least squared error between the filtered observations and the standard "bell-shaped curve" template t(x), which was:

$$t(x) = A.\exp[-((x-X)/\sigma)^2] + A.\exp[-((x-X+180)/\sigma)^2] + A.\exp[-((x-X-180)/\sigma)^2]$$

where t(x) was the predicted number of counts in the bin x°; "A" was a postulated amplitude (number of filtered counts in the bin); X° was the postulated orientation for the set; and $\sigma°/2$ was the postulated standard deviation of the set.[5]

Although this process was automated, it is not entirely objective. For example, two sets of lines with tightly clustered orientations (so tight their separate peaks were not discernible) could also be interpreted as a single set with more widely-scattered orientations. In such cases, at the risk of being subjective, the choice as to which solution to adopt was made on the

[5] The extra terms for t(x) are required to ensure that t(x) is cyclic; that is n(x) = n(x ±180). Weighting of results was done using only "A" rather than "Aσ", the effect of which was to give normal emphasis to sets of lines which contained the most lines, but less than normal emphasis to those sets where the lines were scattered rather than tightly clustered. For example, a set with A=50 and σ = ±10º was given twice the weight as one with A=25 and σ = ±20º even though the sets contain the same number of lines.

basis of comparisons with the orientations of sets at other locations.

Locations

The island was divided into three regions: one northwest of the fault from Leboeuf Bay to Cox's Bay; a central area; and a third southeast of the fault from the Maples to Dragon's Keep.

Northwest

Observations in the northwest region were made from the fault along to the Malaspina Galleries (**DE**);[6] from the galleries all along to Berry Point (**BP**);[7] and at Lebeouf Bay (**LB**).[8]

Central

Only about half the number of measurements were made in this region compared to the other two due to the lack of sandstone beaches—most are shale—and the lack of exposure of the bedrock in the interior of the island. Observations were made on the west side of Descanso Bay (**DW**);[9] Brickyard Beach (**BY**);[10] in the interior of the island west (**IN**)[11] and east (**IS**)[12] of Ferne and Tait Roads.

Southeast

Observations in the southeast region were made sporadically between the Maples (east of the fault) and Degnen Bay (**MP**);[13] continuously along the Drumbeg Park shoreline all the way to the entrance to Silva Bay (**DG**);[14] and around Dragon's Keep, but east of the fault (**DK**).[15]

Site reports

The letters assigned to fracture sets—A, B, and so on—are just arbitrary choices I made very early on in the project; they have no significance other than being identifiers in my field notes. Membership of sets was based on orientation alone. Dan Mackie recorded both dip and the character of the fault but I have made no use of this data other than to exclude fractures that were not bedding-plane-perpendicular type. The fractures observed and their orientations are plotted in the rose diagrams (polar plots). These are simple linear graphs, no fancy processing or expensive software was used.

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6 43 observations, well clear of the fault, mostly in the Descanso Bay Park. Dan Mackie's detailed observations around the location of the fault were not used as they were uncharacteristically complicated because of the fault.

7 294 observations evenly spread along the coast. Dan made 71 observations at the Malaspina Gallery (DM-00-022), Taylor Bay (DM-00-023), Clark Bay (DM-00-024), and Berry Point (DM-00-025).

8 Too complicated for me because of the major fault. I report only Dan's 202 authorative measurements at (DM-00-025).

9 61 observations mostly from the Spray/Geoffrey contact at Descanso Valley Road along to the southwest point of Descanso Bay. Dan made 32 observations at the ends of this stretch of sandstone/conglomerate (DM-00-020A & B).

10 23 observations. Dan made made 97 observations here. The sandstone is an interlayer in the predominantly shale Northumberland formation.

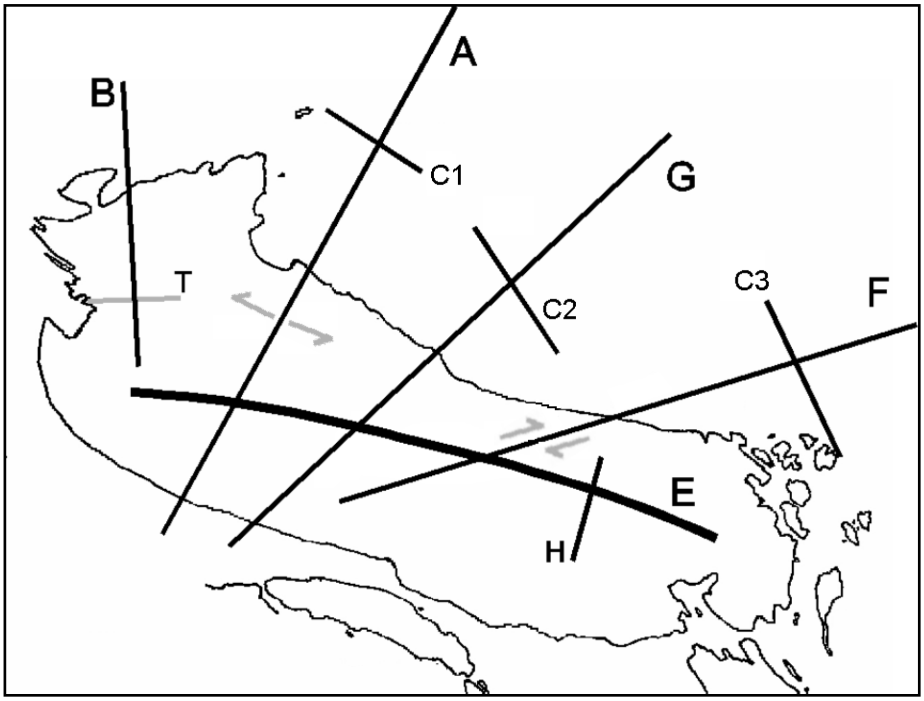
11 34 observations, mainly in the area north of the No.1 Firehall and in the new (un-named) 707-acre park. Dan made no observations away from the beaches.

12 50 observations mainly in and around the area north of South Road and the Kensington lands.

13 38 observations, mine only.

14 277 observations of mine, and 93 of Dan's at Silva Bay (DM-00-15) and the main entrance to Drumbeg Park (DM-00-16).

15 73 observations, mine only.



The orientation of the 5 set-pairs: A-C1, E-H, G-C2, F-C3, B-T(conjectured). The E-set line is shown gently curved to symbolically represent the clockwise rotation of lines within all sets except the B-set as one moves from west to east. The A-set are extension fractures and the F-set are slip fractures (shown here as right-slip but the sense is not consistent).

The E-H-pair fractures were possibly the first to occur and are the result of folding along the central syncline of the island. The compression stress axis was that of the H-set, N16ºE. Later events created the A-C1-, G-C2-, and F-C3-pairs, either simultaneously or at different times. The A- and F-set may be conjugates (about the G axis?), but if so, still later events must have opened up the A-set and produced compression and slip along the F-set. B-set and F-set fractures were not seen at the south end of the island.

Formations

Although a thorough study would require the recording of the formation (Gabriola, Spray, Geoffrey, Northumberland) in which the observed fractures were seen, I have not used this data here, mainly because I found it impossible on an island with limited exposure of some of the formations, particularly the Spray, to distinguish between associations of orientation with formation, and associations of orientation with geographical location.

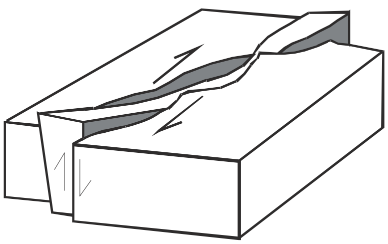
Fracture sets

In all, six major sets of fractures were discovered plus a further set—the C-family set—which was problematic in that the spread of orientations within this set was much wider than in the others, making it "difficult"—actually "impossible"—to be sure how many sets there were in the C-family. In the end, I settled on three C-sets, C1, C2, and C3. This brings the total number of sets up to nine.

Nine is a lot, but pairs of these were clearly related by being at right angles to each other, and two sets are possibly conjugate fractures.

A-set (N29ºE ±15º)
with C1-set (N56ºW ±15º) associate

The A-set fractures (393 observations, 28%—NW 25%,C 8%, SE 42%)[16] were the most numerous of all. They are extension (pull-apart or tensile) fractures with minor irregular strike-slip—two are shown on the front cover. The dip of the fracture planes apppears in many cases to be vertical, so pairs would be qualified to be *wrench faults* as shown below.



The C1-set fractures (230 observations, 17%—NW 21%,C 14%, SE 12%) ran, on weighted average, at 84º to the A-set, and were, in my estimation, related.[17]

The orientation of the sets showed a regional bias, which increases the island-wide average deviation (σ). The northwest, central, and southeast regional weighted average orientations were respectively for the A-set: 26º, 26º, and 33º (all NE); and for the C1-set: 59º, 56º, and 48º (all NW). Both sets indicate clockwise rotation moving east.

In the handful of cases where the cross-cutting of an A-set fracture by a shear fracture created an offset, it was the continuity of the A-set fracture that was disrupted indicating that the A-set fractures are older.

E-set (N76ºW ±5º)
with H-set (N16ºE ±16º) associate

The E-set fractures (190 observations, 14%—NW 5%,C 27%, SE 18%) run nearly parallel to the island's syncline (N68ºW).[18]

The H-set (122 observations, 9%—NW 5%,C 12%, SE 12%) ran on weighted average, at 88º to the E-set, so they are lateral fold fractures.[19] The scarp running north from the northeast corner of Degnen Bay past Belvedere Farm to the old Grande Hotel site is probably an H-set fracture.

The northwest, central, and southeast regional weighted average orientations were respectively for the E-set: 82º, 73º, and 73º (all NW); and for the H-set: 14º, 16º, and 17º (all NE). Both sets indicate clockwise rotation moving east.

G-set (N47ºE ±13º)
with C2-set (N36ºW ±9º) associate

The G-set fractures (114 observations, 8%—NW 8%,C 2%, SE 11%) run parallel to the major slip fault across the island (N49ºE).

The C2-set (30 observations, 2%—NW 2%,C 7%, SE 1%) ran on weighted average, at 83º to the G-set, and so may be related.[20] The C2-set orientation is the same

[16] Meaning 393 observations, which is 28% of the total number of observations island-wide, 25% of those in the NW region, 8% of those in the Central region, and 42% of those in the SE region.

[17] See for example the site report for the Maples (ND-MP-A and -C1).

[18] This is also the general trend of Vancouver Island as a whole (N67ºW), and of the west coast of the Strait of Georgia north of Hammond Bay N68ºW. At the north end of Gabriola, the syncline apparently veers northward (clockwise) to N32ºW.

[19] See for example the site reports for Descanso West (ND-DW-E and -H) and Interior South (ND-IS-E and -H).

[20] Although the evidence is weak. Possibly observed at Drumbeg (ND-DG-G and -C2) and the Brickyard (DM-BY-G and -C2), but on the Twin Beaches peninsula, G-set fractures appear to terminate on C3-set fractures.

as that of the Gulf Islands south of us (Valdes, DeCourcy Group, Galiano, N37ºW).

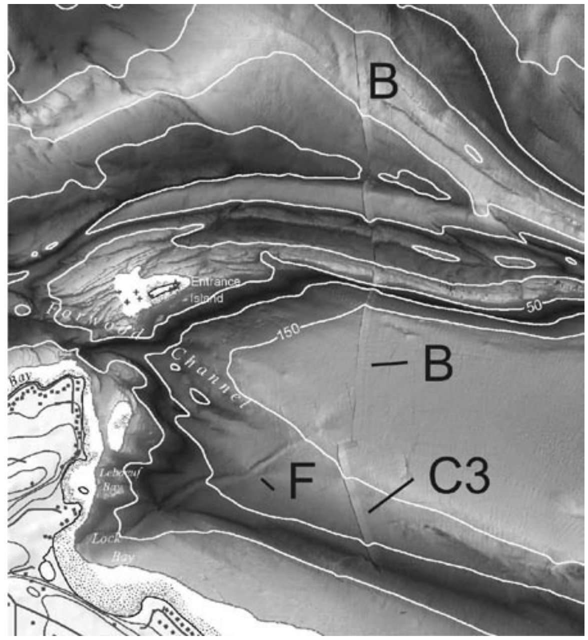
The northwest, central, and southeast regional weighted average orientations were respectively for the G-set: 40º, 46º, and 49º (all NE); and for the C2-set: 36º, 38º, and 35º (all NW). Both sets indicate clockwise rotation moving east, except for the C2-set in the central region.

F-set (N73ºE ±18º) *with C3-set (N25ºW ±14º) associate*

The F-set fractures (87 observations, 6%—NW 9%,C 12%, SE 0%) were not seen in the southeast region, though in one or two places it seemed possible that they once existed but have since healed. The F-set orientation corresponds very closely to the trend of the coast from Malaspina Point to Berry Point (N73ºE) and long straight C3-set fractures are locally common on the Twin Beaches peninsula.

The C3-set (109 observations, 8%—NW 13%,C 2%, SE 4%) ran at about 98º to the F-set, so they are likely related. The C3-set runs nearly parallel to the island's syncline at the north end of the island near Twin Beaches (N27ºW).[21]

The northwest, central, and southeast regional weighted average orientations were respectively for the F-set: 73º, 77º, and non-observed (all NE); and for the C3-set: 26º, 25º, and 20º (all NW). Both sets indicate clockwise rotation moving east.



Geological Survey Canada

Bathymetric map of the seafloor off Berry Point and Entrance Island shows fractures underwater can be instructively matched with those on land. The F-set fracture at the north end of Sandwell Park, which is probably the major north-end fault, apparently terminates just off shore or is buried.

B-set (N3ºW ±8º) *no associate identified*

The B-set fractures (113 observations, 8%—NW 12%,C 16%, SE 0%) were seen only at the north end of the island. B-set fractures might define the orientation of the coast south of Berry Point, and south of the west tip of Descanso Bay parallel to Canso Drive.

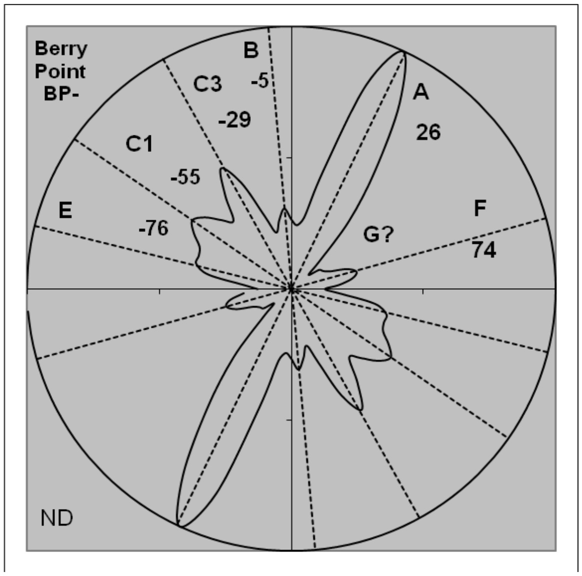
Any associate, I'll call in the T-set, would be at N87ºE, which is almost exactly east-west. Lines were occasionally observed running in this direction, but not in sufficient numbers to register in the analysis.

The northwest, central, and southeast regional weighted average orientations were respectively for the B-set: 3º, 3º, and non-observed (all NW). There was no reliable indication of rotation.

[21] The general trend of the west coast of the Strait of Georgia south from Link Island is N35ºW. The association is however weak, clearly seen in numbers only at the Brickyard (DM-BY-F and -C3).

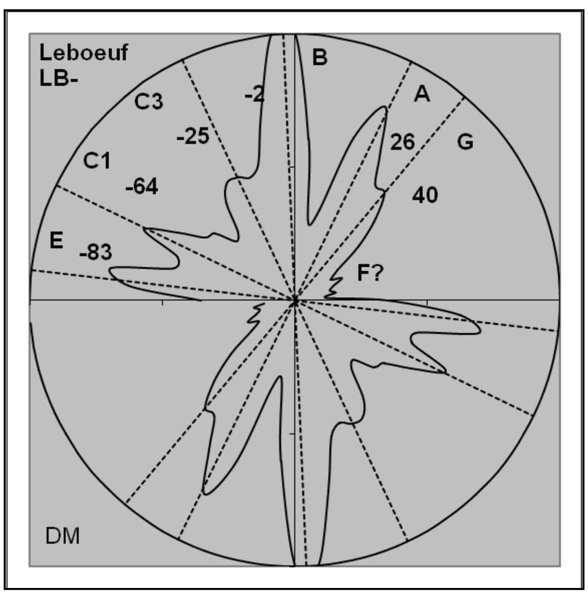
Observations

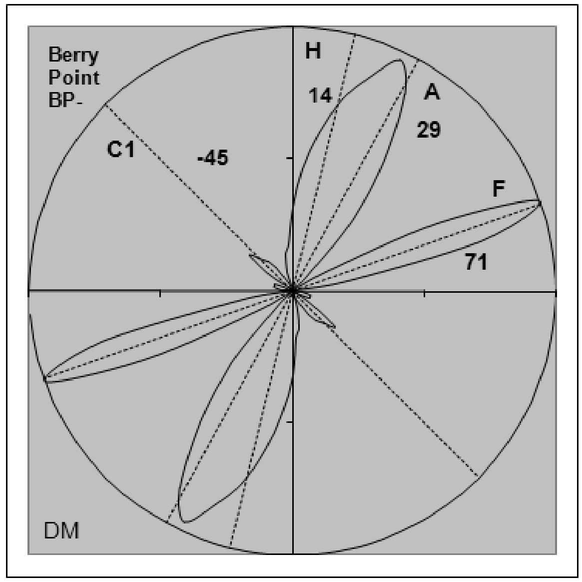
Site observations. Some sites have two rose diagrams, one for observations by Dan Mackie (DM), and one for observations made independently by myself (ND).



NW: Berry Point: Observations: 294, ND

	dev.	ori	amp	σ/2	%
ND-BP-E	+0°	N76° W	0.2	±3.8°	4
ND-BP-C1	+1°	N55° W	0.5	±9.0°	24
ND-BP-C3	−4°	N29° W	0.5	±4.8°	13
ND-BP-B	−2°	N5° W	0.3	±6.1°	10
ND-BP-A	−3°	N26° E	1.0	±6.7°	36
ND-BP-G	trace	N51° E observed			
ND-BP-F	+1°	N74° E	0.2	±11.9°	13





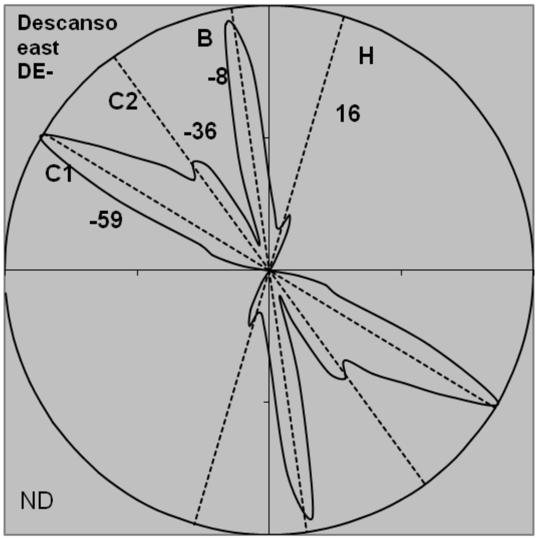
NW: Berry Point: Observations: 71, DM
DM-00-022, DM-00-023, DM-00-024, DM-00-025

	dev.	ori	amp	σ/2	%
DM-BP-C1*	+11°	N45° W	0.2	±7.0	10
DM-BP-H	−2°	N14° E	0.6	±9.0	37
DM-BP-A	+0°	N29° E	0.6	±6.0	25
DM-BP-F	–2°	N71° E	1.0	±4.0	28

*or DM-BP-C2? (dev. = −9°)

NW: Leboeuf Bay: Observations: 202, DM
DM-00-018, DM-00-019

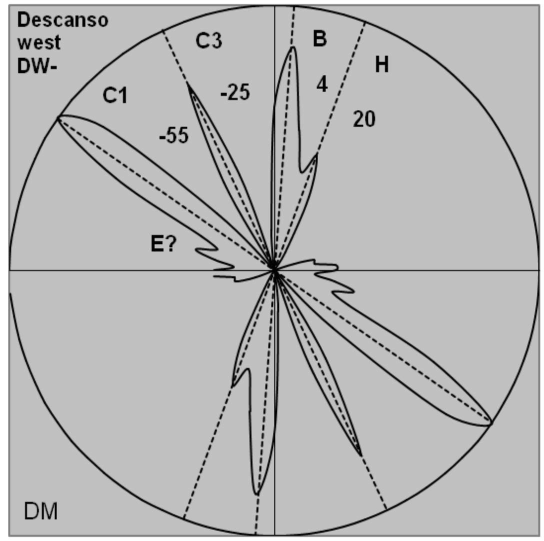
	dev.	ori	amp	σ/2	%
DM-LB-E	−7°	N83° W	0.5	±3.5°	8
DM-LB-C1	−8°	N64° W	0.5	±8.0°	17
DM-LB-C3	+0°	N25° W	0.5	±10.0°	22
DM-LB-B	+1°	N2° W	0.9	±4.0°	16
DM-LB-A	−3°	N26° E	0.5	±6.0°	13
DM-LB-G	−7°	N40° E	0.3	±18.0°	24
DM-LB-F	trace	N73° E?			



NW: Descanso (east): Observations: 43, ND

	dev.	ori	amp	σ/2	%
ND-DE-E	trace	N76° W ?			
ND-DE-C1	−3°	N59° W	0.9	±5.5°	37
ND-DE-C2	+0°	N36° W	0.5	±6.0°	23
ND-DE-B	−5°	N8° W	1.0	±4.0°	30
ND-DE-H	+0°	N16° E	0.2	±6.5°	10

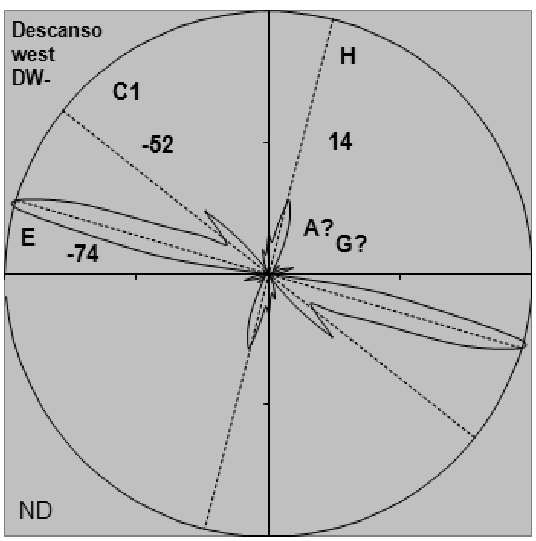
Dan Mackie's results not included as they involve detail around the fracture in Cox's Bay.



C: Descanso (west): Observations: 32, DM
DM-00-020A, DM-00-020B

	dev.	ori	amp	σ/2	%
DM-DW-E	trace	N76° W ?			
DM-DW-C1	+1°	N55° W	1.0	±5.0°	40
DM-DW-C3	+0°	N25° W	0.8	±3.0°	19
DM-DW-B	+7°	N4° E	0.9	±3.5°	25
DM-DW-H	+4°	N20° E	0.5	±4.0°	16

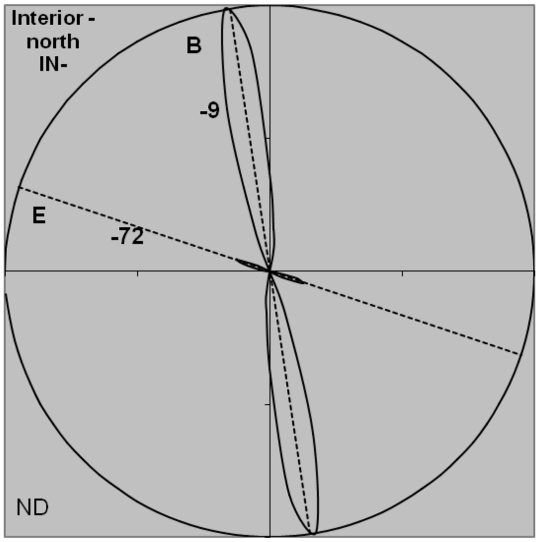
DW-C1 (DM) are pinnate fractures and wouldn't have been counted by me.



C: Descanso (west): Observations: 61, ND

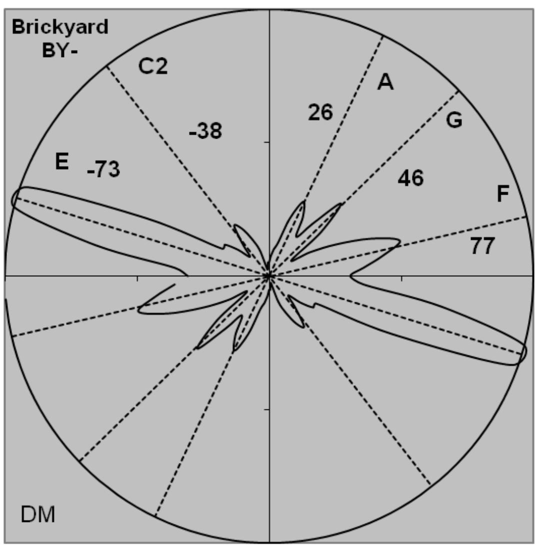
	dev.	ori	amp	σ/2	%
ND-DW-E	+2°	N74° W	1.0	±2.0°	31
ND-DW-C1	+4°	N52° W	0.3	±8.0°	38
ND-DW-H	−2°	N14° E	0.2	±10.0°	31
ND-DW-A	trace	N35° E	observed		
ND-DW-G	trace	N60° E	observed		

Observations along whole stretch compared with DM observations at two fixed stations at the ends of the stretch.



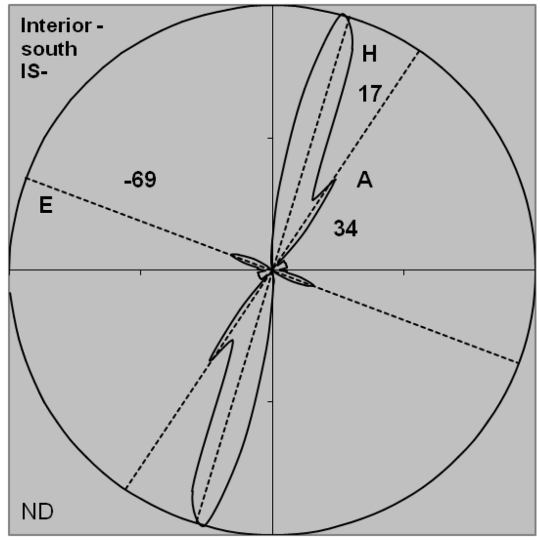
C: Interior (north)*:* Observations: 34, ND

	dev.	ori	amp	σ/2	%
ND-IN-E	+4°	N72° W	0.1	±5.0	10
ND-IN-B	−6°	N9° W	1.0	±4.5	90



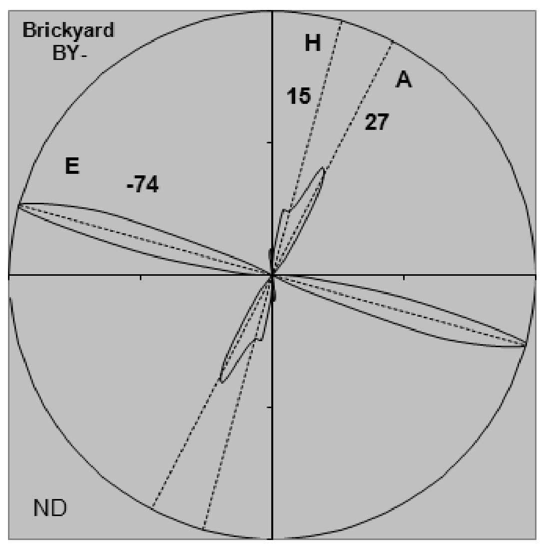
C: Brickyard Beach*:* Observations: 97, DM
DM-00-017. *All readings rotated –10°.*

	dev.	ori	amp	σ/2	%
DM-BY-E	+3°	N73° W	1.0	±4.5°	31
DM-BY-C2	−2°	N38° W	0.2	±12.0°	17
DM-BY-A	−3°	N26° E	0.3	±7.5°	15
DM-BY-G	–1°	N46° E	0.3	±3.0°	6
DM-BY-F	+4°	N77° E	0.6	±7.5°	31



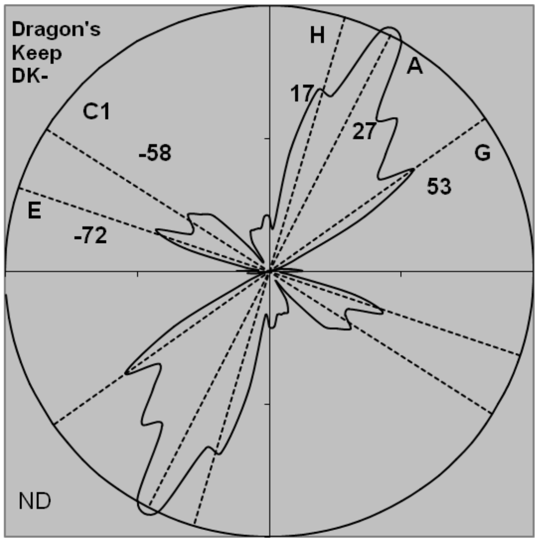
C: Interior (south): Observations: 50, ND

	dev.	ori	amp	σ/2	%
ND-IS-E	+7°	N69° W	0.2	±6.0°	17
ND-IS-H	+1°	N17° E	0.9	±6.5°	80



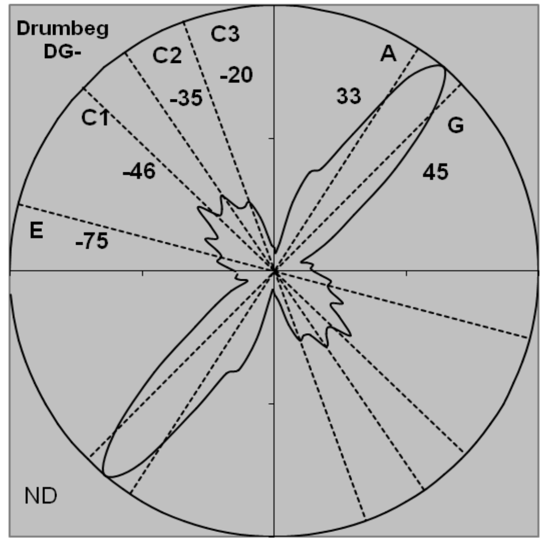
C: Brickyard Beach*:* Observations: 23, ND

	dev.	ori	amp	σ/2	%
ND-BY-E	+2°	N74° W	1.0	±3.5	60
ND-BY-H	−1°	N15° E	0.2	±7.0	24



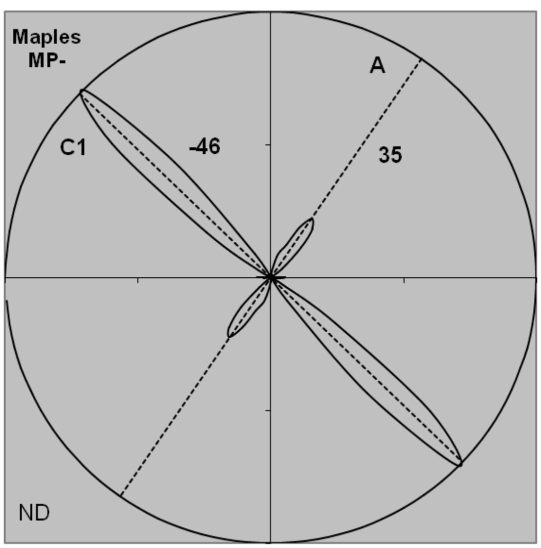
SE: Dragon's Keep: Observations: 73, ND

	dev.	ori	amp	σ/2	%
ND-DK-E	+4°	N72° W	0.2	±2.0°	2
ND-DK-C1	−2°	N58° W	0.3	±13.0°	22
ND-DK-H	+1°	N17° E	0.3	±17.5°	29
ND-DK-A	−2°	N27° E	0.8	±7.0°	31
ND-DK-G	+6°	N53° E	0.5	±5.6°	16



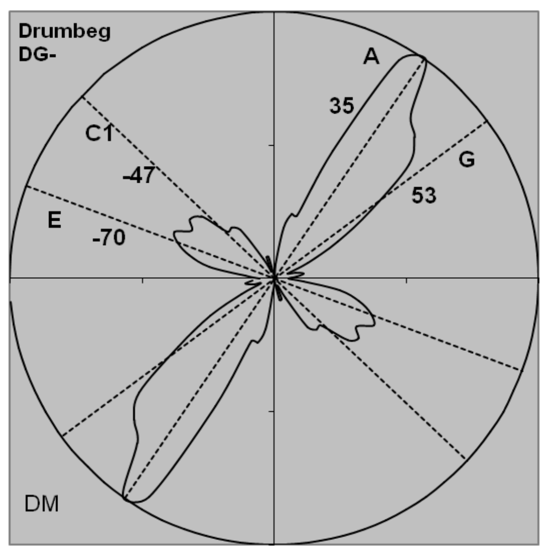
SE: Drumbeg: Observations: 277, ND

	dev.	ori	amp	σ/2	%
ND-DG-E	+1°	N75° W	0.2	±17.4°	24
ND-DG-C1	+10°	N46° W	0.1	±8.6°	6
ND-DG-C2	+1°	N35° W	0.1	±2.4°	1
ND-DG-C3	+5°	N20° W	0.2	±5.4°	7
ND-DG-A	+4°	N33° E	0.6	±12.1°	50
ND-DG-G	–2°	N45° E	0.4	±4.3°	12



SE: Maples: Observations: 38, ND

	dev.	ori	amp	σ/2	%
ND-MP-C1	+10°	N46° W	1.0	±4.0°	66
ND-MP-A	+6°	N35° E	0.3	±7.0°	34



SE: Drumbeg: Observations: 93, DM
DM-00-015, DM-00-016

	dev.	ori	amp	σ/2	%
DM-DG-E	+6°	N70° W	0.3	±9.0°	22
DM-DG-C1	+9°	N47° W	0.1	±9.5°	8
DM-DG-A	+6°	N35° E	0.9	±7.3°	53
DM-DG-G	+7°	N54° E	0.4	±5.4°	17

Compared to the southern Gulf Island

Dan Mackie's analysis of his survey of bedding-plane-perpendicular fractures in the southern Gulf Islands[22] shows five trends:

Mackie Trend 1: (N22ºE ±18º)

Mackie's Trend 1 may include my H-set on Gabriola (with dev. +6º); however, given that the H-set appears to be related to the folding and the folding angles are different further south, a more significant contributer to Trend 1 is probably the A-set (with dev. –7º).

Mackie Trend 2: (N57ºE ±19º)

Mackie's Trend 2 likely includes my G-set (with dev. +10º) or is a combination of the G- and F-sets (mean N60ºE).

Mackie Trend 3: (N88ºW, N92ºE ±19º)

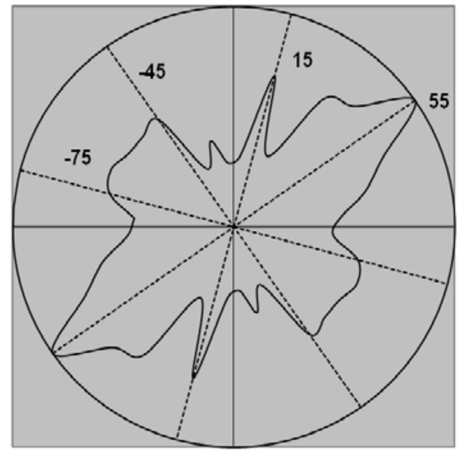
No obvious equivalent, the conjectured T-set (N87ºE) is too local.

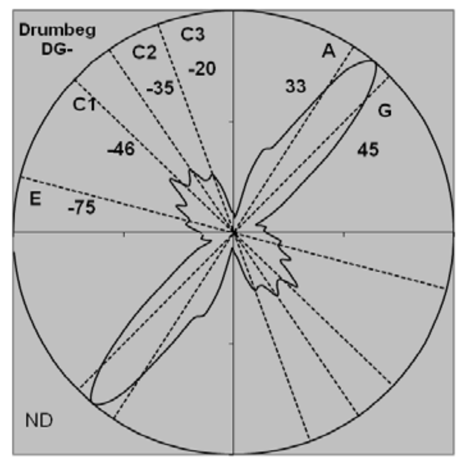
Mackie Trend 4: (N52ºW ±22º)

My C1-set (with dev. +4º).

Journeay Neogene fractures

In his analysis of "recent" Neogene (around 24 million years ago) structures of the region, Murray Journeay examined 694 fractures.[23] The orientations of these are shown in the diagram at the top. While these orientations show some resemblance to some of the orientation of fractures observed on Gabriola, particularly at Drumbeg as shown in the lower diagram, I have no reason, and certainly no expertize, to assert that there actually is a connection. Establishing that the fractures were of Neogene rather than Eocene age by studying fractures on Gabriola alone is impossible because all rocks on Gabriola are much older than both.





Top: Neogene brittle structures in the forearc region. Normal faults peak at roughly N55°E and N15°E; strike-slip faults peak at roughly N45°W. Fractures west of N45°W to N75°W were mostly uncharacterized.

Bottom: A repeat of my observations around Drumbeg Park for comparison.

[22] Gabriola, Valdes, Galiano, Mayne, Saturna, Pender, and Saltspring. His Table 6, p.106.

[23] Forearc region which included the southern Gulf Islands but not Gabriola or Valdes. N=694 including 44 strike-slip faults and 90 normal faults.

Interpretations

This section is not going to break new ground (so to speak) in the field of research into the geological history of Gabriola. A single stress can create a considerable number of different types of fracture, including shear stresses (single and conjugate), faults, and joints. When these fractures are stressed a second and third time in different directions, the resulting mozaic is going to require way beyond my level of skill of interpretation to sort out. Also, an analysis that treats fractures as 2- and not 3-dimensional structures, as does this one, is bound to be flawed. But for what it's worth, here's my take.

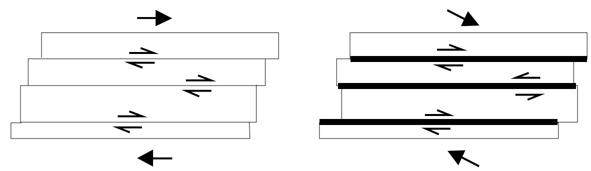
E-set fractures

E-set fractures define the orientation of most of both the south and north coasts of Gabriola (approximately N70ºW). They are most numerous in the central region and at places like Brickyard Beach, their relationship with the folding is pretty clear; they are longitudinal fold (axis-parallel) fractures. The H-set fractures are almost certainly the related lateral fold fractures.

F-set fractures

F-set fractures are shear fractures and for most of the time during this investigation, I thought of them together with the A-set as part of a conjugate set. Certainly this seems likely at Berry Point. However, the arithmetic is not that good—the separation is only 44° compared to the expected 60°.

An alternative idea comes with the realization that the north-end fault might well be an F-set fracture. If so, the set is predominately a right strike-slip set with a strike that runs perpendicular to the folding and faulting on adjacent Vancouver Island. The coast from Dodd Narrows to Yellow Point for example follows the general trend and runs N25°W which is the F-set minus 98°. The F-set are therefore according to this interpretation lateral fold fractures or cross fractures that have subsequently been slipped.



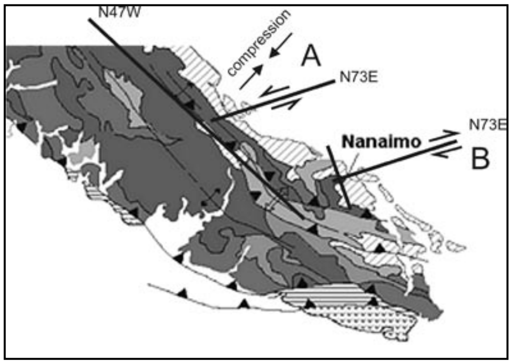
Fractures such as the F-set fractures generated by simple shear stress as shown on the *left*, tend to have the same sense of slip, in this case right (dextral) slip. In contrast, offset shear stress (providing some compression) acting on pre-existing fractures shown on the *right* would be more likely to develop fractures with a mix of senses depending on how firmly locked together the segments are, in this case two right (dextral) slips with a left (sinistral) slip between them. Such a pattern also seems to me to be likely to develop when pre-existing parallel fractures are subsequently sheared.

This second pattern is the one that matches the F-set fractures—their displacement directions (left or right) are variable.

G-set fractures

Just as the F-set fractures may be related to the north-end fault, so the G-set fractures may be related to the south-end fault. The south-end fault is a left strike-slip and evidently related to folding and faulting south of Gabriola.

The simplest interpretation is that the G-set are conventional oblique strike-slip fractures. The Cowichan Lake Fault Zone and other major faults on Vancouver Island to the south run increasingly counter-clockwise moving south, implying a compression axis of very roughly N15°E at the longitude of the southern Gulf Islands.



Two possible origins of the north-end fault and related F-set fractures.

A: the fault is a strike-slip fault generated by the thrust that developed the Beaufort Range Fault Zone, which strikes N47°W. The fault is offset from the NE trending axis of the compression stress by 30°, as is common.

B: the fault is a lateral fold (cross) fracture that has been subsequently been slipped by unequal stress on the north and south sides.

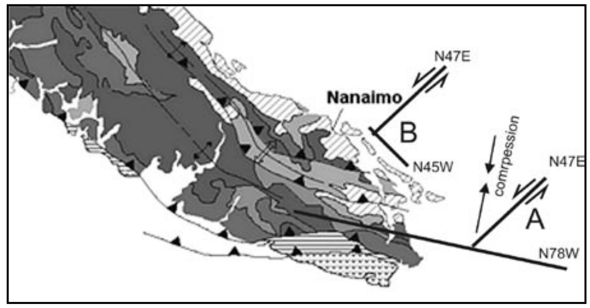
The evidence favours B; the fault is a right not a left strike-slip fault as required by A; and the Chase River fault on Vancouver Island, which is a likely continuation of the north-end fault, sinuously crosses axes of folds and other faults in the Nanaimo coalfields at right angles, not obliquely. These axes and faults run locally more northerly than in central Vancouver Island possibly as a result of the basement topography.

A classical 30° offset fom this puts a classical left strike-slip fault at N45°E.

However, there are several alternative interpretations. The one I like best is that the south-end fault is similar in character to the north-end fault in that it runs perpendicular to the folding and faulting on the adjacent Strait of Georgia seabed—the Outer Islands Fault Zone.

B-set fractures

B-set fractures may be related to the north-end "hole" discussed earlier.[24]



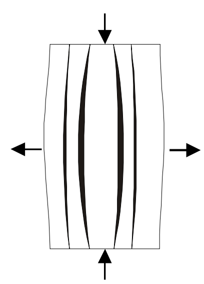
Two possible origins of the south-end fault and related G-set fractures.

A: the fault is a strike-slip fault generated by the thrust that developed the Cowichan Lake Fault Zone, which strikes N78°W in the south. The fault is offset from the NNE trending axis of the compression stress by 30°, as is common.

B: the fault is a lateral fold (cross) fracture that has subsequently been slipped by unequal stress on the north and south sides.

The evidence again favours B. The geometry is a better match; the fault runs at right angles to the Outer Island Fault Zone, which incidently is likely still active, and to the "third" major fault on Gabriola through the Flat Top Islands.

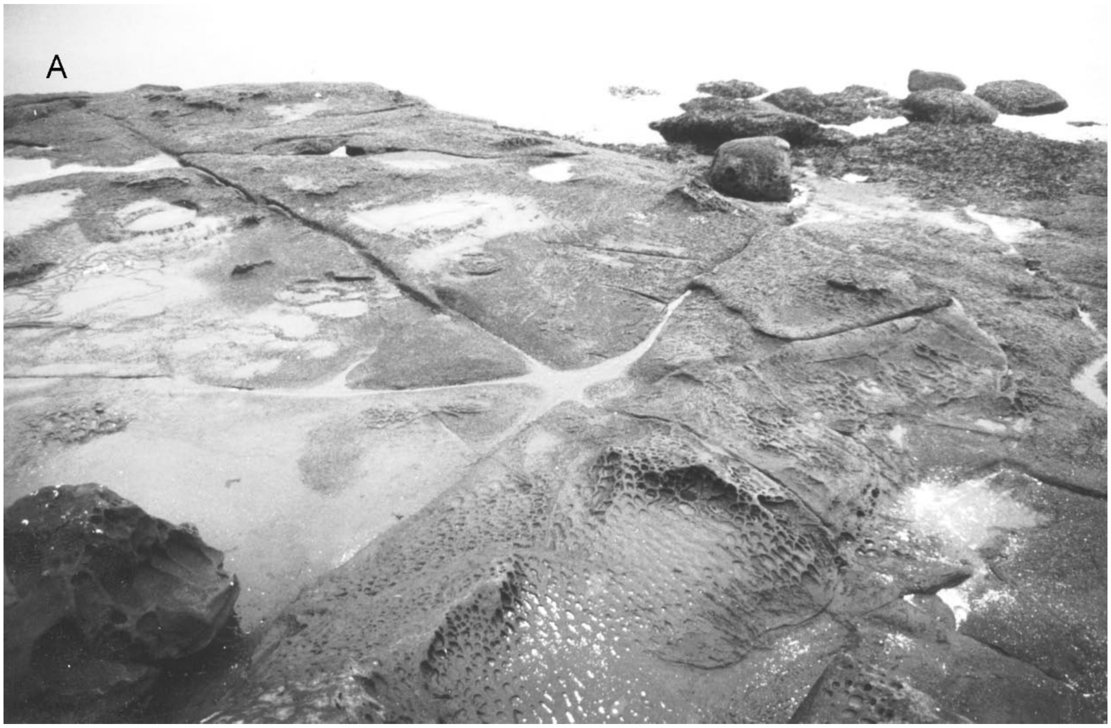
A-set fractures



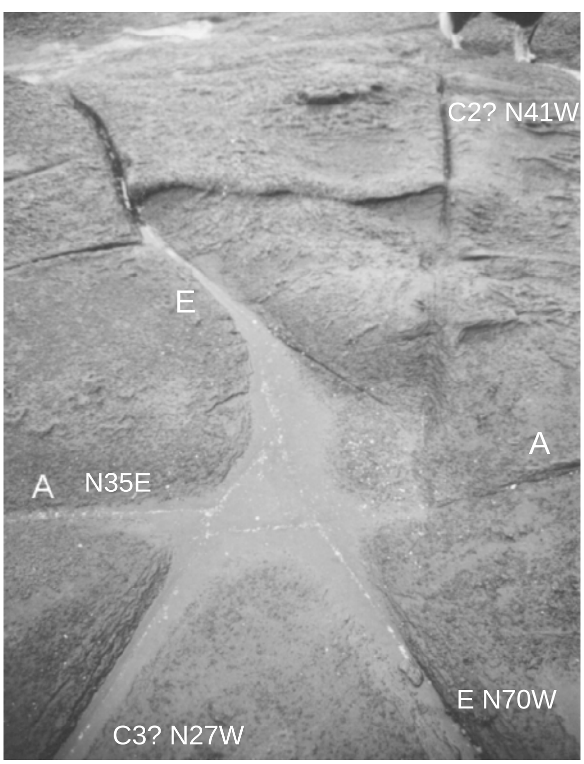
A-set fractures are normal faults with a distinctive pull-apart characteristic. The tensile stress appears to have acted roughly NW-SE. The island was evidently stretched at one time in a direction parallel with its syncline axis.[24] A-set fractures occur all over the island and although they do not appear to be related to a major fault, they likely are related to the elongation by normal-slip faulting observed on both the north and south shores of the island.

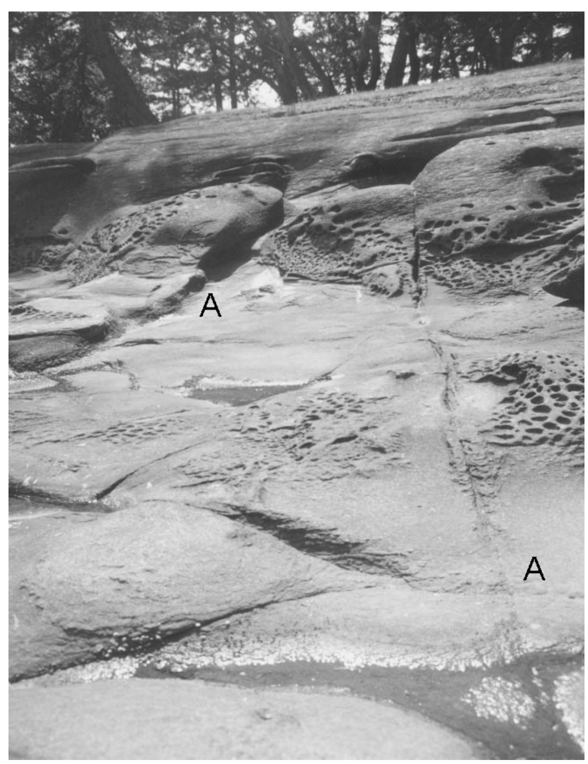
My guess is that these are fractures generated during Eocene folding, and that there is a strong relationship between the A- and H-sets and the E- and C1-sets.

[24] *SHALE* 20, pp.31–2.



Above and below: The “rockstar” in Drumbeg Park. These fractures look like the result of purely local stress, but they aren’t. The fracture running to the *top left* in the picture *above* is an A-line fracture, shown also running horizontally to the left in the picture *below left*. It belongs to a set that at the south end of the island run N 33º E, which is very close to the orientation of the fracture shown on the *front cover* near Seagirt Road. The Drumbeg A-set fractures shown running up to the top of the beach *bottom right* are, like those at the other end of the island, tensile fractures.





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J.M. Journeay & J. Morrison, *Field Investigation of Cenozoic structures in the northern Cascadia forearc, southwestern British Columbia, Canada*, Geol. Survey of Canada, Current Research, pp.239–50, 1999-A/B. ◊