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Errors and omissions:

This is the second printing. The tables in the first printing contained errors.

Later references:

Note added in 2011: I see increasing evidence that the Type B nodules are the fossil remains of either the inoceramids' siphons or their feet. What is not clear is, if they are siphons, why they so commonly appear vertical relative to the bedding plane. It makes sense to think they are feet, but that theory raises biological objections. Did inoceramids have feet? and if so what were they for? Supposing that they didn't have feet, could it be that they were able to use their siphons to dig themselves out of the muck when they were buried and in danger of suffocating? This might explain why some Type A sites on Gabriola and Denman Island show very little evidence of vertical Type B modules compared to the Community Cemetery site on Gabriola.

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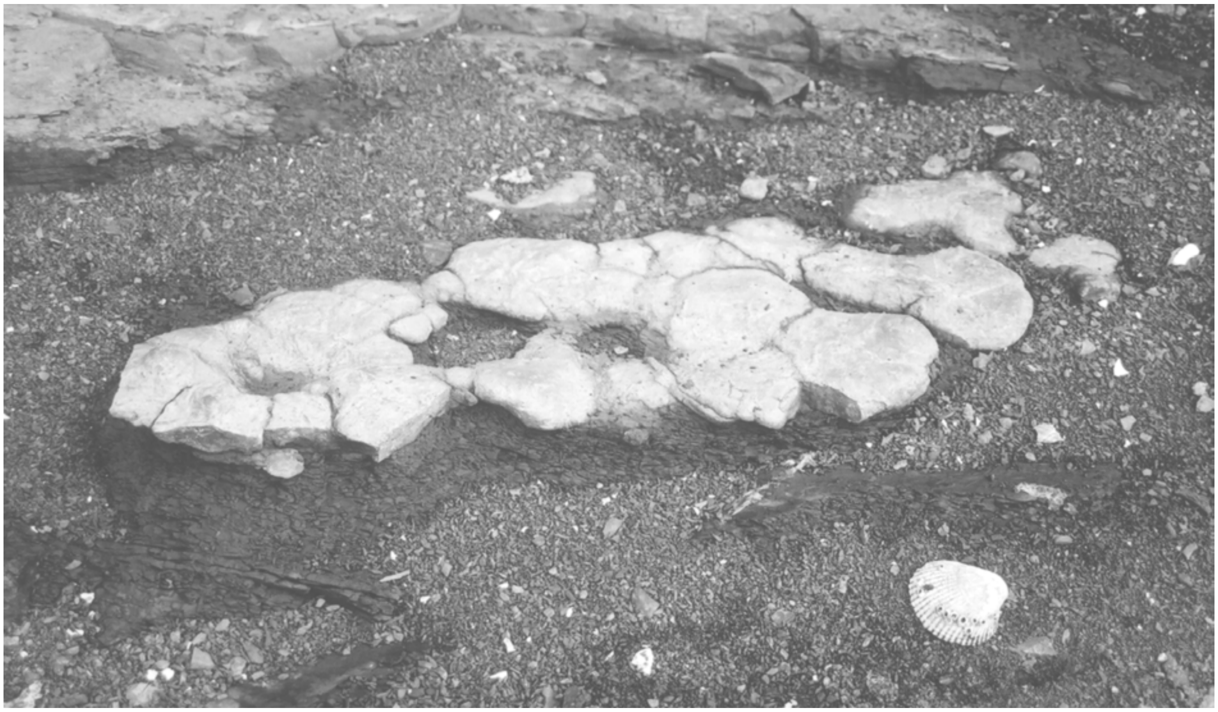
Calcareous nodule in the late-Cretaceous Northumberland Formation showing typical surface trace fossils. When broken open the interior looks like flint and there are almost never any fossils inside.

Curious nodules

by Nick Doe

This article is dedicated to Judy Preston, who asked the key question, "what the heck are they?"



Like the root of a ginger plant, beds of *calcite* nodules on the shale beaches of Gabriola (*modern shell bottom right for scale*). They have a yellowish-, orangy-brown-, or rose-coloured coating with a dark grey, flint-like interior. Although very likely of biological origin, the nodules have been so completely mineralized, it is difficult to figure out what they once were.

Nodules may not be as "showy" as concretions, and you could easily pass your days on Gabriola without noticing them, but it wasn't until I began looking at them in earnest last summer that I realized how curious they are, and how little anyone knows about them.

First off—what's the difference between a "nodule" and a "concretion"? Well definitions vary, and the terms are often used interchangeably, but for me, *concretions* are composed of grains that are the *same* as those in the host rock. A sandstone "concretion" is still sandstone. What makes it different is the efficacy of the cement that binds the grains of sand together. *Nodules* on the other hand have a composition that is very different from that of the host rock. The minerals in nodules have been precipitated (usually) from water percolating through the host rock, although, as the textbooks say, the chemistry within the confined spaces where the nodules form is often not "fully understood".

A familiar example of a nodule for me is the flint found in chalk. Flint is made of silica (silicon dioxide), while chalk is a form of the much softer calcium carbonate.

Surface of a *calcite* nodule, Northumberland Formation (*tree-stump rings for scale*).

The nodules were originally voids in the soft mud, filled with water or gas. Gradually, the voids were filled with *calcite*, which was precipitated from groundwater, and as they were, the mineral infillings swelled slightly, making perfect casts of the walls of the voids. What may look like fossil twiglets (*top centre*), are actually casts of burrows (*chondrites*) left by small critters systematically foraging in the mud. Thicker tubes are the infilling of burrows known as *thalassinoides*. Possibly the intensity of the biological activity revealed in these casts of the surface of the voids has something to do with the original biological nature of the nodules themselves, but nobody is sure of that.

Agates are another example of a nodule—they're typically found lining the cavities in lava rock.

Although there are other types of nodule around on Gabriola, *chert* for example, the one I want to discuss here is found only in shale—no pun intended—and is made of *calcite*.

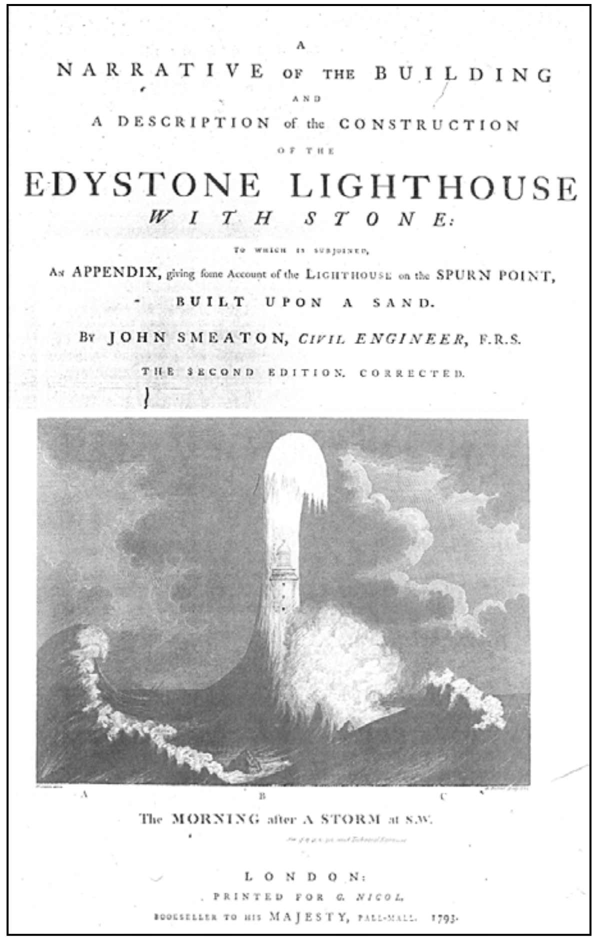
Oddly, and everything about these nodules is odd, they often occur in shale that contains conspicuous fossils of "giant

Ichnofossils and the Eddystone lighthouse

In the 1790s, John Smeaton, an engineer, was working on the task of rebuilding the Eddystone Lighthouse in Cornwall, England. After lots of testing, he found that by adding clay and *calcite* to ordinary cement he could produce *hydraulic cement*. Hydraulic cement is cement that swells slightly as it sets, and is not affected by seawater. The swelling seals any hairline cracks in the concrete, making it watertight. John Smeaton was so pleased with his discovery (actually a re-discovery) that he wrote extensively about it in a book—that's the title page on the *right*.*

What has this to do with nodules? Well, what you see on the beach is the work of a perfectly natural hydraulic cement just like the one used to build the lighthouse. The nodules were originally voids in the soft mud, filled with water, gas, or decaying organic matter. Gradually, the holes, which were rich in both *calcite* and clay, were cemented along with the host mudrock, and as they were, the mineral infillings swelled slightly, making perfect casts of the walls of the voids.

* John Smeaton, *A narrative of the building and a description of the construction of the Edystone* [sic] *Lighthouse with stone: to which is subjoined an appendix giving some account of the lighthouse on the Spurn Point built upon a sand*, G. Nicol, London, 2nd edition corrected, 1793.


A NARRATIVE OF THE BUILDING AND A DESCRIPTION of the CONSTRUCTION OF THE EDYSTONE LIGHTHOUSE WITH STONE: TO WHICH IS SUBJOINED, AN APPENDIX, giving fome Account of the LIGHTHOUSE on the SPURN POINT, BUILT UPON A SAND. BY JOHN SMEATON, CIVIL ENGINEER, F.R.S.

THE SECOND EDITION. CORRECTED.

The MORNING after A STORM at S.W.

LONDON: PRINTED FOR G. NICOL, BOOKSELLER TO HIS MAJESTY, PALL-MALL. 1793.

clams".[1] The beach below the Pioneer Cemetery on the south side of the island is a good place to find them. The beach there is covered with nodules, and you only have to look at the rapidly eroding, 40-foot cliff behind you to see where they are coming from. Good specimens also occur between the Maples and Spring Beach—and anywhere else, Whalebone, for example, where the bedrock is predominately mudrock (shale).

The nodules fit comfortably in the palm of your hand; they feel heavy; and they are often coated with yellow-brown *limonite* (iron oxide) and clay. These nodules commonly have trace fossils (ichnofossils) on their surfaces, and they contain extraordinarily high concentrations of manganese [*endnote* 1].

If you crack one open, you'll see a dark blue-grey, sometimes iridescent interior,

[1] *Inoceramus vancouverensis*—big clams, *SHALE* 4, pp. 9–15, June 2002. Gabriola's paleontologist, Dr. Rufus Churcher, points out that they should be called "oysters" (Order *Pterioida*) rather than "clams", but "clams" is the name that's stuck. Sorry Rufus.

which, once exposed to the air, will, within a few days, turn black, probably as a result of oxidation of the sulphides they contain.

Although nodules elsewhere commonly contain a fossil at their core, they never seem to on Gabriola, and I've cracked open a lot of Gabriolan nodules [*endnote* 3].[2]

Some of the nodules, not associated with clam fossils, are smaller, and most often brown, though sometimes a striking pale-yellow, possibly because they contain iron disulphide (*marcasite* which weathers to *pyrite*, fool's gold), although they contain rather more phosphorous than sulphur. The insides of these smaller nodules are well weathered, black, like coal, with veins of greenish clay, stains of steel-blue iron minerals, and "rusts" of various shades of brown. Aluminum, a common end-product of clay weathering, seems to have replace some of the calcium in these nodules.[3]

Trace fossils on the surfaces of the nodules all have names—*chondrites*, *thalassinoides*, and so on—which makes it sound as if someone knows all about them, but the reality is that the critters responsible for most trace fossils are unknown.

Type A and B

One thing I have observed about Gabriola's *calcite* nodules is that there are two distinct types of nodule: "Type A", which is an interconnected horizontal bed, as seen in the photograph on the first page of this article; and "Type B", which is solitary, vertically oriented, and has what appears to be a central core, see *photograph below*. The two types appear to go together. Certainly, I've never seen an example where there are Type Bs but no Type As, though I'm not so sure about the reverse.

An inoceramid relationship?

It's pretty much at this point in the story that the textbooks peter out and we have to branch out on our own if we want to make any progress in understanding these things.

Type B nodules, arranged as they are usually seen, poking vertical out of the shale on the beach. Each has a central "core" feature—some have two. Diameters are in the ½–3 inch range; they're 1½–3 times deeper than they are wide; and when not broken, they have well-rounded bottoms and flat tops.

[2] Graham Beard at the Vancouver Island Paleontological Museum at Qualicum Beach tells me it is common in all of the Nanaimo Group shale formations to find locations where there are either lots of fossils inside the nodules, or none at all.

[3] Type S in *endnote* 1. These do not contain *calcite*.

So here we go.

On the *left*, an inoceramid (giant-clam fossil);
and on the *right*, a Type B nodule still partially embedded in the bedrock, and uncharacteristically in a near horizontal position. Other large objects (*bottom right corner* for example) are Type A nodules. Garry-oak leaf added for scale.

Jenni Gehlbach was the first to point out to me that there appears to be a relationship between the giant clams—*Inoceramus vancouverensis*—and the nodules. You seldom, if ever, see the former without the latter,[4] and they occur in the same bedding plane, or close to it. For some reason too, the inoceramids tend to lie, as do the nodules, parallel with the strike of the bedding. Actual contact between a nodule and a fossil shell has been observed, but it's not that common. Usually, they are a foot or so apart.

A good suggestion as to what these Type A nodules might be therefore is that they are inoceramid "turds". It would account for their proximity to the clams, and their seeming organic richness. However, the trouble with this hypothesis, apart from any biological objections, is that it does not explain the mineralogical evidence that the nodules were originally voids in the mud.

I think a better theory is this:

- the nodules were originally bubbles of gas derived primarily from the decay after death of the nearby inoceramids
- the inoceramids died when they were buried under an avalanche of silt and mud, as happened from time to time on the unstable slope of the submarine fan where they lived;[5]
- the gas from the decay of the inoceramids was trapped under the same silt and mud that killed the inoceramids—the gas could only spread out horizontally, and was unable to rise through the mud to the surface. The voids containing the gases, primarily carbon dioxide and methane, were subsequently infilled with first water, and then *calcite*;
- the silt that buried the inoceramids subsequently formed a "roof" of siltstone over them, and this protected them as they fossilized.

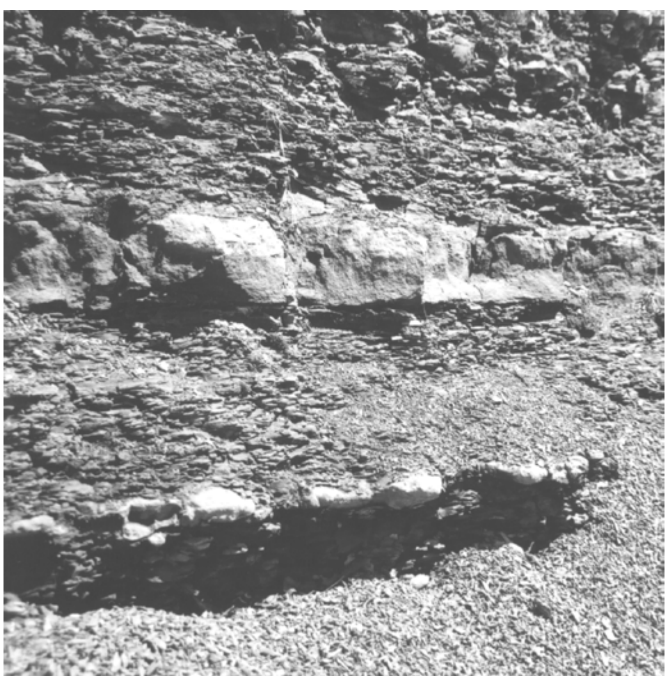
This theory provides the following explanations for several observations:

- because it was the relatively rare event of an avalanche that created

[4] The relationship is qualitative. Lots of inoceramids means some nodules, but not necessarily lots. I have found nodules without a sign of inoceramids (Spring Beach is a good example), but I've never yet found inoceramids without nodules.

[5] *Gabriola's submarine-fan formations, SHALE* 7, pp.15–24, January 2002.

Siltstone is relatively coarse-grained compared with *claystone* (lithified mud), and erodes more slowly. When the two are interbedded in shale, and the bedding is only gently tilted, “pavements” of siltstone, like the one shown *above*, are seen on the beaches. The silt was deposited from a cloud of sediment kicked up by a distant landslide down a submarine slope. Minor faults and sandstone-filled dykes are common in such locations, and attest to the instability of the sediment from which the rock was formed (*SHALE* 7, p.17) (Northumberland Fm., False Narrows). The siltstone is finely laminated, corresponding to the Bouma sequence D (*SHALE* 7, p.22).



Left: In cliff faces, nodules form well-defined beds that are only sparsely distributed vertically, indicating that it was not an everyday event that created them. It’s nodules that are forming the ledge (and shadows) in the lower half of this picture. Because they go rusty as they weather, beds of nodules provide good identification tags for geologists measuring displacements of faults.

Note the sandstone layer 220 mm above the nodules. Some sandstone “sills” like this were likely injected during an earthquake, for although they conform to the bedding in some places, at others they dip down at a high angle to the bedding. Some thin sandstone-filled fractures on the beach interact with nodules in a way that suggests they were formed at about the same time, before lithifaction was complete.

Putting it all together, as this picture does, I think a sudden influx of silt and mud smothered and suffocated the inoceramids (giant clams), the fossils of which we see on our beaches today. Their decay created bubbles of gas that were trapped in the mud beneath the silt, and these voids eventually became *calcite*-filled nodules. Those are Type A nodules peeking out from underneath a "pavement" of siltstone. Often, the siltstone overlay has eroded exposing nodules to full view.

Siltstone pavements have relatively smooth upper surfaces, but the undersides are often pitted and black from coalified organic matter. This is not unusual; you often find thin seams of coal and coalified vegetation in the mudstone immediately beneath a bed of sandstone in all the Nanaimo Group formations. Burial is just not good for your health.

the conditions for fossilization, the fossils occur in thin, well-defined beds that are only sparsely distributed vertically in the mudrock formations

- the decaying inoceramids provided an exceptionally rich environment for scavengers; hence, all the burrowing activity around them
- these particular nodules don't have shellfish or crab fossils at their core because that's not what created them.

And the Type B nodules. My guess is that they are holes "dug" by the "clam" with its muscular foot, but I will admit I'm not sure about that. Modern bivalves don't lie flat on the mud, so we've nothing much to give us guidance.[6] Although the holes do appear next to the clams, there aren't all that many of them and they seem too small to have been an effective anchor. But that's the best suggestion I have. The other possibility is that were formed from bubbles of gas moving upward through the substrate.

[6] "The muscular foot [of modern bivalves] is used for crawling, anchoring, digging, and even leaping. In many forms, the foot is extended into the sediment and anchored by causing the free end to swell by infusing blood into a cavity in the foot. Once anchored, longitudinal muscles in the foot contract, shortening the foot and drawing the animal forward." H.L. Levin, *Ancient invertebrates and their living relatives*, p.240, Prentice Hall, 1999.

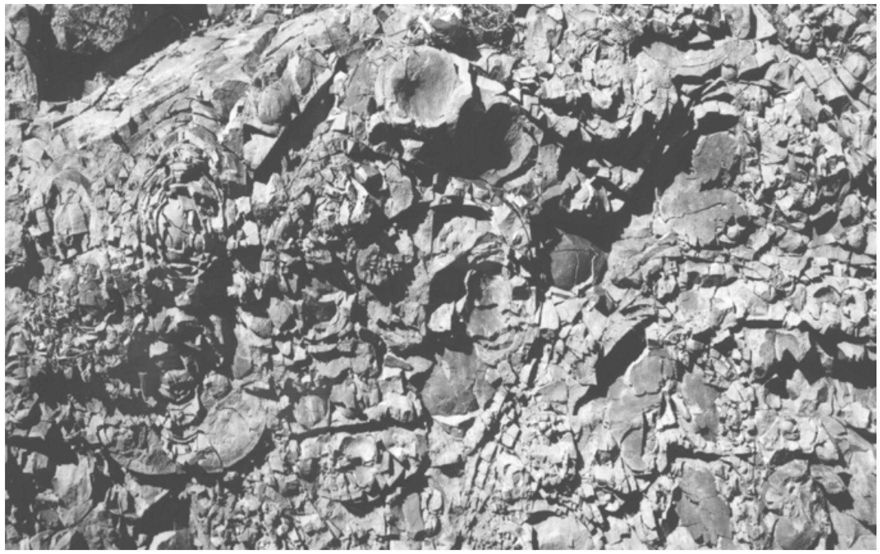
Non-nodules

(revised Sept. 2004)

Perhaps we shouldn't leave the topic of nodules without briefly mentioning *spheroidal weathering*.

Spheroidal weathering produces patterns that superficially may look like nodules, but which are in fact a result of modern weathering. However, the textbook explanation of spheroidal weathering is that it is the result of excess weathering of the corners of cubes of rock created by mutually perpendicular fractures and joints. This certainly explains why some boulders are rounded, but the explanation doesn't work for these mudrock "non–nodules"—there are no such regularly-ordered fractures and joints.

A more likely explanation is that the patterns are *not* the result of classical spheroidal weathering, but that they are lightly concreted mudrock concretions with varying degrees of cementation, and as such are very ancient (Cretaceous).



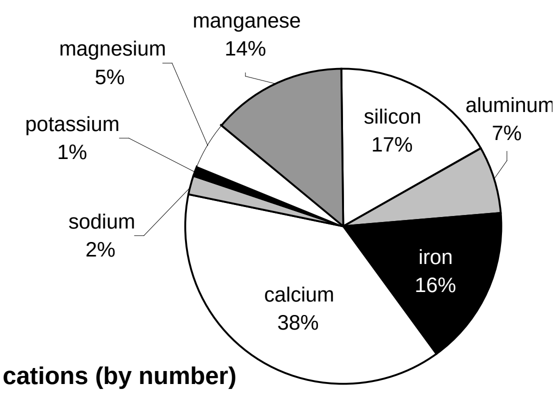
Weathering in the Spray Fm., Easthom Road. Spheroids vary in size; footballs (the ellipsoidal kind) and *boules de pétanque* wouldn't look out of place here. The spheroids are concentric shells of well-weathered mudrock, and unlike true nodules, are extremely friable.

Unweathered mudrock from the Northumberland Fm., False Narrows. The "spheroids" here are actually asymmetric ellipsoids with radii in the ratios 6:4:3. The axes all lie in nearly the same direction; suggesting that they were once spherical, but that they have since been deformed, along with the host rock. Some ellipsoids have smaller ellipsoids within them, which is not easily explainable in terms of weathering. The ellipsoids sometimes contain a speck of material, possibly a shell fragment, at their centres. You can see the beginnings of exfoliation if you break open a freshly exposed lump. The exposed, often-conchoidal surfaces, will have a steel-blue veneer on the host mudrock, which is khaki-green (*fougerite*?). This veneer is *hematite* α-Fe_2O_3 and *manganite* $MnO(OH)$ and is the result of the ingress of oxygenated water. In time, the veneer spreads, creating blue shale that rapidly goes dark grey as it oxidizes. Finally, the mudrock goes rusty, the colour of soil.

ENDNOTES (revised Sept. 2004)

[1]. Whole rock analyses

Nodule Type A from the beach at cemetery (Sample 01, Gabriola I., Northumberland Fm., shale) ACME File: A302906. Analyses made using inductively coupled plasma (ICP) with a mass spectrometer (MS), plus LECO analysis for carbon and sulphur. Oxygen was excluded from all calculations. The measurements were made by ACME Analytical Laboratories, Vancouver BC.

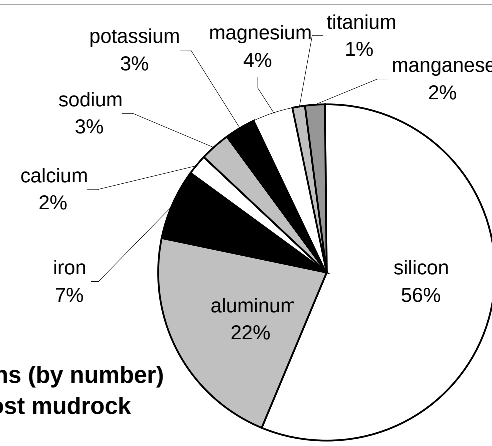


cations (by number)
nodule (Type A)

Cation atoms*	% weight	[% number]	
calcium	43	[46]	as CaO
iron	25	[19]	as Fe_2O_3
manganese	22	[17]	as MnO
	90 %		
aluminum	5	[8]	as Al_2O_3
magnesium	3	[6]	as MgO
sodium	1	[2]	as Na_2O
potassium	1	[1]	as K_2O
	10 %		
others**	0		
	100 %		

* after ignition, excluding P and Si, calculated from measured weight of oxides

** in order of occurrence, traces of titanium, barium, and strontium. Only minute amounts, if any, of yttrium, nickel, zirconium, chromium, scandium, and niobium.

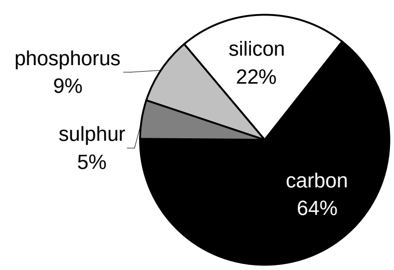


cations (by number)
host mudrock

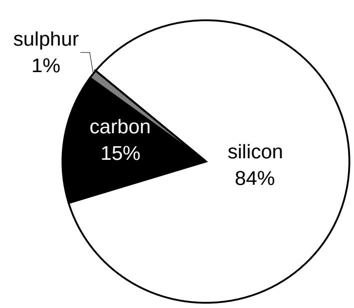
anion atoms C/P/S/Si	% weight	[% number]	LECO
carbon	42	[64]	7.1%
silicon*	35	[22]	
phosphorus*	15	[9]	
sulphur	8	[5]	1.3%
	100 %		

loss on ignition: 24.1%

* Si calculated from SiO_2, P calculated from P_2O_5, assuming no loss of P or Si on ignition.



anions (by number)
nodule (Type A)



anions (by number)
host mudrock

Host mudrock figures taken from *SHALE* 7, p.46–7 (green shale)

A second nodule, **Type A**, from Spring Beach, where there are no inoceramid fossils and no Type B nodules (Sample 17, Gabriola I., Northumberland Fm., shale) ACME File: A305008 showed the following ratios (Sample 01 in parentheses):

calcium 44(46); iron 28(19); aluminum 11(8); magnesium 8(6); manganese 6(17); sodium 2(2); potassium 1(1);

carbon 65(64); silicon 25(22); phosphorus 10(9); sulphur 1(5).

A third nodule, **Type B**, from Cemetery Beach, (Sample 16, Gabriola I., Northumberland Fm., shale) ACME File: A305008 showed the following ratios (Sample 01 in parentheses):

calcium 56(46); manganese 18(17); iron 11(19); aluminum 7(8); magnesium 4(6); sodium 3(2); potassium 1(1);

carbon 60(64); silicon 21(22); phosphorus 14(9); sulphur 5(5).

A fourth nodule, **Type S**, from False Narrows, (Sample 27, Gabriola I., Northumberland Fm., shale) ACME File: A403430 showed the following ratios (Sample 01 in parentheses):

calcium 29(46); iron 20(19); manganese 19(17); aluminum 18(8); sodium 6(2); magnesium 5(6); potassium 3(1);

silicon 65(22); phosphorus 23(9); carbon 11(64); sulphur 1(5). Type S nodules, unlike the Type As and Bs, showed no reaction to cold dilute HCl and only a slight reaction when warmed. Concentrated HCl rapidly dissolves the nodules forming a dark-brown liquid indicating **manganite** MnO(OH).

Oxygen was excluded from all calculations. The measurements were made by ACME Analytical Laboratories, Vancouver BC.

[2]. Petrographic description

The following petrographic report is almost entirely the work of Craig Leitch, Saltspring Island. Craig is the petrologist for Vancouver Petrographics Ltd., Langley, BC. Craig's original report contained more technical detail than I am recording here, and this summary may contain errors that are mine alone.

Nodule Type B from the beach at cemetery (Sample 06, Gabriola I., Northumberland Fm., shale).

The sample examined was dark greenish grey, very fine-grained, with a suggestion of an outer rim (paler coloured), and it containing two circular features in the core, both rimmed by fine sulphides. The rock was very weakly magnetic and showed strong reaction to cold dilute HCl. Modal mineralogy in polished thin section was ***calcite*** 80%, ***chlorite*** 15%, ***sulphide*** (***pyrite*** partly after ***marcasite***) 3–5%, and traces of quartz, feldspar (plagioclase), biotite, and magnetite.

Chlorite (a mica-like mineral) was interstitial to the carbonate, and optical properties suggested an iron-rich variety. ***Sulphide*** (***pyrite*** FeS_2) was in significant, locally patchy, concentrations.

Paler-coloured zones around the internal circular (axial) structures appeared to be enriched in carbonate and depleted in chlorite. Inside the zone of carbonate enrichment was a 2–3 mm zone of chlorite and sulphide enrichment, succeeded inward by a concentration of clear calcite bladed subhedra up to 1.5 mm long separated from the surrounding rock by a rim of sulphide that appeared to be mainly **pyrite** that had possibly replaced former **marcasite** (also FeS_2 but less stable). Within the core of the axial features, there was a very thin 0.1-mm) zone of framboidal [aggregated] pyrite grains.

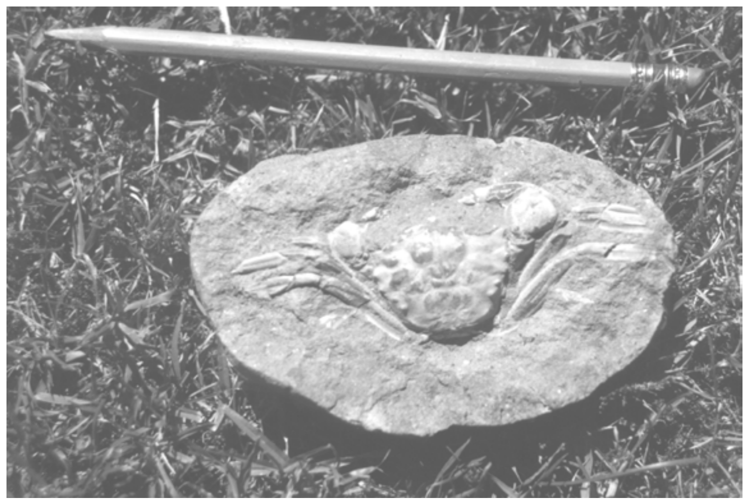
The axial features showed concentric structure and are the result of the mineralization process.

Comments

The most remarkable thing, mineralogically speaking, is the amount of manganese the nodules contain. Deposition of manganese is often associated with nodules in the deep ocean, but shallow-water deposits are also known, for example, in the Gulf of St. Lawrence. The depositional mechanism is being researched—though the manganese often occurs as a very thin coating or crust when manganese- and iron-containing water passes into a higher-pH (less acidic) and higher-redox-potential (oxidizing) environment. Phosphorus in the nodules is evidence that they have a biological origin.

[3]. **Fossils in concretions & nodules**

Nodules on Gabriola very seldom contain fossils, but this by no means rules out their being of biological origin. The fossils may be microscopic (although no trace of fossils was seen in microscopic examination of a thin-section) or, more likely, the original organic material, including any shells, may have been completely dissolved before being re-precipitated as *calcite*. The photographs *right* show examples of calcite nodules/concretions where this hasn't happened. These lovely specimens are from the late-Cretaceous, lower-Nanaimo Group (Haslam Formation [Trent River]), which is mainly mudrock.



Ammonite and crab fossils inside nodules, unfortunately not from Gabriola, but nevertheless from a Nanaimo Group rock formation south of Courtenay on Vancouver Island. Such fossils are rare on Gabriola, probably because all the original organic material inside our nodules, including shells, has been completely re-worked into other minerals.

Courtesy of Graham Beard
Vancouver Island Paleontological Museum
Qualicum Beach (well worth a visit !)

A whole rock analysis of one of these nodules, (Sample 28, Vancouver I., Haslam/Trent River Fm., mudrock) ACME File: A403430 showed the following ratios (Sample 01 in parentheses):

calcium 66(46); aluminum 16(8); iron 8(19); magnesium 4(6); sodium 2(2); manganese 1(17); potassium 1(1); titanium 1(0)

carbon 51(64); silicon 41(22); phosphorus 6(9); sulphur 2(5).

Compared to the Gabriola nodules, there is more silicon, calcium, and aluminum; and less iron, phosphorus, and manganese.

[4]. **Pearls?**

There is one more type of calcium carbonate nodule that *might* be found on Gabriola, and that, believe it or not, is pearls—fossil pearls. Pearls are made by just about anything that forms a shell, including ammonites. They begin as an irritant, and to reduce the irritation, the creature, in our case an inoceramid, coats the intruder with layers of a slick material called nacre, which consists of thin layers of *aragonite* $CaCO_3$, a mineral chemically identical to *calcite*. Because *aragonite* is translucent, light interacts with the overlapping layers to give a lustrous appearance.

The suspected site of an inoceramid pearl, just below the quarter coin. This fossil clam was exposed for only a couple of days during mid-winter storms before being broken up. When first seen, the "pearl nodule" was completely encircled with nacre (mother-of-pearl), but the nodule itself was not. Gabriola Island, Northumberland Formation.

(revised Sept. 2004)

The suspected fossil pearl (*SHALE* 9, p.52) probably isn't according to an expert who has seen several photographs of it. It is just too rough and irregular in shape. Gently dissolving the *calcite* nodule in acid revealed only a darkish green, irregular-shaped core, made of what looks like *glauconite*. This clay mineral is commonly found in organic-rich marine sediments, but its presence here gives no clue as to its biological origin (Richard C. Selley, *Applied Sedimentology*, pp.338–339, 2nd Edition, Academic Press, 2000).

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