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The Revolution in Tidal Science

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Exact tidal study extends back to a fourteenth century record containing sexagesimal times. Earlier commentators have taken these times to be high water. This study shows they are for the later moment of when the flood ends; and, that eighteenth and nineteenth century elevation measurements formed a completely different way of considering the tide, leading directly to reliable predictions. The result shows the Thames tide to have been more consistent than previously stated; and consequently the actual change more accelerated. Therefore tidal current predictions are shown to have a longer history than have water surface elevation levels.

KEY WORDS

1. Tidal predictions. 2. History.

1. INTRODUCTION. Studies of historical tidal records for London Bridge cite John Flamsteed's (1646–1719) predictions (Amin, 1983 & Cartwright, 1999). Flamsteed, the first Astronomer Royal, deriving predictions from a motley collection of observations, said his tide times were for High Water, the moment of maximum elevation (Flamsteed, 1683). I assert that Flamsteed's description is misguided, and that his predictions actually pertain to the last of flood, the moment of minimum current. Tide-turn at London Bridge – equally the moment of slack, or of the ebb setting in – occurs some forty-five minutes after High Water.

The table illustrated in Figure 1 is from St Albans. David Cartwright includes study of its tidal part, as if those times were for High Water too. They are not. This paper demonstrates that the table's London Bridge tide times are for the last of flood, and that the previously assumed dating should be shifted to later, probably the early fourteenth-century.

From 1828–37 John Lubbock (1803–1865) did investigate actual High Water times, including data from the nearby London Docks. From these various records I show that the tide's phase at London Bridge had been sensibly constant for the five centuries preceding him. However, because of a cumulative massing of civil engineering works since the beginning of the Industrial Revolution, the phase has become 21 minutes earlier in the 171 years since Lubbock's work. Hence the phase change is at a more accelerated rate than Mohamed Amin indicates.

2. EXAMINATION. The tides of shallow seas, such as the continental shelf of North-West Europe, are more complicated than in the ocean from which they

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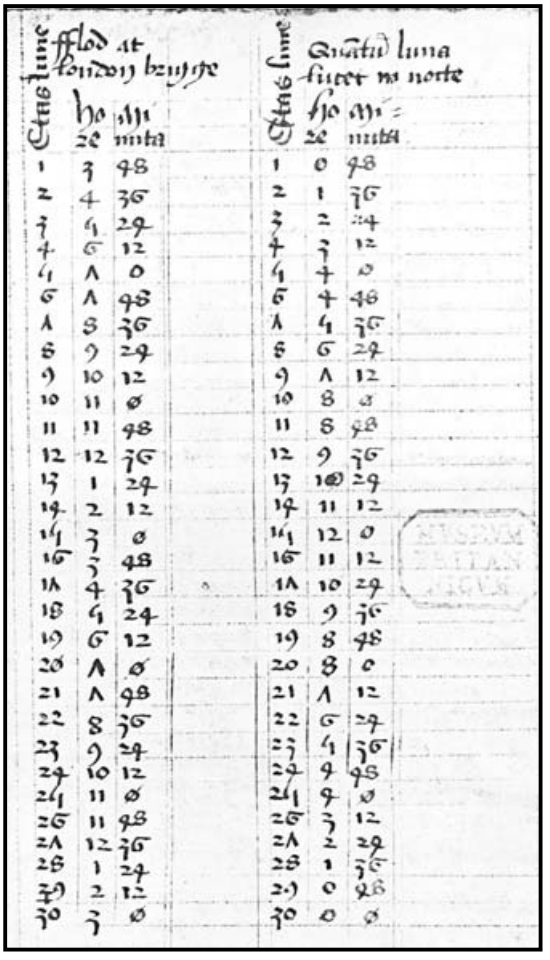


Figure 1. The St Albans table (Reproduced by courtesy of the British Library Cotton Julius DVII folio 45b).

come – the North Atlantic. Yet for most commercial uses, such tides are understood sufficiently to allow accurate enough prediction by the harmonic method (Admiralty Tide Tables, annually). In addition, the more recent response method provides a higher quality of prediction (Munk and Cartwright, 1966), than those so readily available. Within an estuary however, the open ocean tidal signal distorts to a greater extent than can be easily appreciated. One estuary effect is the flood tide continuing to run inwards for some time after High Water. Hence by the time the tide does turn its direction, the water surface level has markedly dropped. This run is for some 25 minutes within the Humber's upper reaches at Goole; and – as will be demonstrated – Figure 1 constitutes an early record of the 45 minute run on the Thames.

Figure 1 holds two tabulations related to the moon, running from the moon at one day old, through Full Moon, round to New Moon. By then, each old moon has aged for thirty days, and so we say it changes into a new moon. Change day functions as

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both the zero and thirtieth day – as on a clock face, where twelve also marks zero hour. The left hand part of the table gives the time of flood at London Bridge; the other shows the duration of time the moon shines at night. The increment, to tide time and duration of useful moonlight, is the same for both; it elapses by forty-eight minutes per day. The whole month's tide predictions are based on a constant. This is for the two days when the effects of sun and moon yoke together, and produce the same tide time. A tide table for another place, further along the coast with a different constant, would bear a strong resemblance but have different numerical details. In that era, it was acceptable for the daily consideration to be the same for both the AM & PM tides.

Early tidal diagrams, usually in the form of a rota, were also the commonest way for presenting lunar information (Hughes, 2005). Among all the early tidal archive only one other linear list is known (Anonymous, 848). That list employs Roman numerals, but has the same lunar age layout as the St Albans table. A list is an easier way to present information than in a circular form, but this table is probably founded upon such a rota.

The double tabulation of Figure 1 indicates the Full and New Moon when aged 15 and 30 days old respectively. But beginning with the moon already one day old, it is this which suggests that the scribe has copied the linear lists from a rota, one setting lunar age in a continuous circle. As the cycle is about 29 $\frac{1}{2}$ days, circular diagrams are then self-correcting. Except at an eclipse, it is impossible to see the New Moon, but easy enough to calculate when it should be New and when Full. Rotas orientate New Moon starting out from the top; this tidal list does not. While the heading of the tidal list predicts flood at 3 hours 48 minutes, that is not the tidal constant. Found next to Full and New Moon in the list, the London Bridge flood constant is 3 hours 00 minutes.

Although now arcane, this simple fact about the flood – the constant – eventually became known as the *establishment of the port*. The table then presents an early but precise fact about the tide. For Jarrow, the Venerable Bede (672–735) had given an earlier but similar fact about the flow. Although Bede's way of timing the current is rather crude, it is nevertheless clearer then Strabo's (64–23), and hence constitutes the establishments's origin. This table carries Bede's establishment concept forward. The concept endured through Flamsteed's time into Lubbock's period, when, with interests changing to tidal elevation, the concept was already obsolete from a scientific viewpoint.

However Lubbock's investigation was contemporary with the remaining practical interest that had to be taken in the slightly later moment of tide turn. Centring on maximum elevation, he failed to notice this difference of moments, taking the view that the tide had changed (Lubbock, 1837). David Cartwright has pointed out that a part of Lubbock's error was in him misunderstanding lunar age. Notwithstanding lunar age, the misunderstanding of what the phrase *High Water* actually means, existing through Trinity House and Admiralty usage in the intervening century (Thrower, 1981), dates back to seventeenth century natural philosophers. Although this problem had been identified (Proudman, 1941), the assertion calls into question Mohamed Amin's conclusion, that the phase of M_2 has advanced by 33·3 minutes. Also thinking that the 3 hours 00 minutes referred to highest elevation, Cartwright took the opposite view to Lubbock, suspecting that the constant may be too great (Cartwright, 1999). As the St Albans table is explicitly about the flood, this paper

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argues that it is indeed for the end of flood rather than High Water, and that neither Lubbock's nor Cartwright's view is applicable.

3. THE END OF FLOOD & HIGH WATER. The English word *flood*, of Germanic origin and found as early as 825, developed its narrower meaning of flood-tide by 1000 AD. Because the St Albans phrase is *Flod at london brigge*, this form of the word is clearly referring to tidal flow. However, the table is inexplicit as to which particular moment of that flow. Yet after seven centuries, its approximation to a modern time value for the last of flood, shows its close association to that event. Another significant and slightly earlier event is the moment of highest elevation. At London Bridge, rainfall can reduce the interval between the two moments. But as the river rises six metres at that spot, and with the draughts of medieval ships much less, the very moment that the water achieves its highest level can not then have been of primary interest. The fact of utmost vitality, to manoeuvring ships and to the progress of both rowers and sailing craft alike, is that moment when the tide turns, the moment when no more flood can be found and the ebb's away. Explicitly referring to current and not to elevation at all, this must be what the table actually means.

One of several obsolete forms of the word flood, *flod* remained in use until about 1470 (OED, 1992). The significance of its moment to navigation, is supplied in two early quotations and continues into Lubbock's period: *at þe fulle flod þei ferden to sayle* (c1350) (Skeat, 1867. P.2745), *they cast anker and abode the fludde* (1523) (Froissart, 1927. I.xcii 114), *we must sail at the first of the ebb* (Rushbrook, 1841. P.xxxviii). These quotations demonstrate the practical importance of the simultaneous moment, last of flood and first of ebb. The definition of explicit nautical lexicography then develops further. But not being the same in all places it allows confusion: *flood is when the water beginneth to rise, which is young flood as we call it, then quarter flood, halfe flood, full Sea, still water, or high water* (Smith, 1627), *top of flood or high-water* (Smyth, 1867). In both of these two, the term High Water is being given to the end of flood – *flod*. This is the major case. For around the open coast, rather than within the confines of a river, the tide does turn its direction of flow closer to the moment that it achieves the High Water mark. Unfortunately for general understanding, at the very heart of England and its dominating maritime world, London is forty miles up an estuary, where the flood tide peters out forty-five minutes after attaining its highest level.

Giving two citations for *pinch-tide*, the Oxford English Dictionary also fails to discriminate between the two moments. In one, as a noun, it gives *the critical* (*highest or lowest*) *point of the tide, the turn of the tide*. In the other, as a verb, *of the tide: to pass its lowest or highest level* is a direct misinterpretation of its actual citation; which is, *as soon as the tide pinched, the ebb came down at once*. Flamsteed uses this very same word, *Our highest spring floods happen when tis pinch water betwixt 4 and 5 a clock* (Forbes, Murdin and Willmoth, 1997. P. 254).

All of the earliest tidal diagrams and tables are concerned with tidal flowing, some quite wittingly so. Most have an ecclesiastical orgin. Clerics, with a direct interest in accurately calculating time because of Easter, were among the few people capable of setting them out. So the St Albans table rises to a high practical usage. Later, though within decades of this table, the tidal cannon carried on within

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maritime interests, also primarily concerned with flowing (Benson, 1987). This primary interest, in the time of flood and ebb, continued beyond the quarter millennium ensuing from the table (Hughes and Wall, 2004a). By then mariners were asking, *what moon makes a full sea*. Therefore, both the preceding and following context to this word *flod*, is a further indication that its meaning is the last of flood – not High Water.

The present day concern with High Water did not begin to arise until another two centuries after the era of the St Albans table. Delimiting the shore in the phrase high water mark, it is first recorded only in 1553 (OED, 1992). High Water, as a property of the actual tide, is not found until later still, in the 1627 quotation. Up an estuary, the moment of first of flood can often be a dramatic and clearly defined event, particularly at springs. In contrast, the slack, mostly coming after High Water – when the water level has dropped – is incoherent, and notoriously exhibits a simultaneous flood within a river's outer curve and ebb around the inner curve.

During their actual development, the times of these separate high and slack events are difficult to determine. This is shown by the stress in titles of papers read at the early Royal Society. Henry Phillippes (fl.1648–77), a teacher of mathematics, hoped to find the *true* time of London Bridge tides. His employment of the phrase high-tide sits satisfactorily with the end of flood, but lacks definition (Philips, 1668). Flamsteed repeats this, adding the emphasis *correct*. However Flamsteed shows that something is amiss, remarking how some tide table makers deduct an hour. This suggests that at least some of his contemporaries appreciated a distinction. Both he and Phillippes were referring to corrections of the astrologer John Booker (1603–1667). Flamsteed journeyed on the tideway himself, and saw the need to correct Phillippes' calculations. Yet in contrast, he was openly sceptical of what seamen told him about the wind altering the tide. This effect was well known about, and is one which continues to endure. In the absence of good quality predictions, knowledge of the wind (but more strictly the atmospheric pressure), cutting or bloating the tidal height could only be got from experience. In addition, his tidal observations were over separate periods, taken at much different places – Tower-Wharfe and Greenwich – by several people. These included his servants and himself, and Joseph Hone (fl.1682–1704), the ingenious friend of Tower-Wharfe.

While the St Albans table is the first known to give daily predictions, Flamsteed improved upon that, and was rightly proud for giving both AM and PM times. But significantly, he is predicting times and not heights. When he sought to apply his table universally, it is primarily the duration of flood and ebb which he enquired about (Forbes, Murdin and Willmoth, 1997). Referring to the surface slack's great incoherence, Flamsteed found it hard to determine the exact moment of what he was measuring. I assert that Flamsteed's tide times are actually for the end of flood at London Bridge.

4. THE TRANSITION TO ELEVATION MEASURE. Flamsteed's inability to come to the necessary discrimination between the moments of High Water and slack is at the very heart of his tidal argument with Isaac Newton (1642–1727). Following unusual information from Tonkin, Newton wanted a measure of the tide's vertical range at London, and Flamsteed was unable to give it to him. This points toward Flamsteed not having a tide pole. In addition, which

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elevation would one measure? For occupying 170 feet of the river's width, the massive starlings squeezed the flow, producing a higher water level on one side of the bridge than the other (Hawksmoor, 1736).

Even if not a measured tide pole at either the bridge or wharf, some sort of gauge is absolutely essential to determine the moment of greatest elevation. Neither he, nor any contemporary, are known to have mentioned any sort of gauge; and not until much later do we find any actual height measurements. Had Flamsteed the use of a gauge, the large difference at London between the time of the two moments would have been obvious to him.

For sailing barges, the endurance of the flood tide was of such practical importance that, without the assistance of horses, it was abnormal for them to get up to Richmond, beyond London Bridge, in one tide (Rennie, 1833a). With its primary interest in current, wind power persisted as a significant part of the shipping scene until well after steam's introduction. However, when they had to deal with shallow berths, sailing ships did find a secondary interest in tidal elevation. But well before the advent of steam, that interest sharply increased during the eighteenth century, as enclosed docks and locks connected with the tideways.

As the conduit to many berths, the new locks became a significant focus for shipping interests. Having both a lower sill and an upper coping level, the locks brought a dual interest to elevation. Liverpool docks built up a remarkable record of High Water times and heights from 1764 onwards. By then Newton had published a working hypothesis of tidal theory and several suggestions existed on how prediction might be improved. Within six years of the record's start, the good quality Liverpool tide predictions comprised both High Water times and elevations (Woodworth, 2002).

This contrasted with London, where predictions were still hung on the old current method, with the three hour constant indicating end of flood. However by the start of the nineteenth century, several forces came to act there. William Vaughan, chairman of the planned London Docks received good advice about his local tide; this came from Joseph Huddart (1741–1816), an Elder Brethren of Trinity House. Then, directly wishing to emulate the success of Liverpool's prediction facility, Vaughan also began recording his river levels twice a day maximum elevation and its time – High Water.

Highbury Avenue
24th September, 1794

Sir, – "I have extracted the following remarks from the observations on the tides made at Fresh Wharf, which is a few yards below London Bridge.

"The fall of the ebb tide thro Bridge occasions the tide of flood to rise on a mean about 4-ft. 6-in. before the stream of tide run upwards; and at high water it falls about 1-ft. 6-ins. before the tide sets downwards.

"The time of high water at London Bridge is I believe in general meant for the change of the stream thro bridge which is about 55′ after high water.

"At full and change the tide flows about 2^H-10′ after the moon's southing and northing to which if we add 55′ give 3^H-5′ high water slack.

"At the moon's Quarters it flows 0^H-55′ after the moon passes the meridian's + 55′ gives 1^H-50′ for the high water slack.

"The greatest difference between the highest Spring and the lowest Neap tide at high water from May 15th to June 6th was 4-ft. 9-ins. but for the Mean not more than 4-ft. should be

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allowed for the difference and the greatest rise from Low water to High Water during this time was 18-ft. 6-ins.

I am, Yours sincerely,
J. Huddart. (*Hall, 1944*).

Huddart confirms that in this period of transition of insight, discrimination between the two moments was being addressed. Up to then, the term High Water in London had always been applied to the end of flood. This was the singular establishment figures then carried in sailing directions for all tidal coasts. However Huddart's admission came at the high noon of the establishment constant, for private individuals were already producing elevation predictions there. Taking the form of a simple yearly sheet, or a small month-a-page booklet, at a shilling each they were not cheap. In contrast, an almanac, containing a whole compendium of information and a daily tide prediction for London, could be had for two shillings and sixpence. From the Society for the Diffusion of Useful Knowledge, this almanac became an instant success, with the 1828 first issue selling out. Then its second issue mixed up the moon data a little, and allowed the tide table to revert from considering elevation back to the current. This led to an active discussion of what the establishment actually was, and demand for improvement. In turn, and partly because his family banking firm had a financial interest in the dock next to London Dock, this brought about Lubbock's investigation into tides.

So Lubbock and his computer, Joseph Foss Dessiou (1769–1853), became the almanac's new predicters in 1829. For their first issue of 1830, they only had a preliminary system to hand. Until then, for commercial reasons, no one had ever published how to produce elevation predictions. Crucially, Lubbock laid out his method in the 1830 *Companion to the Almanac* (Lubbock, 1829). In addition to papers in the academic press, Lubbock then made his method more widely accessible throughout later almanacs (Lubbock, 1831–7). By then the theoretical revolution was complete. It had turned from partly expressing the tide in terms of its current, to fully addressing the actual elevation of the water surface.

Yet even several decades later, the difference between High Water and slack remained a misunderstood concept at the Royal Society. The distinguished scientist Thomas Huxley stated, *at the end of the flood tide it* [the Thames] *is deepest* (Huxley, 1881. P.2). While this is vary rarely so, it is possible that what Huxley sought to express is the culmination of the Thames tide at London Bridge, where the river narrows (Beardmore, 1852. P.lxix).

Nowadays we habitually consider tide tables as predicting time of elevation. Examples from different centuries, of tidal rotas for predicting current duration, show that mariners confusingly called those prediction devices tide tables also (Moore, 1569) (Southgate, 1794). On first publication in 1833, the Admiralty resorted to Lubbock's method for their familiar elevational tide tables. However, initially including much stream information they began to publicise the difference between elevation and current predictions. Then, since at least the beginning of the twentieth century, numerous editions of an atlas of the tidal stream now collates this information (Brown, 1905).

5. HALF A MILLENIUM OF STABILITY.

Little can be directly construed from the St Albans constant, though it would appear that both Phillippes

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and Flamsteed validated it. Theirs were constants for the current. How they formed constants in the seventeenth century is rather vague (Seller, 1677). However, living in a house on London Bridge, Henry Phillippes observed the tide himself. With his constant for the days of Full and Change, he then marked his tide table out according to the hour of when the moon bore due south. His constant, implying the tide time nearest the celestial event, is probably the simplest. Nor does John Flamsteed say anything about his, but does explicitly refer to the moon's southing. Bringing southing into the account makes the constant slightly later in time than the simplest – for two reasons. One is because the moon comes to the south up to 24 hours and 50 minutes after the actual events of Full and Change. The other is because of the inevitable shift from the tide nearest the celestial event, to the tide falling after it.

In order to convince the Admiralty of the quality of his predictions Lubbock made several comparisons. He compared his own, with predictions for sale from Bulpit, Innis, White and Epps (Hughes and Wall, 2004b). Very few of those now survive. Comparing the early almanac figures with those of James Epps indicates variation, but Lubbock had yet to properly develop his method.

In one of his papers, Lubbock gives 2 hours 19 minutes for a High Water constant (Lubbock, 1831). (He gave a constant for London Docks; to which, he stated, one adds 10 minutes for the Bridge.) He also omits a precise definition of his constant. Yet while he was developing and publishing his method, establishment constants were then defined for theoretical cotidal map purposes.

Despite Lubbock's lack of discrimination, his co-worker, Dessiou, provides a clear and unambiguous set of figures for the time of High Water at London Bridge. A mean High Water elevation constant, derived from Dessiou's almanac predictions for 1831–7, and amounting to 2 hours 15 minutes, is very different to Flamsteed's constant, for flood. Yet merely adding the 45 minutes that the flood still runs produces Flamsteed's 3 hours 00 minutes. This again provides further evidence that Flamsteed's constant is for the end of flood, and not for High Water. However it also shows that at London Bridge on Full and Change days, the slack near high water had been at three o'clock for half a millenium.

6. RECENT CHANGE AT LONDON. Observing the celestial event of Full or Change is not straightforward. Practically, the New Moon's southing cannot be observed; and, in order to make tidal observations following its actual event, pragmatically, the time of the Full Moon's southing has to be calculated.

The mean of several tide times easily provides a basic constant. To appropriately compare like with like I have chosen to replicate constant figures in a simple but regular way. Note the constants produced in Table 1 and Figure 2 are elevational. I have taken the time of Full and Change from the almanacs and extracted the time of the next High Water following. These were then averaged for the year, or the relevant collection of years. This method comes some way between the simplest, and that which involves southing. My derivations could therefore vary between about five minutes too early to ten minutes too late.

Note also that the extracted times are predictions rather than observations. Amin stated that he was comparing Flamsteed's predictions with modern observations. Past tidal observations are scarce, and none form a series with a continuous basis.

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Table 1. The mean time of first High Water after New and Full Moon.

	James Epps		British Almanac	
1828			London	2 h. 31 m.
1829	London	2 h. 32 m.	London	3 h. 16 m.
1830	London	2 h. 31 m.	London	2 h. 09 m.
1831	London	2 h. 34 m.	London Bridge	2 h. 18 m.

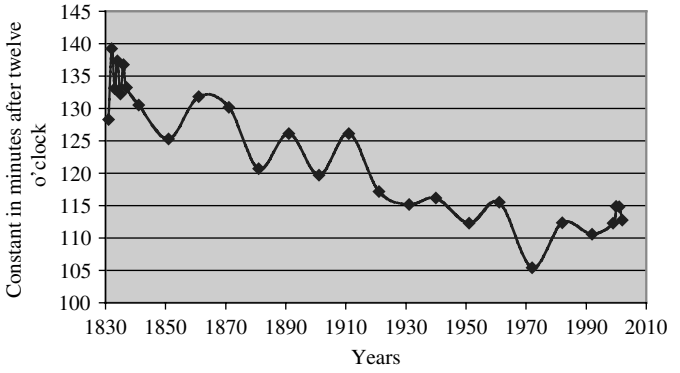


Figure 2. London Bridge high water constant.

Sadly, observations for the period 1801–36 remain indecipherable in their re-arranged form (Lubbock and Russell, 1836). Consequently I have used prediction figures from which to make the several nineteenth to twenty-first century constants. For the mean constants this is within the bounds of acceptability.

Additionally, as the Thames tidal barrage interferes with the tide, then actual observation of the end of flood can not now be had across that part of the cycle of the very biggest springs. However, in 1999–2002, the elevation constant for London Bridge had a mean value of 1 hour 54 minutes. Adding the stated 45 minute lapse, then produces a flood constant of 2 hours 39 minutes. This gives a historic difference with the old 3 hours 00 minutes constant of only 21 minutes.

In the past two centuries there has been much change made to the Thames banks: with London Bridge rebuilt twice, several bridges added both upstream and downstream, and the embankment, tidal barrage, and numerous jetties constructed out into the tideway. Therefore Amin's change of 33·3 minutes is much more likely to have arisen since Lubbock's period rather than Flamsteed's. The 21 minutes of change arose between 1831 and 2002. This 21 minutes also relates well to the change of 17 minutes endured at Liverpool over a slightly longer period (Woodworth, 1999). In addition there is some indication of a similar change in China (Zuosheng, Emery and Yui, 1989).

The changing trend over the 171 year period is shown in the chart of Figure 2. The two end periods are set out for each year, but the intervening period is sampled approximately every ten years. While in the nineteenth century there may have been a little upswing, overall the trend is downward, with a possible trough in the late

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twentieth century. Therefore, it can be seen that this change is at a more accelerated rate than Amin's, wrought over three centuries.

References to flow endurance change stem back to measurements taken by Saumarez in 1720, and then compare measurements from 1849 (Beardmore, 1852). The amplitude of the tide also appears to have changed in the intervening 171 years, for George Rennie's (1791–1866) measurement of an average rise and fall of 14 feet 5 inches (4·3 metres) at the bridge, is appreciably less than at present (Rennie, 1833b).

7. THE ORIGINS OF THE SCIENCE. The only undoubted fact about the provenance of Figure 1 is that it arose from St Albans. Bringing attention of the St Albans tidal list to the scientific community, Lubbock dated it to the thirteenth century (Lubbock, 1837), permitting consideration of it as Europe's oldest (Cartwright, 1999). It is not; as ten tidal diagrams and tables date from about five centuries earlier (Jones, 1943). Therefore the above no longer enjoys such a pre-eminence. In addition, this examination indicates a slightly younger age for the table than his nomination led to.

The table comes in a book, between two separate and unassociated texts on history. The preceding passage arrives at its conclusion on a recto folio. The table is on what was a blank verso side. The disjointed continuation of the present binding, then resumes abruptly within the middle of another passage. However, those preceding and following passages are in the same minuscule hand. The table, by a different hand using larger characters, appears as a later addition to the folio, utilising a vacant space on expensive vellum. Standing in such isolation, the table functions in the office of a jotting.

James Yates (1789–1871), a British Museum librarian and antiquarian was also a committee member of the Society for the Diffusion of Useful Knowledge. Yates informed Lubbock about the table by letter. Conveying that existence, Yates merely indicates that the table lay among the papers of John of Wallingford (d.1258), abbot of St Albans (Yates, 1837). With Lubbock's preoccupations other than palaeography, he linked the table to John; thereby unwittingly and unintentionally fixing the date to a period prior to John's death. For several reasons, this date is too uncomfortably early. In recently viewing the table, Tony Dyson must have felt that same discomfort; but, he concludes with a justification of the earliness and ascription to John (Dyson, 1996). However, the way in which Lubbock gained his intelligence about the table recently coming to light, demands its further examination.

The whole book is the otherwise unremarkable product of a medieval English abbey. Yet, as the illustration shows, this one folio holds more than the four visible influences: Latin, English, Hindu and Scandinavian (Wallingford, c.1300). In thirteenth century England, numerals were normally Roman; whereas this table uses Hindu. Here, several of the numerals resemble forms more prevalent later. A mixture of both a simple circle and the ø symbol, derived from the Scandinavian letter 'o', represent zero. As Latin language inadequately expresses explicit tidal action, early medieval writers most often took their tidal terms from Celtic (Hughes, 2003). An alternative was to use a roundabout expression, as did Robert Grosseteste (d.1253); and in later formal writing, Isaac Newton did similarly in his Principia.

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Here in the left title, the scribe resorts to a vernacular phrase. This discontinuity has the appearance of English as opposed to Anglo-Saxon; and English phrases are said to only appear from the late fourteenth century. As these influential deployments – particularly of Hindu numerals and sexagesimal notation in the West, together with the English phrase – would be so early, the former dating of the list has to be called into question.

While St Albans Abbey is somewhat inland, its nearest port lay only a full day's walk away, on the tidal Thames. Here, rather than the usual fractions of an hour, the use of sexagesimal minutes is in a mathematical vernacular. As this is quite independent of any trace of its origin, it stands as an indicative example of this science's casual new use in the West. Additionally, although the vastly much earlier Rosetta stone divides among three scripts, it is unusual to find more than one alphabet in almost any document. Therefore the breadth of scope within this table indicates a particularly active mind. Which individual's was it?

With John a historical writer of little merit, he is an unlikely candidate. In addition, nowhere else does he employ Hindu numerals. Richard (1292–1336), a slightly later abbot of St Albans than John, also came from Wallingford. In the liberal sciences and mechanical arts, this most skilful man of his times constructed a magnificent clock and forecast the weather. For more than two centuries, his clock held a dial relating to the tides at London Bridge. In particular, the table's numerals distinctly resemble those found among Richard's few surviving manuscripts (North, 1976). So this Oxford educated Richard is a much more likely author, or scribe, than John; making the table the best part of a century younger than previously considered. This is a temporal difference significant enough to allow ordinariness to these otherwise exceptionally early scribal elements.

These tide and moonlight times advance regularly each day; whereas actual observations advance irregularly, particularly of the tide. Hence, the table is one of predictions. This theoretical approach, together with choice of numeral, strongly suggests an Arabic source. The Arabic science, represented in the list, entered western minds by the twelfth century. Robert Grosseteste, Bishop of Lincoln, studied at Paris and taught at Oxford, then within his diocese; by 1225 he had based his tidal treatise on Arabic science (Dales, 1966). Perhaps it is worth considering the Grosseteste material as providing the inspiration for the tables. Present thinking is that the tidal treatise of Walter Burley (1275–1345), and of Grosseteste's school, was then influential (North, 1976).

However, the table includes another strand of origin. A mean lunar day, the time between two successive lunar meridian passes, is a function of the mean synodic month. Pliny's (23–79 AD) value of a lunar day's excess over the solar, forty-seven and a half minutes (Rackham, 1991), differs from the fifty and a half minutes of Hipparchus (c. 146 BC) (Porter and Ogilvie, 2000). Although it must be noted that they expressed the portion of the hour in parts, rather than in sexagesimal minutes. Much later, Bede explicitly cites four-fifths of a lunar hour for this. Previous commentators have taken Bede's words as amounting to forty-eight minutes (Wallis, 1999); but as there are about sixty-two minutes in a lunar hour, he must be indicating forty-nine and a half minutes. The modern value equating with that of Hipparchus, to a few seconds, shows his remarkable accuracy.

Although the methods of Hipparchus are presumed to have been advanced, they were unavailable to Bede. This is because those methods reappeared from out of

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that Arabic science within work on time at Paris and Oxford. Therefore, there were two clearly independent workings. For as every alternate, biggest spring tide coincides with first sighting of the moon, Bede had a stimulus for astronomy unavailable to Hipparchus. Bede's very correction of Pliny demonstrates actual measurement, but these two closely corresponding values diverge from numerous others (Goldstein, 2003).

An alternative explanation for the usage in this table could be the want of simplicity, as forty-eight minutes is exactly one thirtieth part of a day; and the tidal diagrams which arose from out of Bede's exposition were thirty day rotas.

Figure 1 holds this simple figure, which even Flamsteed asserted was appropriate. Yet the table is not so simple, for the period that the mean equinoctial full moon shines is more than the duration of one night. Rising before sunset and setting after sunrise, the full moon shines for more than the mere twelve solar hours indicated in the list of night light, built up from the daily increments.

8. CONCLUSION. The earliest tidal rotas were highly complex, leading to several scribes drafting errors into them. However the concept survives with late twentieth century examples. In between the levels of list and rota, were several grouped tabulations; but even they were not free of error. This tidal list has its own dynamic, presenting a tidal cycle, rather than a civil epoch. Down to the present day, yearly and monthly tidal groupings, or newspaper tidal listings, are often profuse with error.

The two lists of the St Albans table enjoy a different nature. The tidal prediction list deals with the particular, whereas the duration of nightly moonlight list is universal. Although the tidal list has a universal cast to it, its constant pertains to a specific place. So long as one remembers it is the mean duration, the list of night light remains relevant to all of the earth below the polar regions. For example, the Full Moon shines for considerably more than twelve hours in winter, and less in summer. The purpose of the St Albans presentation, identical to a usage for the Normandy landings of 1944, is to identify those tides with good natural light (Zabler, 1991). Whilst it is obvious that the tides nearest Full Moon have the potential for this maximum natural illumination, and hence greater utilisation, what this combination readily shows are the tide times that that particular set of days possess; and the remoter consequence at St Albans for arrivals and departures. Hence the combination had an extra usefulness in winter. However, as its divergence from actuality was rarely noted (Parry, 1968), use of the lesser quantity of forty-eight minutes cannot be resolved.

The table should really be thought of as from the fourteenth century. That this tabulation should not be as early as the thirteenth century, enables its orderly integration into medieval tidal science. Whilst the utility of the information within this tabulation is essentially timeless, this type of prediction concerned with current was only superseded by those which Dessiou and his near contemporaries produced concerning elevation. However the table still retains its utility, enabling this exposition of a previously hidden revolution in tidal science.

It is inconceivable how Lubbock, in a pre-gas or electric light period so dependent on moon-light, could have misunderstood lunar age. While discussing the establishment quantity he also confused High Water with the end of flood; but it is a

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confusion which still continues to endure. Yet with good roads and carriages by his time, the Thames was ceasing to be the important highway it had been. Lubbock was an academic, not a seaman. However, publishing a still valid prediction method, he promoted a rapid change of thought. It is ironic that upon the walls of the dock entrances, which his tables so addressed, the tide came to be visibly measured in Roman rather than the familiar Hindu numerals.

Early tidal information was mostly for places on or near the coast, where the tides do turn close to high water. London is unusual, in that it lays high up the Thames where the flow distorts, running on past High Water. By its consideration of the flow's turn near maximum elevation, the St Albans table carries the establishment concept forward from Bede's insight concerning the flow's turn near minimum elevation, to the later consideration concerning the moment of greatest height.

The lapse between High Water and end of flood is now an historic value, but one preserved over a record period in this old St Albans table. The eye can see the tide turn, but in the absence of a mechanical recorder, the actual event of high is an imperceptible moment, and has to be judged. This study shows that an ordinary term, for a straightforward tidal event, was one whose meaning repeatedly evaded understanding among Fellows of the Royal Society.

The inference with Flamsteed is that he did not test his supposed elevation prediction against observation, and thereby complete the scientific method. While mariners were recording the tide's vertical range before Newton's interest, his hypothesis led directly to an intrinsic scientific interest in tidal elevation. Then during the early Industrial Revolution, the rush towards building docks with locks onto the tideway, brought an increased interest in elevation. Steam power then finally freed the navigator from the tidal current's dominion over a ship's progress. At the same time, Lubbock and Dessiou commenced the familiar tide tables, which, because of reliability, arrest interest firmly in elevation. To this day, only North America and a few individual ports publish tidal current predictions. Those tables imply an accuracy of 5 minutes and 0·1 knots. While this precision is demonstrably not realistic, mariners would still find practical benefit from one less demanding.

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