THE WOOLHOPE NATURALISTS' FIELD CLUB

(ARCHAEOLOGY RESEARCH SERIES)

RESEARCHING THE LEOMINSTER CANAL

Paper 7 : ON THE LEVEL?

("Ancient Rome to nearer home")

Recalling the Survey of 1789

by

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(revisited with Gerry Calderbank)

SURVEYING and WATER MANAGEMENT

Beginnings. . . *how the Romans worked*

As Cohen's history of the Leominster Canal reminds us, there's a long 'pre history' of canal and river navigation enterprise but with much of it very distant, as in China or ancient Mesopotamia; whereas those physical remains are sometimes fairly evident, there seems little written account of how such early engineering work may have been achieved – until, that is, we come to the Greeks and Romans!

During the late Republic, under the jurisdiction of Senators and/or their designates, specialist civil engineers seem to have gradually evolved as did (military) surveyors. It appears that in earlier days, there was little distinction between engineers and surveyors. By the time of Trajan, any large-scale work had undergone both technological and administrative change: all decision making now lay directly at the discretion of the Emperor who responded in writing to nearly all public building and engineering requests from his provincial Governors. This we know because when Pliny was the Governor of Bithynia *(c.AD 112)* his correspondence with Emperor Trajan requesting permission for a new canal has been preserved. Pliny's proposal was intended to save transhipment of goods:

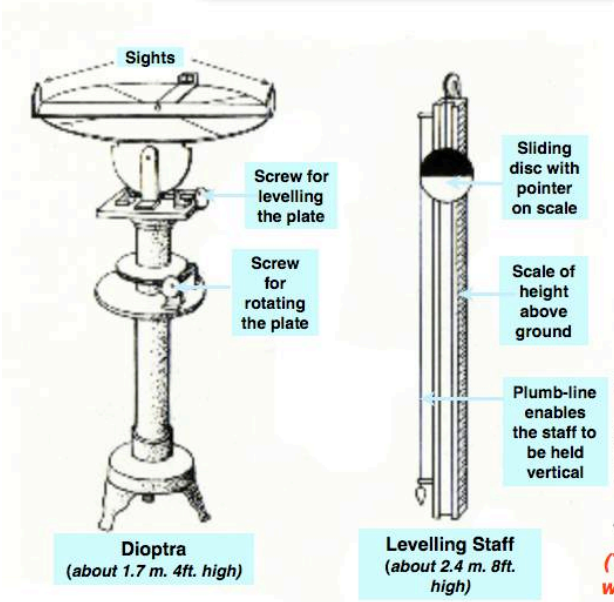
> ***There is a sizeable lake in the area of Nicomedia. Across this, marble, farm produce, wood and timber are conveyed in ships with little effort or expense right to the road, from which, with great effort and even greater expense, vehicles take them to the sea . . ."***

Pliny continues at some length to explain his discovery of an earlier abandoned canal, which he attributes to a former king of Bithynia, and from the general tone of his letter he is obviously seized with enthusiasm - having completed considerable research into the local opinion, manpower and resources available. However, Pliny is unsure of the lake's elevation and relative height above sea level, except that the locals think this to be about forty cubits *(c.66ft.)* ; but nevertheless, if the Emperor should feel fit to grant his approval - and send a surveyor? - then it would surely be to his greater imperial glory, in succeeding with what kings had merely begun!

Whereupon Trajan responded:

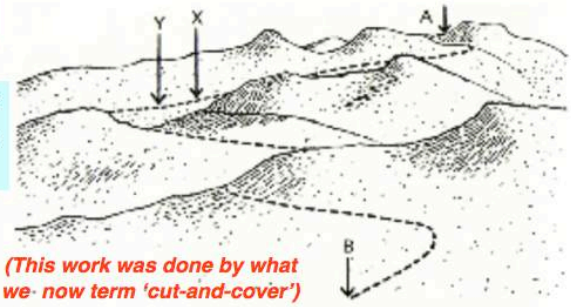
> ***"This lake of yours intrigues me, and I should like to see it connected to the sea, but there must be a thorough and accurate reconnaissance of the source and quantity of water flowing into it, otherwise, once given an outlet, it may all empty straight into the sea. You may apply to Calpurnius Macer* for a surveyor, and I myself will send you someone experienced in this type of work . . ."***
>
> * The nearest army commander with a surveyor

- ROMAN SURVEYING & LEVELLING : 2 -



Left: The dioptra. When the surveyor was taking levels he would first adjust the horizontal plate with a small water level; he would then sight on a staff held by an assistant and signal him to move the target disc up and down until it lay on the horizontal line of sight.

Below: In the diagram the aqueduct has its source at A and will emerge from the underground at B. Before the surveyor can mark out the length X-Y for men to start work, he needs to obtain both the distance between A-B and their difference in height.



(This work was done by what we now term 'cut-and-cover')

- ROMAN MEASUREMENT -

The *pesa* (Roman foot) was usually sub-divided into 16 'fingers' *(digiti)*, like the Greeks before them, but sometimes into 12 inches *(unicae)* – depending upon the region and historical context.

In 1639 John Greaves examined 3 Roman sites and pronounced an average equivalence (to the English foot) of 297mm (0.975%). The modern value is generally taken to be 296mm.

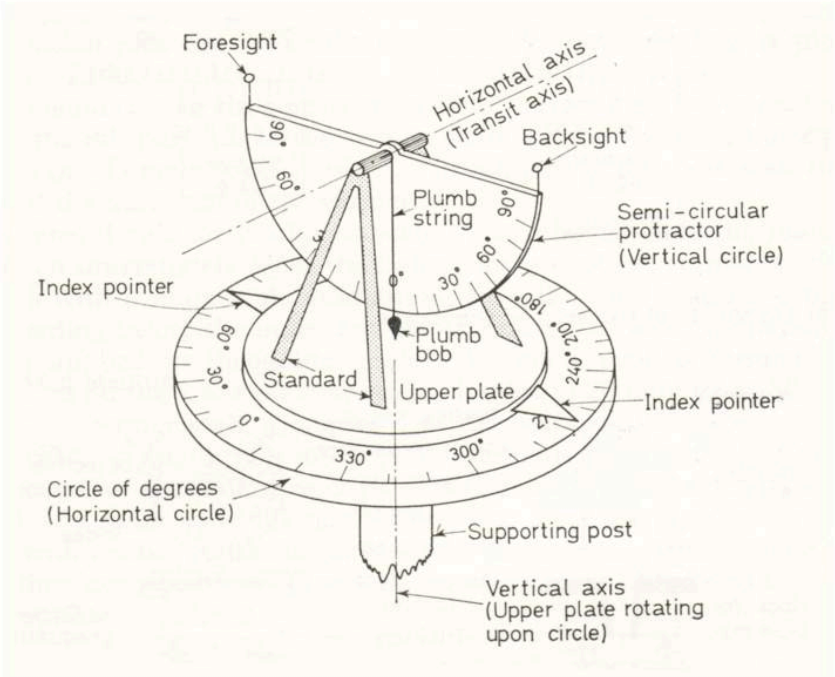
As early as the 3rd century BC Greek astronomers were using the dioptra to determine the relative position of stars, and the Roman instruments were very similar; it was also an effective surveying tool over relatively short distances, limited only by the efficacy of human eyesight. The WARS borrowed a dumpy level when available, but otherwise a builder's level (with temporary sights) was nearly as effective when surveying small canal features.

- LIMITATION & IMPROVEMENT -

- **Roman-style 'Line of Sight' was visually restrictive - but there were no advances until Galileo (1564 - 1642) improved the 'Dutch' telescope by his introduction of an eye-piece with concave lens.**
- **An English mathematician - Leonard Digges - published his description of a <u>proposed</u> simple *'theodolite'* as early as 1571 although nothing practicable came of this for over a hundred years.**
- **London craftsmen (Guild of Clockmakers) were well established amongst the finest instrument makers by the seventeenth century, and they invented and refined many scientific instruments.**
- **Of these, Jonathan Sissons invented the *'plain theodolite'* in the early eighteenth century - but this lacked a telescope and was also limited to 45 degrees of arc in the vertical plane.**
- **Next, the plain *'transit theodolite'* - with 360 x 90 degree transit range - was developed and then further refined within a few years.**

EARLY EIGHTEENTH CENTURY 'PLAIN' THEODOLITE

(no optics, but with 90 degrees of vertical arc)



The Precision Transit Theodolite

- Basic Components -

V.S. - Vernier Circle *(rotating scale)*

m **- Vernier Arm** *(with microscopes m3 & m4)*

T - Telescope *(bubble omitted on sketch)*

d **- Diaphragm & Reticule** *(assembly)*

e **- Eyepiece**

c **- Reticule**

o **- Object Lens**

P - Pillar/s

H.S. - Upper Plate *(rotating scale)*

m - Vernier Arm *(with microscopes m1 &m2)*

f.s. **- Foot Screws** *(on bottom plate)*

The vernier instruments were rapidly developed in the Eighteenth Century, and optimal accuracy was obtained by the 1790s when used by Dadford's generation .

They're no longer in surveying use, and are now also largely displaced by laser technology for most other work.

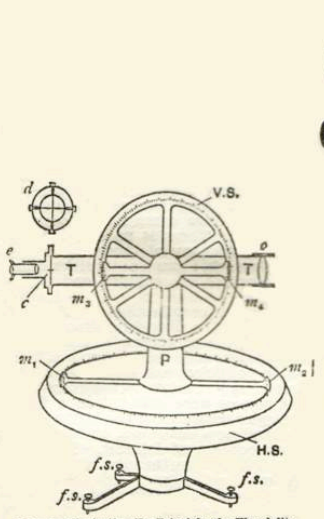
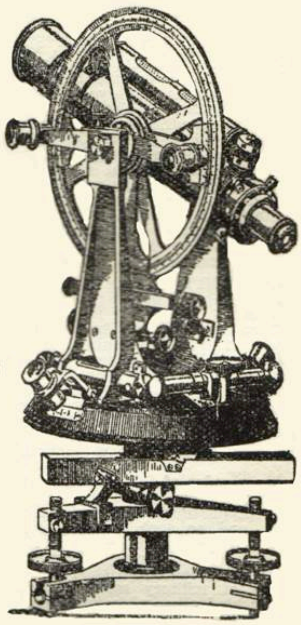


Diagram illustrating the Principle of a Theodolite


Stanley's Transit Theodolite

GEORGE LAMBTON'S 'GREAT THEODOLITE'

Probably the most accurate instrument of its kind, this theodolite was built by William Cary of London and used to plot the 'Great Arc of India' - a project which commenced early in 1800.

Whilst in Canada, Lieutenant Lambton had specialised in geodesy so when promoted to the Indian Survey in 1796, he soon obtained permission to commence a (third) survey of the sub-continent.

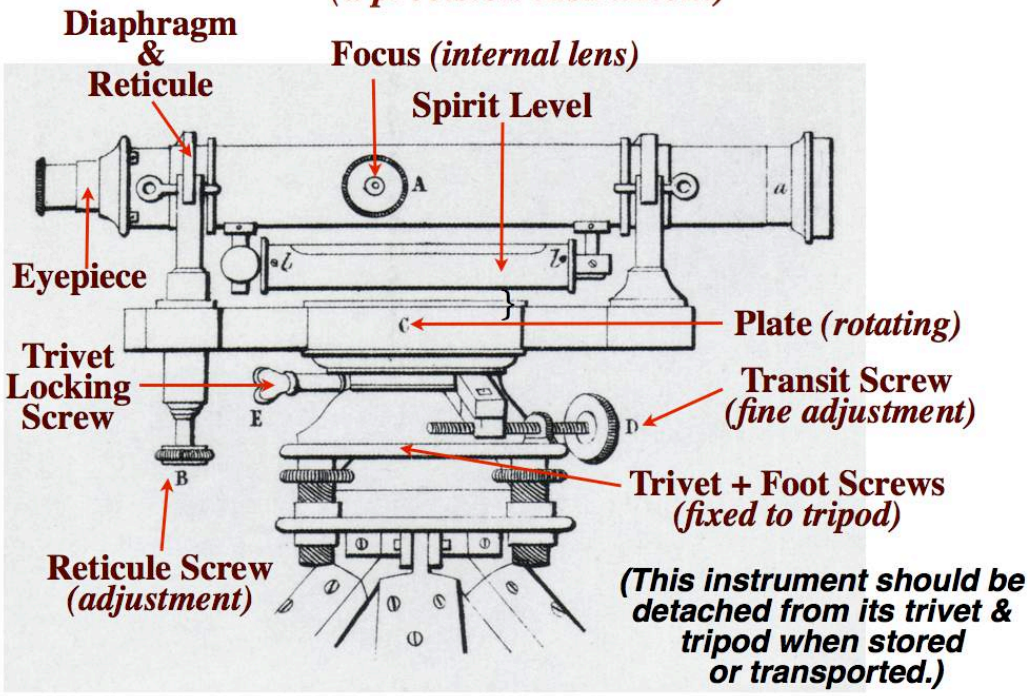
Before establishing his base-line, the theodolite was tested from mean sea-level at Madras to the roof of the racecourse grandstand - a distance of 19,208 feet - to a vertical accuracy of three decimal places of a foot!

When chaining his base-lines, Lambton fastidiously strove for an accuracy of seven thousandths of an inch per chain - all this despite the problems of heat expansion, together with atmospheric diffraction - and marauding tigers!

Whereas Lambton's geodesic instrument was likely the most accurate of all time, Whitworth, Dadford and their like would all have used the more mundane 'Precision Transit' version for sighting their contour canal level/s. Sighting cross-valley over a range of several miles, their assistants could then readily be hand signalled in the usual fashion to peg out a survey line of sufficient accuracy. In fact, their instruments could measure well beyond what was required at this stage, so in practice they would probably be sighting to the nearest tenth of a foot. When working on-site they would likely resort to dumpy levels, of near similar accuracy (at short range) but easier and quicker to set up.

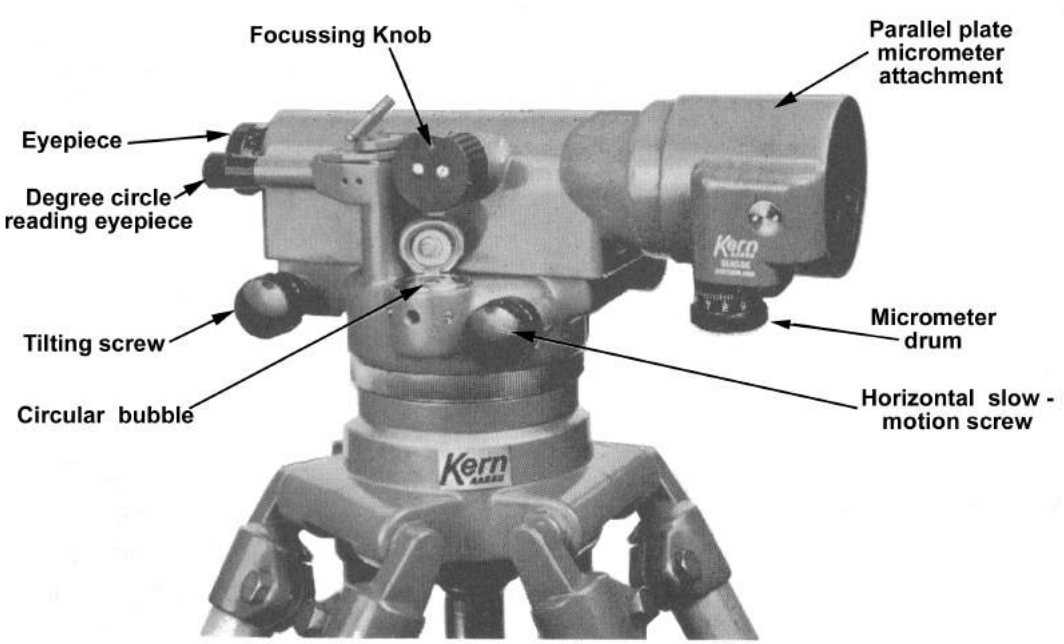
EARLY NINETEENTH CENTURY DUMPY

(a precision instrument)



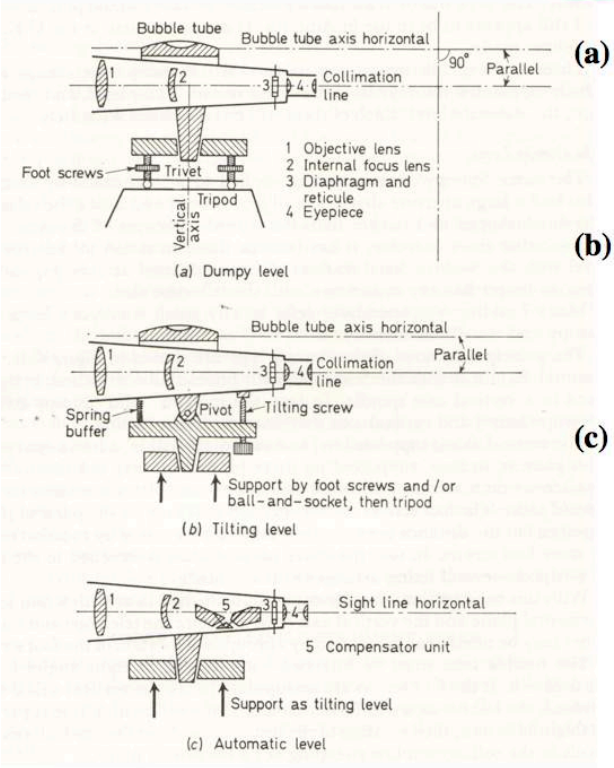
The WARS Leominster Canal investigations were pre-metrication and so we levelled to the nearest one tenth of a foot, whereas much greater sophistication is usually demanded for engineering purposes. Our novice might possibly be disconcerted at reading inverted numerals but quickly became accustomed and there never seemed much chance of error, other than simple arithmetical miscalculation, although even that was eliminated with the Woolhope Scale deployed (described later). Nevertheless, on balance, a dumpy single-user was preferred, rather than readjusting the eyepiece.

The Kern precision level was typical of its class, possessed of certain (optical) features required to overcome the deficiencies of human vision, since accuracy even as much as 0.5mm/km might sometimes be required!



Kern Precision Engineer's Level

THREE TYPES OF LEVEL



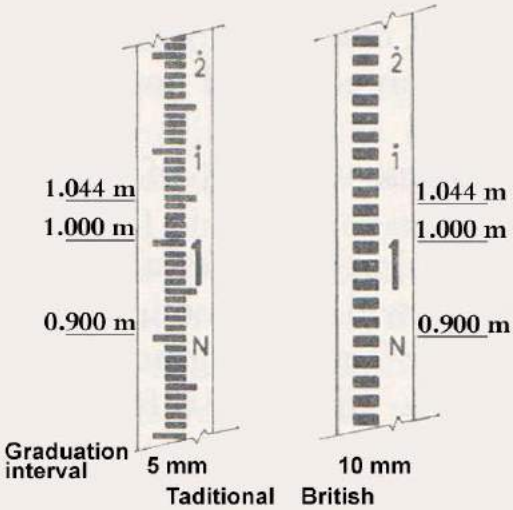
(a) DUMPY - this traditional instrument is fiddly to set up but rock solid once in use

(b) TILTING - shares identical optical principles but is easier to adjust and therefore quicker to set up

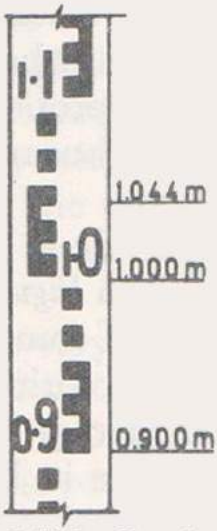
(c) AUTOMATIC - works on a different optical *(pendulum + prism)* principle requiring little manipulation, and has largely superseded the older versions.

- Laser instruments have now also rendered these ocular levels largely redundant -

METRIC STAVES . . . *old and new*



Not recommended – difficult to read



British Standard Metric Staff (BS 4484 : 1969)

Some variations - colour pattern in red alternative metres

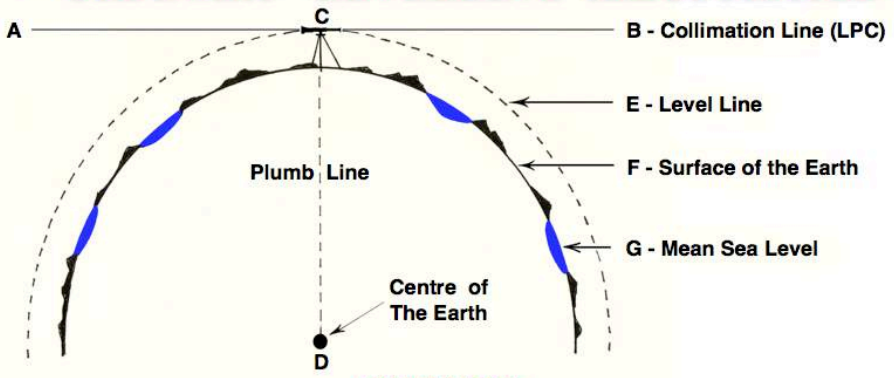
LeveIs & Metric Scale diagram from W.S.Whyte's book, Chapters 6 & 7 - listed below

- 'ORDINARY' LEVELLING . . . *terms and definitions* -

1. **'LEVELLING' - is an operation for determining the relative heights (or differences in heights) of places on the surface of the earth.**
2. **A 'LEVEL LINE' - is not actually 'level' because it is a notional line of constant or uniform height, relative to mean sea level – and is therefore a curved line.**
   More formally (and correctly) it is best defined as a purely imaginary line linking an infinite number of points, at each of which the line is 'normal' (perpendicular, or at right angles) to a 'PLUMB LINE' pointing to the gravitational centre of the earth.
3. **'L.P.C.' - *The Level of Plane of Collimation* - is a horizontal sight-line through any of the points on this level line, meaning it's also at right angles to the centre of the earth. Since it is obviously tangential to the earth's surface, the LPC is therefore infinitely 'level'.**
4. **'SPHERICAL EXCESS' - It therefore follows that the two are only coincidental at any given point - and the further their distance from this common point, then the more excessive is their vertical separation.**
   In ordinary practice, such difference is negligible - for sightings within about 200 metres - but with geodesy, as the discrepancy accumulates, it becomes problematical!
5. **A DATUM SURFACE - is any common reference point from which sites are measured, and may be directly taken from OD Mean Sea Level or from a localised benchmark and/or its temporary derivative known as the SITE DATUM *(frequently marked 'SD' on a plan)*.**
6. **ORDNANCE DATUM - The 'O.S.' originally used the bottom sill of Liverpool Dock (1844), but this was found to be unreliable - Newlyn having been used since 1915 - 1921.**

(Summarised from W.S.Whyte's book, Chapters 6 & 7 - listed below)

- 'ORDINARY' LEVELLING ILLUSTRATED -



- SUMMARY -

- **The Line of Collimation (A-B) is tangential to the surface of the earth at the instrument (C), from which its Plumb Line (C-D) is perpendicular at the point of intersection. This gives the (infinite) *Level of the Plane of Collimation* ('L.P.C.').**
- **The Level Line is a (conceptually) curved line which is constantly separated from Mean Sea Level at a fixed vertical interval and it is therefore 'normal' (i.e. perpendicular) to the direction of gravity at all points throughout its length.**
- **For example, the water levels of canals follow Level Lines between locks and/or inclined planes.**
- **Only at one point (C) are the Collimation and Level lines coincidental - and the further their divergence, from this common point, then the greater the vertical discrepancy in their relative levels.**
- **In 'Ordinary' levelling (small local sites) the difference is negligible and can be ignored, but beyond about 200 m it becomes increasingly important - especially so for geodetic purposes. This is because triangulation then encounters 'spherical excess'.**

- A METRIC MUDDLE -

France was formerly plagued with a profusion of ancient *(and frequently regional)* units of measure.

Upwards of 250,000 different units were criticised by the visiting English agriculturist, Arthur Young, just before the Revolution.

Reform had long been contemplated by the *Ancien Regime*, but with nothing agreed by its leading scientific experts – that is, until the eve of the Revolution.

In August 1793 the now Republican government finally decided to proceed and so they ratified the fresh start.

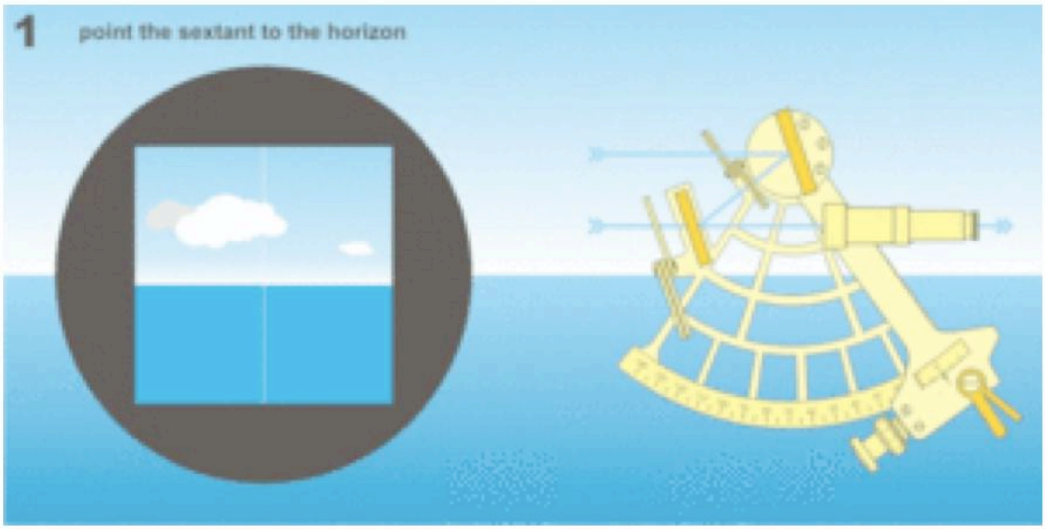
It was decreed that the the new national unit of length should be 10^{-7} of the earth's quadrant on a meridian passing near Paris – with two survey teams deployed and each independently working, respectively, N and S from the city.

This work required high-grade instruments – like some of those previously depicted – but, in order to verify their geo-position, there was the daily need for astronomical (angular) readings of unprecedented accuracy.

To this end, sophisticated maritime sextants *(above)* were deployed. These instruments shared many of the earlier-mentioned features, such as vernier scales with magnifiers.

Furthermore, they also utilised a silvered mirror – with sighting slit – plus a set of deployable filters for observing the sun.

- Operating a Sextant -



Horizons are required for sighting - so no problem when you're at sea! - but for terrestrial use an (optical) artificial horizon may be substituted. However, this may become a somewhat more difficult operation, mainly because of the much shorter viewing range.

The shorter the viewing range to an horizon, then the greater the difficulty with accurately reading the angle. Observational accuracy is paramount, but this eventually caught out the southwards-heading French team – because an error subsequently occurred.

When traversing the Spanish sector, there was a slight angular mistake with a routine sextant reading - not noticeable at the time, although revealed much later when routine checks were made - but it was nevertheless sufficient to throw the overall measurement into jeopardy.

- The Muddle! -

- **Whereas the concept was admirable, it had been somewhat hampered by the turbulent political climate – and there was was also that error with the S sector!**
  The survey was nevertheless completed within five years and the new 'metre' duly recorded on three platinum bars, plus several iron copies.
- **Sadly, when the survey was found to be inaccurate, this was initially 'hushed up' : but worse still, instead of adjusting the metre to the corrected data, it was simply defined as *"the distance between two points on a bar"* – whilst still using the same (inaccurate) platinum and iron bars!**
- **Despite such a shaky start the metre steadily gained ground throughout the nineteenth century, although many scientists were perhaps distressed with its flawed origins and resultant definition!**
- **So it was later redefined spectroscopically, firstly in terms of the red line of cadmium, then ultimately (since 1960) by reference to the Krypton wavelength.**
- **Arguably – and despite this re-definition – the metre might still be criticised on the grounds of oversize, as compared to Imperial and American systems.**
- **For example, the British field archaeologist will likely need to record his precise metric levels to two decimal points - instead of its Imperial equivalent, which was one tenth of a foot.**

- A VERY LOCAL METRIC AFTERMATH -

The 1960s and very early 70s seemed a particularly busy time for the WARS because not only was there a great deal of research in hand, but we were also constantly interrupted with a seemingly endless stream of more urgent (mostly weekend) rescue excavations; this is almost certainly because there was as yet no H.C.C. archaeology structure in place. It seemed that anything archaeological in the county must devolve upon the Woolhope Club or possibly the Archenfield Archaeology group?

Even whilst living just over the county boundary in Burford (Ludlow Rural District) there was ongoing involvement with research at Croft Ambrey, Dorstone Hill and Midsummer Hill, plus the rescue excavations on Hereford City Walls, and the three sites in Leintwardine village, to name the most time consuming and/or demanding. Frank Noble and, in particular, Stan Stanford were the leading lights, with the rest of us pitching in whenever available, although I was fortunate enough to have the school and college vacations at my disposal. Even so, the aftermath of all the field recordings continuously piled up, awaiting such time that we could give attention to things like washing the finds then bagging and labelling them, etc., etc. We were then young, enthusiastic and very involved, but even so there was one particular aspect that can only be described as tedious - and it sprang from a quirky and decidedly unorthodox way that Stan Stanford made his field notes, *viz*. the way he registered all his levels recorded day-by-day. Instead of using a surveyor's notebook, Stan jotted the readings on his draft field sheets as he went along, instead of logging them.

One winter evening in the mid sixties, Stan phoned me requesting some assistance at his then home (Ashfield Cottage, Luston) with processing some of these (temporary) jottings. Lucton was only a short drive and I quickly joined Stan and Yvonne for what became the first of several such sessions; I don't recall which excavation pertains, but the work, although simple enough, seemed tediously repetitive. It was simple arithmetic, comprising the repeated subtractions of each foresight reading from the daily backsight setting (we tended to set up the dumpy, undisturbed, for the whole day if at all possible). After a second such evenings, it occurred to me that, in theory, there was a potential way of automating the task because, in basic mathematical terms, we were simply engaged in an 'iterative process'. I recall those were the days before widespread PC ownership, and neither did we have a programmable calculator, but through my work I was well into 'Programmed Learning' and the then current craze for teaching machines and other allied aspects of the so-called 'Modern Maths'. For a short while my then employers Methuen Educational did good business with 'programmed textbooks' whereas they wisely steered clear of teaching machines!

THE WOOLHOPE SCALE . . . *metrication and other reminiscences.*

Although programming wasn't called for, maybe a simple analogue calculator might do the trick, so it was away to the drawing board and my home workshop. Devising and accurately drawing the 50 segments, each subdivided by ten, was quite tricky without incurring a cumulative error, but a week or two later, a calculator appeared, which Stan promptly named 'The Woolhope Scale'.

The device may be described as a single function slide rule but (unlike a logarithmic slide rule) the scalar progressions are each linear. So in other words, it is an automated 'subtractor' that reads off instantaneous heights above sea level - when set up and given the appropriate data.

The graphic scales were drawn on high grade card, sandwiched between a marine plywood base and the protective perspex cover. Reading clockwise, the fixed outer (LPC) scales shared two sets of numerals 0-50 outer in black, and 50-100 red inners. Splitting the 0-100 total range was done simply in order to reduce the overall diameter of an already sizeable instrument!

The moveable inner (Sopwith staff) scale – calibrated 0-16 – reading anticlockwise, was analogous to the height of our most commonly used Sopwith staff and - when 'zero adjusted' - this Staff Scale was locked in place with a wing nut. A chinagraph pencil was used on the perspex to note the backsight datum after taking an initial backsight. There seemed some risk of reading and recording from the wrong LPC scale - although a fifty foot error would be very obvious! - and Stan later confirmed that this never occurred or, at least in his experience, it was certainly neither reported nor perpetuated.

I rarely had occasion to use the scale, except when instructing students and newcomers, but in any case it was always intended for Dr. Stanford's own use, so it became a case of "out of sight, out of mind" until, that is, many years later when three of us retirees were by invitation to visit the Stanfords in Leinthall Starkes. But meanwhile, shortly after starting to use the scale, there had come the national decision to drop Imperial measure in favour of metrication and so various plans for developing and promoting more extended usage of the Woolhope Scale were instantly abandoned. It was obsolete, confined to the scrap heap and just a mere half memory - or so we thought.

HAPPY ENDING!

Our visit was timed to follow a ramble that included Croft Ambrey. As Iris, Rosamund and I sat in the Stanford's lounge enjoying tea and cakes, we chatted about old times, including the Ambrey excavations, and similar places when somehow, a glancing mention was made of the scale. Stan suddenly got to his feet and after excusing himself, left the room briefly, only to shortly return carrying a sealed bag containing the scale. He insisted that we take custody because ill health meant that it hadn't been used since his retirement and he certainly had no further use for the scale - but then neither did he wish it to be scrapped at some future date.

Nothing further was said about the Woolhope Scale as the conversation turned to various other reminiscences - including canoeing. The Stanfords were long-time members of The Canoe Camping Club and had also been founder members of our Hereford County Canoe Club. I only ever canoed with Stan and Yvonne on one occasion when my Canadian canoe was out of commission and he loaned me a leaky German Klepper folding kayak in order to paddle the Teme from Knightsford Bridge to Powick - a very wet experience!

Returning to the Woolhope Scale: when we arrived home I took the scale out of its wrapper and at first glance there seemed something different about it; clearly, the numerals and lettering had received some sort of attention - but what else? The outer LPC numerals 0-50 . . . 50-100 were untouched and exactly as I remembered them, whereas the moveable inner Staff numerals had been partially altered so that some now read differently. Furthermore, my original scrawl had been meticulously overwritten and new instructions were added. Nothing had been mentioned about this but, yes, Stan had clearly metricated his Woolhope Scale in some way or other and must have continued using it right up to his retirement.

The adjustable SOPWTH STAFF inner scale

Stan Stanford possessed high-grade late Victorian surveying equipment – including a dumpy fairly similar the the above illustrated 'C.19 Precision'– all of which he'd purchased from a recently retired county surveyor, and which we were allowed to use (with great care!) on occasion.

My original adjustable scale was calibrated in feet, sub-divided by tenths to comply with the former standard British archaeological usage, and it extended to 16ft. (just off-screen above) which matched the Sopwith staff that we used. In practice, when, for example, recording trench wall-section objects like pottery, bones, brooches - or features such charcoal layers, depth of post-holes, etc - we recorded their elevation, in relation to our site datum, to the nearest tenth of a foot.

However, for some unknown reason, I noticed that Stan had only metricated up to 09 'units' (each still with ten subdivisions) which suggests he probably purchased one of the adhesive metric overlays that were marketed at that time. I'm only guessing, but if so then Stan's Victorian 16ft (telescopic, three-section, mahogany cased) staff would have fallen way short of 9 metres (c.29.5ft) - a length that, in any case, would surely have been totally excessive and decidedly unmanageable in anything but light winds! To further complicate things, these metric substitute scales were available in three different patterns. I've never levelled other than Imperial, nor had cause to retrain, but suspect that, of the metric staves, the plain, alternating sub-divisional pattern must have been easiest to sight - and clearly superior to the: *"Traditional British - not recommended - difficult to read"*. *(Whyte, p.76).*

I was intrigued to see that Stan had added two (parenthesised) notes regarding the LPC outer scale (it's not shown above) which seem to suggest that his metrication was possibly a straight substitution of metres for feet? If so, then presumably he would have continued to use the 10 subdivisions also? However, there seems no indication regarding the magnitude of this sub-gradation - but if we're assuming tenths and that 10cm = c. 3.97 inches, then such coarse gradation would surely have been considered too insensitive in our day!

After we closed the WARS Leominster Canal Investigation there were several loose ends and unanswered questions - only rarely revisited on the odd occasion - but having entirely finished with actual site surveying, I never had cause to undertake any further levelling. Nevertheless, upon moving to Ross (1968), a few things were either lost or permanently mislaid, including an Imperial edition of Whyte (our surveying bible!) so I acquired a secondhand (but metric) replacement.

- SELECTED FURTHER REFERENCE -

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