GOTHENBURG: HAVE A GNEISS DAY*

Wes Gibbons 2019

The rocks exposed in the islands southwest of Gothenburg are very old and in places exquisitely beautiful. One of the best localities for admiring them is on the west coast of Vrångö, the joyously car-free southernmost inhabited island in the archipelago and an easy ferry ride from the mainland. The number 281 ferry departs from the city tram stops of Saltholmen or Stenpiren. Allow at least half a day, with an hour or two on the rocks, and consider extending your visit another hour by walking the peaceful nature trail around the south of the island.

This Holiday Geology guide firstly provides an illustrated description of the rocks encountered, then places them in context by briefly explaining the background to their geological history and setting. For the non-geologist (and, actually, for many geologists) it is true that these rocks are rather challenging to understand: they have been subjected to high temperatures and pressures deep in the Earth's crust and in the process have been greatly transformed ("metamorphosed"). They are thus "metamorphic rocks". However, that does not mean that they are not interesting and attractive to look at: far from it. They stimulate the imagination. As Roy Batty partly said: "I've seen things you people wouldn't believe. Attack ships on fire off the shoulder of Orion. I watched C-beams glitter in the dark near the Tannhauser gate, and witnessed the Gneisses of Vrångö roiling slowly in their metamorphic heat. All those moments will be lost in time, like tears in rain."

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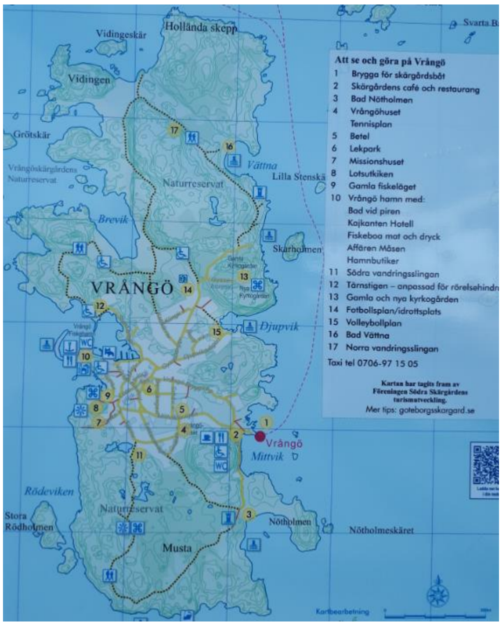

Alighting from the ferry on the east coast of Vrångö (1 on map) follow the tarmac road (Mittviksvägen) west for 800m then bear left (southwest) to locate the Missionshuset (7) alongside of which a path runs out to the rocky shoreline south of the lookout of Lotsutkiken (8), perched precariously on the rocky summit (images below).

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As the vegetation gives way to bare rock you will see vertically banded grey rocks ("gneisses") with thin pale granite-like veins and darker areas. The banding runs north-south towards the hilltop lookout of Lotsutkiken. Now make your way west to the shoreline to discover splendid clean exposures of these banded gneisses, the colour banding in which reflects differences in chemical, and therefore mineralogical, composition. The prominent thin, curving dark band shown lower left, for example, is rich in dark minerals containing iron (Fe) and magnesium (Mg) and typical of rocks with a composition similar to basalt lava. Such rocks are described as having a "mafic" composition (mafic: a portmanteau of **ma**gnesium and **f**erri**c**). The grey bands on either side of the dark layers are less mafic and instead richer in silica (Si): the original rock that they represent (the "protolith") was probably a fine, sandy sediment once deposited on an ocean floor.

A third component of these gneisses is seen as thin pale white layers and veins which have a granitic composition and texture. Granite is an igneous rock, i.e. one formed by crystallisation from a liquid melt. The presence of granitic layers in this gneiss reveals that temperatures were once high enough to begin melting the solid rock. Such a texture is called “migmatitic”, and so these rocks are therefore **migmatitic gneisses**, part metamorphic, part igneous. Many of the pale granitic areas run parallel to the gneissic banding, but in some places they can be seen also to cut across the older banding. In the adjacent image (left) you can make out the original sediment (banded grey layers curving around folds, e.g. centre and lower centre left) and pale granite melt that sometimes follows the sedimentary layering (“bedding”) and sometimes has become mobilised to cut across the bedding.

Thus one can begin to appreciate how complicated these rocks are. Firstly you have some kind of original rock consisting of different compositions such as basalt and layers of sandstone, then you subject it to high temperatures so that it softens and begins to melt and sweat out granitic layers and veins. All of this migmatitic mess is folded by tectonic forces applying directed pressure to the thermally softened rocks to produce graceful curving shapes known as folds. The folding is accompanied by continued melt generation and mobilisation to produce granitic veins that intrude across the older banding. This is the typical texture of many banded migmatitic gneisses found all over the world, both in the field and as polished ornamental stone adorning countless banks and kitchen tops.

The image on the right shows a close-up of folds in migmatitic gneiss showing dark mafic and grey bands forming a host to pale granitic layers that mostly lie parallel to the banding but sometimes intrude across the older layering where the melt has become mobilised (e.g. lower centre).

In this image (right) much of the rock has been “granitised” by extensive melting but in the centre there is a rare example of the original rock texture as it was before migmatisation, curving around a tight fold. This small area has resisted melting, presumably because it has a composition with a higher melting point that the surrounding rock (it is probably richer in quartz and may have originated for example as a cherty sediment deposited on some ancient ocean floor). Note the curiously broken texture of the sedimentary layers curving around the fold. This is reminiscent of the chaotic rocks known as “melanges” that are characteristically found in subduction zones where one tectonic plate slides below another to create great “accretionary prisms” of deformed oceanic sediments and lavas. The top of the image shows coarse crystals of pinkish feldspar typical of the granite component of these migmatites (i.e. the melt), whereas the lower part shows a deformed mixture of granitic melt and what is left of the original solid host. One can imagine how continued and increasing migmatisation of gneisses produces granite as the entire rock becomes liquid igneous rather than solid metamorphic and evidence for the rock’s origins is lost. The exposure provides an eloquent example of the “rock cycle”, a key concept in geology that describes transformations in rocks through geologic time, in this case from sedimentary to metamorphic to igneous.

In places there are dark pods of mafic (or even “ultramafic”: unusually MgFe rich) rocks isolated within the migmatitic gneiss. In this example (centre) one such ultramafic pod comprises coarse, green-black amphibole crystals.

In this second example above the dark pod is mafic, with a speckled appearance caused by small white feldspar crystals that preserve an igneous crystalline texture. We can begin to understand where these pods came from by examining the exposures on the rocky southern side of the Gamla fiskeläget harbour inlet (9 on map). This can be done either by climbing up to the Lotsutkiken lookout then taking the stairway down, or by clambering carefully north then east around the lower shoreline.

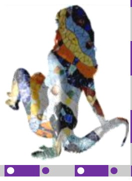
The southern shore of Gamla fiskeläget exposes large pod-like masses of mafic rocks which in places still preserve an originally igneous texture: this case above shows a coarsely crystalline mosaic of white feldspar and black pyroxene that define the texture of a gabbro (right close up).

Many of the mafic pods, unlike the previous example, have a much finer crystalline texture that indicates that they were not given enough time to crystallise large crystals as they became enveloped within the surrounding gneisses.

These finely crystalline mafic masses show intricate textures with the granitic component of the gneisses, with the two melts mingling immiscibly at high temperatures. The mafic component is basaltic in composition and would have been much hotter than (and therefore cooled against) the gneiss host. Conversely, the hot gneiss would have been further heated by the intruding basalt magma, encouraging it to produce yet more granitic melt which interfingered with and back-veined the basaltic intruder. A good example of the delicately interfingering contact between these two components is seen above (on the lower right side) and in the two images below:

In these photos above one can make out a paler grey outer zone encasing some of the basaltic areas. This is interpreted as the result of chemical mixing whereby the silica-rich surrounding granitic melts are contaminating the more mafic basaltic melt to produce rocks that are intermediate in composition between granite and basalt.

In this glacially smoothed exposure above, the dark basaltic magma can be seen to have mingled with grey intermediate igneous melt containing pale feldspar crystals (presumably dioritic-granodioritic composition, for the igneous enthusiast). Note the gloopy, pillow-like textures of the chilling basalt, reminiscent of the lava lamps containing immiscible fluids invented in 1963 by British entrepreneur Edward Craven Walker (see Wikipedia).



Delicate network of intermingling magmas showing a mix of softly rounded ductile shapes and angular brittle fracturing defined by some of the paler granitic veins. Note how the original igneous textures are in places deformed by flattening and shear imposed during the deformation of this hot rock mass.

With increasingly extreme deformation the original igneous texture in these mixed magma rock complexes becomes lost and replaced by a purely metamorphic appearance: effectively a banded gneiss (e.g. the zone top centre above the granitic area).

In many gneiss exposures the rocks are so thoroughly deformed that original textures have become obliterated and there are few clues left to decipher the geological history. One therefore has to comb the rock exposures carefully, searching for clues that provide insight into the complicated history of these old basement gneisses. It is part of the fun.

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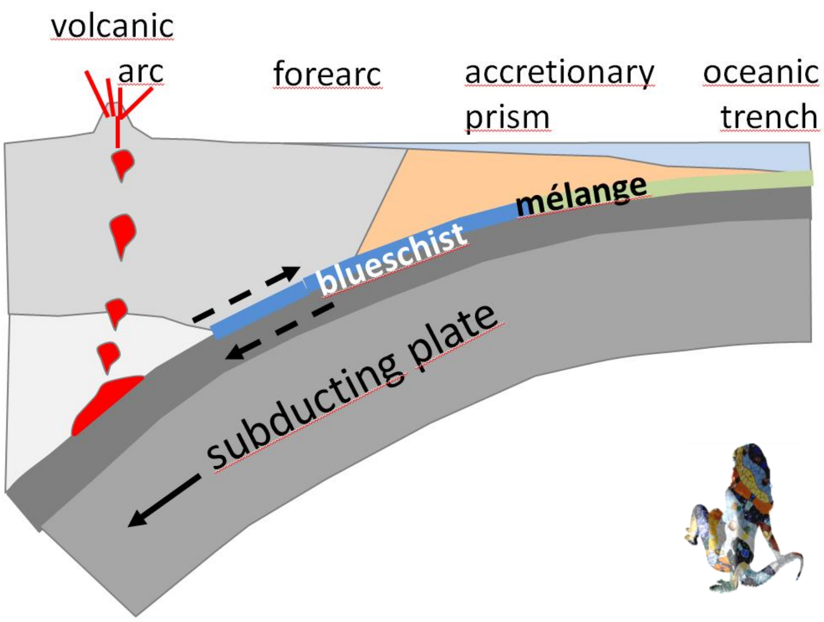
The Vrångö rocks became gneisses during a tectonic event called the Gothian accretionary orogeny which occurred around 1.5-1.6 billion years ago. Such orogenic events occur at plate margins where an oceanic plate is subducted beneath another tectonic plate, such as is occurring today in many places around the western margin of the Pacific Ocean. The subducting plate heats up as it descends deep into the Earth, releasing hot fluids which rise to promote melting of mantle rocks. These melts rise into the overlying crust, heating it and inducing metamorphism and further melting. Some of the melts rise high enough to erupt from arc volcanoes, whereas others (as in Vrångö) solidify in the roots of the arc.



Idealised cross section through a subduction zone on the western side of the Pacific Ocean, looking north. The oceanic Pacific Plate (darker grey) is subducting beneath the Eurasian continental plate. The green area at the contact between the two plates (the "Benioff Zone") is where rocks slide slowly downwards, accompanied by earthquakes that become increasingly common with depth. Mélanges form as oceanic sediments and lavas are scraped off and mixed in the downgoing plate to form a triangular “accretionary prism” (orange). Below this the rocks become increasingly dry and metamorphic under temperatures reaching up to 350-450°C and recrystallizing to form blueschists (blue area). At greater depths, release of fluids from the subducted rocks results in melting of the overlying plate and the production of magma (red) which rises to induce hot metamorphism and migmatisation in the lower crust and build a volcanic arc at the surface (from Holiday Geology Guide to Ishigaki: http://barcelonatimetraveller.com/).

Overviewing what we have seen, we conclude that the exposures described on Vrångö can be interpreted as follows. The gneisses belong within an area called the Östfold-Marstrand Belt and were originally mostly sediments deposited on the sea bed on one side of a volcanic arc. The fact that there are suggestions of melange-like textures in the metamorphosed sediments offers the possibility that the rocks originally formed part of an accretionary prism scraped off the subducting plate as it bulldozed its way down to metamorphic depths. It is not uncommon for such accretionary rocks to later find themselves as part of the hot volcanic arc roots, as arcs evolve in space and time. Such an eventuality would explain the hot metamorphism and migmatisation accompanied by intrusion of basaltic (and probably intermediate) magmas from the mantle that locally mixed with the partially molten gneisses to create the magma-mingled textures revealed on the south side of Gamla fiskeläget. Continued hot reworking of this mixed magma-metamorphic complex by tectonic stresses further deformed the rocks, stretching, flattening and slowly tearing the rocks apart so that, for example, coherent areas of mafic intrusions became dissociated into pods and dispersed through the soft, ductile, partially granitised migmatitic gneisses. Finally, the tectonic pressure eased and the temperature dropped as the rocks rose from the depths of the arc root towards the surface, leaving a solid high grade metamorphic gneiss terrane for us all to enjoy 1,500,000 years later......

Background to Holiday Geology Guides

The author and geologist Wes Gibbons has always had an interest in writing short geoguides aimed at inquisitive tourists, offering them the opportunity to learn about the landscapes and rocks of scenically attractive places. His argument is that there is so much more to know about rocks and Earth history than the superficial descriptions offered by tourist guidebooks, which rarely even scratch the surface of Deep Time.

His first attempt in this direction produced *The Rocks of Sark* (1975), published jointly with John Renouf of Manche Technical Supplies in Jersey, a venture that taught a youthful Wes to always be the one responsible for the final proof reading. In 1976 Wes moved from Sark to begin a PhD supervised by Greg Power (Portsmouth University) and Tony Reedman (British Geological Survey). Living in a former Post Office in the village of Greatham on the Hampshire-West Sussex border, Wes decided to pass his spare time preparing a guide to the geology of the Weald in southeast England. He sold the idea to the publishers Allen and Unwin who commissioned other authors to develop a mini-series: *The Weald* (1981), *Snowdonia* (1981), *Lake District* (1982), and *Peak District* (1982).

His next field-based guidebook surfaced in 1985, fruit of several years research work in Corsica (*Corsican Geology: a field guidebook* by Gibbons and Horák). Two years later Wes launched the Holiday Geology series, using a simple, inexpensive format later described as “a single A3 laminated sheet …. folded into three and (with).. six portrait panels … filled with a lively mix of colour photos, maps, sections and text” (review by Nigel Woodcock in Geological Magazine, 2000). The first two Holiday Geology guides were *Scenery and Geology around Beer and Seaton* (1987) and *Rocks and Fossils around Lyme Regis* (1988). The Holiday Geology concept attracted the attention of the British Geological Survey who went on to expand the series to over 20 titles.

Following his retirement in 2004 to live in Barcelona with Teresa Moreno, Wes maintained his interest in publishing field guides by writing the text to *Field Excursion from Central Chile to the Atacama Desert* (Gibbons and Moreno 2007), *The Geology of Barcelona: an Urban Excursion Guide* (Gibbons and Moreno 2012), and *Field Geotraverse, Geoparks and Geomuseums* (in central and southwest Japan: Gibbons, Moreno and Kojima 2016). His most recent publishing project, the most ambitious so far aimed at a general readership, has produced the book *Barcelona Time Traveller: Twelve Tales* (2016, Spanish translation 2017: Bimón Press Barcelona) and the resurgence of the Holiday Geology concept, although this time in virtual format linked to the *Barcelona Time Traveller* webpage.

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http://barcelonatimetraveller.com/