Context:
Geology, fossils, Gabriola, inoceramids

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Errors and omissions:

Convection currents in the earth's mantle and the breakup of Pangea are nowadays (2013) regarded as being a little less well understood than they used to be. The pot-of-water-on-a hot-stove analogy, though still a popular model, probably over-emphasizes the role of heating, which occurs throughout the mantle, not just in the core, and under-emphasizes the role of cooling in the crust. Continental rifting may be due as much, or more, due to plates being pulled or dragged apart as crust sinks as them being pushed apart from rising magma. The evidence suggests that the asthenosphere below continents is cooler rather than hotter. See the literature on cabonatite and alkaline lavas in continental rift-related tectonic settings.

Later references:
Relationship to calcite (calcareous) nodules, *SHALE* 9, pp.41–52.

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Inoceramus vancouverensis—big clams

by Nick Doe

There's a lot of talk these days about global warming—its causes, its consequences—but for some who used to live here, it was not "warming" that was a problem, it was the reverse—"global cooling". To get to the bottom of this particular story however—and it's a rather murky story—we have to go back quite a long way.

Setting the scene

Most of the rocks—sandstones, shales, conglomerates—that make up Gabriola and nearby islands were formed from relatively deep-water marine sediments[1] way back in the *Campanian* and *Maastrichtian* ages of the *late-Cretaceous*,[2] between about 65 and 80 million years ago. The Cretaceous period came to an end rather dramatically when the earth was hit by a large meteorite, an impact that came (confusingly for earth scientists) just as major changes were underway in the earth's climate and the earth's geography. The meteorite made a large hole in what is now the Yucatán peninsula of Mexico,[3] and in the process threw so much stuff into the stratosphere that the sun was obscured all over the world. Some say the subsequent darkness may have lasted for more than a year—long enough to ensure that dinosaurs and many other species died out, never to be seen again, except, of course, in movies.

The Cretaceous, together with the earlier *Jurassic* and *Triassic* periods were very different times from today. For a start, it was much warmer. The mean annual temperature of Axel Heiberg Island in the high Canadian Arctic was around 14ºC rather than near freezing.[4] Subtropical plants and animals, mainly cold-blooded animals, lived far poleward of their present limits (to 60º latitude rather than 30º). It used to be thought that the main reason for this was that the disposition of the earth's landmass allowed warm ocean currents to flow unimpeded to high latitudes. Recent research, however, suggests that a much more potent reason was the on-going release of huge quantities of carbon dioxide (CO_2) from volcanic eruptions, some of which lasted hundreds of thousands of years.[5] This carbon dioxide stimulated greenhouse

1 Typically a few hundred metres deep. The rocks of the Gulf Islands and SE Vancouver Island are known to geologists as the "Nanaimo group".

2 See back inside cover for a time-scale. In the context of geological time, "late" and "upper" have the same significance as more recent rocks usually, but not always, overlay older ones. The end of the Maastrichtian age of the Cretaceous period is marked by the now famous K-T (*Kreidezeit*-Tertiary) boundary, on our side of which, the T side, is the modern era, known to scientists as the *Cenozoic* or "time of new life". [*kreide* = chalk, *zeit* = time]

3 It is a little disappointing (to some) that there are no known rocks in the Gulf Islands laid down exactly at the K-T boundary. Almost all of the islands' landmasses date from a slightly earlier time. Any layer at the K-T boundary itself, assuming there was one, has been scraped or eroded away. At numerous other locations in the world, a fine layer has been found that carries evidence of the huge blast that occurred. The layer often includes solidified glassy globules of molten rock known as *tektites*, and unusual amounts of iridium and niobium; metals that are rare on earth but relatively common in meteorites.

4 J.A. Tarduno et al., *Evidence for Extreme Climatic Warmth from Late Cretaceous Arctic Vertebrates*, Science, pp.2241–2243, 282, 5397, Dec. 18, 1998.

5 These immense basaltic lava flows are known as *traps*, the Deccan region of central India being just one of several examples dating from the Cretaceous.

warming in the same way that driving your truck around the island does today.[6]

The second thing that was different about the Cretaceous was, as mentioned, its geography. The Triassic saw the beginning of the breakup of the supercontinent called "Pangaea". By early-Cretaceous times (144–119 million years ago), there were narrow, but growing seaways between Africa and break-away India, between North and South America, and between Africa and a single continent comprising what has now become Australia and Antarctica. Also about to go their separate ways were North America, Greenland, and northern Europe. Pangaea had been too big for its own good. Heat from the earth's interior had gradually accumulated under its thick blanket of rock until even volcanic eruptions lasting a million years couldn't get rid of it. The supercontinent had to go. And so, in places where the continental crust had been elevated and thinned beneath rising plumes of hot magma, rift valleys formed, widened, flooded, became waterways…and the supercontinent was slowly torn asunder.

Here in western North America, a shallow inland sea extended all along the eastern side of where the Rocky Mountains are now—a consequence of both higher sea levels in the absence of continental and polar ice-sheets, and of the land being depressed as cold, dense Pacific seafloor sank beneath it.[7] The westward movement of the continent, and the opposing eastward movement of the Pacific seafloor, swept volcanic arcs, oceanic plateaus, and microcontinents up against the continent's leading edge. Among the arriving microcontinents was "Wrangellia", part of which is now Vancouver Island. The "Gulf of Georgia" came into being. It was at the time, truly a gulf, open only at its northern end.

This was a time, not only of dinosaurs and many other unfamiliar living things, but also of big clams—the *inoceramids*.[8]

Fossils

Although a wonderful place to live, one thing that you can't say about Gabriola is that it's a great place for finding fossils. To be sure, you can always break open a piece of shale and find traces of the small creepy-crawlies that found a living in the murky bottom sediments. You can even find small specks of black tarry-looking substances, which presumably are the remains of their bodies, or of decayed vegetation. It's hardly enough though to fill a world-famous paleontology museum. What you can find in the shale, however, fairly easily, are the shells of a species of giant clam, *Inoceramus vancouverensis*, first described by paleontologist, Benjamin Franklin Shumard (he was American), in 1858.[9] They occur most often just below the high tide level on the beach at the southern entrance to False Narrows (by the cemetery), and on the beach

[6] The immediate effect of volcanic eruptions is to cool, not warm, the earth due to the blocking of sunlight by first, dust, and then sulphate aerosols. I am assuming here that the net long-term effect was nevertheless warming, but this is a debatable topic.

[7] Michael Gurnis, *Sculpting the Earth from inside out*, Scientific American, pp.40–47, 284, 3, March 2001. The descending seafloor that was responsible for Alberta's ocean is still detectable, now deep in the mantle beneath Hudson Bay and the eastern United States.

[8] Peter Harries & J. Crampton, *The Inoceramids*, American Paleontologist, pp.2–6, v.6, 4, Nov. 1998.

[9] Shumard, *New Fossils…from the Cretaceous of Vancouver's Island*, Transactions of the Academy of Science of St. Louis, pp.123–124, 1, 1859. I'll stick with "giant clam" even though, as a pterioid bivalve, they were actually a kind of oyster or scallop, albeit one that probably wouldn't have tasted very good.

Inoceramid fossils on the beach near the cemetery on Gabriola Island. The shells protect the shale from weathering and sometimes stand a few inches proud like hoodoos in the badlands.

in the Whalebone Drive area.[10] The "*I-vans*" are most striking on bright sunny mornings when the sun is still low in the sky, and a falling tide has left them still wet. Seen at the right angle, these 75-odd million-year-old shells can still dazzle with their iridescence.

As you can see in the photographs, some of these clams were big. One shell of an *Inoceramus steenstrupi* in a Copenhagen Museum from Nûgssuaq, Greenland, is almost six-feet (178 cm) long. Those commonly found on Gabriola are quite a bit smaller—a bit less than two feet, say 60 cm—but, by modern standards that is still some clam. One of them would have been equivalent, culinary-wise, to about four-dozen modern Japanese oysters. Evidently, the *Mesozoic* (Triassic, Jurassic, and Cretaceous—180 million years duration) was a fine time to be a clam. Which raises a question. Why, by the end of the Cretaceous had every species of inoceramid, without exception, gone extinct?

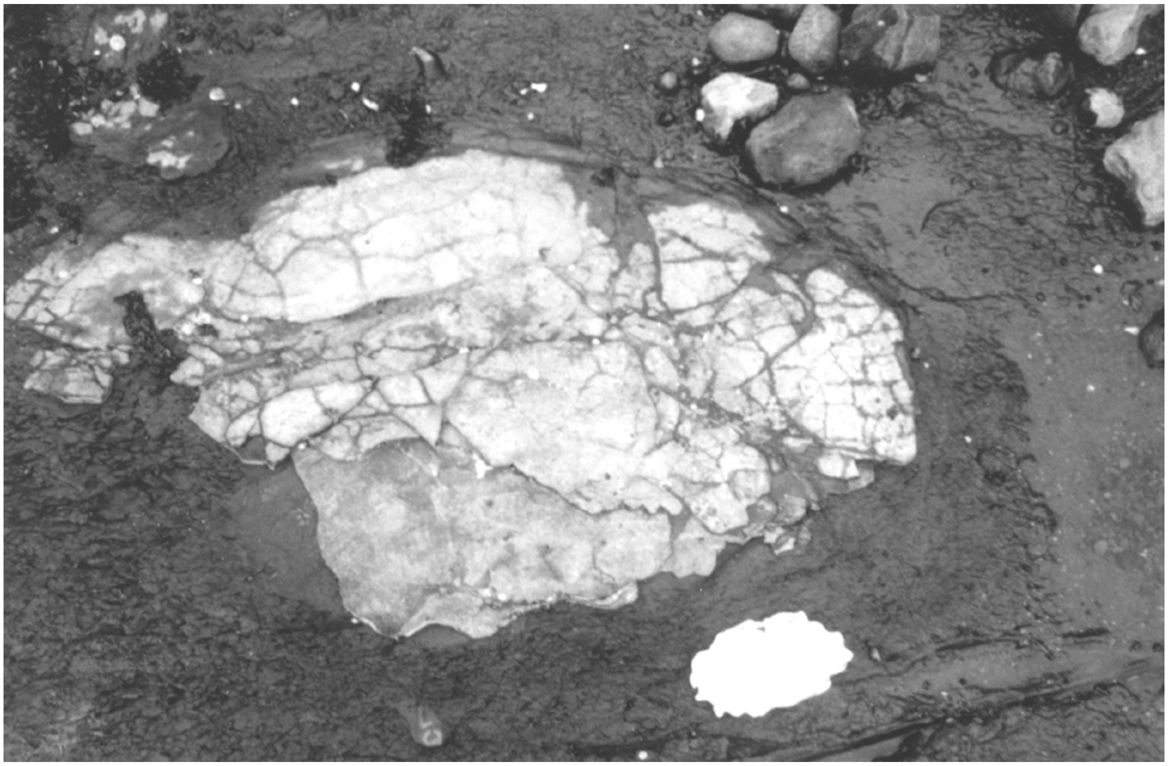
An easy answer is, of course, because it got colder. But that won't do. They could easily have moved their range southward toward the tropics—the temperature of the oceans changed slowly enough.

Maybe falling sea levels took away their favourite habitats? Sea level did most certainly drop towards the end of the Cretaceous as the climate and oceans cooled, perhaps even enough for continental and polar icesheets to develop.[11] But then, the evidence is that the inoceramids lived in fairly deep coastal water, like the Strait of Georgia, and it's hard to see why such habitats should disappear with falling sea levels—move yes, but disappear?

A flurry of research papers recently has given a much better response. We now have a good idea of how the inoceramids lived, why they grew so big, and why their world came to an end.

[10] The late-Campanian shale on these beaches is known as the Northumberland formation.

[11] The evidence for cooling is widely accepted, but that for glaciation is scant and debatable. See Liangquan et al., *Late Cretaceous sea-level changes in Tunisia: a multi-disciplinary approach*, Journal of the Geological Society, pp.447–458, 157, 2000.



Bigger than a dinner plate—one of the shells photographed on the previous page. The white shell, lower right centre, is a modern Japanese oyster—about 4½ inches long [11–12 cm].

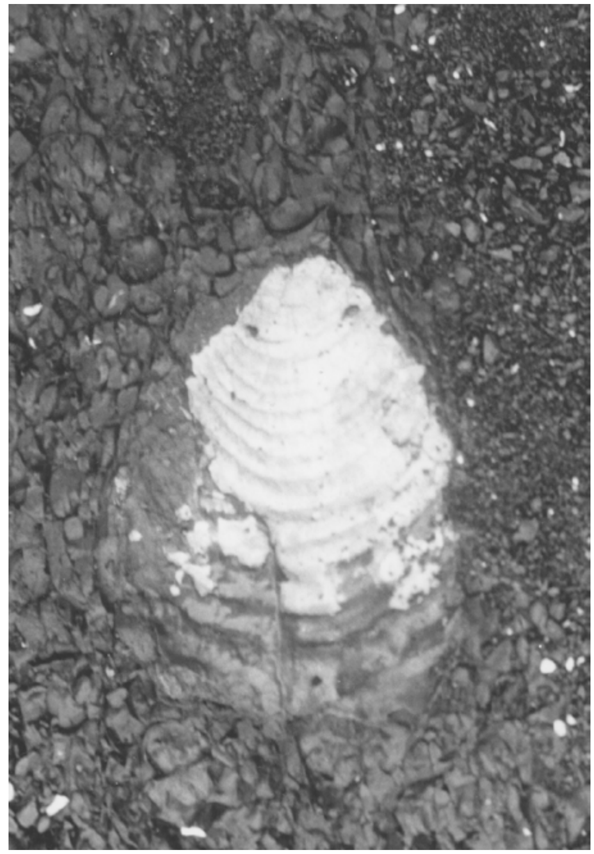
Life at the bottom

Very nearly all life in the sea gets its energy ultimately from the sun. With its help, photosynthetic bacteria, plants, and algae that live in the surface layer use atmospheric carbon dioxide as the source of carbon that they need to build their body tissues. Anything living below a hundred metres or so depends in one way or another on the productivity of the surface layer. Bottom-feeding scavengers like worms, crabs, deep-water mussels and clams, and many other invertebrates, depend for their food on meagre leftovers and organic debris that gently rains down from the organisms living high above.

Just by observing the fossils, we can say something about the environment in which the inoceramids lived. It must have been pretty calm, for example. Shale is produced from fine silt that typically slowly settles in deep water some distance beyond the delta-front of a major river.[12] The shells of the inoceramids commonly form "pavements", indicating that they rested horizontally on the surface of the seafloor. Compared to other bivalves, they were unusually flat, an adaptation that probably helped them avoid sinking too far into the very soft substrate.

There was no shortage of food; judging by their size and the width of the growth rings. In fact, although it has long been known that the darker shales contain relatively high proportions of organic carbon (kerogen), it has only recently been discovered that some modern micro-organisms (bacteria) are

[12] It is tempting to identify the river as the Fraser, but few geologists are confident that they understand the paleogeography of the lower mainland that well.



Left: a collector's specimen of *Inoceramus vancouverensis* from the shale (*formerly* Lambert formation), Denman Island. Right: a similar specimen, flatter and slightly larger [32 cm], on the beach at the south end of False Narrows. The fossils are the same geological age, and are now thought to be from the same Northumberland formation (Georgia Basin).

Author's photographs. Left: courtesy Vancouver Island Paleontological Museum

actually "eating" it. These little guys are thereby pumping carbon dioxide into the atmosphere as the shale is weathered.[13]

If there was lots of food, yet relatively few animals other than inoceramids to take advantage of it, we can conclude that their environment was probably short of oxygen. A shortage of oxygen would explain the apparent absence of shell-crushing predators. The colour of the shale in which the inoceramids are found, blue-grey rather than brown, also indicates a lack of oxygen.

With a little help...

So…Can we guess how the inoceramids managed to thrive in such a warm, dark, oxygen-deficient environment—an uncommon talent for such a large organism? Yes, we can. For about twenty years now, it has been known that some modern species of bivalves make a living in "difficult" environments by forming a symbiotic relationship with microbes that are fuelled

[13] Perhaps even enough to influence global warming calculations! See S.T. Petsch et al., *^{14}C-dead living biomass: Evidence for microbial assimilation of ancient organic carbon during shale weathering*, Science, pp.1127–1131, 292, May 11, 2001. Also, in the same journal, Elizabeth Pennisi, *Shale-eating microbes recycle global carbon*, p.1043.

by the energy of chemical reactions rather than by that of the sun. The muscular bivalves provide streams of nutrient-bearing water to their friends; and in return, the bivalves get to feed on their protein-rich bodies when they die. Such micro-organisms play a crucial role in the ecosystems around both hot- and cold-water vents on the ocean floor. One species of bivalve, *Solemya reidi*, even thrives in pulpmill and sewage outfalls thanks to its symbiosis with bacteria that rely on sulphur compounds in the effluent for their energy. Other common energy sources for "chemoautotrophs", as they are called, are easily-oxidizable compounds such as ammonia and methane. [see box next page]

The inference that inoceramids depended on chemosymbiosis is not conclusive, but it is, I think, appealing. By analysing the ratios of isotopes in the fossil shells, it is possible to show that the oxygen in the shells was probably derived from oxygen dissolved in deep, cooler bottom water [enriched in ^{18}O compared to ^{16}O]. The evidence of the ratio of carbon isotopes in the shells is much less easy to interpret, but it shows strong similarities to the isotope ratios found in modern bivalves that lead a chemosymbiotic lifestyle [enriched in ^{13}C compared to ^{12}C]; and a distinctly different ratio to that found in the shells of bivalves that, in the usual fashion, rely on dissolved inorganic carbon dioxide for their shell-building material.[14]

Cue—sunset

So here, as far as we know—nothing in science is ever final—is the story of the giant clams. The supercontinent Pangaea prevents heat from the earth's interior from reaching the surface; massive volcanic eruptions load the atmosphere with carbon dioxide; the earth warms up due to the greenhouse effect; the seas become warm and ocean currents cease or become very weak; the water at the bottom of the ocean becomes still and stagnant; the clams develop a relationship with bacteria that enables them to thrive in this marginal environment with few competitors or predators. Eventually, Pangaea begins to break apart into separate continents; carbon dioxide levels in the atmosphere fall; ocean currents change and strengthen bringing cold, oxygen-rich bottom water to the lower latitudes; the improved circulation brings to an end much of the stagnant habitat of the inoceramids and most of the inoceramids with it. If there were any surviving species, which is unlikely,[15] they share in the cataclysmic disaster that befalls life on earth at the end of the Mesozoic era. Their 200-million year spell on earth at an end, the last of the inoceramid shells are buried deep in mud that becomes shale; and, finally, 70–80 million years later, earth movements and erosion bring the shells back to the surface again for the interest and pleasure of all who like to walk Gabriola's beaches.

Acknowledgements

My thanks to Graham Beard, curator of the Vancouver Island Paleontological Museum, for patiently searching through his large collection of fossils to find some photogenic ones; to Dr. Steven Earle of Malaspina University-College, who gave the manuscript a much-needed review; and to Dr. Rufus Churcher, who, as always, had interesting comments on the topic. ◊

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14 Kenneth G. MacLeod & Kathryn A. Hoppe, *Evidence that inoceramid bivalves were benthic and harbored chemosythetic symbionts*, Geology, pp.117–120, 20, February 1992. See also, Ethan Gossman, *Comment on…*, Geology, pp.94–96, 21.

15 Kenneth MacLeod, *Extinction of Inoceramid Bivalves in Maastrichtian Strata of the Bay of Biscay Region of France and Spain*, Journal of Paleontology, 68, 5, pp.1048–1063, 1994.

Biological power generation—*but nothing to do with BC Hydro*

The cells of all organisms—be they from eel-grass, eagles, earthworms, or editors—store the energy they need for life in an identical manner. A cell's "battery", so to speak, when fully charged, is a compound called ATP (adenosine *tri*phosphate). The ATP battery discharges by shedding the first, and then the second of the string of three phosphate groups, releasing energy each time it does so, ending up in the "discharged" state as AMP (adenosine *mono*phosphate).

To recharge the battery, (reconnect the two ATP phosphate groups), the cell needs an external source of energy. The known processes for acquiring this energy are:

Process 1: capture of the energy in sunlight (photosynthesis). This process consumes atmospheric carbon dioxide and releases oxygen. Plants do this.

Process 2: oxidation of complex organic compounds (consuming food and breathing). This process ultimately releases carbon dioxide. Animals do this, almost by definition.

Process 3: oxidation of inorganic compounds. Only a relatively few known microbes do this.

"Oxidation" does not necessarily involve oxygen, or even a compound of oxygen. A candle, for example, will burn in an atmosphere of chlorine, and chlorine in this role is said to be an "oxidizing agent". All oxidizing agents work by "absorbing" electrons into an electron-starved environment that exists in the outer electron shell of their atoms. Happy to find a home, these absorbed electrons release energy and excite the atom, just as does dropping stones into a well.

Oxidizing agents (electron recipients), other than oxygen, include the halogens (fluorine, chlorine, bromine, etc.), sulphur, and the transition metals (iron, manganese, etc.). Frequently oxides and halides (including those of nitrogen), and organic compounds containing sulphur or iron or both, are also oxidizers. In cells, nicotinamide adenine dinucleotide, more popularly known as NAD^+, acts as an oxidizing agent by gratefully accepting two electrons and a proton to form NAD-H.

The digestion of complex organic matter (**Process 2**) proceeds in stages.

Stage 2.1: protein, polysaccharids, and lipids (fats) are first oxidized anaerobically to amino acids, sugars, and fatty acids, and then to relatively simple compounds, particularly pyruvate and ketoacids (glycolysis).

Stage 2.2a: *in the presence of oxygen*, products of stage 2.1 are oxidized to carbon dioxide and water in two complex stages (pyruvate oxidation and citric-acid cycling), both of which require coenzymes (adenine dinucleotides and cytochromes). The mostly serial nature of the reactions involved reflects their evolutionary origins as "add-on improvements" to cellular respiration.

Stage 2.2b: *in the absence of oxygen*, products of stage 2.1 are reduced (by oxidation of NAD-H) to form truly simple acids, like lactic acid, and alcohols, like ethanol (fermentation). Some organisms, like patrons of the White Hart, specialize in using oxygen to consume these products as they move through the environment.

There are two sources of inorganic matter available for energy generation (**Process 3**):

Source 3.1: inorganic compounds that are mainly by-products of process 2, stage 2.1. The products of stage 2.1 metabolism include such easily-oxidizable compounds as hydrogen sulphide, ammonia, methane (natural gas), and hydrogen.

Source 3.2: inorganic compounds of mineral origin, primarily from deep below the earth's surface where they have not been in contact with the atmosphere. These are often chemically identical to the 3.1 sources, but are easily distinguished by their atypical ratios of stable isotopes.