**Industrial Archaeology Hiding in Plain sight**

**Ordnance Survey Benchmarks and Trig Points**

**Simon Ritchie**

Humans used maps long before we could read and write. Paintings on rock faces made by hunter-gatherers centuries ago turn out to be, amongst other things, maps showing where and when game would appear in the locality.

The ancient Greeks made geographic maps (ones that represent the real world to scale). From the 16th Century onwards, European cartographers produced globes and maps to help plan sea voyages and military campaigns.

Before the bicycle was invented, you rode a horse or you walked. Horses are expensive to buy and to keep so most people walked. The town of Guildford built up around a ford across the river Wey ("The golden ford"). It was a useful stopover, being half-way between London and Portsmouth and a day's walk from each. William the Conqueror built a castle there to control that route.

So most people were confined to their local area, which they knew very well. They didn't need a map to get around.

People who owned large pieces of land were often fond of maps, especially of the bits that they owned. In the 9th Century AD, Caliph Al-Ma'mun commissioned a map of the known world, apparently because he wanted to know how much of it was his. Quite a lot, it turned out.

Surveying equipment was primitive: at first, measuring by footsteps, then the surveyor's chain and the perambulator. (In this case, not a baby carriage but a wheel on a stick with a revolution counter.) Maps were inaccurate and expensive, but by the 18th Century, European instrument makers were creating new measuring devices. These days we take portable clocks and wooden rulers with accurate divisions for granted, but this was the very beginning of the scientific revolution and they were the new state of the art. Land surveyors were using optical devices such as the French repeating circle and British theodolite.

According to John Gribbin's "Science, a History", the English astronomer Leonard Digges invented the theodolite around 1551 and then the telescope. He backed the wrong side in the insurrection against Henry VIII's daughter Mary when she became Queen. He survived but he was ruined and his work went unnoticed. In any case, working versions of his devices may have been impractical given the quality of lenses at the time.

Lens making advanced and the telescope was reinvented in Holland sixty years later by spectacle maker Hans Lippershey, then improved by Galileo. Even then, lenses suffered from distortion and scattered light of different colours in different directions, causing a fuzzy image (“chromatic aberration”).

In the 18th Century “achromatic” lenses were invented. These greatly reduced the scattering effect, although they didn’t eliminate the problem altogether. Modern lenses suffer from the same problem, albeit to a much lesser extent.

All these improvements made the theodolite a practical proposition. This is a very simple version:

The device in the picture is a toy, not nearly accurate enough for surveying, but it illustrates the principles nicely. It has a telescope with two angle scales, vertical and horizontal. It has three adjustable feet and a spirit level so that you can set the base horizontal. If you align the base with a distant object and point the telescope to it, then swivel the telescope to point at another object, the scales give you the vertical and horizontal angle between the two objects. You can then use the mathematics you learned at school to find their positions.

(For the details of that mathematics, see my companion document https://goblimey.com/courses/triangulation.pdf.)

In 1772 Louis XIV of France hired the Cesar Casini to map his kingdom. According to https://en.wikipedia.org/wiki/Cartography_of_France, the survey were carried out between 1756 and 1789 by four generations of the Casini family using the new technique of triangulation. The 181 sheets of the map were published from 1756 to 1815.

The French project provoked a plan to survey Britain, but this soon collapsed for lack of funding. Cartography here was piecemeal. Owners of large estates commissioned maps of their properties and some County maps were produced. If you owned a big house you wanted it to be “on the map”.

The first large-scale mapping project by the British government was William Roy’s survey of Scotland, soon after the Union. Originally the interest was from the Army for the purposes of control, which is why the Board of Ordnance ran the project, but gradually it became more about getting to know our own nation.

The Army was a good choice to run the survey. If you wanted to move a detachment of troops or some large cannon then it was useful to know which roads to take and what gradients you were going to encounter on the way. Army officers were already trained to use survey devices and draw maps, in fact many of the survey devices had been developed for them.

At this time, the idea that the Government should do useful things for the public good was new. The Postal Service and the survey of Scotland were two of the first such projects.

In 1783 the French Government proposed that the British should survey a few points in the South of England and link their survey with the French across the Channel. The aim was to measure the relative positions of telescopes at the Paris and Greenwich observatories as accurately as possible. Amongst other benefits, this would give a long baseline to allow a better estimate of the size of the Earth. France and Britain were both building empires abroad and this project would lead to better navigational tables.

In 1784 Roy and his team measured a ***baseline*** across what was then Hounslow Heath, in those days a piece of open country to the South of London. The terrain is fairly flat. One end of the baseline is about ten metres higher than the other and between them is a gentle slope.

As London expanded later, Hownslow Heath was mostly built over. The position of the south-east end of the baseline became Roy Grove, a quiet close in the suburbs.  Eventually Heathrow Airport was built around the north-west end of the baseline and that position is now just within the northern perimeter fence.  It wouldn't be practical to have surveyors wandering around a busy airport so the end point was moved along the baseline to just outside the fence, creating a slightly shorter version.  The new end point is on Nene Road.

Roy soon found that his chains and wooden rulers expanded and contracted with changing humidity and temperature, so to measure the baseline the team used eighteen-foot long glass tubes, the most stable material of the day. Starting at one end, they laid two tubes butting up to each other on trestle tables and sighted down them to the other endpoint.  Then they moved the first tube along the line and repeated the operation, over and over until they reached the other end, four weeks later.

This is the south-east end of the baseline at Roy Grove, with one of my GPS survey devices sitting on the top.  The signs by the fence give a short history of the baseline:

The south-east end of the Hounslow baseline

Roy's team measured the length of the baseline as 27,404.7 feet (5.190 miles).

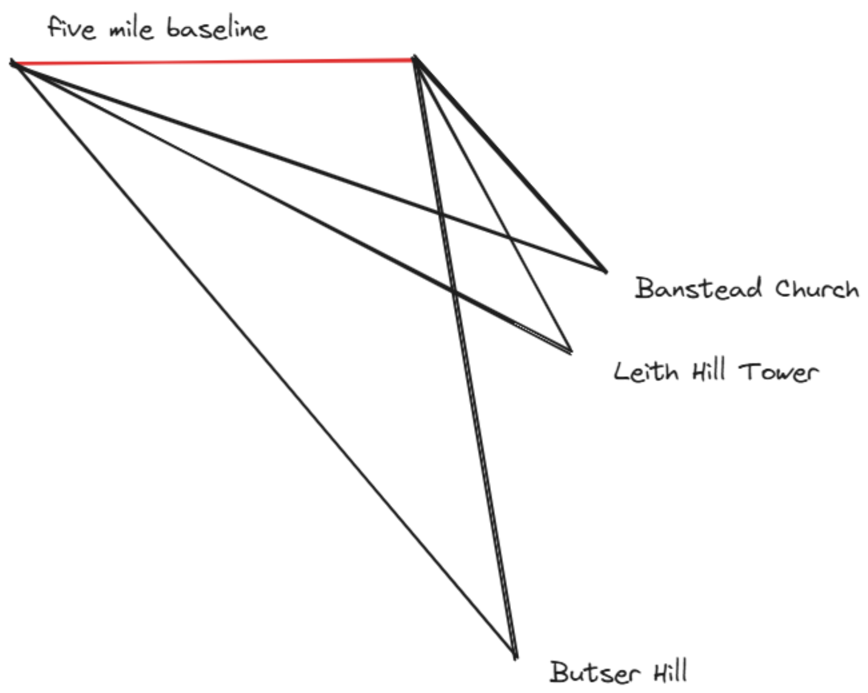
A few years later, Mudge's team (see below) corrected some small errors in Roy's methods and measured the length as 27,404.3155 feet, shorter by 0.3845 feet (about 117 millimetres).

The OS remeasured the baseline using modern accurate GPS technology and found the length to be 27,376.8 feet (5.185 miles), so the original $18^{th}$ Century work was remarkably accurate.

Once he had his baseline, Roy needed a theodolite but there was a delay. London instrument maker Jesse Ramsden designed and built the most accurate device for him,  accurate to one second of arc, but he spent three years building it and Roy had to wait.  The resulting device weighed two hundred pounds.

In theory the process is very simple.  Put the theodolite at each end of the baseline (the red line in the picture) and measure the angles between the baseline and some distant objects.  That gives a set of large triangles spanning the landscape.

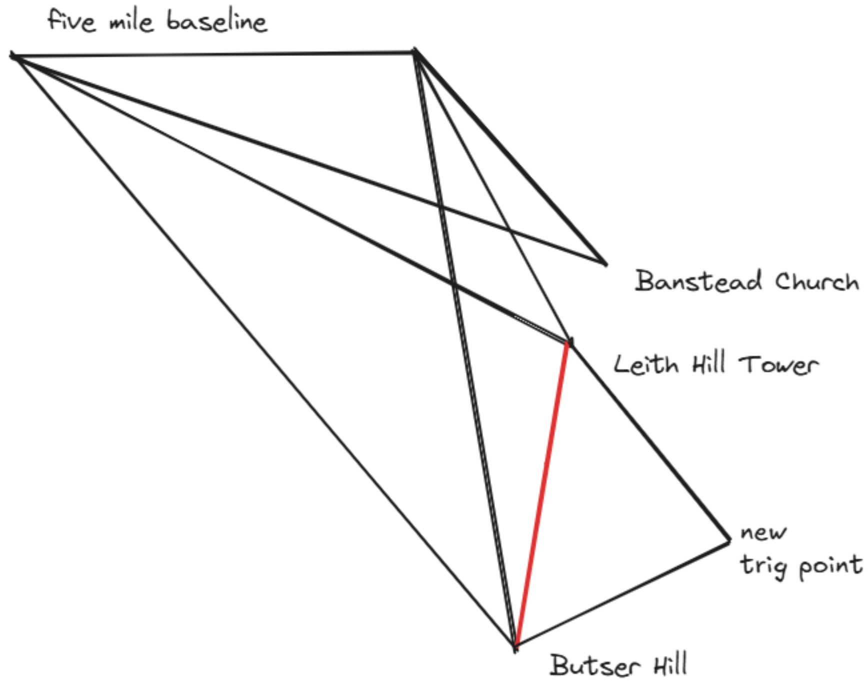
The survey began in 1787.  The positions they measured included Banstead Church, Leith Hill Tower, the highest point in Surrey and Butser Hill, the highest point in Hampshire:



In theory, the two angles give the position of each point relative to the baseline. In practice you need to repeat the same measurements over several days and record any factors that might distort the theodolite and cause errors in the measurements – temperature, pressure, humidity and so on. Then you need to correct your measurements using some complicated mathematical processes. The Ordnance Survey call these conditioning equations.

The points they measured became trig points - reference points for the next stage, which was to expand the network of triangles. The surveyors used them to create new baselines. They moved the theodolite to the line and measured more trig points further away.

In the picture below, Leith Hill Tower and Butser Hill form a baseline and a new trig point is measured from that, further out:




Some of the observations were best made at night using lamps. Burning various chemicals produced a bright light, but only for a few minutes. Coordinating signals and observations miles apart from each other took a lot of careful planning.

Roy always envisaged producing maps of Britain. That would involve surveying many more trig points and finding their height, but for the current project, to extend the French survey into southern England and find the relative positive of the two national observatories, measuring these large triangles was sufficient.

Roy's surveyors worked their way to the south coast and then the French and the British measured to points across the Channel to link the triangles to the triangles of the map of France. Bearing in mind that this involved lugging 200 Pounds of delicate equipment around the South of England, it took a little time.

In those days, the complicated conditioning equations had to be done by a human computer. Roy's computers spent another year conditioning the measurements to correct them.

The end result of the survey was data - the angular distance between the two telescopes and therefore the time difference between stellar observations by those telescopes. The result was produced in 1790 – noon at Greenwich is nine minutes and nineteen seconds after noon at the Paris observatory.

This groundbreaking work by Roy was his last. He died at his desk at the war office in 1790, a year before the creation of what became the Ordnance Survey.

**The Ordnance Survey**

Accurate maps of Britain and the emerging empire were needed for all sorts of reasons such as town planning and poor law administration, but military concerns were the final catalyst. The French Revolution bought fear of invasion and the defence of Britain required decent maps. Roy's dream of a project to map the whole of the nation became reality.

The project was put under the control of the Board of Ordnance and in 1789 they created a small organisation to do the work, directed by the Ordnance corps' Major Edward Williams with lieutenant William Mudge as his deputy. The organisation had various names, but eventually became the Ordnance Survey.

According to Rachel Hewitt's book, Mudge was the one who actually ran the survey, including working hands on in the field. Williams had other interests, including a reorganisation of the Woolwich Arsenal. When Williams died in 1798, Mudge was given complete control of the survey.

Mudge had noticed a source of error in Roy's original work, a failure to compensate properly for variations in temperature. His team remeasured and recomputed the length of the Hounslow baseline, this time making it 117 millimetres shorter than Roy's result.

Ramsden, Mudge and the whole science community were beginning to get to grips with the new field of accurate measurement, which had only recently become possible. Given that no equipment is perfect and all measurements contain some level of error, what does a measurement actually mean and how should it be represented? Moreover, given that Ramsden claimed that his theodolite was more accurate than any other instrument, there was nothing else to compare it with, so how could anybody check that he was right?

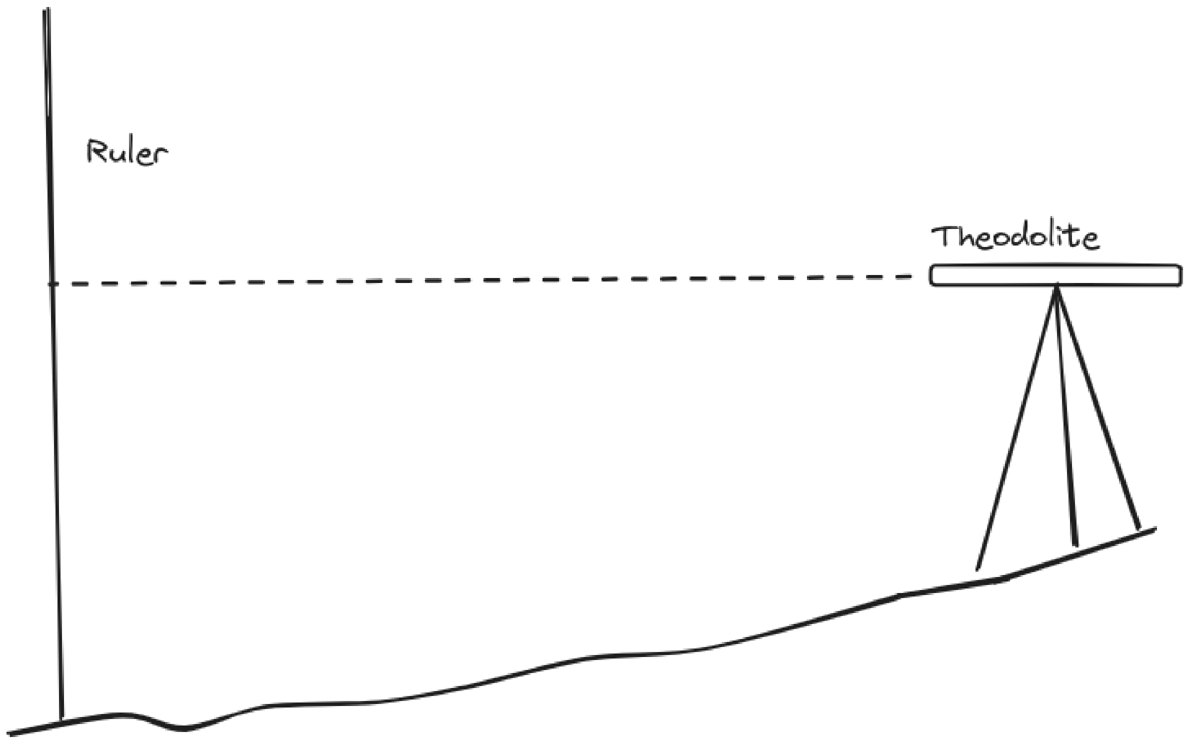
Roy had marked the ends of the Hounslow baseline with wooden posts and they were already rotting. Mudge replaced them with a pair of partially buried cannon. They are still in the ground, although one of them had to be moved some time in the $20^{th}$ Century and the baseline is now a few hundred metres shorter than Roy's.

Ramsden provided a new theodolite with some improvements over his previous effort. It still weighed 200 Pounds. He also came up with a smaller instrument, less accurate but cheaper and more portable. The heavy instrument was used to measure a connected series of large triangles very accurately. This ***primary triangulation*** repeated and extended the work that Roy had done, creating a network of large triangles across the while of Britain.

The survey began in 1790. The south coast of England was the obvious landing point for a French invasion so they started by remeasuring Roy's triangles and then moved on westwards, creating new trig points as they went. Initially they marked them using cairns of stones but they had endless problems with them collapsing or being moved by animals and humans.

**Measuring Height**

This survey needed the height of each trig point as well as its position. The landscape in the south of England is composed of low hills with gentle slopes between so the surveyors could use a technique called ***spirit levelling***. Essentially this involves using a horizontal sighting device at one point - a theodolite or a telescope with a spirit level - to find a point at the same height on a vertical ruler standing on a point downhill. That gives the difference in height of the two points:




Spirit levelling

You can see a picture of surveyors using spirit levelling here: https://geodesy.noaa.gov/INFO/history/spirit-leveling.shtml

Repeating that operation in a series of “hops” gives the difference in height of points further apart. Each hop introduces a small error. The error accumulates over many hops, but you can reduce it by following several paths between the two points.

Spirit levelling isn’t feasible in the mountains of Wales, Scotland, Ireland and the north of England so you need a different technique. You can measure the height of a distant point more directly using a theodolite – Set the base plate horizontal and tilt the telescope to point to the target. Use the two scales to find the vertical and horizontal angles to the target. Do that from three points of known height and use trigonometry to find the height of the target. You could use the same process on the South Downs, but the OS found that when spirit levelling is feasible, it’s more accurate.

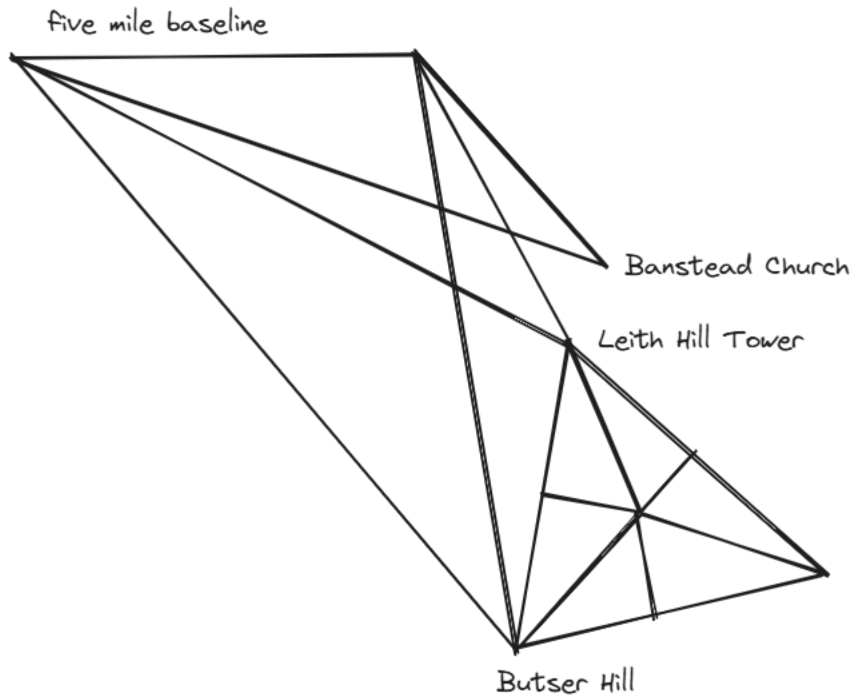
Both techniques only give the relative height of the points – this point is five feet four and five sixteenths of an inch above that point, and so on. You need some base level from which to measure the height of everything else. All dry land is above the sea, so sea level is a good choice. The surveyors triangulated down to the sea, found sea level and then worked backwards to find the height above sea level of all the trig points and many others.

The result of all that was a set of ***benchmarks***,  points in the landscape whose height was known accurately.  You can use them to find the height of any other nearby point, but you need a lot of them – there are currently about 750,000 across the UK.  This one is marked on the wall of a pub in Leatherhead:

**The First Survey of Britain**

In 1791, Mudge and his surveyors started at the baseline and headed for the South Coast, measuring the large triangles of the primary survey as they went, building cairns of stones to mark the positions that they measured

The next stage was the ***interior survey***.  Those surveyors used the smaller Ramsden theodolites to fill in the big triangles with a series of smaller ones, to create extra trig points within them.  In the picture below, every corner of every triangle is a trig point:




Finally the real work of the survey could begin.  The surveyors used theodolites, surveyors' chains and the trig points to measure the positions of all the features they wanted to put onto their maps – field boundaries, churches, the paths of roads and rivers and so on.

As well as measuring the landscape, the interior team had to get to grips with place names in local dialects and the various forms of Celtic.  People on different sides of a mountain might know it by different names, and rules had to be created to decide which one was "correct".

Distortions in the instruments due to changes in temperature, heat haze or just transcription errors when the surveyors wrote down the results all produced errors.  In any case, small errors are inevitable in any measurement and when the result of one depends on the result of a previous one, they accumulate.

The interior survey used less accurate equipment than the primary survey, but the network of primary trig points kept the overall errors within acceptable bounds.

As the surveyors worked they sent their measurements to the back office in London where the human computers applied the conditioning equations to correct the data.

To reduce the errors further, the surveyors created a second baseline on Salisbury Plain, between Old Sarum and Beacon Hill and measured positions of the same trig points from there. The computers then cross-checked the positions given by the two baselines.

Once the data was conditioned, the draftsmen drew the maps and they were prepared for printing.

In these days of motor transport, computers, desk top publishing and the Internet, it's useful to think about what all this involved in the 18th Century. The surveyors travelled on foot or on horseback, sometimes on terrible roads in terrible weather. The primary survey team had to move the 200 Pound theodolite around and winch it into place at each trig point.

They recorded their measurements in paper notebooks using pen and ink and sent them by post to the back office. The computers read (or misread) the data from the notebooks and put them through a complicated algorithm using log tables, slide rules and hand calculations. Draftsmen drew the maps. At the printers, engravers cut the copper printing plates by hand, as close as possible to the drawing. The plates were good for a few thousand impressions and when one failed, another had to be cut, again by hand.

In 1801, ten years from the start of the survey, the map of Kent was the first to be printed. It cost three guineas – three Pounds and three shillings or £3.15p in today's terms, then about twenty day's wages for a skilled man. Ordinary folk could access them in the new lending libraries. Maps of other areas emerged one by one. As the market expanded, OS maps became cheaper.

The first complete survey of England, Wales, Scotland and Ireland took 80 years. It was one of our great projects of the Enlightenment and it generated widespread public interest. Roy, Mudge and other members of the survey became minor celebrities.

Once that was done, work started on surveys and maps of the whole British Empire.

Through the 19th Century, the landscape changed. Towns and cities expanded, roads and railways were built, all of which meant constant resurveying and republishing. Meanwhile the technology of measurement improved, partly driven by the OS. Theodolites became smaller and more portable. When one of the first long-duration spotlights emerged from chemistry research, it was developed by OS Surveyor Thomas Drummond into an instrument to allow more reliable night surveying. The light was driven by burning a small pellet of lime. Originally known as "the Drummond Light", later it was used in the theatre and became known as "the limelight".)

People, animals and the weather continued to interfere with the cairns that marked the trig points. Eventually the OS came up with the idea of marking them with ***freestones***, buried stones of material not native to the area (so maybe sandstone blocks in an area where the native rock was granite). The records for each freestone trig named a trusted local who knew exactly where it was.

## Maps and Society

As OS maps became cheaper, the middle and working classes of the cities used them to discover the countryside, as many of us still do. There was an interesting change of attitude amongst townsfolk. William Shakespeare was bought up in a small village in Warwickshire and moved to the big city to find success. Plays such as *A Midsummer Night's Dream* portray the English countryside as a dangerous anarchic place, which no town dweller in their right mind would visit. Once the dark satanic mills emerged in the towns, romantic writers such as Wordsworth popularised the countryside as the equal of the finest European landscapes.

The resulting staycation vogue coincided with the later years of the first OS survey, and the surveyors wrote of the nuisance caused by tourists from the cities infesting the landscape while they were busy measuring it. It's not clear whether they realised that they were the indirect cause of the problem.

I was bought up in a suburb on the edge of Manchester which is surrounded by green belt land. At 600 acres, nearby Heaton Park claims to be the largest municipal park in Europe. In the nineteenth century it and other local estates were a magnet for mill workers from all over the city on their one day off each week. There's a pub called The Railway and Naturalist, a name that seems to be unique. One theory is that it served the thousands of Manchester Ramblers who came in by train every Sunday. Another theory is that it commemorates railway surveyor and early evolutionist Alfred Wallace. One way or another, it's all about maps.

This invasion by the great unwashed was not always welcomed by landowners, resulting in conflicts such as the Kinder Scout Mass Trespass of 1932: https://www.prints-online.com/mass-trespass-kinder-scout-4458573.html. Nowadays we see this as a landmark in moves to open access to the countryside but the headline in the local newspaper at the time was: "Peak District ramblers in trouble".

James Walker Tucker's 1936 painting ***Hiking*** shows a more respectable version of the country walk. Three examples of The New Woman, smartly dressed in hiking clothes with all the right camping gear, consulting their OS map. Their local paper would probably have found them much more acceptable than a few hundred northern mill workers heading for a rich man's grouse moor: https://www.theguardian.com/artanddesign/2019/may/10/james-walker-tucker-hiking

**The 1935-1962 Retriangulation**

By the early 20th Century, the OS had major problems. Budget cuts had led to whole areas of the national map becoming out of date as the land was redeveloped. Previous surveys had left buried freestones to mark the trig points, but the people who knew precisely where they were long gone. Searching for the stones would cost too much, so those trigs were effectively lost. It was also suspected that the error in the height of each measured point increased gradually to the west.

Meanwhile new ideas about cartography had emerged including the Universal Transverse Mercator (UTM) system with its notion of eastings and northings.

From 1915 to 1921 the OS measured the height of the sea every hour at Newlyn in Cornwall to produce Ordnance Datum Newlyn (ODN) – a more rigorous version of mean sea level.

In 1935 they started a complete new national survey using state of the art equipment. Results were expressed as eastings, northings and height above ODN. Interrupted by the Second World war, it was completed in 1962.

The OS had by then adopted the SI (Metric) system, the norm in European scientific institutions, so they measured in metres and millimetres. The rest of the UK didn't go metric until 1971 so before then the measurements were converted to Imperial miles and feet when the maps were drawn.

They created new baselines, this time measuring them with metal tapes made of invar, an alloy which is very stable across changes in temperature. While using the tapes, they erected windbreaks to protect them from wind pressure. The tapes were sent regularly to the National Physical Laboratory to be checked and recalibrated.

They used the latest theodolites, much smaller and more portable than the 18th Century models. This allowed them to use the same devices for the whole project.

This survey introduced the four-foot high concrete trig pillars that we recognise today. The foundation go at least 2.5 feet (75 cm) deep so they are pretty robust. This one in the picture on the previous page is in Reigate Park, now somewhat hidden in the undergrowth.

Other markers used include surface blocks, concrete blocks about 18 inches wide sitting on or just below the surface with a metal bolt marking the reference position. See the second picture on the previous page for one of those.

In buildings such as the Goblin Teasmade factory in Ashtead, a large bolt in the roof marked the reference point. That building was demolished years ago, but the bolt in the centre of the roof of Leith Hill Tower is still there:

The surveyors created all these markers themselves as they worked, which could involve them climbing a mountain, carrying building materials as well as survey equipment.

Once again, the trig points formed a hierarchy, this time first order (primary), second, third and fourth order. The primaries were laid down and measured first, but the same model of theodolite was used throughout, so the measurements were all of the same accuracy. What made the difference was the time spent processing the data to reduce the errors – applying the conditioning equations. Electronic computers existed by then but they were expensive and the project budget didn't stretch to one.

The computations were done by human computers sitting at desks using calculating machines – state of the art at the time but very primitive by today's standards. The computers could only do so much in the time they had, so they had to compromise. The position of the three hundred or so primary trig points were corrected more rigorously than those of the second order trig points, and so on.

The result is a network of markers with positions known to the best accuracy that could be achieved at the time. Now taken for granted, this network is distributed across the whole of Britain, a monument to a huge and heroic project run for over two centuries to map the Nation.

**Redundancy**

In the last few years, the OS has adopted new technology such as aerial photography, Lidar and GPS. In particular, they now use a smaller network of Active (GPS) Stations, accurate to 2cm.

As far as the OS is concerned, accurate GPS has made their physical markers redundant. They now form a large piece of industrial archaeology. The facility at Newlyn for measuring mean sea level is now a listed structure, but the trig points and benchmarks are not, and with a few exceptions, nobody takes responsibility for them. Many are on private property in gardens and farmers' fields – one near Leatherhead is used as a garden ornament. Some trig pillars will probably last for centuries, but others are more exposed to the weather than others. The one on Box Hill is already badly cracked, letting in the frost each winter.

The surface blocks are in the most immediate danger, easily buried and forgotten. Bookham was served by three of them, all now disappeared. The bolts and the benchmarks on the walls of buildings are also vulnerable, easily removed during construction projects.


Damage to the Box Hill trig pillar

When the OS lost interest in the trig points, they put their benchmark and trig point data into the public domain.  Enthusiasts used them to create the Trigpointing website https://trigpointing.uk and a new hobby, trigpointing, which involves visiting trig points while out walking and logging reports about their condition.

There's also the Benchmarking website https://bench-marks.co.uk which you can use to find the benchmarks scattered around your town.

Accurate GPS equipment used to be prohibitively expensive, but lately it's got much cheaper and I've been experimenting with building my own system.  I face the same problem as Mudge and his colleagues – if your survey equipment claims to be more accurate than any other, how do you test that claim?  A good start is to survey some objects which already have reasonably accurate published positions.  If my results don't agree within the expected margin of error, my equipment is not as good as the manufacturers claim.  That's how I came to be wandering around Surrey and Sussex, remeasuring the positions of OS trig points.

## Sources

I made my talk and these notes from a variety of sources as well as my own adventures with accurate GPS surveying systems.

### Books

Map of a Nation by Rachel Hewitt, pub Granta 2010 is an excellent history of the Ordnance Survey.

Hewitt's book stops short of the retriangulation in the 20th Century but the OS published their own description of that in a 400-page book, The History of Retriangulation of Great Britain 1935-1962. It's long out of print and they directed me to a version on Google Books that you can download for free: https://storage.googleapis.com/retriangulation/The History of the Retriangulation of Great Britain 1935-1962.pdf

The OS also publishes a very useful guide explaining the various ways that a geographical position can be represented: https://www.ordnancesurvey.co.uk/documents/resources/guide-coordinate-systems-great-britain.pdf

**TV and Radio Programmes**

In cooperation with the Open University, the BBC has made a number of programmes about maps and mapping. It repeats them every few years and they stay on the iPlayer website for a time afterwards. If the whole programme is not available, there are often at least clips. Some of these programmes are also available on various pay-per-view systems.

- Mapping the Nation – the story of the Ordnance Survey
- The Figure of the Earth – how three French scientists measured the shape of the Earth in the 18th Century https://www.bbc.co.uk/iplayer/episode/b0074t5l/voyages-of-discovery-the-figure-of-the-earth/
- A Very British Map – the Story of the Ordnance Survey - https://www.youtube.com/watch?v=w5_kWzUahQU
- Maps: Power, Plunder and Possession
- The Beauty of Maps https://www.bbc.co.uk/programmes/b00s2w83

A radio programme about Mercator is also available on the BBC Sounds website https://www.bbc.co.uk/programmes/w3cszjv7.