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Errors and omissions:
Some of the captions omitted scales in the printed version. This version is correct.

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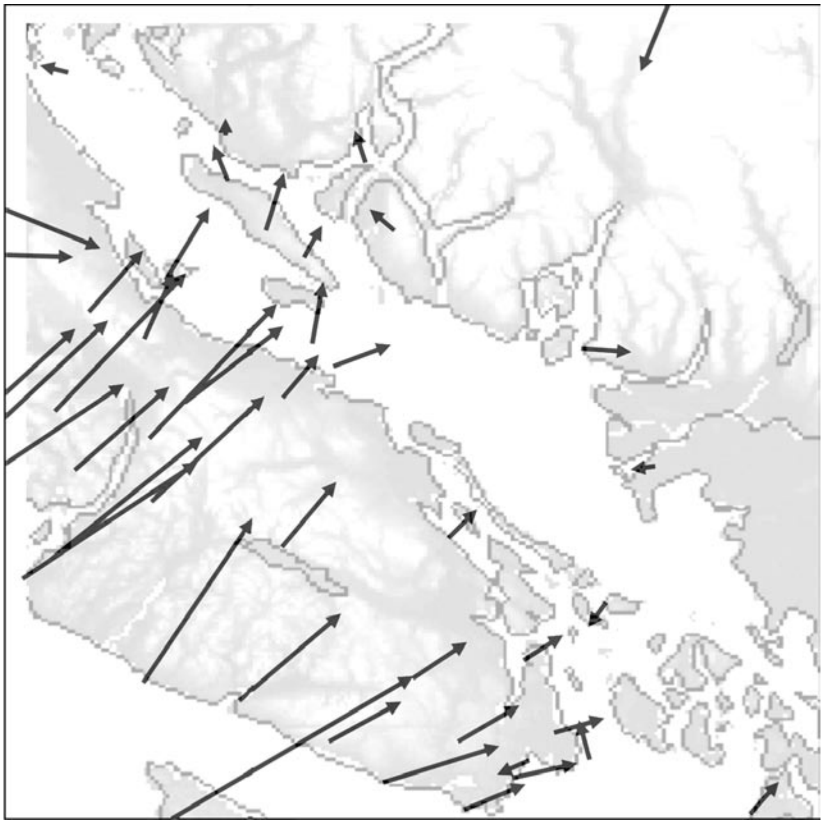


Horizontal movements of GPS stations in the southern Vancouver Island and Strait of Georgia area. All movements have been calculated relative to Gabriola Island (the Folklife Village).

The base of the arrows indicates roughly the location of the GPS stations, and the length of the arrows, roughly the speed of the motion—the average is around 4 mm per year.

Note the slightly diverging motion to the north and south of us. This accords with the observation that the southern shore of Gabriola has been stretched—normal faults to the right and left are common there

Terra firma?—
GPS measurements around Gabriola

by Nick Doe

One of the seemingly miraculous achievements of modern technology is the development of techniques for actually measuring the rate at which distances between "fixed" locations on the Earth's surface change. The speed at which rocks move about the surface of the Earth as a result of plate tectonics is generally in the range of a few millimetres per year, about the speed that toenails grow,[1] and this motion is detectable by present long-range sub-millimetre differential global positioning systems (GPSs).[2]

Here on the west coast of North America, GPS measurements of motions indicate that some parts of the coast are moving at different rates than others. While this is to be expected of points on different tectonic

[1] On average, toenails have been found to grow at about 18 mm/ year. Some plates move faster than this, some slower. At 18 mm/year, enough time has elapsed since the formation of the Earth, 4.55 billion years ago, for a continent to have drifted completely around it twice.

[2] Devices for measuring distortion known as "strain gauges" only work over a few inches and require the two ends to be physically connected. Within a few years, it is anticipated that even inexpensive car navigational systems will be able to measure the vehicle's position with near-centimetre accuracy—sufficient perhaps to give help at last to those who never did learn how to parallel park.

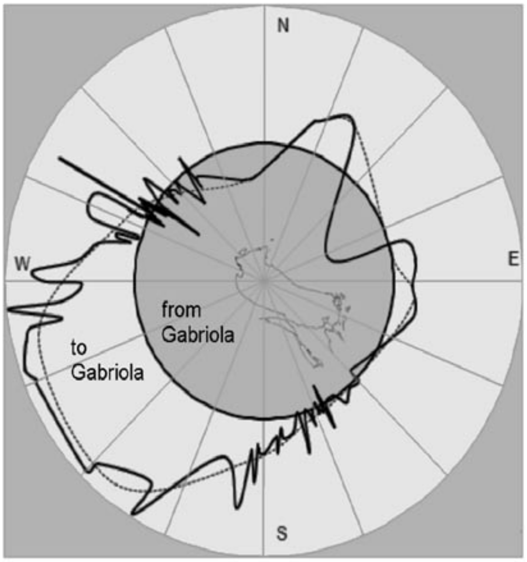


Figure 1: RADIAL SPEED

Movement of distant land toward and away from Gabriola as a function of compass direction.

[dε(θ)/dt scale: ±6 mm/100km/century ε = strain]

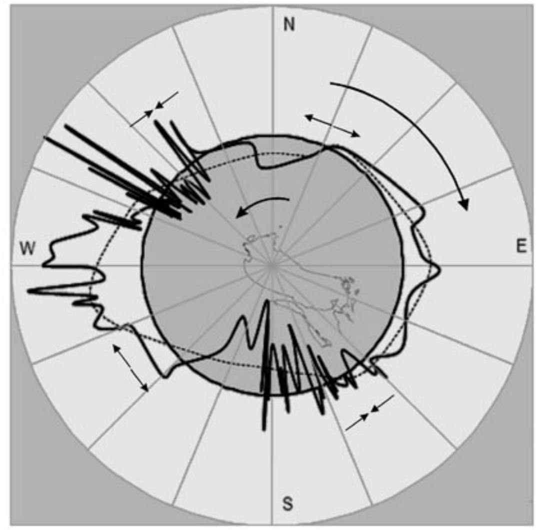


Figure 2: ROTATIONAL SPEED

Rotation of distant land clockwise and counter-clockwise relative to Gabriola as a function of compass direction.

[dθ/dt scale: ±3.3°/million years]

plates, the data shows that there is also horizontal movement between points on the *same* plate, which means that either the rocks between them are being strained (distorted), or they are being tilted.

I thought it might be fun to use these measurements to see what is happening specifically on Gabriola. The results are surprising—geology isn't just about the distant past; it includes things that are happening right now.

Movement of 110 GPS stations in the late 1980s and early 1990s within about 1000 km of Gabriola are available,[3] but only the 57 closest ones were used to compile most of the diagrams.[4] The movements are the horizontal movements—measurement of vertical movement is more difficult and was not made at many of the stations providing the data.

"Gabriola" was taken to be located at the Folklife Village.

Radial speed—Figure 1

The first diagram shows the movement of land around Gabriola away from, and toward, the island.

The black squiggly line in Figure 1 that circles around the centre (Gabriola) is sometimes within the inner shaded circle and sometimes outside it. Where the squiggly line is within the inner circle, the motion of distant land in that direction is away from Gabriola. Where the squiggly line is outside the inner circle, the motion of distant land in that direction is toward Gabriola.

You can see for example, that all land southwest of Gabriola is moving toward the

[3] Specifically from 338 km north (52°N the latitude of Ocean Falls), to 668 km east (114°W the longitude of Calgary), to 978 km south (40°N the latitude of Redding CA), and to 336 km west (129°W the longitude of Cape Scott).

[4] Those within 100 km north; 150 km east; 200 km south; and 150 km west.

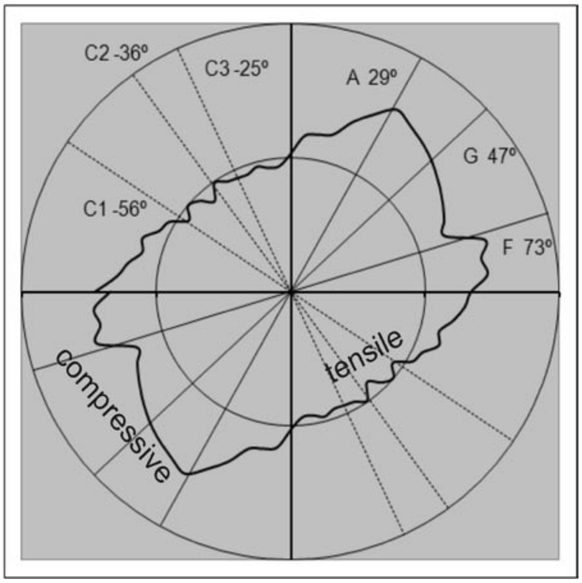


Figure 3: RADIAL STRESS—within the inner circle stress is tensile, outside, compressive.
[dε(θ)/dt + dε(θ+π)/dt scale: ±6 mm/100km/century]

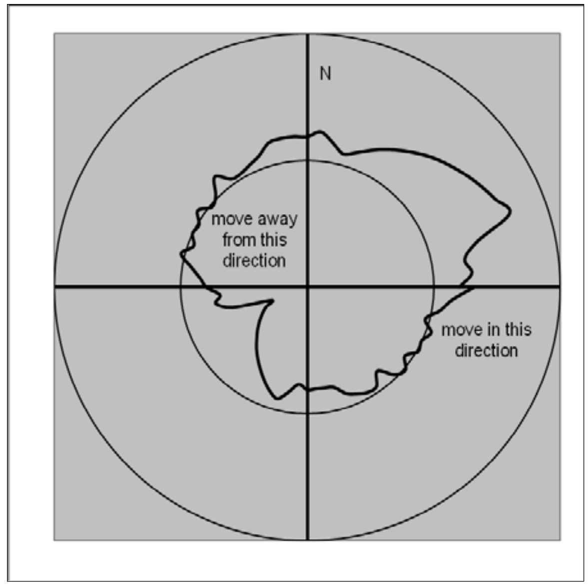


Figure 4: DIRECTIONAL FORCES—within the inner circle, the implied forces are trying to move Gabriola away from this direction, outside, in this direction.
[dε(θ)/dt – dε(θ+π)/dt scale: ±6 mm/100km/century]

island, while land to the north-northwest is moving away. The rim of the outer circle represents about 6 mm/100km every century toward Gabriola; the inner circle itself marks "no movement"; and the point in the centre of the circles represents about 6 mm/100km every century away from Gabriola.

Rotational speed—Figure 2

The second diagram shows the rotation of land around Gabriola.

Where the squiggly line in Figure 2 is within the inner circle, the relative motion of the distant land is counter-clockwise. Where the squiggly line is outside the inner circle, the motion is clockwise.

You can see for example, that distant land to the east and west of Gabriola is rotating clockwise, while distant land to the north and south is rotating counter-clockwise. The rim of the outer circle represents about 3.3 degrees of clockwise rotation every million years; the inner circle itself marks "no rotation"; and the point in the centre of the circles represents about 3.3 degrees of counter-clockwise rotation every million years.

One of the results of the impact of the Crescent terrane with Vancouver Island in the Eocene was the counter-clockwise "rotation" of the southern part of Vancouver Island relative to the northern part about a vertical axis just northeast of Port Alberni.[5] It was this counter-clockwise rotation that opened up Barkley Sound and the Alberni Inlet on the outer coast, and contributed to the compression and folding on the inner coast where the Gulf Islands are now. It's interesting to note that, whether related to events in those far off times or not, the distant land between southwest and southeast of Gabriola appears still to be rotating counter-clockwise.

[5] Johnston & Acton, 2003. The "rotation" was mostly bending facilitated by slip faults with minor "pure rotation" late in the process.

Radial stress—Figure 3

The third diagram is similar to Figure 1 but differs in that it shows motion away from, and toward, the island as the average of the motion in opposite compass directions.

If the squiggly line is within the inner circle, the average motion along that axis is away from Gabriola, implying tensile stress along that axis.

If the squiggly line is outside the inner circle, the average motion along that axis is toward Gabriola, implying compressive stress along that axis.

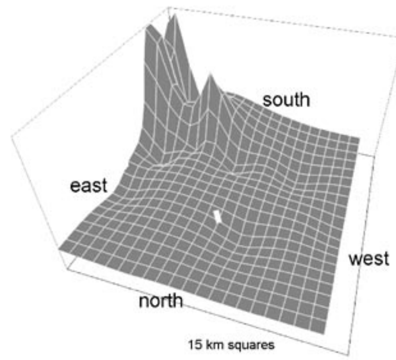
The inner circle itself marks "uniform motion", that is the motion to Gabriola in one of the directions along that axis is equal to the motion away from it along that axis in the opposite direction.

The lines A, F, G, C1, C2, and C3 in Figure 3 mark orientations of sets of fractures on Gabriola.[6] What is very surprising to me (I'm tempted to say "astounding") is that the modern stress, inferred purely from GPS measurements, matches very nicely, thank you, the orientation of fractures that are considered to be tens of millions of years old.

Directional forces—Figure 4

The fourth diagram also shows motion away from, and toward, the island but as the average of the difference in motion in opposite compass directions. That needs explaining, but is quite simple.

If the squiggly line is within the inner circle, the average differential motion is toward Gabriola, implying Gabriola is acting as an obstacle. Gabriola "ought" to be moving away from that direction so as to reduce the relative motion.



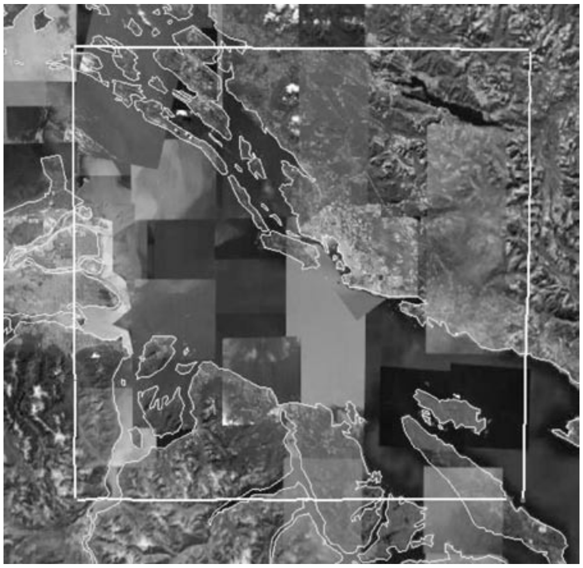
Vertical land movement around Gabriola. The aerial view *above* shows the Strait of Georgia from the northwest. The diagram *below* shows vertical movements from the same perspective as detected by GPS. The short white line near the centre marks Gabriola. Vertical grid scale is 1 mm/year.

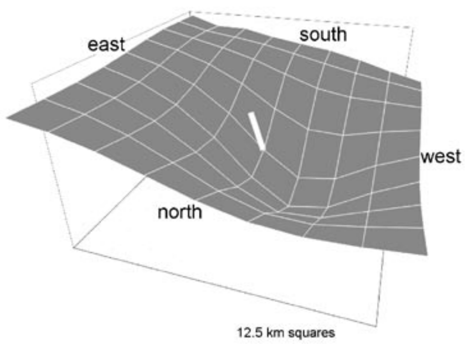
If the squiggly line is outside the inner circle, the average differential motion is away from Gabriola, implying that Gabriola is acting as a laggard. It "ought" also to be moving in that direction.

The inner circle itself marks no differential motion. The implied forces along that axis are zero or are stressing Gabriola rather than trying to move it.

If Gabriola were to "slip its moorings", you can see that it would drift away east-northeast (N68°E) in the general direction of

[6] See *SHALE* 20, pp.43–58.





Vertical land movement around Gabriola. The aerial view *above* shows the Strait of Georgia from the northwest. The diagram *below* shows vertical movements from the same perspective as detected by GPS. The short white line marks Gabriola.

West Vancouver. Readers who have read this far will also note that this is pretty much the direction the north and south ends of the island have already moved along the north- and south-end faults.

Vertical motion

Although, as I said earlier, measurements of vertical movements are more difficult to make, there is some interesting information in the available data.

The tilting and bowing of Vancouver Island combined with the sinking of the Fraser delta is what most people have in mind when considering such data, particularly in discussions about rising sealevel, but it is the growth of the mountains around Mount Baker that is outstripping all other vertical movements in the region.

Finally, to stretch the data more than I ought once again, I can't help pointing out that the vertical motion of the land in the immediate vicinity of Gabriola seems to indicate that the "hole" off the north end of the island talked about earlier[7] is getting deeper.

So, is this "hole":

- a fundamental feature of the architecture of the Nanaimo Basin that is many million of years old;
- a remnant lack of isostatic rebound left over from the removal of the ice ten thousand years ago; or
- geology demonstrating once again that geology is not stuck in the past but is happening right now?

One way or another, only time will tell. ◊

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[7] See *SHALE* 20, pp.31–2.