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Malaspina University College is now Vancouver Island University.

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The ups and downs of Gabriola —sea-level changes

by Dr. Steven Earle

Introduction

Next time you're stuck in a ferry line up, consider this. If you had lived on Gabriola, twelve thousand or so years ago,[1] the chances are that you wouldn't have had to take a ferry at all! You could have driven all the way to Nanaimo without even getting your tires wet. On the other hand, a few thousand years before that, only a very small part of Gabriola Island would have been above sea level. The lots on the cliffs near the golf course would have had walk-on access to the beach in those days.

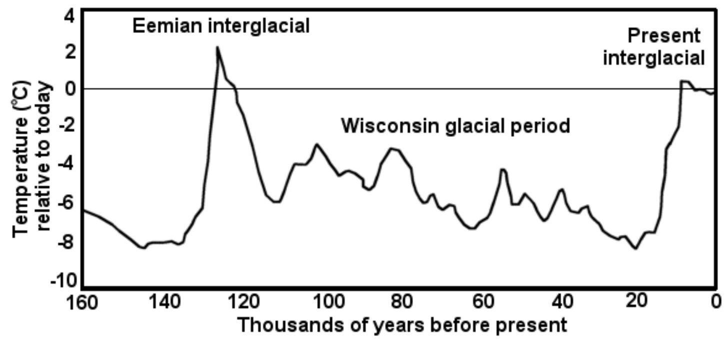

Figure 1: Global temperatures for the past 160 000 years, showing the extent of the Wisconsin glaciation. (after Crowley, 1996)

Like the rest of coastal British Columbia, Gabriola Island has been on a bit of a roller-coaster ride during the past twenty thousand years—a result of the processes of glaciation and de-glaciation.

Canada has been affected by at least five major episodes of glaciation over the past million and a half years. The most recent glacial period is known as the Wisconsin, after the US state to which the ice extended, and this lasted from 120 000 years ago to around 17 000 years ago (Figure 1).

The peak of the Wisconsin Glaciation occurred close to 20 000 years ago—and at this time, thick ice sheets covered nearly all of British Columbia. Although much of nearby Washington State was ice-free, ice did extend down the Strait of Georgia into Puget Sound, and some distance south beyond Tacoma and Olympia (Figure 2).

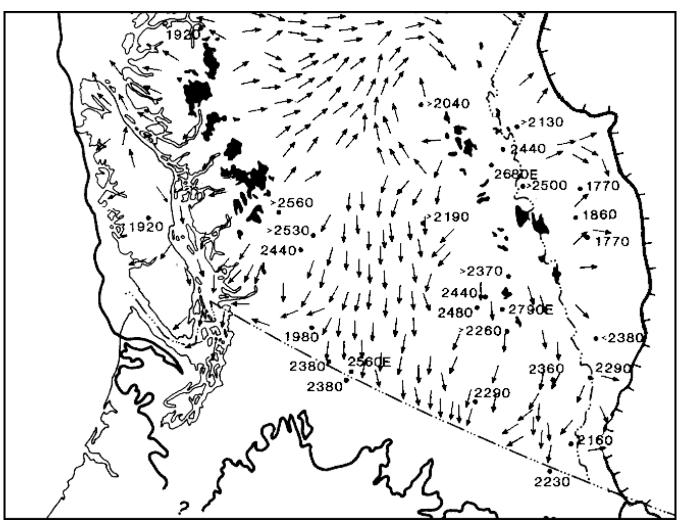

Figure 2: Late Wisconsin glaciation in southwest British Columbia, showing generalized ice-flow directions and ice thicknesses in metres. (from Clague, 1989)

[1] All dates in this article are calendar years before 2000 AD. They are not ^{14}C BP dates.

Glacial melt-back began sooner in eastern North America (around 19 000 years ago) than it did here (around 17 000 years ago), so for a couple of thousand years Toronto actually had better weather than we did!

It's all relative

Eustatic adjustment

Over geological time, the earth has had a relatively constant amount of water. At present, most of this is in the oceans, with only a small proportion existing as ice, primarily on Antarctica and to a lesser extent on Greenland. As continental ice-sheets grow during a glacial period, more and more of the earth's water is tied up in ice, and sea level gradually drops—by as much as a few hundred metres.[2] When the ice melts again, sea level gradually rises. Sea-level changes of this type—which are global in scope—are known as *eustatic* adjustments (Figure 3).

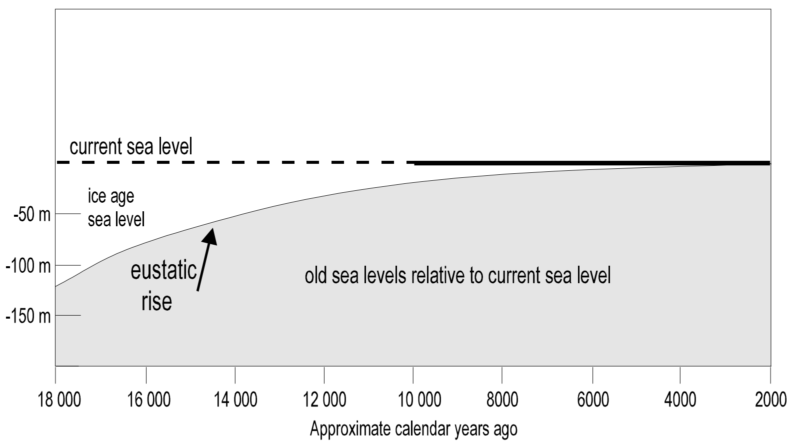

Figure 3: Eustatic adjustment. The rise in global sea level as the ice melted and the climate warmed toward the end of the Wisconsin glaciation.

The curve illustrates a general principle, and may not be accurate in detail.

Isostatic adjustment

Although we are accustomed to the level of the sea going up and down—it does it every day—a less familiar phenomenon is the rise and fall of the land. It's less familiar of course because, except during catastrophic earthquakes, it happens only very slowly.

The earth's crust floats on the semi-liquid mantle in the same way that the crust of a fruit pie floats on the filling. If you push down gently on the piecrust, it will sink in a little way. When you let go, it will gradually spring back. When covered with ice-sheets that are hundreds of metres thick, and therefore very heavy, the earth's crust will slowly sink down further than normal into the semi-plastic mantle. As the ice melts, the crust slowly rebounds back to its ice-free position. This causes *relative* sea level to change, and changes of this type are known as *isostatic* adjustments (Figure 4).

Unlike eustatic adjustments, which are global in nature, isostatic sea-level adjustments only affect the areas covered by the ice and the adjacent few hundred kilometres.[3] The rate

[2] We say "continental" because floating ice and ice-shelves that aren't grounded have no effect on sea level. As Archimedes pointed out, the water locked away in floating ice occupies exactly the same volume as that portion of the floating ice that is below the surface.

[3] When crust is depressed by the weight of ice, unglaciated land immediately adjacent to the ice-sheet may bulge up, just as the filling of a pie might ooze up round the edges of the depressed crust. Haida Gwaii (Queen Charlottes) remained largely unglaciated during the ice age, and was pushed up by just such a bulge. Parts of the Hecate Strait were above sea level. (Fedje and Josenhans, 2000)

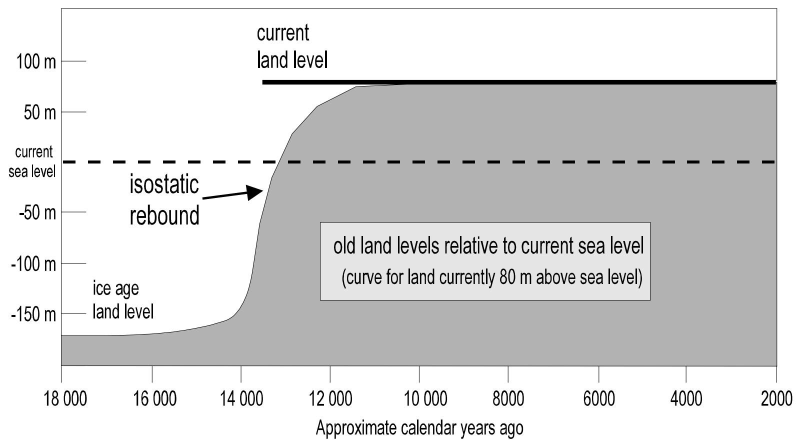

Figure 4: Isostatic adjustment. The rise in local land level as the ice melted at the end of the Wisconsin glaciation.

The curve illustrates a general principle, and may not be accurate in detail.

at which the land sinks down, or bobs back up, is determined by the viscosity of the mantle. We aren't actually certain of the viscosity of the mantle beneath us, but we have a pretty good idea, and that is part of what this paper is about.

The sequence of post-glacial events

As the largest North American (Laurentian) and Eurasian ice sheets began to melt back around 19 000 years ago, global sea level started to rise. Meanwhile, the ice sheet in this region–the Cordilleran ice sheet–continued to push south into Puget Sound, and the local crust remained depressed by the weight of the ice. By the time that the Cordilleran ice sheet had melted back to north of Vancouver Island around 15 000 years ago, global sea level had risen significantly, but the crust of our area had only just started to rebound. As a consequence, the low-lying parts of Vancouver Island and most of the Gulf Islands were submerged (Figure 5).

Over the next few thousand years, with the ice gone from Vancouver Island and the adjacent mainland, the crust rebounded by as much as 250 metres, raising the level of the land relative to the sea higher than it is today. However, the land

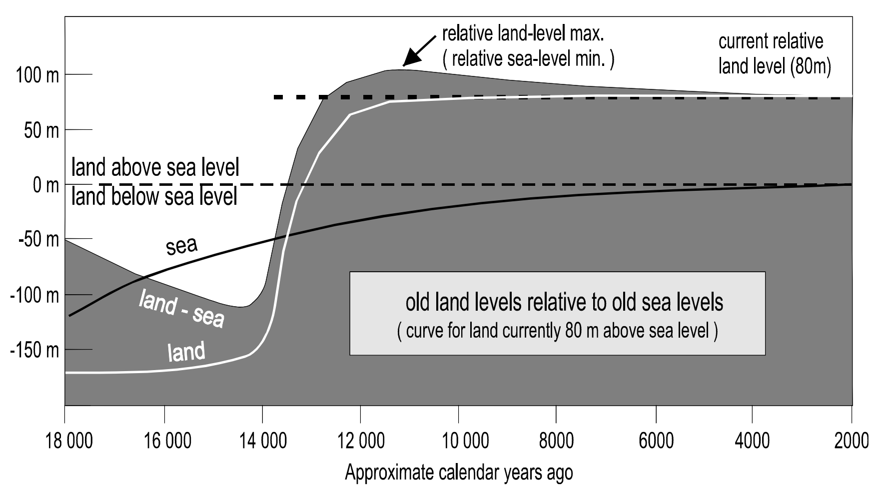

Figure 5: The level of the land relative to the sea (shown for land that is currently 80 m above sea level). *Relative* land level is the difference between absolute land level (Fig. 4, the white line here) and absolute sea level (Fig. 3, the black line here).

The curve is intended to demonstrate general principles, and may not have the accuracy of Figure 10, for example. Levels and times also varied somewhat at different locations around the Strait of Georgia.

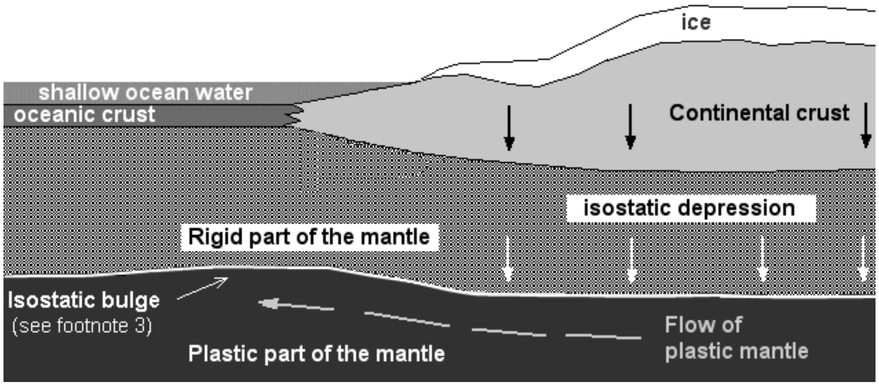

Figure 6: During the ice age, up to about 20 000 years ago, sea level was low because so much water was locked up in the ice. However, the land beneath the ice-sheet was even lower because the earth's crust had been pressed down into the underlying mantle by the weight of the ice. Around the fringes of the ice-sheet, unglaciated land was locally elevated as displaced mantle material accumulated beneath it (the isostatic bulge). [Unrelated subduction is not shown]

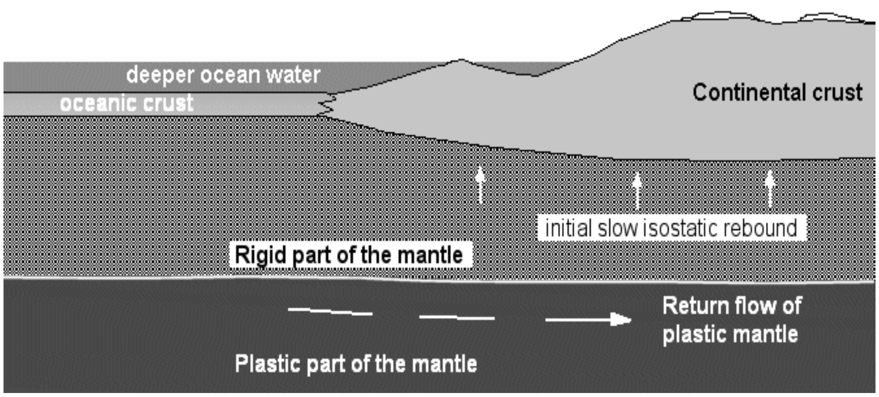

Figure 7: By the time that the ice-sheets in this area had melted and the land had began to recover from the removal of the ice, global sea levels were already rising due to the earlier melting of ice-sheets elsewhere in North America and Eurasia. This was the time, about 15 000 years ago, when relative sea level was at its highest.

rebound (isostatic adjustment) was over relatively quickly, and so relative land level slowly declined toward its modern value as the huge Laurentian ice sheet continued to add its meltwater to the sea. By 6000 years ago, relative sea level was within a few metres of what it is today. The rate of rise of relative sea level over the past few thousand years has been only a fraction of a millimetre per year.

Figures 6–8 illustrate the physical events underlying these changes. These diagrams show the crust and mantle relationships along Canada's western margin at various glacial- and post-glacial times. Note that, for clarity, the unrelated, but ongoing subduction of oceanic crust beneath the continental crust has not been shown in these diagrams.

Our knowledge of these events has been gained partly from fossil evidence, and partly from a study of the physics of the processes involved.

Based on what is known about the history of global (eustatic) sea-level rise, and the calculated rate of isostatic rebound in this region, relative sea levels around Vancouver Island could have been as much as 200 metres above current levels around 15 000 years ago (Figure 7).

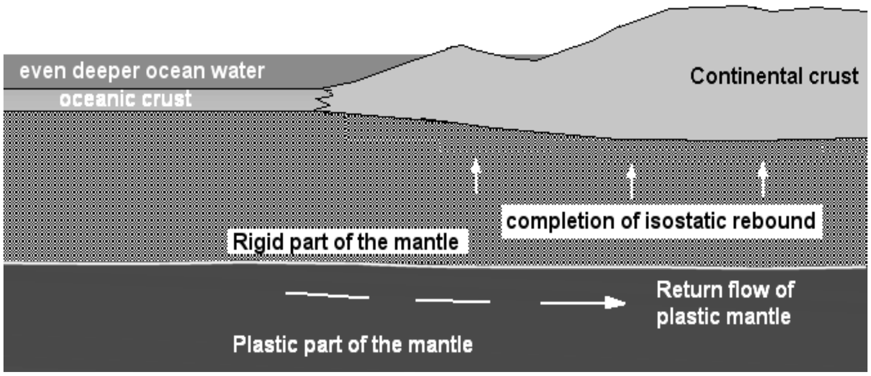

Figure 8: After the local ice-sheets had melted, the land reverted to its normal (ice-free) height fairly quickly. Relative sea level dropped, and then for thousands of years, began to rise slowly toward its present value. Sea level was within a few metres of its present level about 6000 years ago, although it continued to rise, almost imperceptibly, right through to the last century. It is doubtful that today's changes are related anymore to post-glacial recovery.

Fossil evidence

Vancouver Island has numerous examples of marine fossil deposits of immediate post-glacial age, at elevations ranging up to nearly 200 metres above current sea level. Examples are sites in both the Courtenay and Parksville areas, near to the Nanaimo Hospital, close to Malaspina University College, and at Cedar-by-the-Sea. Marine fossils of post-glacial age have also been observed at an elevation of around 30 metres in the gravel pit off Dorby Road at the southeast end of Gabriola Island.[4] These fossils (Figure 9), about 20 species in total, are probably over 13 000 years old and situated within unconsolidated blue-grey silty-sand, which is underlain and overlain by brown sand and gravel. Most of the shells are of molluscs, including the bivalves chalky macoma (*Macoma calcera*), pink scallop (*Chlamys rubida*), and butter clam (*Saxidomus giganteus*); and the gastropods moon snail (*Polineces lewisii*) and arctic saxicave (*Hiatella arctica*). The contorted tubes of scaly tube snail (*Serpulorbis squamigerus*) are also abundant. Many of the species observed on Gabriola, and at similar sites on Vancouver Island, are typical of relatively cold waters.

There is conclusive fossil evidence that sea level in the Nanaimo region was at least 100 metres above the present level at around 15 000 years ago. At that height, almost all of Gabriola Island would have been submerged (Figure 11).

Theoretical physical evidence

We have no fossil evidence of how low the post-glacial sea level fell, and so we are dependent on calculations that are based on the viscosity of the mantle. Thomas James and colleagues from the Pacific Geoscience Centre and Simon Fraser University have done calculations using values that are consistent with other mantle viscosity studies carried out elsewhere.

At the low-viscosity end of the scale the crust of this region would have responded quickly to the removal of ice, and would have rebounded to current-day levels by around 14 000 years ago (Figure 10).

4 This is a working pit. Public access during non-working hours is at own risk and courtesy of the landowner, Mr. G. Boulton.

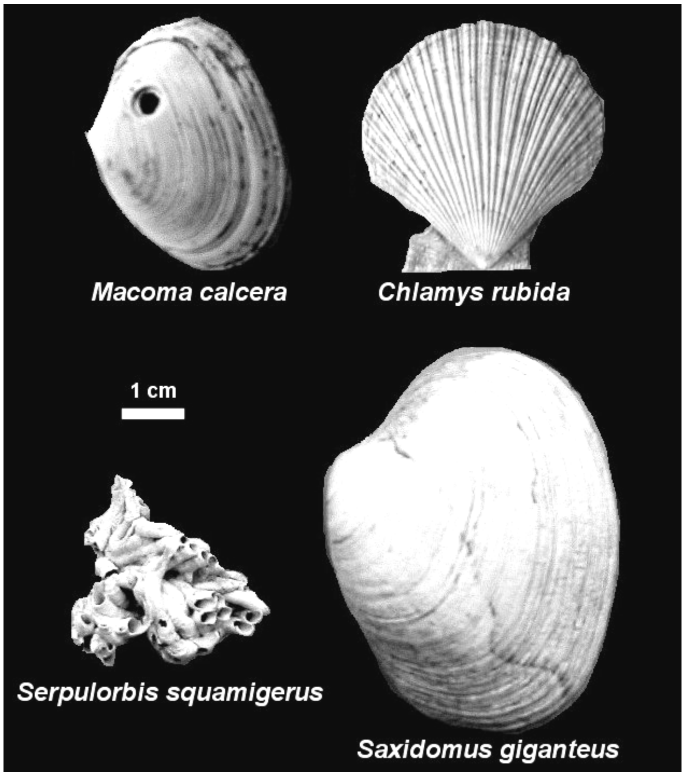

Figure 9: Some of the pelecypods and gastropods found in the Gabriola Island gravel pit. The hole, top left, was probably drilled by a moon snail.

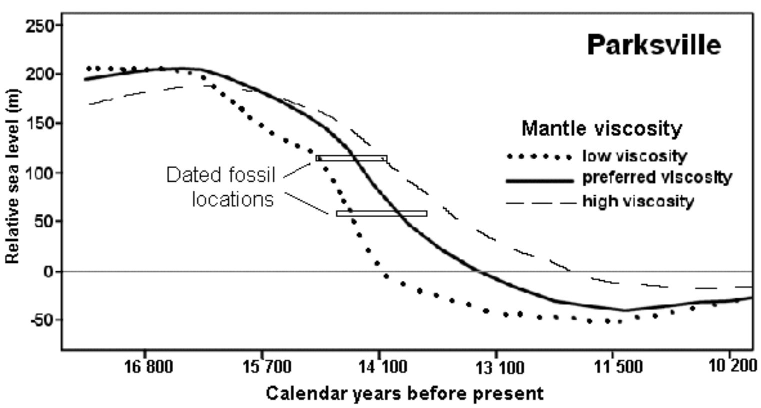

Figure 10: Relative sea-level curve for central Vancouver Island from 16 000 to 10 000 years ago. (after James et al., 2000)

Since eustatic (global) sea-levels did not reach current-day levels until about 6000 years ago, relative sea level could have been tens of metres below current-day levels for several thousand years during the early post-glacial period.

At the high-viscosity end of the scale, rebound would have been much slower, and the eustatic and isostatic adjustments might have been completed at roughly the same time, in which case relative sea level might never have been significantly below the current-day level.

Based on the "most likely" viscosity values, James et al. suggest that sea level could have been close to 50 metres below the current level at around 11 500 years ago. At that time Gabriola would have been merely a peninsula, and, as you can see (Figure 12), there would have been no need for a ferry to get to the big city!

Implications for archaeologists

Variation of relative sea level over the past ten thousand years has important ramifications for archaeologists. Depending on the period of interest, former coastal sites may be either above current sea level in the forest and consequently very difficult to find and poorly preserved, or they may be below current sea level with all the attendant difficulties for investigation that that entails. Sea level changes can also make changes to the ecology of an area, particularly in small bays and river estuaries.

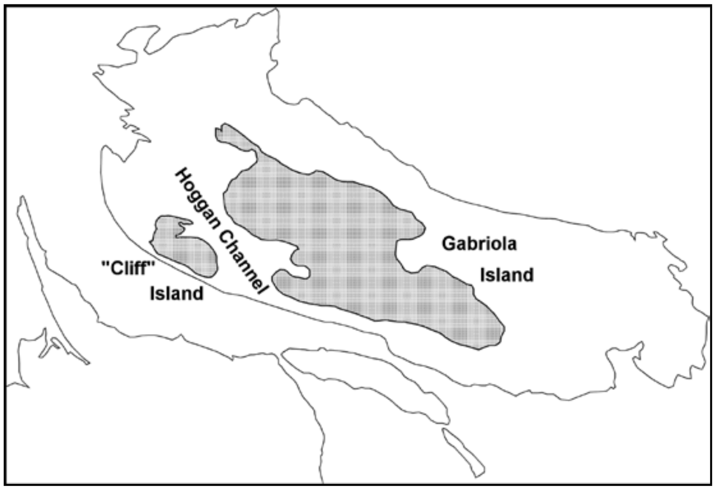

Figure 11: Possible coast line in the Gabriola area at around 15 000 years ago (100-m contour).

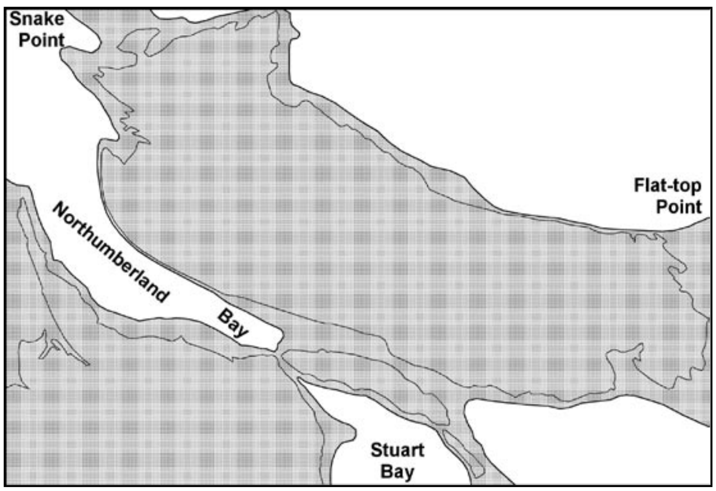

Figure 12: Possible coast line in the Gabriola area at around 11 500 years ago (50-m deep contour).

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Note: The author is interested to know about marine shell locations at higher elevations on Gabriola Island. If you have found marine shells similar to those shown here, that you think may be of interest, please contact Steven Earle at earles@mala.bc.ca.

Acknowledgement

The inspiration to study post-glacial sea levels on and around Vancouver Island came from the work of Dr. Keith Ketchen of Nanaimo, who described the fossils of the post-glacial marine sediments in the Nanaimo Hospital area and wrote an unpublished report in 1996, entitled *The Clams and Scallops of Dufferin Crescent*.

Author Dr. Steven Earle lives in Nanaimo and teaches geology at Malaspina University College. He maintains a general-interest, earth science website, with a Vancouver-Island flavour, at

http://www.mala.bc.ca/~earles/index.htm

He also leads field trips, which non-students are usually able to arrange to attend. ◊