book reviews

The Tides: A Scientific History. David Edgar Cartwright. 1999. 292 pp. $74.95. Hardbound. Cambridge University Press. ISBN 0 521 62145 3.

The study of tides has everything: it relates to rich and intellectually challenging phenomena of widespread occurrence in the oceans, the earth, and the biosphere; it permits a rare and satisfying precision for the physical oceanographer; and it has a long and fascinating history.

British oceanographer David Cartwright is one of the leading tidal investigators of the late twentieth century, a scholar who one feels would be as much at home, and as welcomed, in the company of Newton, Laplace, Kelvin, and other giants of past eras as he has been in the boardrooms of NASA while planning and using satellite altimetry. He refers at the end of his book to a symposium held in London in October 1996 (Ray and Woodworth 1997). What he modestly does not mention is that the symposium was held in honor of his 70th birthday.

The early part of the book nicely recounts fanciful early ideas (involving the breathing of monstrous sea gods, for example) on the causes of tidal changes in sea level, though with much less detail than earlier works to which the author refers. He does, however, follow Lord Kelvin in stressing the quality of observations 2000 years ago and the perception of Roman and Arabic scholars in noting small changes in the tides and their relation to the positions of the sun and moon. He also corrects earlier histories by citing recent research showing that the Chinese were making predictions of the time of the bore in the Chhien-Tang River a full century before thirteenth-century predictions of the time of high water at London Bridge.

Francis Bacon, Galileo Galilei, Johannes Kepler, René Descartes, and others all proposed tidal theories, though Cartwright, in common with other writers, does not mention Leonardo da Vinci's curious denial of the role of the moon. A physically based understanding of tides had to await Newton's 1687 theory of gravitation, though Newton mistakenly attributed the tides to the vertical, rather than the horizontal, tidal force. Leonhard Euler corrected this in 1740, sharing with Daniel Bernoulli and two others a prize offered by the Académie Royale des Sciences in Paris. Pierre Simon, Marquis de Laplace, was the first to formulate the correct dynamical equations, particularly in his classic paper in 1776. All this is nicely described by Cartwright, with a sprinkling of mathematics where appropriate and occasional enlivening quotations, such as that from Nathaniel Bowditch, the American translator of Laplace's *Mécanique Celeste*: "Whenever I meet the words 'Thus it plainly appears . . . ', I am sure that hours, perhaps days, of hard study will alone enable me to discover *how* it plainly appears."

I particularly enjoyed reading the author's account of the gradual development of tidal observations under the auspices of the Royal Society of London and the French Académie Royale des Sciences. The observations at Brest from 1711 to 1716 were perhaps the most impressive, though surprisingly accurate observations were also made by the British as far afield as the island of St. Helena during an expedition in 1761 to record a transit of Venus across the face of the sun. Many of the observations there appear to have been made by Charles Mason, who had just, along with Jeremiah Dixon, observed the transit from South Africa and later surveyed the Mason–Dixon Line. [In another entertaining recently published history, Jardine (1999) recounts how this expedition was attacked by a French frigate within a day of leaving England, with the loss of eleven men. This prompted Mason and Dixon to request of the Royal Society that they be allowed to observe the transit of Venus from Turkey rather than the planned destination of Sumatra, but they were firmly told, "Your declining . . . at this critical juncture . . . cannot fail to bring an indelible scandal upon your character and probably end in your utter ruin." A rejection letter on a modern grant proposal seems easy to bear by comparison! The astronomers finally dug their heels in when they arrived at the Cape of Good Hope and learnt of the French capture of their destination in Sumatra.]

Cartwright himself (1972a,b) has carefully analyzed these historical data, finding significant tidal changes in the last few hundred years, but he does not mention this here. This modesty is disappointing, as the results would have tied in well with the emphasis later in the book on normal modes of ocean basins and on the tidal dissipation in the oceans.

Much of the book is occupied by a discussion of nineteenth-century developments in measurement, analysis, and prediction, as well as a continuing quest to describe and understand tides in the ocean basins away from land. Measurement was aided by the development of continuous tide recorders in 1831; harmonic analysis with the associated prediction were introduced by Sir William Thomson (later Lord Kelvin) in the 1860s and refined by George Darwin, son of Charles Darwin, who extended the rather peculiar notation for tidal constituents that persists to this day. Kelvin was also responsible for the development in 1872–73 of the first mechanical tide-predicting machine, with the first American machine being built in 1882 to a design by William Ferrel. A second machine was used by the U.S. Coast and Geodetic Survey from 1912 until as recently as 1966. All this is described in a comprehensive and readable manner, along with reminders that a "computer" in those days meant a diligent human assistant. Tidal predictions were often provided not by government agencies but by private entrepreneurs such as H. W. T. Roberts, the son of Edward Roberts who had been Kelvin's "computer" and also designed improved tide predicting machines. Tidal prediction was almost the human genome project of a hundred years ago.

Mapping global cotidal lines was a research topic for many decades. Even the local waters of the southern North Sea provided a lively debate. William Whewell predicted a "point of no tide" (later called an "amphidromic system" by the American tidal enthusiast and historian Rollin Harris) as a consequence of rotary tidal progression around the coasts of Britain and Europe. This was supported by careful logline measurements at a maintained station above a shallow midchannel bank but was ridiculed by the Astronomer Royal G. B. Airy. His scheme consisted of interfering wave trains, apparently failing to recognize that two sinusoids with different phases sum to a sinusoid; he also claimed that the presence of tidal currents at the anchor station ruled out the possibility of a nodal point. These seem strange lapses for such an eminent mathematician.

Many other authors attempted to describe global tidal maps, usually based on unsound physical ideas. The fine Victorian manners of George Darwin were apparent in his reluctant but firm criticism of Rollin Harris: " It is an ungrateful task to find oneself constrained to criticise adversely," and "I can, in conclusion, only hope that I am not doing an injustice to Mr. Harris in dissenting so absolutely from his views." Would that reviews were still as polite!

Cartwright also recounts the history of investigations of tides in the solid earth and the atmosphere as well as the interaction of these with ocean tides. He recounts his own research to identify the first person to record the 12-hourly oscillation in surface air pressure. This was Robert de Paul, chevalier de Lamanon, who sailed with La Pérouse in 1785 and, at the age of 23, made barometric observations in the Atlantic within 1° of the equator. Lamanon was massacred by the inhabitants of Tutuila (Samoa) two years later (and the whole expedition perished in 1788), but he had managed to send a report back to France before this. Cartwright reproduces the first three pages of this historic paper, regrettably without translation into English even though translations are provided for French quotations in the text itself.

The latter part of the book includes an account of the history of investigations into the problem of tidal dissipation together with the associated changes in the moon's orbit and an increase in the length of the day. Tension between English and French scientists seems to have reached an extreme when John Couch Adams, who had in 1846 been involved in a bitter dispute with Le Verrier over priority in the discovery of Neptune, now in 1853 found an error in calculations by Laplace himself of the effect of the planets on the moon's orbit. This left a discrepancy with observations that could only be associated with tidal dissipation. Cartwright reviews the late twentieth-century resolution of this topic, with remarkable agreement now between estimates based on (i) the rate of working against ocean tides (mapped by radar altimetry from satellites and found to be in good agreement with numerical solutions of the tidal equations), (ii) the perturbations of satellite orbits by ocean tides, (iii) analysis of the earth's gravity field, again using measurements from satellites, (iv) historical telescopic observations of the moon's longitude and earth's rotation, and (v) laser ranging to the moon. Cartwright writes with authority on all of these topics, making this section of the book particularly valuable for a reader less interested in the history of the science or the personal element. The results of the lunar laser ranging (Dickie et al. 1994) are particularly mind-boggling, with about a Joule of energy from a laser source being reflected by small reflectors left on the moon by space missions of the United States and former Soviet Union and giving a return signal of a photon every few seconds. Timing these over about 25 years has established the lunar recession rate of less than 40 mm per year to an accuracy of a few percent.

It is this success in mapping and modeling ocean tides and in resolving the dissipation problem that leads Cartwright to suggest that we have reached the end of an era. In a thoughtful final chapter, however, he does recognize outstanding problems. These include a determination of the role of tides in deep ocean mixing (as opposed to having all the dissipation occur in shallow seas) and prediction of dissipation rates in the past for studies of the evolution of the earth–moon system on geological timescales. It is with respect to the latter that I would have welcomed more discussion, especially in view of the author's own fine work, mentioned earlier in this review, of changes in the tides over a few hundred years. Cartwright also discusses a normal mode interpretation of tidal responses in the later part of his book. This is one approach that may provide insights into paleotides, but I had to remind myself that this book is primarily a scientific history, not a research monograph.

The author deliberately avoids discussion of tidal effects on continental shelves, though these are many and important, referring the reader to the fine book by Pugh (1987) and the symposium compendium by Parker (1991). I did, however, find some personal favorite topics (as well as the secular trends mentioned above) where more discussion seemed warranted, even in a historical context. One is the "age" of the tide, the lag between full or new moon and spring tides. This is usually neglected in modern texts, though it is typically a day or two and was recognized by Pliny the Elder as long ago as A.D. 66 (his charming comparison with lightning and thunder unfortunately fails if light and gravitational forces travel at the same speed). Cartwright attributes the name "age" to William Whewell, but without explaining that this was to fit in with Whewell's idea that tides originated in the

Southern Ocean and took a day or two to reach Europe. Modern ideas associate the effect with the excitation of damped normal modes near resonance; an analogy with the simple pendulum goes back to Thomas Young in 1823 (see Pugh 1987). In later correspondence, which Cartwright quotes, Airy apologizes for overlooking some of Young's results, but states, "There is one of mine, however, which he has not got, namely the effect of friction in producing an apparent retardation of the day of spring tides." Airy's work involved solving for the tides in channels along lines of latitude and also showed an age, but it would be nice to unravel the chronology of these ideas. As Cartwright states in his preface, there are still topics for the specialist historian.

Another topic I would like to have seen discussed further concerns the significant tidal variations over the 18.6-year nodal cycle in which the declination of the moon's orbit varies. It is usually assumed that the modulation of the response follows the modulation of the forcing (though Cartwright states that this is not the case for a weaker modulation over 8.85 years), even though there are places where the combination of nonlinear friction and proximity to resonance reduces the modulation of the response. This strikes me as a topic worthy of continuing investigation and I would have welcomed more discussion of the history.

These are small quibbles, however; perhaps I clamor for more because the book is so instructive, well written, and entertaining. It is also greatly enlivened by numerous well-chosen illustrations of the key individuals, diagrams from early papers, and photos of pages of text. Scientifically it is particularly timely because of increasing acceptance of the possibility that tidal mixing plays a major role in determining ocean circulation and hence climate. The book certainly fills a niche and, as stated on the elegant dust jacket (combining pictures of Newton and Laplace with a photo of the 1681 tidal clock at King's Lynn and a tidal map based on TOPEX/Poseidon results), will appeal to specialists in many disciplines as well as to those interested in the history of ideas. I also kept feeling that a more popular version of the book, perhaps with more anecdotes on the international rivalries, brilliance, and frailties of the personalities involved (including those still living, about whom Cartwright is rather discreet!), could become a bestseller to rival other recent accounts of scientific and mathematical advances. How about it, David?—*Chris Garrett.*

Chris Garrett is Lansdowne Professor of Ocean Physics at the University of Victoria, in a city surrounded by strong tidal currents and named after the monarch in a previous era of fruitful tidal research. ●

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