The spark that fired the Great Trigonometrical Survey of India: the triangulation survey made between Fort St. George (13°08′N) and Mangalore (12°91′N) by William Lambton in the early 1800s*

Anantanarayanan Raman and Vancheeswar Balakrishnan

In 1800, the English East-India Company at Fort St. George (≈ Madras) ordered surveys of peninsular India for political reasons. William Lambton of the 33rd Regiment of Foot – who had just arrived in Madras to join the army marching against the Mysore Tiger Tipu Sultan in 1799 – started the scientifically accurate landscape measurement using trigonometric methods in 1801, one of the three major surveys that were concurrently launched and referred in the pages of India's science history as the Great Trigonometrical Survey of India (GTSI). Lambton led this project until his death in Hinganghat (presently in Maharashtra) in 1823. From then, his trainee George Everest took over and completed the project. Much has been written about the Lambton–Everest GTSI, but little has been mentioned on the preliminary survey that Lambton carried out from 1804 of the landscape between Fort St. George (Madras), Bangalore and Mangalore, and on fixing the global coordinates of the towns in between. The science used in this survey of c. 360 miles (570 km) between the Coromandel and the Malabar Coasts is stunning in terms of its accuracy of details, given the quality of tools and gadgets Lambton and his team used. This survey was the spark that fired GTSI. The Fort St. George–Bangalore–Mangalore survey on completion in 1810, progressed slightly northwards and southwards initially and later got extended all over British India. The Madras Observatory established by Michael Topping and the pioneering astronomy and physics – built on elegant mathematics – marshalled by his successor John Goldingham offered considerable scientific back-up and clarity to Lambton's GTSI project.

Land surveyors use astronomy and stellar positions to measure land and to determine positions of natural and man-made objects on the land surface. Astronomy-based determinations empower cartographers with accuracy. The larger the area surveyed and represented in a small-scale map, more critical it would be to include appropriate reference points of the surveyed landscape, enabling the reader to recognize and understand the map and relate it to the landscape in context. The rule in cartography is that surveys, and consequently, maps are always oriented towards the Geodetic North, necessitating the surveyor to use astronomy and stellar measurements by characterizing the longitude and latitude of the land point in question, the azimuth, and dimensions of the Earth[1]. These reasons triggered the establishment of an observatory in the late 18th century Madras, which, in more than one way, enabled surveying of not only the Madras region, but also much of the remainder of the subcontinent over the next two centuries.

Archibald Young Gipps Campbell, President, Fort St. George Council (1786–89, note 1) ordered that an astronomical survey of the Fort St. George region be made in 1786. He employed Michael Topping (note 2), a person of high mathematical and geographical acumen, to determine the latitudes and longitudes of principal coastal towns in the Carnatic (note 3). In 1788, Topping began surveying the Coromandel Coast for shipping reasons. Unfortunately, no documentation currently exists explaining how this survey went about. Topping recruited John Goldingham to assist him with astronomical observations, which were made in a private observatory in the then Madras town, set up by one William Petrie, who served as the relieving Governor of Madras between September 1807 and February 1808. Topping requested for a new building for the observatory at the site where Petrie's private observatory existed. The Fort St. George Council approved Topping's request, in spite of disgruntlement of George Maule, Chief Engineer. A new, but small building was completed in 1792 and the Madras Observatory (MO) commenced functioning. Charles Oakeley (President, Fort St. George Council, 1792–94) remarked that the MO was necessary to promote astronomy, geography and navigation in India, since it held the key for a rich and extensive Empire. The MO was the first Western science-based observatory in India, operational from 1787, continuing today as the Regional Meteorological Centre (RMC) located on College Road, Chennai.

The Madras Observatory

Topping published the paper 'A determination of longitudes by eclipses of Jupiter's satellites'[2]. It was Goldingham, however, who determined the longitude of the MO as 80°18′30″E ($5^h21^m14^s$), calculating from the eclipses of Jupiter's satellites and lunar culminations in 1796. In 1812, Goldingham corrected the longitude of the MO as 80°17′21″E, which remains valid to date. A remnant of the telescope-supporting pillar stands at RMC[3], with an inscription declaring this event. This was the reference point which Lambton used when he commenced the Fort St. George–Mangalore survey.

Goldingham became the Madras Astronomer in 1794. He maintained a register of long-term atmospheric pressure readings made each day at 0600, 1000, 1200, 1400 and 1800 h from 1796 to 1825, which are the earliest formal

---

meteorological observations in India. Thomas Glanville Taylor, successor of Goldingham, maintained this record until 1843 (ref. 4, Figure 1). Goldingham calculated daily mean and monthly values of atmospheric pressure from those data, correcting them with temperature readings. Additional notes in this record refer to incidences and strengths of storms that occurred between 1796 and 1821. For example, notes on the low-atmospheric pressures in May–June 1813, October 1818 and May 1820 are available. The MO became well known for its star catalogues by Goldingham (note 4). A particularly significant contribution that Goldingham made while in Madras was establishing the 'standard time' for India in relation to Greenwich Mean Time. Consequently, the MO clock kept time for the whole of India, since the time announced by it was recognized as that for the newly launched railways in India (see https://www.irfca.org/faq/faq-misc.html, accessed on 25 April 2019). At 2000 h every day, a gun fired announcing the time (note 5). The MO clock was directly connected to a gun and triggered firing at the designated hour[5]. One exciting experiment that Goldingham did was to test an invariable pendulum, sent to him by Henry Kater (note 6) from London in 1820. Goldingham tested its swings in Madras in 1821 and published the findings in the *Philosophical Transactions of the Royal Society*[6] (Figure 2).

Surveying in India

James Rennell, a British-Navy Midshipman, was the first, formally appointed Surveyor of Bengal – and therefore of India – in 1764. He served with the Bengal Engineer Corps and was promoted as the Surveyor-General in 1766, because of Robert Clive's (note 7) personal interest in him. Rennell served until 1776. During this time, he surveyed the landscape from Bengal (Calcutta, 22°58′N,
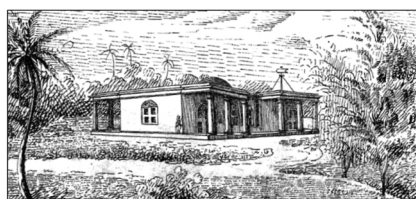

Figure 1. The Madras Astronomical Observatory, *c.* 1838 (public domain)[50].

88°37′E) to Agra (27°18′N, 78°02′E), and from the foothills of the Himalaya (27°59′N, 86°55′E) to Chotta Nagpur Plateau (23°00′N, 85°00′E). In the following years, he mapped Bengal[7] (Figure 3) using data from his own surveys and corroborating them with the maps earlier made by Jean Baptiste Bourguignon d'Anville (1697–1782) (e.g. *Carte de l'Inde: dressée pour la Compagnie des Indes* 1752, *de Coromandel* 1753) (ref. 8), further to using many other short-distance route maps made by the English East-India Company's (EEIC's) army personnel[9].

Crude surveys and consequent 'primitive' maps were used in ancient and medieval India, prepared during battles[10]. Size was one marked factor in map construction by medieval Indians, based on one-plane sightings of the landscape viewed from a height (e.g. hilltop). However unsophisticated they were, these maps indeed, served a purpose[11,12].

Captain Robert Kelly of the 14th Regiment of Madras Infantry proposed to Thomas Rumbold (President, Fort St. George Council, 1777–80) in 1778 (ref. 13, p. 172):

> 'a general map of the Deccan and Carnatic be made from professionally driven surveys, corrected by astronomical observations, and divided into parallelograms each containing one degree of latitude and longitude, each of which to be illustrated by a particular sketch on a large scale.'
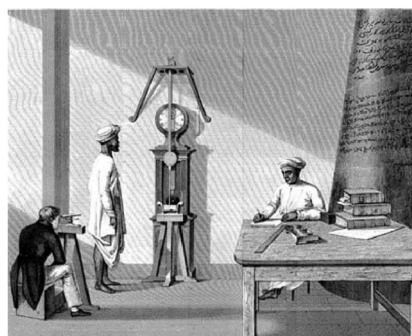

Figure 2. Measurement of the acceleration of gravity with an invariable pendulum by John Goldingham at Madras Observatory in 1821. Using the telescope Goldingham is assessing the lags in the swings of Kater's pendulum against the pendulum of the Haswell clock. Thiruvenkatachari (his Second Assistant) is reading the clock; Srinivasachari (his First Assistant) is jotting notes. (Source: Goldingham[6]) (artist not identifiable).

The Council of Directors of EEIC, Fort St. George, rejected this proposal. The EEIC later invited Patrick Ross of the Military Engineer Corps to submit a proposal on the same subject. Ross's communication (*Madras Public Consultations*, 28 October 1783, **CXXXI**):

> 'A General Survey of the Countries immediately belonging to, and dependent upon, the Hon'ble Company in this part of India has long been an object of attention. Some attempts have been made at different Periods, but these failed almost in the Origin. ... I can almost venture to assert we are at this moment possessed of less materials towards furnishing a complete Chart of the Southern Part of India than we were at the period ten years back.'

reinforces that. Unfortunately nothing further is known about either Kelly or Ross. To know about different surveys launched by the EEIC, see Jervis[14].

Surveys launched in Madras in 1800

Knowing India's landscape for better revenue administration and infrastructure development was a mammoth task for the EEIC in the later decades of the 18th century. With the fall of Srirangapatna (12°41′N, 76°70′E) of the Mysore Tiger Sultan Fatéh Ali Sahéb Tipu (1750–99)[15,16], the EEIC contemplated a survey of the Indian landscape under their control. Three surveys were launched from

Portrait 1. William Lambton (source: https://artuk.org/discover/artworks/lieutenant-colonel-william-lambton-17561823-192290).

Fort St. George (note 8) in 1800: (i) an agricultural and other land-use survey led by Francis Buchanan (ref. 17; note 9), (ii) a topographic survey by Colin Mackenzie (ref. 18; note 10), and (iii) a trigonometric survey, started as 'triangulation survey', by William Lambton (ref. 9; Portrait 1).

Trigonometric surveys, in principle, refer to constructing a series of connected triangles on a vast stretch of land, commencing from an accurately measured baseline determined using astronomical observations. When these measurements are subsequently transferred onto paper as a map, the points of the triangles refer to the most obvious surface objects, such as hilltops. In contrast, topographical surveys relate to an understanding of the horizontal space with an accurate representation of objects that occur on that land surface. Traditionally topographic surveys involve relatively smaller landscapes, e.g. between 600 and 700 km[2], with no trigonometric measurements. Topographic surveys will delineate every natural and artificial object occurring on the surveyed surface: forests, rivers and man-made buildings, canals and villages. Since much has been written on the Great Trigonometrical Survey of India [GTSI][19–21], the present article deals with the spark that fired the GTSI led by Lambton.

William Lambton

Lambton was born in 1753. The town of his birth – whether Lancashire (53°48′N, 2°36′W) or Durham (54°46′N, 1°34′W) – is unclear. What is, however, clear is that he lived in Darlington (54°53′N, 1°55′W) during the early part of his life and was under the tutelage of the famous British mathematician William Emerson (1701–82), who is remembered for the *Treatise of Algebra* (refs 22, 23). Recruited in the 33rd Regiment of Foot (Duke of Wellington Regiment), Lambton was first posted in colonial America as a Surveyor to measure the lands granted to new settlers. He arrived in Calcutta in 1797 as a Lieutenant, still attached to the 33rd Regiment of Foot. When the EEIC waged the fourth Mysore battle, Lambton was transferred to the EEIC army marching from Madras in 1798 (ref. 24). After the fall of Srirangapatna in 1799, Lambton proposed his interest of the triangulation survey of peninsular India. He was inspired to launch this survey by the works of William Mudge and Isaac Dalby, who had published several papers on the trigonometric surveys of England and Wales in the *Philosophical Transactions of the Royal Society* during 1784–96 (ref. 25).

The Lambton survey[26] – later labelled as the GTSI – spanned a little more than two decades, first by spreading grids of triangles over the peninsula, and later spreading into Bengal, during the leadership by George Everest (note 11). A meticulous and humongous work (Figure 4). Execution of this project won Lambton election to the two British Royal Societies. From 1810, he suffered severe asthma attacks. He died in 1823 holding the rank of a colonel, while camping at Hingin Ghat (presently, Hinganghat, 20°57′N, 78°83′E). At the time of Lambton's death, both Everest and Henry Voysey (note 12), his assistants, were not beside him[27]. Everest brought the GTSI project to fruition.

Lambton's triangulation survey across the peninsula

Preliminaries

Lambton formally proposed his intent of a survey of the peninsula using trigonometric methods to the Asiatic(k) Society,
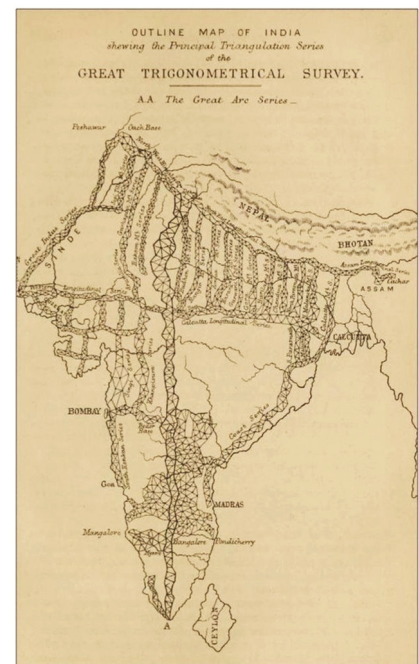

Figure 4. Frederick Charles Danvers's (1833–1906) illustration of the Great Trigonometrical Survey of India[19]. This illustration by Danvers of Bengal Government Service, in spite of it being dated 1870, is faulty in many respects. Two examples: (1) Pondichéry, which lies south of Madras, in this image, occurs at the same latitude as Bangalore and Mangalore, whereas Madras, Bangalore and Mangalore occur on almost the same latitude. (2) The outlines of Ceylon (Sri Lanka) and the Rann of Kutch are incorrectly shown.

Figure 3. Map of Bengal by James Rennel (1781)[21].

Calcutta (note 13) and the Finance Committee of the Government, Fort St. George, in 1801. His intents were to 'geographically' construct the landscape by fixing the latitudes and longitudes of principal inland towns occurring along the Coromandel and Malabar Coasts, and in between.

The Asiatic(k) Society, Calcutta, referred Lambton's proposal to James Rennel for opinion. Rennel confused this proposal with the previously approved topographic survey proposed by Colin Mackenzie and rejected it. To him, a near-identical project was redundant. Mackenzie, who would be delineating the country geographically, could as well carry out the necessary astronomical observations for correcting the geographical locations of principal stations in the Carnatic. Fort St. George also looked at the Lambton proposal sarcastically. A member of the Finance Committee, Fort St. George Government, remarked (ref. 27, p. 78):

Figure 5. The great Cary theodolite with a 36″ azimuth circle used by William Lambton. [Source: Philimore[34], plate 6, between pp. 94 and 95]. The legend supplied by Philimore[34]: 'The William Cary great theodolite used by Lambton and his assistants 1802–1822, and by Everest 1823–1825, reconstructed by Henry Barlow in Calcutta 1831–1834, and from 1835 to 1866 in constant use. Now standing in Survey Museum in Dehra Dun'. [Note: Lambton's portrait in the background.]
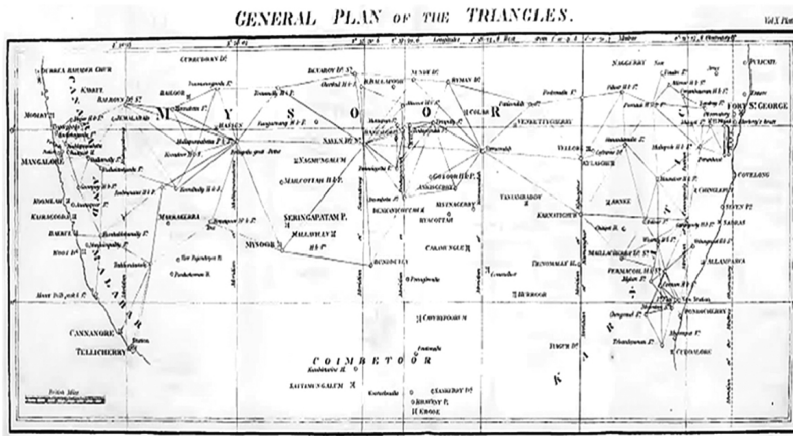
'If any traveller, wished to proceed to Seringapatam, he need only say so to his head palankeen (palanquin) bearer, and he would find his way to that place without having a recourse to Lambton's map.'

Shortly after, nevertheless, Arthur Wellesley, an influential and a high-ranking officer of the British-India army and younger brother of the Governor-General of India – Richard Colley Wesley – applied pressure on Henry Cavendish Bentinck (Governor at Fort St. George, Madras, 1803–07) to support Lambton's project. William Petrie was another strong force in support of Lambton's request. Neville Maskelyne, Astronomer Royal in London, who had read a copy of Lambton's proposal was another reckoning factor in this context[28]. Lambton's project commenced on 10 April 1802.

Lambton used a great theodolite constructed by William Cary (1759–1825, note 14). Cary built one for Lambton as an exact replica (Figure 5) of the then famous Jesse Ramsden great theodolite[29], since the government at Fort St. George refused a Ramsden for Lambton. The Cary, was equally accomplished as the Ramsden: for example, angles could be measured because of the built-in micrometer. An altitude meter and an azimuth circle, attached to the Cary, were added strengths[30]. The Cary arrived in Madras in 1801. Other equipment used by Lambton's team were a zenith sector of 5′ (1.54 m) radius, a Ramsden chain and a chronometer, sent by James Dinwiddie (1746–1815) in Calcutta[31]. A barometer, borrowed from Benjamin Heyne (EEIC naturalist; note 15), and a thermometer were used. Hygrometers were a problem. Henry Kater of the MO suggested Lambton to construct hygrometers using the locally available bearded seeds of the grass *Andropogon contortus* (referred as *Andropogon contortum*). Kater had previously found that the seeds of *A. contortus* were as helpful as the bearded seeds of *Avena sativa* (oats), another grass, used in constructing the 'oat-beard hygrometers' in England (note 16). Three such innovative *A. contortus*-beard hygrometers were used by Lambton's team in the east–west coast survey.

In geodesic measurements, a meridian arc is the distance between two points located on the same longitude, which can be described either as the segment of a meridian curve or as its length. Early

attempts to measure the size and curvature of the Earth necessitated the determination and use of a meridian arc[32]. In the Fort St. George–Bangalore–Mangalore survey by Lambton, the triangles from which those arcs were deduced formed a part of the survey taking in upwards of 2° of latitude starting from a site near Bangalore (see the succeeding section for details). A series of triangles was laid out in a meridional direction, from which an arc of 3° was deduced and upwards in amplitude, giving the length of the degree on the meridian, after multiple observations of various stars[27].

The Fort St. George–Bangalore–Mangalore survey

Lambton established a meridian arc as a base in Bangalore first in October–December 1800 (ref. 33). He rejected it himself, because the chain he used was variously expanding due to local temperature variations. Discrepancies in data were also noticed at some of the observation stations, because of variations in deflections of the plumbline. Procuring a dependable Ramsden chain in 1803, Lambton's assistant John Warren (note 17) determined another baseline at Dodagoontah near Bangalore (Doddigunta, southeast of Halasuru, anglicized as Ulsoor, 12°99′N, 77°62′E). A series of triangles was set up between the parallels 12 and 14, for the measurement of three bases in 1803 (ref. 27, Figure 6) from the Doddigunta baseline. A verification base (30793.7 ft = 9386 m) was measured at this point by Warren in May 1804. On comparing the Madras baseline – St. Thomas Mount (13°02′N, 80°11′E) determined in April 1802 (ref. 33) – with the Doddigunta baseline, the plumbline measurements varied negligibly: about half-inch (1.27 cm) in a mile (1.6 km)[34]. Lambton's team then triangulated their passage to Bangalore, from where the survey extended westward, ending in Mangalore. At three stations, the zenith distances were exact. One was the Ceded Districts (note 18; exact location not indicated). Another was on the plateau, close to Bangalore and the most southerly one was in Coimbatore. The arc, positioned between stations at 11° and 13°, gave the measure of the degree as 60,530 fathoms (note 19). Local temperature variations caused deflections in the plumbline, which he explains in his

Figure 6. The plan of triangles shows Lambton's trailblazing work surveying the landscape between Fort St. George (Coromandel Coast) and Mangalore (Malabar Coast). To execute this survey, he used triangulation to mathematically characterize the geography and to establish earth's curvature. He established a grand meridian line across the peninsula, which was interconnected by a series of smaller meridians and triangles[33].

Asiatick Researches paper published in 1810 (ref. 33). To resolve the problem due to temperature-influenced deflections, Lambton obtained the mean of two readings, and reduced them to the same latitude, viz. 11°59′55″. This method – which he obtained from the then recent measurements made in England and France[29] – was to arrive at the mean ellipticity of the Earth, 1/321 nearly; therefore the polar to the equatorial diameter will be at the ratio of 1 : 1.003125.

In 1806, Lambton began his latitudinal measurement north of Bangalore. He also surveyed southwards towards Cape Comorin (Kanyakumari, 8°08′N, 77°55′E). Lambton then recommenced survey northwards, which got labelled as the GTSI, continued until his death in 1823.

To illustrate how he went about with the task of surveying the Coromandel–Malabar Coasts, we reproduce his words. [Current names of localities are shown in brackets along with their coordinates, wherever possible]:

'In the constructed triangles of 1803, the distance was determined between Carangooly (Karunkuzhi, 12°55′N, 79°9′E) and Carnatighur (Jawadi Polur Reserve Forest, 12°35′N, 78°50′E), wherein pole-star observations were made for determining the longitudes of those two places. … that longitudes of other places could then be determined in succession, west of Carnatighur to afford standard measurement of distances for connecting meridian lines. But a little afterwards Lambton discovered that Kylasghur (Kailasagiri, between Oomerabad and Ambur, 12°84′N), was a better choice, and it was accordingly chosen for continuing those distances to the westward, that between Carangooly and Carnatighur. Kylasghur was laid down from the side Carnatighur and Hanandamulla (Perumugai in Vellore city? 12°94′N, 79°19′E) being given in the 39th triangle, and the side Hanandamulla and Poonauk of the 21st triangle, was the base for finding the distance of Poonauk (not identifiable) from Pilloor Hill (Nagari, 13°32′N, 79°59′E). From this last, and from the side Kylasghur and Hanandamulla, each as a base, the side Kylasghur and Pilloor Hill has been obtained as a mean of the two results. From this, as a base, the series has been carried onto Yerracondah (Red Hills, 13°20′N, 80°20′E) and Kylasghur, depending on the measured line near St. Thomas's Mount (Chennai, 13°01′N, 80°19′E)' (ref. 33, p. 292).

'The relative positions of Savendroog (Savanadurga, 12°92′N, 77°29′E), Mullapunnabetta (Mullayanagiri, 13°23′N, 75°43′E), and Yerracondah, having been fixed with great accuracy, the connection with the observatory at Madras is effected, by working back to Carangooly, by means of the oblique arcs, and then using the northing and easting, and computing spherically, by converting the easting into an arc at right angles to the meridian of Carangooly, and passing through the observatory; and also using the co-latitude of the point of intersection of the said arc and meridian. From this computation, the latitude of the stone pedestal in the centre of the observatory is had equal 13°48′7″. The position of the flagstaff at Mangalore (12°91′N, 74°86′E) is deduced from the meridian of Balroyndroog (Ballalarayanadurga, 13°13′N, 75°41′E), by using the southing and westing, in a similar manner as at Carangooly, with respect to the observatory. It is thence found to be in lat. 12°51′38″N and 34′50″W from the meridian of Balroyndroog. By summing up the respective differences of longitude, we shall have, 5°25′23″ for the longitude of Mangalore west from the observatory: to which add 2′22″, the easting of the church steeple in Fort St. George (13°08′N, 80°29′E), we get 5°27′45″ for the difference of longitude between the steeple in Fort St. George and the flag-staff at Mangalore' (ref. 33, pp. 297–298).'

Lambton[33] indicates that his use of triangles would present an overall idea of the landscape he surveyed to future surveyors. He supplies the following additional details[33]:

- Series of triangles taken up at Hanandamulla and Pilloor Hill, and carried to the base near Bangalore (pp. 299–305).
- Measurement of the baseline at Bangalore (pp. 306–375).
- Table of latitudes and longitudes of some of the principal places, as deduced from the operations in general (pp. 376–381).
- Elevations and depressions, contained in the arcs, terrestrial refractions, together with heights above the level of the sea, of all the principal stations (pp. 382–384).

Lambton remarks that the Madras–Bangalore–Mangalore survey had grown to a magnitude far beyond what he had estimated initially. He further says that this task, although unimaginably massive, has been interesting, and by no means arduous (ref. 33, p. 299):

'Freed from restriction of every kind, and permitted to act under the most liberal conditions, I have been enabled to obviate every difficulty; which otherwise must have embarrassed my exertions, and defeated the ultimate objects of my labours.'

The following text occurs in his 1818 paper[35], possibly the last of his several papers on this theme. Information with respect to the landscape west of Bangalore sparkles here (ref. 35, p. 62):

'After passing the range of hills, in which Savendroog, Paughur, and several other stations are situated, the country has a sudden descent, and continues low considerably to the westward of Seringapatam, where it begins again to rise towards the mountains called the Western Ghauts, which are, in general, from two to three thousand feet higher than those which form the Eastern Ghauts. Seringapatam, therefore, and all the country north and north-easterly towards the ceded districts, is a valley, upwards of a thousand feet below the tableland round Bangalore, descending as we advance to the northward. The Savendroog range forms a kind of barrier to the east, but a more complete one is formed to the westward, by those stupendous mountains which form the Ghauts, a number of which are from five to six thousand feet above the sea. The countries of Canara and Malabar lie immediately below these Ghauts, and the sea is everywhere in sight. These countries are low, but broken, and much interspersed with back-water, rivers, and extensive ravines, shaded with forest and jungle, and filled with population; for the upland is barren, and it is in these ravines, and on the banks of the rivers, where all the inhabitants reside. In the month of February, the low country becomes excessively hot, and the vapour and exhalation so thick, that it is difficult to see to the distance of five miles. I have viewed this curious laboratory from the tops of some of the highest mountains, where I was scarcely able to bear the cold. The heat increasing during the months of March and April, a prodigious quantity of this moisture is collected, which remains day and night in a floating states, sometimes ascending nearly to the height of the mountains, where it is checked or condensed by the cold; but immediately after descending, it is again rarefied, and becomes vapour before it can reach the earth; and in this state of floating perturbation it remains till the setting in of the western monsoon, when the whole is condensed into rain, some falling on the low country, some among the mountains, and what escapes is blown across the Mysoor, and immediately over this valley, which I have just mentioned. This account is foreign to my present purpose; but I trust I shall be pardoned for the digression, as it is a statement of facts relative to a part of the country, which has been a grave both to Europeans and natives, ever since the fall of Seringapatam.'

Remarks

Lambton, in the Fort St. George–Bangalore–Mangalore survey, used mostly triangles, occasionally quadrilaterals and polygons, by setting up their sequences either along the meridians or running them parallel to the coast. The peninsular India afforded Lambton a fabulous opportunity for constructing long-legged triangles, as evident from some of the legs that were nearly 60 miles (96 km) long. Everest appreciates the construction of long-legged triangles, although, during his leadership phase of the GTSI, he preferred triangles with legs no longer than 20–30 miles (32–48 km)[36].

At the time when Lambton executed this project, he was just adequately equipped. Although he used a Cary that required 12 strong men to lift it for transport, it was severely damaged at one time and Lambton had to spend close to six weeks in restoring it by himself. Lambton's work impresses as colossal, when we consider the modern electronic theodolites (METs), far lighter than either a Ramsden or a Cary. The METs include a laser-rotary encoder to read the horizontal and vertical measurement signals of both altitude and azimuth. It is noteworthy that the METs include charge-coupled device sensors and integrated electro-optical distance measuring devices with a capacity to download raw data onto external electronic microprocessors. Lambton's 1808 communication includes lengthy tables referring to preliminary datasets gathered during the determination of the Doddigunta baseline, which was established in relation to the first baseline determined on a flat terrain of about 8 miles^2 ($\approx$ 20.71 km^2) off Fort St. George[37]. From the Doddigunta baseline, triangles were extended along the Coromandel Coast up to Cuddalore (11°45′N, 79°45′E). His papers explain how much care he exercised while determining measurement stations: the stations were enclosed either with picket fences or with built structures; the exact point for geodesic measurement was watchfully ascertained using criss-crossing silken threads[37]. This process was repeated over the entire distance of (c. 360 miles, ≈570 km), as a crow would fly, between the Eastern and Western Ghats along the mean latitude between Fort St. George and Mangalore. Lambton acknowledges the support he got from the Fort. St. George government on the one hand and from Dodda-Vira-Rajendra Wodeyar (note 20), the Raja of Coorg, on the other during this project. Lambton's calculations relating to the measurement of the grand meridional arc, and his mathematical determinations of the dimensions of the Earth are available in the literature[38,39].

Lambton's determination of the great meridional arc in southern India was the stay wire for later work by Everest[40]. Lambton's determination of the meridian by astronomical azimuths and by observations of zenith distances, whereby a definite amplitude of arc could be expressed in linear measure, was a reliable practice followed by many for nearly a century[41]. His carefully established primary values for longitudes and latitudes and the shape of the Earth formed a logical predecessor for tables of geographical coordinates. The observation of azimuths for regulating the direction was made at the start and end of every triangulation series that Lambton launched, whether meridional or longitudinal. Intermediate observations were also made at stations 1° apart. To determine the direction of the True North, Lambton observed his azimuths viewing the polestar, whereas Everest from 1833 included viewing of other circumpolar stars, still keeping to the time of greatest elongation[36].

Between 1802 and 1810, Lambton explored the peninsula as high as 15° with a network of triangles. He says 'The whole of the peninsula is now completed

from Goa on the west, to Mausilapatam (Masulipatnam) on the east, with all the interior country from Cape Comorin to the southern boundaries of the Nizam's and Marhatta's (approximately modern Maharashtra) territories. In that great extent of country, every object that could be of use in geography or in facilitating the detailed surveys of the provinces, has been laid down with precision. All the great rivers sketched in a general manner, and all the great ranges of mountains slightly depicted' (ref. 42, p. 7).

Words of the anonymous biographer of Lambton overpoweringly capture his pioneering contribution made towards an accurate understanding of the geography of southern India (ref. 20, p. 81):

'In fact, to Colonel Lambton we owe that we know of precision in the geography of the south of India, and if the northern parts or the Bengal presidency can furnish no map of equal accuracy, it is because we have had no Lambton. Or perhaps it would be more just to say, because we have had no patrons like those which it was Colonel Lambton's good fortune to meet with.'

Everest, a trainee with Lambton during the Fort St. George–Bangalore–Mangalore survey, succeeded Lambton as Superintendent of GTSI from 1823 after Lambton's death. Everest brought GTSI to fruition, covering the reminder of India, travelling up to Nepal. Everest was appointed the Surveyor General of India in 1830 and returned to England in 1843 on retirement. James Prinsep[43], Secretary of the Asiatic Society of Bengal, provides a brief and personalized commentary on the splendid work led by Everest.

Notes

1. After AD 1800, the President of the Council at Fort St. George, Madras was re-titled as the Governor.

2. Michael Topping (1747–96) was the Chief-Marine Surveyor at Fort St. George who was singularly responsible for establishing the oldest, modern technical (engineering) school in India: the Survey School with an intake of eight students functional from 17 May 1794. This is the oldest engineering school outside Europe. It became the Civil-Engineering School in 1858 and metamorphosed as the College of Engineering, Guindy (13°84′N, 80°21′E), in 1861. Topping was also the first full-time modern professional marine surveyor of India, who surveyed the seas off Coromandel Coast. He died in 1796.

3. 'Carnatic' is an obsolete term, which referred to a major section of peninsular India that excluded modern Kerala. The erstwhile Carnatic could be broadly equated with the oft-used term 'Deccan'.

4. We could not access the originals. We extracted the following detail from Ansari[44]: Goldingham, J., Astronomical observations made in the Honourable East India Company Observatory at Madras, vol. II (1812), vol. III (1824), Madras. Ansari[44] indicates vol. I (1793) is in manuscript form.

5. A unique expression 'being on gun time' prevails only in Madras and its neighbourhood. This implies to 'someone absolutely punctual'. This unique-to-Madras expression arose from gun firing of blank cartridges from Fort. St. George, announcing 12 noon and 8.00 p.m. each day.

6. Henry Kater was assistant to William Lambton in the trigonometrical survey project. He returned to England in 1808, due to poor health. Kater continued his physical and mathematical research after his return to England[45]. He is remembered for research in compasses and pendulums. While at Madras, Kater was interested in metallurgy and metal properties. He made precision-measurement units and instruments. In 1817, Kater designed and constructed a convertible pendulum for the absolute determination of gravity in London. Systematic survey of the gravity field of the earth began to receive attention throughout the world following Kater's return to England.

7. Robert Clive (1725–74) first arrived as a Factor (=trader) with EEIC in Fort St. George in 1744. He later won Bengal (Calcutta) for EEIC in the battle of Plassey (Palassi) in 1757. He returned to England as a wealthy person.

8. The Madras city, was recognized as Fort St. George, until the 1820s: the administration was the 'government at Fort St. George'.

9. Francis Buchanan (1762–1829), also known as Francis Hamilton, Francis Buchanan–Hamilton, was a trained surgeon from Scotland, who made significant contributions as a geographer and naturalist. He first described the iron-rich laterite material from Angadipuram (10°98′N, 76°18′E)[17].

10. Colin Mackenzie (1754–1821) came from Scotland to Madras, and later became the Surveyor General of India. He was an avid antiquarian and orientalist. He surveyed southern India topographically, utilizing local scholars, studying religious practices, oral histories, inscriptions, first out of personal interest and later as the Government Surveyor. He surveyed the Mysore region, soon after EEIC's victory over Tipu Sultan in 1799. Mackenzie first generated maps of Mysore region in addition to providing illustrations of the landscape and notes on Mysore archaeology.

11. George Everest (1790–1866) was a British surveyor and geographer. Mount Everest celebrates his name.

12. Henry Wesley Voysey (1791–1824), a trained surgeon, worked in India in the service of EEIC as a geologist–mineralogist. He made the first geological map in India covering the Hyderabad region, submitted to the Asiatic Society of Bengal in 1821.

13. The Asiatick Society was founded in Calcutta in 1784 on the initiative of William Jones. The name was re-spelt as the Asiatic Society in 1825, transformed as the Asiatic Society of Bengal in 1832.

14. William Cary was a leading precision-instrument maker in England, who had trained with Jesse Ramsden in London. Ramsden was a big name in the 18th century Europe in the production of precision instruments, including optics. The achromatic eyeglass used in telescopes is known as the 'Ramsden lens'[46].

15. Benjamin Heyne joined the EEIC service in 1793. He was the Botanist in the Samakottah Botanic Garden (Samarlakota, 17°3′N, 82°11′E), previously supervised by William Roxburgh.

16. For details of oat-beard hygrometer, see Pike[47].

17. John Warren (Jean Baptiste François Joseph de Warren) (1769–1830) was an officer attached the 33rd Regiment of Foot of the British army in Madras. He was a surveyor and an amateur astronomer. While associated with William Lambton in the GTSI project, Warren discovered the gold mine site in Mysore, later the Kolar Gold Fields. He settled in Pondicherry in later years and wrote a book *Kāla Sankālitā*, referring to the Indian practice of astronomy and time-keeping[48].

18. In 1796, Asaf Jha II, the Nizam of Hyderabad, sought British protection under Lord Wellesley's Doctrine of Subsidiary Alliance. In compliance with this, Asaf Jha conceded a large portion of his land to the British to be added to the Madras Presidency, referred as the Ceded Districts, which included the present-day Anantapur, Cuddapah, much of Kurnool, Bellary and parts of Tumkur and Davanagere (Harappanahalli Taluk)[49].

19. A fathom is a length unit in the dated Imperial system, equalling *c.* 6 ft (1.83 m). Fathom is usually used to

measure water depth. Because it evolved from the span of an adult human's outstretched arms, it naturally varied: length of a fathom would be between 5 and 5½ ft (1.5–1.7 m).

20. After whom the town Virajpet – Virarajendra-pettah, 12°12′N, 75°48′E – in Kodagu is named.

1. Papworth, K. M., *Irish Astron. J.*, 1952, **2**, 89–94.
2. Ananthasubramaniam, C. K., In *Vistas in Astronomy* (eds Beer, P., Meadows, A. J. and Roy, A. E.), Pergamon Press, London, UK, 1985, vol. 28, pp. 377–378.
3. Ananthasubramaniam, C. K., *J. R. Astron. Soc. Can.*, 1991, **85**, 91–105.
4. Kochhar, R. K., *Bull. Astron. Soc. India*, 1985, **13**, 287–302.
5. Raman, A., *Madras Musings*, 2012, **XXII**, 6–7.
6. Goldingham, J., *Philos. Trans. R. Soc. London*, 1822, **112**, 127–170.
7. Rennell, J., *A Bengal Atlas Containing Maps of the Theatre of War and Commerce on that Side of Hindoostan*, Laurie & Whittle, London, UK, 1781, p. 59.
8. Thackeray, E. T., *Biographical Notices of Officers of the Royal (Bengal) Engineers*, Smith, Elder & Co., London, UK, 1900, pp. 11–20.
9. Markham, C., *A Memoir on the Indian Surveys*, W. H. Allen & Co., Edward Stanford, Henry S. King & Co., London, UK, 1878, p. 481.
10. Tripathy, M. P., *Development of Geographic Knowledge in Ancient India*, Bharatiya Vidya Prakashan, Varanasi, 1969, p. 366.
11. Gole, S., *Imago Mundi*, 1990, **42**, 99–105.
12. Schwartzberg, J. E., In *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures* (ed. Selin, H.), Springer, Heidelberg, German, 2008, pp. 1301–1303.
13. Love, H. D., *Vestiges of Old Madras*, John Murray, London, UK, 1913, vol. III, p. 580.
14. Jervis, T. B., *Madras J. Lit. Sci.*, 1838, **18**, 424–441.
15. Wilson, W. J., *History of the Madras Army*, E. Keys, Government Press, Madras, 1892, p. 382.
16. Naravane, M. S., *Battles of the Honourable East India Company: Making of the Raj*, A. P. H. Publishing Corporation, New Delhi, 2006, p. 261.
17. Buchanan, F., *A Journey from Madras Through the Countries of Mysore, Canara, and Malabar: Performed Under the Orders of the Most Noble the Marquis Wellesley, Governor General of India, for the Express Purpose of Investigating the State of Agriculture, Arts, and Commerce; the Religion, Manners, and Customs; the History Natural and Civil, and Antiquities, in the Dominions of the Rajah of Mysore, and the Countries Acquired by the Honourable East India Company*, T. Cadell & W. Davies, London, UK, 1807, vol. I, p. 424, vol. II, p. 556, vol. III, pp. 479 + xxxi.
18. Howes, J., *Illustrating India: The Early Colonial Investigations of Colin Mackenzie (1784–1821)*, Oxford University Press, New Delhi, 2010, p. 269.
19. Roy, R. D., *Indian J. Hist. Sci.,* 1986, **21**, 22–32.
20. Edney, M. H., *Mapping the Empire: The Geographical Construction of British India 1765–1843*, Chicago University Press, Chicago, USA, 1997, p. 480.
21. Keay, J., *The Great Arc: The Dramatic Tale of how India was Mapped and Everest was Named*, Harper Collins, London, UK, 2000, p. 208.
22. Emerson, W., *A Treatise of Algebra*, J. Nourse, London, UK, 1764, p. 531.
23. Hartley, C., In *British Genius Exemplified in the Lives of Men: Who by their Industry or by Scientific Inventions and Discoveries*, Effingham Wilson, London, UK, 1820, pp. 9–15.
24. Beatson, A., *A View of the Origin and Conducts of the War with Tippoo Sultaun: Comprising a Narrative of the Operations of the Army under the Command of Lieutenant-General George Harris, and of the Siege of Seringapatam*, G. & W. Nicol, London, UK, 1800, p. 265.
25. Mudge, W. and Dalby, I., *An Account of the Operations Carried on for Accomplishing a Trigonometric Survey of England and Wales from the Commencement, in the Year 1784, to the end of the Year 1796*, W. Faden & the Prince of Wales, London, UK, 1799, pp. 128 + 22 plates.
26. Danvers, F. C., *Q. J. Sci.*, 1870, **VII**, 448–458.
27. Anon., *Glean. Sci.*, 1830, **II**, 73–82.
28. Anon., *Asiat. J. Mon. Reg. Br. Foreign India, China and Australas.*, 1831, **V**(N.S.), 312.
29. Roy, W. and Dalby, I., *Philos. Trans. R. Soc. London*, 1790, **80**, 111–614.
30. Insley, J., https://www.fig.net/resources/proceedings/fig_proceedings/fig2008/papers/hs03/hs03_01_insley_2838.pdf (accessed on 8 April 2019).
31. Proudfoot, W. J., *Biographical Memoir of James Dinwiddie, LL.D.*, Edward Howell, Liverpool, UK, 1868, p. 138.
32. Clarke, A. R. and James, H., *Philos. Trans. R. Soc. London*, 1873, **163**, 445–469.
33. Lambton, W., *Asiat. Res.*, 1810, **10**, 290–384.
34. Warren, J., *Trans. Asiat. Soc.*, 1809, **9**, 1–23.
35. Lambton, W., *Asiat. Res.*, 1818, **12**, 1–101.
36. Philimore, R. H., *Historical Records of the Survey of India, 1830–1843, George Everest*, Surveyor-General of India, Dehra Dun, 1958, vol. IV, p. 493.
37. Lambton, W., *Asiat. Res.*, 1808, **8**, 137–194.
38. Lambton, W., *Asiat. Res.*, 1818, **12**, 294–359.
39. Lambton, W., *Philos. Trans. R. Soc. London*, 1823, **113**, 27–33.
40. Everest, G., *An Account of the Measurement of an Arc of the Meridian between the Parallels of 18°3′ and 24°7′: Being a Continuation of the Grand Meridional Arc of India as Detailed by the late Lieut.-Col. Lambton in the Volumes of the Asiatic Society of Calcutta*, Parbury, Allen & Co., London, UK, 1830, p. 337.
41. Chant, A. (ed.), *Transactions of the Royal Astronomical Society of Canada: Selected Papers and Proceedings for 1905*, Royal Astronomical Society of Canada, Toronto, Cananda, 1906, p. 209.
42. Lambton, W., *Asiat. Res.*, 1820, **13**, 1–127.
43. Prinsep, J., *J. Asiat. Soc. Bengal*, 1832, **I**, 71–72.
44. Ansari, S. M. R., *J. Astron. Data*, 2004, **10**, 3–12.
45. Playfair, J., *Edinb. Rev.*, 1818, **30**, 407–426.
46. McConnell, A., *Antiq. Astron.*, 2013, **7**, 41–53.
47. Pike, B., *Pike's Illustrated Descriptive Catalogue of Optical, Mathematical and Philosophical Instruments*, Benjamin Pike, Broadway, New York, USA, 1856, vol. 2, p. 292.
48. Warren, J., *Kãla Sankãlitã: A Collection of Memoirs on the Various Modes According to which the Nations of the Southern Parts of India Divide Time*, The College Press, Madras, 1825, p. 633.
49. *The Imperial Gazetteer of India*, Clarendon Press, Oxford, UK, 1909, vol. 1, pp. 158–176.
50. Taylor, T. G., *Result of Astronomical Observations, Made at the Honourable East India Company's Observatory, Madras, for the Years 1836 and 1837*, Government of Madras, Madras, 1839, vol. IV, p. 262.

Anantanarayanan Raman is in the Charles Sturt University, P.O. Box 883, Orange, NSW 2800, Australia; Vancheeswar Balakrishnan is in the C-23 MES Colony, Venkatapuram, Secunderabad 500 015, India.*
e-mail: anant@raman.id.au