homunculus

Postings from the interface of science and culture

Thursday, March 19, 2015

The Saga of the Sunstones

In the Dark Ages, the Vikings set out in their longships to slaughter, rape, pillage, and conduct sophisticated measurements in optical physics. That, at least, has been the version of horrible history presented recently by some experimental physicists, who have demonstrated that the complex optical properties of the mineral calcite or Iceland spar can be used to deduce the position of the sun – often a crucial indicator of compass directions – on overcast days or after sunset. The idea has prompted visions of Norse raiders and explorers peering into their "sunstones" to find their way on the open sea.

The trouble is that nearly all historians and archaeologists who study ancient navigation methods reject the idea. Some say that at best the fancy new experiments and calculations prove nothing. Historian Alun Salt, who works for UNESCO's Astronomy and World Heritage Initiative, calls the recent papers "ahistorical" and doubts that the work will have any effect "on any wider research on navigation or Viking history". Others argue that the sunstone theory was examined and ruled out years ago anyway. "What really surprises me and other Scandinavian scholars about the recent sunstone research is that it is billed as news", says Martin Rundkvist, a specialist in the archaeology of early medieval Sweden.

This debate doesn't just bear on the unresolved question of how the Vikings managed to cross the Atlantic and reach Newfoundland without even a compass to guide them. It also goes to the heart of what experimental science can and can't contribute to an understanding of the past. Is history best left to historians and archaeologists, or can "outsiders" from the natural sciences have a voice too?

What a saga

The sunstone hypothesis certainly isn't new. It stems largely from a passage in a thirteenth-century manuscript called *St Olaf's Saga*, in which the Icelandic hero Sigurd tells King Olaf II Haraldsson of Norway where the sun is on a cloudy day. Olaf checks Sigurd's claim using a mysterious *sólarsteinn* or sunstone:

Olaf grabbed a Sunstone, looked at the sky and saw from where the light came, from which he guessed the position of the invisible Sun.

An even more suggestive reference appears in another thirteenth-century record of a Viking saga, called *Hrafns Saga*, which gives a few more clues about how the stone was used:

the weather was sick and stormy… The King looked about and saw no blue sky… then the King took the Sunstone and held it up, and then he saw where the Sun beamed from the stone.

In 1967 Danish archaeologist Thorkild Ramskou suggested that this sunstone might have been a mineral such as the aluminosilicate cordierite, which is dichroic: as light passes through, rays of different polarization are transmitted by different amounts, depending on the orientation of its crystal planes (and thus its macroscopic facets) relative to the plane of polarization. This makes cordierite capable of transmitting or blocking polarized rays selectively – which is how normal polarizing filters work. (Ramskou also suggested that the mineral calcite, a form of calcium carbonate, would work as a sunstone, based on the fact that calcite is birefringent: rays with different polarizations are *refracted* to different degrees depending on the orientation with respect to the crystal planes. But that's not enough, because calcite is completely transparent: changing its orientation makes no difference to how much polarized light passes through. You need dichroism for this idea to work, not birefringence.)

Because sunlight becomes naturally polarized as it is scattered in the atmosphere, if cordierite is held up to sunlight and rotated it turns darker, becoming most opaque when the crystal planes are at right angles to the direction of the sun's rays. Even if the sun itself is obscured by mist or clouds and its diffuse light arrives from all directions, the most intense of the polarized rays still come straight from the hidden sun. So if a piece of dichroic mineral is held up to the sky and rotated, the pattern of darkening and lightening can be used to deduce, from the orientation of the crystal's facets (which reveal the orientation of the planes of atoms), the direction of the sun in the horizontal plane, called its azimuth. If you know the time of day, then this angle can be used to calculate where north lies.

Ramskou pointed out that polarizing materials were once used in a so-called Twilight Compass by Scandinavian air pilots who flew over the north pole. Their ordinary compasses would have been useless then, but the Twilight Compass allowed them to get their bearings from the sun. So maybe the Vikings did the same out on the open sea? Might they have chanced upon this handy property of calcite, found in abundance on Iceland? Perhaps all Viking ships set sail with a sunstone to hand, so that even on overcast or foggy days when the sun wasn't visible they could still locate it and find their bearings.

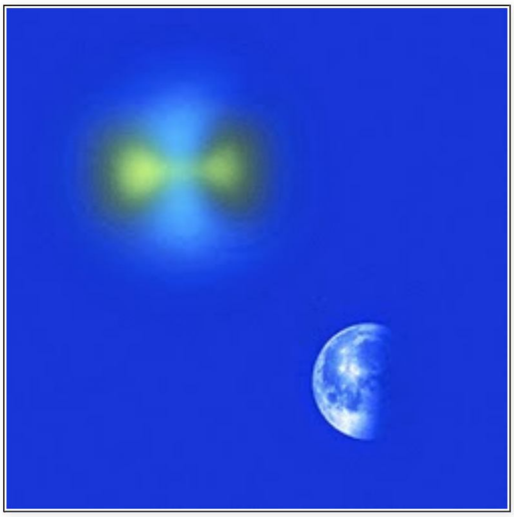
The idea has been discussed for years among historians of Viking navigation. But only recently has it been put to the test. In 1994, astronomer Curt Roslund and ophthalmologist Claes Beekman of Gothenburg University showed that the pattern of darkening produced by a dichroic mineral in diffuse sunlight is too weak to give a reliable indication of the sun's location. They added that such a fancy way to find the hidden sun seems to be unnecessary for navigation anyway, because it's possible to locate the sun quite accurately with the naked eye when it is behind clouds from the bright edges of the cloud tops and the rays that emanate from behind the cloud. The sunstone idea, they said, "has no scientific basis".

That was merely the opening sally of a seesawing debate. In 2005, Gabór Horváth at the Loránd Eötvös University in Budapest, a specialist in animal vision, and his colleagues tested subjects using photographs of partly cloudy skies in which the sun was obscured, and found that they couldn't after all make a reasonably accurate deduction of where the sun was. Two years later Horváth and collaborators measured the amount and patterns of polarization of sunlight in cloudy and foggy skies and concluded that both are after all adequate for the "polarizer" sunstones to work in cloudy skies, but not necessarily in foggy skies. All this seemed enough to rehabilitate the plausibility of the sunstone hypothesis. But would it work in practice?

Double vision

Optical physicists Guy Ropars and Albert Le Floch at the University of Rennes had been working for decades on light polarization effects in lasers. In the 1990s they came across the sunstone idea and the objections of Roslund and Beekman. While Horváth's studies seemed to show that it wasn't after all as simple as they had supposed to find the sun behind clouds, Ropars and Le Floch agreed with their concern that the simple darkening of a dichroic crystal due to polarization effects is too weak to do that job either. The two physicists also pointed out that Ramskou's suggestion of using birefringent calcite this way won't work. But, they said, calcite has another property that presents a quite different way of using it as a sunstone.

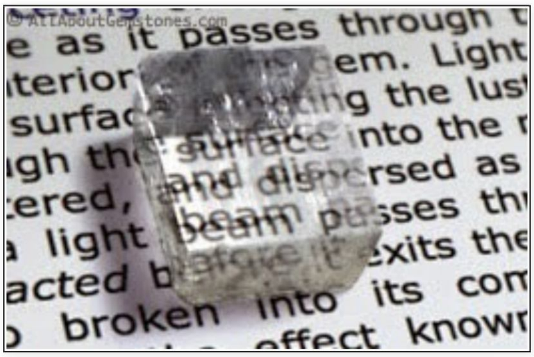
When a calcite crystal is oriented so that a polarized ray strikes at right angles to the main facet of the rhombohedral crystals, but at exactly 45 degrees to the optical axis of the crystal – at the so-called isotropy point – it turns out that the light in the rays at this position are completely depolarized. As a result, it's possible to find the azimuth of a hidden sun by exploiting the sensitivity of the naked eye to polarized light. When polarized white light falls on our eye's fovea, we can see a pattern in which two yellowish blobs fan out from a central focus within a bluish background. This pattern, called Haidinger's brushes, is most easily seen by looking at a white sheet of paper illuminated with white polarized light, and rotating the filter. We can see it too on a patch of blue sky overhead when the sun is near (or below) the horizon by rotating our head. By placing a calcite crystal in the line of the polarized rays oriented to its isotropy point relative to the sun's azimuth, the polarization is removed and Haidinger's brushes vanish. Comparing the two views by moving the crystal rapidly in and out of the line of sight, the researchers found that the sun's azimuth can be estimated to within five degrees.

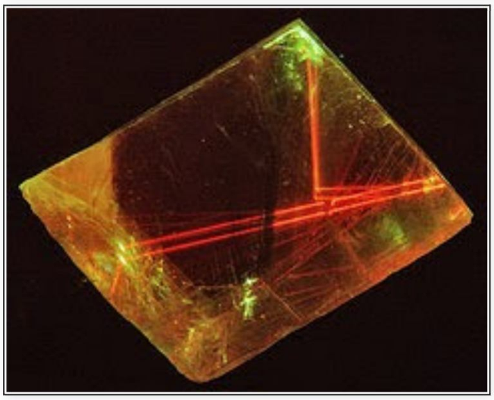


Haidinger's brushes: an exaggerated view.

But it's a rather cumbersome method, relies on there being at least a high patch of unobstructed sky, and would be very tricky on board a pitching ship. There is, however, a better alternative.

Because calcite is birefringent, when a narrow and partially polarized light ray passes through it, the ray is split in two, an effect strikingly evident with laser beams. One ray behaves as it would if just travelling through glass, but the other is deviated by an amount that depends on the thickness of the crystal and the angle of incidence. This is the origin of the characteristic double images seen through birefringent materials. And whereas Roslund and Beekman had argued that changes in brightness for a dichroic substance rotated in dim, partially polarized light are likely to be too faint to distinguish, the contrast between the split-beam intensities as calcite is rotated are much stronger and easier to spot. “The sensitivity of the system is then increased by a factor of about 100”, Ropars explains. At the isotropy point, the two rays will have exactly the same brightness, regardless of how polarized the light is. This means that, if we can accurately judge this position of equal brightness, the orientation of the crystal at that point can again be used to figure out the azimuth from which the most intense rays are coming.





Double images and split laser beams in calcite, due to birefringence.

The human eye happens to be extremely well attuned to comparing brightness contrasts of fairly low-level lighting. So the researchers’ tests using partially polarized light shone through a calcite crystal showed that, under ideal conditions, the direction of the light rays could be estimated to within 1 degree even for low overall light intensities, equivalent to a sun below the horizon at twilight. The method, they say, will work even up to the point where the first stars appear in the sky.

Showing all this is the lab is one thing, but can it be turned into a navigational instrument? Ropars, Albert Le Floch and their coworkers have already made one. They call it the Viking Sunstone Compass.

It’s a rather beautiful wooden cylinder with a hole in the top, through which light falls from the zenith of the sky onto a calcite crystal attached to a rotating pivot turned by a little handle on the lid. There’s a gap in the side through which the observer looks at the two bright spots projected from the crystal. “You simply rotate the crystal to equalize the intensities of the beams”, says Ropars. A pointer on the lid then indicates the orientation of the crystal and the azimuth of the sun, from which north can be deduced by taking into account the time of day. Ropars says that, even though of course the Vikings lacked good chronometers, they seem to have known about sundials. What’s more, studies have shown that people’s internal body clocks (their circadian rhythm) can enable us to estimate the time of day to within about a quarter of an hour.

The Viking Sunstone Compass made by researchers at the University of Rennes. Note the double bright spots in the cavity.

But never mind Vikings – the Rennes team could probably make a mint by marketing these elegant devices as a luxury item for sailors. Ropars says that a US company is now hoping to commercialize the device based on their prototype.

All at sea

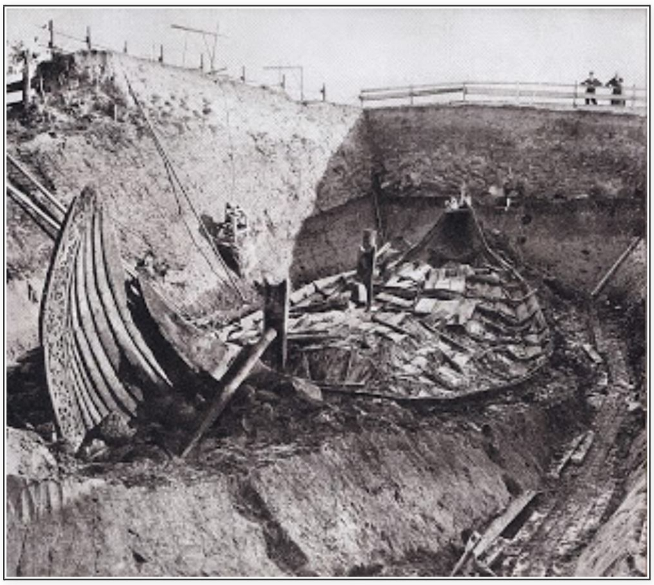
When the findings were reported, they spawned a flurry of excited news headlines, many claiming that the mysteries of Viking navigation had finally been solved. It's not surprising, for the image of brawny Vikings making use of such a brainy method is irresistible. But what, in the end, did the experiments really tell us about history?

There's nothing in principle that might have prevented the ancient Greeks from developing steam power or microscopes. We are sure that they didn't because there is absolutely no evidence for it. So an experiment demonstrating that, say, ancient Greek glass-making methods allow one to make the little glass-bead microscope lenses used by Antoni van Leeuwenhoek in the seventeenth century is historically meaningless. What, then, can we conclude about Viking sunstones?

Because the Viking voyages between the ninth and eleventh centuries were so extensive – they sailed to the Caspian Sea, across the Mediterranean to Constantinople, and over the Atlantic to North America – there is a pile of archaeological and historical research on how on earth they did it. The prevailing view is that, in the Dark and Middle Ages, as much sailing as possible was done in sight of land, so that landmarks could guide the way. But of course you can't cross the Atlantic that way. So if no land was in sight, sailors used environmental signposts: the stars (the Vikings knew how to find north from the Pole Star), the sun and moon, winds and ocean currents. They also relied on the oral reports of previous voyagers to know how long it should take to get to particular places.

What if none of these clues was available? What did they do if becalmed in the open sea on a cloudy day? Well, then they admitted that they were lost – as they put it, *hafvilla*, "wayward at sea". The written records indicate that under such circumstances they would convene to discuss the problem, relying on the instincts of the most experienced sailors to set a course.

However, some archaeologists and historians, like Ramskou, have argued that they could also have used navigational instruments. The problem is that there is precious little evidence for it. The Scandinavian coast is dotted with Viking ship finds, some of them wrecks and others buried to hold the dead in graves. But not one has provided any artifacts that could be navigational tools. Nevertheless, the archaeological record is not entirely barren. In 1948 a Viking-age wooden half-disk carved with sun-like serrations was unearthed under the ruins of a monastery at Uunartoq in Greenland. It was interpreted by the archaeologist Carl Sølver as a navigational sundial, an idea endorsed by Ramskou in the 1960s. More recently another apparent wooden sundial was found at the Viking site on the island of Wolin, off the coast of Poland in the Baltic. A rectangular metal object inscribed in Latin, found at Canterbury and tentatively dated to the eleventh century, has also been interpreted as a sundial, while a tenth-century object from Menzlin in Germany might be a nautical weather-vane.



A Viking ship grave at Oseberg in Norway, and the Uunartoq Viking sundial.

So the “instrumental school” of Viking navigation has a few tenuous sources. But no sunstones. That hasn’t previously deterred the theory’s champions. One of them was Leif Karlsen, an amateur historian whose 2003 book *Secrets of the Viking Navigators* announced his convictions in its subtitle: “How the Vikings used their amazing sunstones and other techniques to cross the open ocean”. One problem with such a bold claim is that the sunstone hypothesis had already been carefully examined in 1975 by the archaeologist Uwe Schnall, who argued that not only is there no evidence for it but there is no clear need either. “Since then, to my knowledge, no research has contradicted this conclusion”, says Willem Mörzer Bruyns, a retired curator of navigation at the Netherlands Maritime Museum in Amsterdam.

In making his case, however, Karlsen presented a new exhibit. In 2002, just as his book was being completed, archaeologists discovered a calcite crystal in the remains of a shipwreck offshore from the Channel Island of Alderney. It has been made misty by centuries of immersion in seawater and abrasion by sand, but it still has the familiar rhombohedral shape. Finally, tangible proof that sailors carried sunstones! Well, not quite. Not only is it totally unknown why the crystal was on board, but the ship is from Elizabethan England, not the Viking age.

The Alderney "sunstone".

All the same, Ropars and colleagues claim that it supports their theory that these crystals were used for navigation. They point out, for example, that it was found close to a pair of navigational dividers. But, says Bruyns, "navigational instruments were kept in the captain's and officers' quarters, where their non-navigational valuables were also stored." All the same Bruyns is sympathetic to the idea that, rather than being a primary navigational device, the crystal might have been used to correct for compass errors caused by local magnetic variations (such as proximity to iron cannons), which was done at that time by looking at the sun's position on the horizon when it rose or set. Ropars points out that birds use the same recalibration of their magnetic sensors using polarization of sunlight at sunrise and sunset. "We're now looking for possible mentions of sunstones in the historical Navy reports of the 15th and 16th centuries", he says. But however intriguing that idea is, it has no bearing on a possible use of sunstones for navigation in the pre-compass era. "The Alderney finding is from a completely different period and culture to the Vikings", Ropars acknowledges.

Finding the right questions

One way to view the latest work on sunstones is that it could at least have ruled out the hypothesis in principle. But don't historians need a good reason to regard a hypothesis as plausible in the first place, before they get concerned about whether it is possible in practice? Otherwise there is surely no end to the options one would need to exclude. And there is the difficult issue of the documentary record. Lots of what went on a millennium and more ago was not written down, and much of what was is now lost. All the same, there is a rich literature, at least from the Middle Ages, of the techniques and skills of trades and professions, while early pioneers of optics like Roger Bacon and Robert Grosseteste in the thirteenth century offer a pretty extensive summary of what was then known on the subject. It's not easy to see how they would have neglected sunstones, if these were widely used in navigation. Ropars says that the Icelandic sagas aren't any longer the only textual source for sunstones, for the Icelandic medieval historian Arni Einarsson pointed out in 2010 that sunstones are also mentioned in the inventory lists of some Icelandic monasteries in the fourteenth and fifteenth centuries, where they were apparently used as time-keeping tools for prayer sessions. But monks weren't sailors.

The basic problem, says Salt, is that scientists dabbling in archaeology often try to answer questions that, from the point of view of history and anthropology, no one is asking. This has been a bugbear of the discipline of archaeoastronomy, for example, in which astronomers and others attempt to provide astronomical explanations of historical records of celestial events, such as darkening of the skies or the appearance of new stars and other portents. Explanations for the Star of Bethelem have been particularly popular, but here too Salt thinks that it is hard to find any examples of a historically interesting question being given a compelling answer. [See, e.g. *J. British Astron. Assoc.* **114**, 336; 2004]. One of the most celebrated examples, also revolving around optical physics, was the suggestion by artist David Hockney and physicist Charles Falco that painters in the Renaissance such as Jan van Eyck used a camera obscura to achieve their incredible realism. The theory is now generally discounted by art historians.

"'Could the Vikings have used sunstones' is a different question to 'did the Vikings use sunstones", which is what most historians are interested in," says Salt. "A paper that tackles a historical problem by pretty much ignoring the historical period your artefact comes from seems to me to be eccentric." Ropars agrees that "experimental science can exclude historical hypotheses, but isn't sufficient to validate them." But he is optimistic about the value of collaborations between scientists and historians or archaeologists, when the historical facts are sufficiently clear for the scientists to develop a plausible model of what might have occurred.

Could it be, though, that we're looking at the sunstone research from the wrong direction? One of its most attractive outcomes is not an answer to a historical question, but a rich mix of mineralogy, optics and human vision that has inspired the invention of a charming device which, using only methods and materials accessible to the ancient world, enables navigation under adverse conditions. It would be rather lovely if the modern "Viking Sunstone Compass" were to be used to cross the Atlantic in a reconstructed Viking ship, as was first done in 1893. It would prove nothing historically, but it would show how speculations about what might have been can stimulate human ingenuity. And maybe that's enough.

The reconstructed Viking ship the Sea Stallion sets sail.

Further reading

J. B. Friedman & K. M. Figg (eds), *Trade, Travel and Exploration in the Middle Ages: An Encyclopedia*, from p. 441. Routledge, London, 2000.

A. Englert & A. Trakadas (eds), *Wulfstan's Voyage*, from p.206. Viking Ship Museum, Roskilde, 2009.

G. Horváth *et al., Phil Trans. R. Soc. B* **366**, 772 (2011).

G. Ropars, G. Gorre, A. Le Floch, J. Enoch & V. Lakshminarayanan, *Proc. R. Soc. A* **468**, 671 (2011).

A. Le Floch, G. Ropars, J. Lucas, S. Wright, T. Davenport, M. Corfield & M. Harrisson, *Proc. R. Soc. A* **469**, 20120651 (2013).

G. Ropars, V. Lakshminarayanan & A. Le Floch, *Contemp. Phys.* **55**, 302 (2014).

Note: A version of this article appears in *New Scientist* this week. A pdf of this article is available on my website here.

Posted by Philip Ball at 3:10 PM

g+1 Recommend this on Google

1 comment:

Chemdiary said...

I read your book "The Devil's Doctor." It is a great work. Thanks for writing it. Here's my post on the book:
http://chemdiary.blogspot.com/2015/04/book-devils-doctor.html

6:29 PM

Post a Comment

Newer Post Home Older Post

Subscribe to: Post Comments (Atom)