COLONEL SIR GEORGE EVEREST, CB, FRS

(1790-1866)

a celebration of the bicentenary of his birth

8 November 1990

at the Royal Geographic Society, London

Keep
this is
important

ISBN: 0-85406-478-8

PROGRAMME

11.00	Opening welcome Sir Crispen Tickell, President, Royal Geographical Society.
Session 1	Chairman Professor Alan Dodson, Vice President, Royal Astronomical Society.
11.05	Systematic surveys and Mapping Policy in British India 1757-1830 Dr Matthew Edney, Department of Geography, State University of New York.
11.40	The Survey of India up to and during the time of Sir George Everest Lt Gen S M Chadha, Surveyor General, Survey of India.
12.15	Lunch
Session 2	Chairman John Lonard, President, Land Surveyors Division, Royal Institution of Chartered Surveyors.
13.30	Everest the Man: A potted biography Mr Jim Smith, Portsmouth Polytechnic.
14.05	Instruments of a very beautiful class Miss Jane Insley, Curator, Environmental Sciences, The Science Museum, London.
14.40	George Everest on the triangulation of the Cape of Good Hope Mr Colin Martin, Department of Surveying, University of Cape Town. Mr Roger Fisher, Head, Department of Land Surveying, Polytechnic of East London.
15.15	Tea
Session 3	Chairman Dr Desmond King-Hele, FRS, The Royal Society, London.
15.45	The achievements of Sir George Everest in geodesy Prof. Sir Alan Cook, FRS, The Master, Selwyn College, Cambridge.
16.15	The development of the Survey of India to the present day Sri V K Nagar, Additional Surveyor General, Survey of India.
16.45	The new map of Mount Everest Prof. Dr A Gruen, Institute of Geodesy and Photogrammetry, Technische hochschule Zurich. Mr W Altherr, Swissair Photo & Surveys Ltd, Zurich.
17.25	Closing comments Mr Alastair Macdonald, The Ordnance Survey, Southampton.
17.30	Close.

PREFACE

The name Everest invariably conjures up an image of the mountain. Some are even unaware that the name is also a personal one.

About two years ago a chance remark was made to me by an eminent member of the land survey profession "You realise that 1990 is the bicentenary of the birth of Sir George Everest?" Whilst I was well aware of Everest as a person I had not, until then, appreciated the imminence of the bicentenary.

The eminence of Everest, both man and mountain, seemed to call for recognition in some form or other and hence this event and others that have already taken place.

For the record, on 4 July, his birthday, a special stamp cover was issued. On the same day a small commemoration was organised at his grave in Hove. Then during 4-5 October, the Survey of India held celebrations in Dehra Hun and Mussourie. Technical papers have appeared in The Professional Surveyor, Land & Minerals Surveying and The Survey Review.

This joint meeting and exhibition forms part of the technical programmes of both the Royal Geographical Society and the Royal Institution of Chartered Surveyors. As will be seen from this volume, the authors come from 5 different countries and I would like to take this opportunity to thank them and the session chairmen most sincerely for their efforts and also those who have assisted by lending items for the exhibition.

A chance remark can thus lead to a variety of activities but not without considerable hard work by a small devoted group of helpers and to these I extend heartfelt thanks for many hours of toil.

It is noticeable that no comprehensive biography of Sir George Everest exists, but these various commemorative events may lead to such a volume. Any readers who can supply additional material are asked to contact me, c/o The Land Survey Division, Royal Institution of Chartered Surveyors, 12 Great George Street, Westminster, London SW1P 3AD.

J R Smith
Chairman, Organising Committee

SYSTEMATIC SURVEYS AND MAPPING POLICY IN BRITISH INDIA, 1757-1830

Matthew H. Edney, Assistant Professor, Department of Geography, State University of New York, Binghampton, NY 13901

We remember George Everest today for his work between 1830 and 1843 as Surveyor General and as Superintendent of the Great Trigonometrical Survey of India. I would like to start the proceedings by discussing the circumstances in which he and his colleagues worked, by considering the East India Company's mapping policies as they evolved in the seven or so decades before 1830. Mapping policies tend to be complex, and the Company's were no exception. They were created through an intricate process of give and take between several factions within the Company's administration. The Court of Directors and its secretariat in London set the basic parameters, which the three Indian governments (or 'Presidencies: Calcutta/Bengal, Madras and Bombay) all interpreted to meet their own ends. Many of the governors, administrators, and bureaucrats actively supported survey activities; others were concerned with keeping the Company's costs to a minimum by eliminating expensive activities and targeted the surveys as principal offenders; but the majority were too busy with other matters. It is important to realize therefore that the Company's mapping policies were usually set by only a handful of individuals. I cannot hope to go into all the intricacies here,(1) but I can present the essential characteristics of the Company's surveys.

The Nature of the British Surveys of India

Even when one accepts the iniquities inherent to, and which resulted from, the East India Company's conquest of India, one cannot help but be fascinated by the sheer spectacle provided by the handful of Europeans who brought a vast empire under their control. The main agency of this conquest was, of course, the Company's British-officered and Indian-manned army. But force of arms alone is insufficient to govern foreign territories. One of the keys to British success in India was their ability to collect and marshall <u>information</u> rather than soldiers. By 1800, the Company placed great emphasis upon a proper education for its civil and military servants; and it actively encouraged those same servants in their inquiries into Indian society and culture.

The mapping of India must, first and foremost, be seen as a major part of this marshalling of information. All levels of the Company's administration needed geographical information for their operations. The district collector and the military commander in the field needed it for their daily work. For example, in 1824, the British Resident at Indore wanted a survey of the Narmada Valley for three reasons: to map the passes through its bounding hills for military purposes; to aid the detection of bandits for the police; and to help track the movement of opium so that it might be taxed.(2) The three Indian governments needed basic geographic data for strategic planning, as did the Company's Directors in London.

Furthermore the British surveyors in India were rarely concerned with only the land. Whenever possible they collected statistics regarding populations, castes, commerce, agriculture, industry, and trade. They recorded information on local languages and local systems of land tenure. They delved into the local geology in search of gold and other precious metals, and they were always on the look-out for stands of good timber.

One example was an 1920 survey to determine the route of a new road between Midnapore and Nagpore which consisted of the cartographic survey followed by investigations into the area's "statistics and political economy", its climate, soils, population, and so on.(3)

As Europeans, the British made surveys in the established European manner. When James Rennell (Bengal Surveyor General, 1767-77) was given the task of mapping Bengal shortly after the Company accepted responsibility for the province's administration in 1765, his techniques were those of contemporary English colonial surveyors in Ireland, Scotland, and North America.(4) Rennell made a series of traverses along roads and rivers; determining the positions of a few places by astronomical observations, he then combined the route surveys into a general map. The same process was used for extensive mapping in India throughout the eighteenth century, and until 1830 in the flat Gangetic Plains.(5) Rennell published his work as A Bengal Atlas in 1780; the other surveys remained in manuscript and so are far less known, but they are no less remarkable.

Route traverses were well suited to the Company's mapping needs. They were fast, simple, and easy to combine into geographic maps. But they were also error-prone and did not lend themselves to high density mapping. By the end of the eighteenth century, European surveys were increasingly based upon frameworks of triangulation. Triangulation -- also known as "trigonometrical surveying" -- provides a dense network of control points whose relative positions are fixed very accurately. It is therefore a far superior method for surveying large regions than the method of route traverses, but it is much more time consuming and much more expensive.

The technique of triangulation had been in regular use for small surveys in Europe since the sixteenth century. The famous Cassini surveys of the eighteenth century were the first to extend a high-quality triangulation across an extensive region, i.e. the entire country of France. Most of Europe followed the French example between 1789 and 1815 and as the popularity of triangulation increased in Europe, so too did it increase in India. The advocates of such systematic mapping in India consciously modelled their proposals after 1799 upon the British Ordnance Survey. By 1830, when Everest assumed his post as Surveyor General, it was accepted Company policy that all detailed surveys in India should be based upon an India-wide triangulation.

There is, however, a contradiction here. Company policy advocated a systematic basis for the survey of India, yet the triangulation was generally too slow to keep up with the many detailed surveys made to meet the huge demand for geographic information. In Europe, centuries of surveying and mapping had produced a solid corpus of information which would suffice until the modern, laborious, and highly-detailed systematic surveys could be finished. And if existing information would not suffice, then there were always commercial surveyors who could provide stop-gap surveys. In India there was neither an existing corpus of geographic data nor any body of commercial surveyors trusted by the Company's officials.

Yet imperial logic is such that peripheral areas are continually subdued to protect core regions. Each campaign which annexed more territory to the Company's direct control, and each treaty which bound another native state to the Company's sovereignty, necessitated another survey to be completed as soon as possible. But there were insufficient funds and personnel available to ensure that each new territory was triangulated before it was mapped topographically or cadastrally. Often there were no official surveyors available, so that field commanders and district collectors directed their own men to make the necessary surveys. There was a huge abyss between the ideal form of the European systematic survey and the pragmatic needs of imperial rule for geographic information.(6)

The Map of India

The Company's mapping policies revolved about this contradiction. Unable to make a single survey of India, the Company instead advocated the creation of a single map of India. The distinction is subtle, but significant. The Company's officials wanted to ensure that once an area had been surveyed, the information could be quickly brought to bear. They treated finished maps as the equivalent of written studies of Indian culture and society. The Directors paid out handsome rewards to the authors when a specimen of either form of study was presented to the Court. Thus, Charles Reynolds was awarded the huge sum of two lakhs of rupees (or about £18,400) for his 1809 map of India.(7)

Moreover, the Company's administrators generally lacked a sophisticated perspective on the quality of different surveys and of the resultant maps. Until explicitly informed to the contrary, the assumed that a map's quality depended not on its internal consistency and accuracy but on how well it had been produced. For example, an 1821 update of Reynolds' map "struck" the Governor of Bombay with "the carefulness, distinctness, and beauty of (its) execution".(8) But John Hodgson, Surveyor General of India, dismissed the map as being out-of-date and as being inferior even to Aaron Arrowsmith's smaller-scale Improved Map of India published in London in 1816.(9) In 1837, the Directors provisionally appointed Thomas Best Jervis, of the Bombay Engineers, to succeed George Everest on the strength of Jervis' map of the Concan.(10) It was indeed a beautiful work, for which the Court also gave Jervis Rs.10,000 (=£960), yet it was soon discovered to be riddled with inconsistencies which prevented its reconciliation with surveys of surrounding areas.

Now, at the start of the nineteenth century, there were several different offices involved in map production. First, each province had its own Surveyor General who spent more time organizing and copying maps than in controlling actual surveys; second, other officers in each provincial government, notably the quartermaster generals and the chief engineers, maintained establishments to make, to copy, and to store maps of different kinds. Attempts to bring this material together into a single map were flawed by the mutual jealousies of the surveyor generals, who wanted their data to bring rewards to themselves rather than to their colleagues. Reynolds, Thomas Call (Bengal SG, 1777-86), and Robert Colebrooke (Bengal SG, 1794-1808) were all unable to create a complete map of the subcontinent. With the lack of communication between the survey officers, the Directors observed

> that the information.. is liable to become obsolete, the authentication of it in memoirs, or other explanations to be lost, or mislaid, or to perish from vermin, or the effects of the climate, before it can be (incorporated into) a general Map of the Country.(11)

They therefore ordered in June 1814 that the three provincial offices of Surveyor General be abolished and replaced by the single office of Surveyor General of India.

The Court directed that the duty of a single Surveyor General of India was not

> to conduct Surveys himself, but to receive and appreciate the Surveys made by others, to arrange the materials existing or which may hereafter be procured, after selecting the best, and reducing them to one uniform scale, to frame from those materials Maps of Provinces, or of Divisions, comprehending a certain extent in latitude and longitude, these to be constructed on a larger scale with all practicable detail, and to be accompanied with a memoir, explaining the authorities, and the Construction of the work. A general Map of India (is) to be carried on at the same time of which the foregoing Separate Maps will constitute the foundation, but reduced to a scale which may confine the general Map within manageable limits.(12)

The Surveyor General of India was to be an armchair geographer par excellence, creating general maps of India and thereby justifying the Company's large expenditures on the actual surveys. The Court was quite willing to pay for its geographic information, but it wanted that expenditure to be applied efficiently. The Court devoted only one paragraph (out of 26) to the issue of the administration of the actual surveys. It directed that all surveys were first to be approved by the relevant government, they were to be made by an officer who had passed through the Company's military academy at Addiscombe, and the results (both map and memoir) were to be passed on to the Surveyor General.

The first two Surveyor Generals of India -- Colin Mackenzie (1815-21) and John Hodgson (1821-23) -- had great difficulty in meeting the duties prescribed by the Court. Mackenzie finally took up his position in August 1817, and spent the next four years either too ill to work or swamped with immediate demands for maps. Mackenzie advocated the solution of publishing an atlas of India at four miles to an inch, and he cited his earlier surveys in southern India as an example of the form that such an atlas might take. John Hodgson went one step further and began the creation of just such an atlas. He consciously modelled the first stage, covering the Gangetic Plains between Bengal and Delhi, on James Rennell's A Bengal Atlas.(13) But his progress with similar maps for the rest of India was made redundant by more decisions made in London.

Mackenzie's and Hodgson's ideas for an atlas of India were parallelled in England by those of one of the period's principal commercial map publishers in London, Aaron Arrowsmith. The Court of Directors underwrote Arrowsmith's production in 1822 of two works: an Atlas of South India and a single-sheet Sketch of the Outline and Principal Rivers of India.(14) The atlas, based extensively on Mackenzie's work, had sixteen sheets at four miles to the inch. The "sketch" also illustrated how the same sheet lines might be extended across all India. With this work before them, the Court accepted the arguments made in India by Mackenzie and Hodgson and ordered the creation in London of an Atlas of India, at four miles to an inch, which would constitute the basic map of all India.

Arrowsmith died shortly thereafter and the Atlas of India lapsed until 1825 when it was taken up by another commercial map publisher, John Walker. Walker established the final sheetlines for the Atlas: 177 sheets for all India, each sheet covering 160 by 108 miles. As Arrowsmith had earlier suggested, each sheet was engraved as suitable materials were received. Thus, the first six sheets issued (in 1827) were compiled from the most recently received materials.(15) With exception of six sheets in Assam, Walker's work on the Atlas for the next twenty-five years was devoted to 29 sheets for the well-surveyed Madras presidency.

But how were the individual surveys to be fitted together and related to Walker's sheetlines? Let us turn now away from the East India Company's mapping policy as set in London and consider the policies pursed by the three provincial governments in India, policies which tended to be more concerned with questions of survey technique and style.

Systematic Surveys in India

Several people had suggested in the eighteenth century that India be the site of a geodetic arc measurement. Alexander Dalrymple, the Company's Hydrographer, proposed it in 1784 and was seconded by William Roy, founder of the Ordnance Survey. The Company accordingly charged the astronomer Reuben Barrow with the task, but he died in 1792 and the project lapsed. Michael Topping , the Company's Astronomer at Madras, intimated that a triangulation could be made of all of southern India, but such a scheme could not have worked until the British had political control of the entire region. That circumstance came with the defeat in May 1799 of Tipu Sultan of Mysore. By a historical accident, a Crown officer who had taken part in the campaign also happened to have an intense personal interest in geodesy.

Faced with a huge territory waiting to be mapped, and heeding Roy's call for geodetic arc measurements in the subcontinent, William Lambton, of His Majesty's 33rd Foot, submitted a proposal to the Madras Government. Lambton was actively supported by several very influential figures, among them his regimental commander, Arthur Wellesley (later the Duke of Wellington), and Wellesley's elder brother, Richard, then Governor General. These supporters were sufficient to override the gainsayers and to allow Lambton to embark upon a program to measure two geodetic arcs. The first ran eastward from Madras to Mangalore across the peninsula of India; the second was an arc of meridian, running north from Cape Comorin, which would soon become known as the Great Arc. Right from the start, Lambton's assistants also surveyed secondary triangles and even some topography, and in 1807 Lambton obtained permission from the Madras Government to extend the secondary triangles across the entire peninsula. Whereas his published and manuscript reports stressed the geodetic aspects of the work, there can be no doubt that Lambton was also concerned with providing high-quality control for topographic surveys.

While Lambton began his trigonometrical survey, Colin Mackenzie was detailed to survey the state of Mysore. Aided by a number of assistants, he undertook the task with a triangulation basis, in a sharp break with his older techniques of route survey. Mackenzie eventually expanded the survey to cover almost all of the southern Deccan. Although Mackenzie's surveyors operated in advance of Lambton's triangulation, the surveys were found to coincide closely when they did overlap. Another batch of surveyors -- the students of the Military Institution at Madras under Anthony Troyer -- used Lambton's triangulation as the basis for the plane-table survey of the Carnatic, the broad coastal belt between the Deccan and the eastern coast of India. Other localized surveys were undertaken on bases of triangulation: Garling's triangulation around Goa was eventually subsumed into Lambton's work; while John Hodgson and William Webb made trigonometrical surveys in the Himalayas.

Lambton's trigonometrical survey was always seen as being distinct from other surveys. He was warned away from topographic surveying and ordered to stick to his geodetic and secondary triangulations . Topographic surveys were different, being mechanical in nature, whereas Lambton's work always bore the social cachet of being 'scientific'. The distinction was heightened yet further when in 1817 Lord Hastings, Governor General, ordered that Lambton's survey be brought under the control of the Supreme Government at Calcutta and was henceforth to be known as the Great Trigonometrical Survey of India. Hastings had previously been Master General of the Ordnance, in which capacity he had learnt something of the Ordnance Survey. For Hastings, Lambton's survey was essential not only because of its geodetic work, but also because

> There is no other solid basis on which accurate geography can so well be founded. The primary triangles thus spread over this vast country establish almost beyond error a multitude of points, and the spaces comprehended within these, when filled up by the details of subordinate surveyors, will afford...to the world, a map without a parallel, whether in relation to its accuracy, to its extensiveness, or to the unity of the effort by which it will have been achieved.(16)

To help Lambton in his future work, especially as he was now sixty years old and needed to train his successor, Hastings appointed to the GTS a young artillery officer of the Bengal army who had displayed exceptional engineering skills: Captain George Everest.

In creating the Great Trigonometrical Survey, Hastings was certainly influenced by the Court's decision in 1814 to unify the offices of Surveyor General. Moreover, Hastings followed Mackenzie's personal interpretation of the Court's order as requiring the prosecution of a single survey of India, and that the Surveyor General should have control of at least the topographic surveys (although it should be realized that Mackenzie also wanted control of Lambton's triangulation). The realization inherent in Hasting's decisions was that detailed surveys were necessarily undertaken without the benefit of an India-wide triangulation, yet the Great Trigonometrical Survey would nevertheless provide the framework for bringing all the separate surveys into a single whole, for tying them together on a standard system of latitude and longitude.

But could the Great Trigonometrical Survey really cover all India? Certainly, Lambton envisioned sending chains of triangulation from the Great Arc westward to Bombay and thence north along the coast to Guzerat, or from Madras along the eastern coast to Calcutta. But Lambton did not consider extending the Great Arc beyond Agra. The problem was the flatness and closeness of the northern plains. Without hills, the surveyor was hemmed in by trees and buildings, whereas a good triangulation required visibility of many miles in all directions. The problem had been encountered before, if only to a lesser degree. James Garling recorded that in his survey of Soanda the flatter, coastal areas were slightly in error, whereas the hilly areas were "generally executed with a minute correctness".(17) Throughout the 1820s, Indian surveyors believed that the vast northern plains could not be surveyed properly unless a commitment was made by the Government to construct expensive towers to raise the surveyors above all obstacles to their vision.

When the Court of Directors deliberated in 1823 the establishment of its Atlas of India, it asked its old cartographic expert, James Rennell, to propose the best method for surveying those tracts of India that had yet to be mapped. Rennell assumed that the Atlas was wanted very soon, and so described a quick system that was no different from his own survey in Bengal of the 1770s: an astronomer would determine the positions of key towns which would then serve to anchor fast route surveys.

The Court modified this proposal so that an astronomical survey would be restricted to those areas where the Great Trigonometrical Survey did not already extend, or could not be extended. That is, the plains were to be surveyed in the old manner, without a triangulated base. The Court subordinated the future progress of the trigonometrical survey to the Atlas.(18) Thus, publication of Everest's 1830 memoir on the Great Arc was sanctioned by the Court as it constituted "part of the materials for the Atlas of India", and as such would be sent to the same institutions as those to which it had already sent maps of the completed triangulation "already published for the Atlas of India".(19)

John Hodgson (SG 1821-23, 1826-29) and Valentine Blacker (SG 1823-26) both supported Lambton's plans to extend his triangulation across Deccan; indeed, they went further by urging the Bengal Government to permit the Great Arc to cross the Gangetic Plains and to push into the Himalayas, to which the Bengal Government agreed in 1824, eighteen months after Lambton died. For the rest of the plains, Blacker initially accepted -- with reservations -- the Court's scheme for astronomical control. He nonetheless made several concise and effective arguments, based on conversations with Everest, now Superintendent of the GTS, for an all-India triangulation.

The plan for an astronomical survey of the plains did not materialize. Instead, the Company's policy underwent a dramatic change between 1825 and 1827. On furlough in England, Everest urged the Directors in early 1827 to commit themselves to pushing ahead with the Great Trigonometrical Survey,(20) but the Court did not reply to Everest's suggestions. No reason readily presents itself, except that the Court had already accepted the principle of triangulating all India, both hills and plains.

This policy shift is borne out by three documents from later in the same year. First, in September 1827, the Court sent to the Bengal Government a copy of the 1824 parliamentary report which had led to the creation of the Ordnance Survey of Ireland. That survey would consist of a strictly trigonometrical survey to be followed by detailed surveys of sufficient scale to show individual fields. Those surveys could then be reduced to give topographic maps. The Court "thought it probable" that the Bengal Government might find the report to "contain information or suggestions which may be useful in the prosecution of Indian Surveys".(21)

In August 1827, James Salmond, the Court's military secretary who was responsible for coordinating all debates on military issues and for drafting military letters to India, wrote a memoir on the subject of a general survey of Ireland. This contained several significant points. First, the Court accepted that the Great Arc would eventually extend to the Himalayas.

Second, prospective delays in the progress of the triangulation should not be allowed to delay the detailed surveys, which would be rectified by the triangulation at a later date. And third, the triangulation was to cover all India.(22) Reinforcing this last point, the third document (a report of a private conversation with the military secretary) quoted Salmond as saying that "it has been found however that the triangulation of Colonel Lambton could be extended to Bengal."(23)

So why the sudden shift away from a cheap and fast, if error-prone, astronomical survey of the northern plains to a slow and expensive triangulation? The answer seems to lie in the Court's inability to find anyone willing to be the astronomer; those approached in England refused, while the Burma War had diverted the few capable officers in India. Moreover, someone within the Court or its secretariat -- most likely Salmond -- found state-of-the-art techniques to be far more appealing than astronomical control which was far more appropriate to the eighteenth than the nineteenth century.

Before Everest returned to India in 1830, the Court appointed him Surveyor General of India. He sailed with the full approval of the Directors for extending the Great Trigonometrical Survey across the northern plains, no matter the cost. As they wrote to the Bengal Government:

> We wish to impress upon the Surveyor General that the points upon which the maps of the Bengal Presidency are to be constructed, must have triangulation for their basis, being convinced that the Atlas can by no other method be rendered a permanent and useful work.(24)

But it must also be stressed that the Court did not want there to be a new detailed survey of, in this case, Bengal. Rennell had, after all, already collected the necessary data which only needed correction to be incorporated into the Atlas of India.

The rejection of proposals for single, systematic surveys -- such as those by Lord William Bentinck (Governor General, 1828-35) and by Thomas Jervis in 1838-39 was reinforced by the poor state of the Company's finances. Bentinck appears in a strange position: a fervent supporter of surveys, he advocated the wholesale expansion of the Great Trigonometrical Survey yet ordered a drastic cutback in topographic surveys. However, both the Court in London and Bentinck in Calcutta realized that the key to the mapping of India was in the efficiency of the surveys: the Great Trigonometrical Survey was highly cost effective, but in the long term "detached, unscientific, and unsatisfactory surveys" were not.(25) As a result, Everest was able to expand the Great Trigonometrical Survey tremendously after 1831.

Thus, total savings effected in the military department in 1833-34 amounted to Rs.300,000, but these were offset by Rs.63,300 of increases "principally from charges on account of the expensive work of the Great Trigonometrical

Survey".(26) The personnel of the trigonometrical survey comprised just Everest and four civil assistants on January 1st, 1831; on the same day, 1833, there were eight military officers and twenty-two assistants!

It is tempting to claim that the Great Trigonometrical Survey in the nineteenth century was the precise equivalent of the great national surveys in Europe. It was however quite different because it was justified for its ability to correct existing detailed surveys, an ability which even at the time was recognized by experts as being dubious. For example Henry Kater, who had assisted William Lambton between 1803 and 1806, testified to the British Parliament that triangulation must precede detailed surveys for the proper corrections to be made; if the triangulation followed the detailed surveys, who could say whether the errors were being reduced or compounded?(27) That the Great Trigonometrical Survey ever consisted of more than the Great Arc, together with its offshoots to Madras, Bombay, and Calcutta, was due not to the dictates of good surveying principles but to the desire for a single cartographic image of India.

NOTES

NB. This material is based upon work supported by the National Science Foundation under Grant No. SES 88-01781. The United States Government has certain rights in this material. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

1. For (almost) the full story, see my "Mapping and Empire; British Trigonometrical Surveys in India and the European Concept of Systematic Survey, "Ph.D. diss. (Geography), University of Wisconsin-Madison, Ausgust 1990. The best source on the surveys themselves, in the early nineteenth century, is the monumental and incomparable Reginald H.Phillimore, Historical Records of the Survey of India (Dehra Dun: Survey of India, 1945-58, 5 Vols).

2. India Office Records F/4/1017 27954, 23-25: Bengal Military Consultations 8 Sep 1826 § 157: Resident at Indore to Bombay Political Secretary, 25 Nov 1824. For contemporary knowledge of the region, see British Library Maps 52450 (23), Map of Central India, including Malwa and the adjoining Provinces, constructed by order of Major Gen. Sir J.Malcolm, GCB, from the routes of his division and the Surveys of officers under his command (London: Aaron Arrowsmith, 1823), in which the lands immediately on either bank of the river were well mapped, but the ridges were stylized and separated from the river by blank space.

3. India Office Records F/4/679 18861, 687-96: Bengal Public Consultations 15 Jan 1819 § 52: Colin Mackenzie to Bengal Public Secretary, 5 Jan 1819, § 3.

4. J.B Harley and Yolande O'Donoghue, "Introduction", in The Old Series Ordnance Survey Maps Of England and Wales .. (Lympne Castle: Harry Margary, 1975 - ,many Vols), 1:xi.

5. Phillimore, Historical Records 3:25: "the last deliberate peace-time survey to be based wholly on traverse and astronomical fixings" was Alexander Boileau's resurvey of the country between Agra and Allahabad in 1827-28.

6. Andrew S. Cook, "More by Accident than Design: The Development of Topographical Mapping in India in the Nineteenth Century, "Eleventh International Conference on the History of Cartography, Ottawa 1985.

7. India Office Records E/4/1023: Court Despatch (military) to Bombay, 7 Sep 1808, § 8-11. One lakh was for expenses, the other as a reward.

8. India Office Records F/4/682 18864, 267-71: Bengal Public Consultations 31 Aug 1821 § 4: Bombay to Bengal Public Secretaries, 26 Jul 1821.

9. India Office Records F/4/682 18864, 273-92: Bengal Public Consultations 28 Sep 1821 § 3: J.A. Hodgson to Bengal Public Secretary, 18 Sep 1821.

10. India Office Library X/2746: T.B.Jervis, "An Atlas Illustrative of a Geographical and Statistical Memoir of ... the Konkan",1934.

11. India Office Records E/4/679: Court Despatch (separate military) to Bengal, 3 Jun 1814, § 10.

12. India Office Records E/4/679: Court Despatch (separate military) to Bengal, 3 June 1814, § 19.

13. India Office Records X/345: J.A. Hodgson, "Atlas of the North-West of India...", in 15 sheets, 1823.

14. The two are bound together as India Office Records X/344/1 and /2, and as British Library Maps 146.e.6. Cambridge University Library has copies of the two with different provenances and bound separately: Atlas 1.82.1 and Maps 360.82.1.

15. Sheets 47,48,65 and 66 were compiled from John Hodgson's and William S.Webb's work in the Himalayas; sheets 69 and 70 were from James Franklin's survey of Bundelcund.

16. India Office Records F/4/679 18861, 385-41: Bengal Public Consultations 25 Nov 1817 111: Hasting's Military Secretary to Bengal Military Secretary, 25 Oct 1817, § 3.

17. British Library Additional MS 14377, ff.1-8: James Garling, "Soanda Survey: Introductory Observations Illustrative of the Map and Manner in which the Survey has been Made" ca.1815, ff.2v-3r.

18. The Court accordingly ordered John Walker to engrave a series of maps of the triangulation to date as the first stage of creating the Atlas of India: (Section of the Great Meridional Arc from Beder to Takhalkara), J.& C Walker sculpt. (London: Horsburgh, 1 Mar 1827); Sketch of the Principal Triangles extending over that part of the Nizam's Dominions laying to the eastward of Nirmal & Kurnool by Lieut.Col.W.Lambton and Capt.George Everest, J.& C Walker sculpt. (London: Horsburgh, 1 Mar 1827); Plan of the Trigonometrical

Operations in the Nizam's Dominions, Extending from Kurnool to the Godavery by Lieut. Col.Wm.Lambton, J.& C Walker sculpt (London : Horsburgh, 1 Mar 1827); Plan of the Trigonometrical Operations on the Peninsula of India from the Year 1802 to 1814 inclusive under the Superintendence of Lieut. Col. W.Lambton, J.& C Walker sculpt. (London: Horsburgh, 20 Jun 1827) in eight sheets. All these are in India Office Records X/Plas Newydd purchase; other copies of the last three are British Library Maps 52450 (25) and (26), and British Library Maps 52415 (25).

19. India Office Records E/4/729: Court Despatch (military) to Bengal, 25 Aug 1830, 2. India Office Records E/1/266 1244: Miscellaneous Correspondence: Court's Secretary to Everest, 27 May 1830. The institutions were the Royal Society, Royal Astronomical Society, Royal Asiatic Society, Geological Society (of London), and the British Museum.

20. India Office Records L/MIL/5/402 205, ff.358-406: George Everest, "Memoir regarding the Survey Establishment in India and particularly the Great Trigonometrical Survey", *ca.iii-27. Other copies are India Office Records F/4/1130 30211B* and *British* Library Additional MS 14380,ff.54v-67v (10-129 only).

21. India Office Records E/4/720: Court Despatch (revenue) to Bengal, 26 Sep 1827, 2-3.

22. University of Nottingham, Portland Papers, Pw Jf 2744/3: James Salmond, "Memorandum Respecting a General Survey of India", nd, but annotated as Aug 1827.

23. *University of Nottingham, Portland Papers, Pw Jf 2127: Anthony Troyer to Lord William Cavendish Bentinck, 26 Nov 1827.*

24. India Office Records E/4/732: Court Despatch (military) to Bengal, 20 Jul 1830, 11.

25. India Office Records E/4/736: Court Despatch (military) to Bengal, 16 Jan 1833, 2.

25. India Office Records E/4/149: Bengal Despatch (military) to the Court, 3 Apr 1835.

27. British Parliamentary Papers 1824 (445) 8: "Report of the Select Committee on the Best Mode .. to Provide a General Survey and Valuation of (Ireland)", 89-90, evidence given, 25 May 1824.

The mountain

What of the mountain? Despite all Everest's efforts for the Survey of India it is the mountain that perpetuates his name. Whilst observations had been taken to the peaks of the Himalayas at every opportunity over many years it was not until 1847 and 1849 that sights were taken to what became know as peak XV. Even then, it took some years to unravel all the intersecting rays to numerous unidentified peaks. It gradually became evident that peak XV was possibly higher than all the others and by March 1856 Andrew Waugh, the Surveyor General felt justified in promulgating the probable heights of the more important points. This he did in a letter to Major Thuillier in Calcutta. "...now have value for peak XV...we have for some years known that this mountain is higher than any hitherto measured in India and most probably it is the highest in the whole world.....I...append an attested statement on the geographical positions and elevations of....Mont Everest.... you are at liberty to make use of these results in anticipation of my forthcoming report..." He gave the mean value found from 7 stations as 29002 feet.

Major Thuillier announced the finding at the August 1856 meeting of the Asiatic Society of Bengal. He quoted further from Waugh's letter to the effect "...that it was his (Waugh's) rule and practice to assign to every geographical object its true local or native appellation, but here was a mountain most probably the highest in the world without any local name that he could discover; whose native appellation if it has any, would not very likely be ascertained before we are allowed to penetrate Nepal...consequently....to perpertuate the memory of that illustrious master of geographical research...Mont Everest".

Before long this became Mount Everest but even so it provoked much discussion even to this day. Various authorities put forward what they considered to be local names including Tchoma Lungma, Devadhunga, Gaurisankar, Chomo Kankar and Chomo Uri. None of the claimants have been able to prove conclusively that the peak in question had a particular local name in the 1850s. One particularly vigorous complainant around the turn of the century was D W Freshfield, Secretary to the RGS but since the name Everest still resides in English speaking atlases it is felt that nothing will now change.

The the height of it has also met with controversy. The original observations to the peak were over distances greater than 100 miles from stations in the plains of northern India at only a few hundred feet altitude. Not until around 1950 was Nepal opened to allow Indian surveyors to observe from ranges in the vicinity of 50 miles from stations at elevations from 8000 to 15000 feet. This resulted in a value of 29028 feet and is the value often found in modern atlases.

It must be remembered however that there are major problems in such observations not just because of the effects of refraction - which could amount to 800 or even 1000 feet, but also to be able to define just what it is that one is measuring. The separation of the geoid from the reference surface could be 100 feet or so. De Graaff Hunter in 1953 likened it to trying to measure the Eiffel Tower and having to decide what constitutes the bottom - the legs, the foundations, or the internal installations.

THE ACHIEVEMENTS OF SIR GEORGE EVEREST IN GEODESY

Alan Cook, Selwyn College, Cambridge

1. INTRODUCTION

The geodetic survey of India was begun by Col.Lambton, whose assistant Everest became, at a time when the earliest measurement of a meridional arc in Europe, that from Spain through France to the north of Scotland, had just been completed (Delambre and Méchain, 1821-1845). Geodetic survey is the determination of the coordinates of selected points on the surface of the Earth so that maps may be based on them. Nowadays the Cartesian coordinates of any point may be found by reference to the orbits of artificial satellites, as in the Global Position System, but of course in Everest's day that was far in the future. The surface of the Earth, although irregular, is close to a spheroid of revolution, as Newton shewed theoretically that it should be. To map the surface of the Earth onto a plane sheet of paper, the shape of the actual surface of the Earth has to be known, or, more realistically, the shape of the spheroidal surface that is closest to the actual surface. Geodetic survey must therefore be carried out in such a way as to determine the form of the surface. Geodesy is not however just a matter of geometry. The spheroidal shape of the Earth is a consequence of the distribution of density within the Earth together with the rate at which the Earth rotates upon its polar axis, and is an important datum for studying the physical state and composition of the interior. The deviations from a simple spheroidal shape likewise depend on the distribution of density, but much nearer the surface and quite closely related to the structure of oceans and mountains. Because the value of gravity at the surface depends on the distribution of density within it, measurements of gravity contribute to the estimation of the shape of the surface and to elucidating the causes of the deviations from a spheroidal form.

A geodetic survey is never independent of the value of gravity over the surface. The form of the surface is found from the relation between distance over the surface as measured by triangulation, and the angular coordinates of points on the surface. The only angular coordinates directly open to observation are those of normals to the surface and if the surface of the Earth were an exact spheroid of revolution, then the radius of curvature, the relation between distance s over the surface and latitude ϕ would be:

$$\frac{ds}{d\phi} = \frac{a(1-e^2)}{(1-e^2\sin^2\phi)^{3/2}}$$

where a is the major semi-axis of the spheroid and e is the eccentricity.

The surface of the Earth is not an exact spheroid and the angles that are observed are those of the directions of the attraction of gravity, that is, normals to the equipotential surface of the gravitational potential through the points of observation. The geodesist determines a spheroid that best fits the observed directions: apart from uncertainties of the actual observations, the differences between observed and calculated angles arise from departures of density within the Earth from a uniform variation with radius.

Newton shewed in the Principia that the surface of a spinning Earth should be an oblate spheroid of revolution and he shewed also that the value of gravity over it should increase from the equator to the poles. When he published the Principia in 1687 there were no survey observations adequate to establish the geometrical form of the Earth, but there were a few observations of gravity (including those of Edmond Halley in St Helena) that agreed with Newton's prediction. Later survey measurements appeared to shew that the Earth had a prolate form, the view of J-D Cassini, but then the French expeditions to Lapland and Peru clearly established the oblate form and in the words of Voltaire, "flattened the Earth and the Cassinis". French academicians went on to survey an arc of the meridian running through France; their work continued even during the Revolution and was extended to the south of Spain and northwards through Great Britain (Delambre and Mechain, 1821-1845). It was supplemented by gravity measurements at a number of principal stations by Arago and Biot in France and Spain, and by Henry Kater in Britain. Those campaigns were essentially completed by about 1820.

The rate of change of the radius of curvature with respect to latitude is zero at the poles and the equator and is greatest in mid-latitudes. Europe is therefore well situated for a determination of the elipticity of the meridian from observations within Europe. At the same time the span of the arc from Spain to Britain is 22 deg which is about one quarter of the whole quadrant of the meridian. A much better determination of the size and eccentricity of the Earth would be obtained if the European results could be combined with those from lower latitudes.

When Col Lambton began the survey of India in 1800 the British and French surveys were the only ones of good accuracy. They owed much to the instrumental developments of Ramsden, whose theodolite was the first that was sufficiently accurate to detect the spherical excess of triangles. Considerable attention was also given to the measurement of base lines and those surveys were the models for the Indian project. By the time Everest had carried the triangulation up to the Himalaya, the results of Struve's survey of an arc of the meridian in the west of Russia were available, so that Everest was able to combine the Indian results with those of two long arcs in much higher latitudes to determine the size and flattening of the Earth.

The Indian surveyors were at a disadvantage compared to their European colleagues in two respects. In the first place, no measurements of gravity were made in India until the work of Basevi and Heaviside fifty or more years after Biot and Kater (Everest took a pendulum out to India but there are no records of its having been used at stations of the Arc).

The second matter relates to the deviations of the true vertical, the actual direction of gravity, from the normal to the best fitting spheroid. The measured astronomical latitude, longitude and azimuth determine the direction of the actual vertical relative to the polar axis of the Earth and the Greenwich meridian. Differences of the angles between normals to an adopted spheroid may be calculated from the elements of the spheroid and the measured distance between the points over its surface. The differences between true directions and calculated directions are connected by a geometrical relation due to Laplace, and points at which astronomical latitude, longitude and azimuth are all observed and compared with the geodetic values derived from the survey are called Laplace points. They are valuable for checking errors of direction that may accumulate in a set of triangles, just as measurements of base lines check the accumulation of errors of scale. However, the measurement of astronomical longitude was difficult prior to the use of the electric telegraph and so there were no Laplace points in the first Indian arc.

2. EVEREST'S ACHIEVEMENTS.

Everest began his geodetic work in India as assistant to Lambton but had to return to England to recuperate on account of ill-health. It seems clear that he intended to return to India and resume the geodetic survey for while in England he arranged for the Indian 10ft standard bar to be compared with the standards of the Ordnance Survey and the Tower of London, as was in fact done after his return to India (Clarke, 1866). He studied the methods and apparatus employed by Colby in Ireland, and he wrote on errors of pendulum observations (Everest 1829). He took over the responsibility for the geodetic survey when he returned to India after Lambton's death; he held in addition the post of Surveyor General. It is clear from his account of his work that he found both staff and methods in poor shape and that he revised the procedures and obtained better equipment in order, as he says, to work to the same standards as the best European practice. He must also have attended carefully to the recruitment and training of his immediate assistants, for while he was clearly dissatisfied with those he found when he returned to India, he was confident enough in his last years to delegate responsibility for substantial independent operations.

Lambton had begun his measurements of the Indian arc in the south in latitude 8deg 9min at Punnae and carried them as far north as 20deg 30min. Everest took them to Kaliana in latitude 29deg 30min, having in the meantime surveyed a parallel eastward to Calcutta. It is ironic that the meridional arc, to which he devoted so much attention and effort, was eventually found to be too disturbed by the attraction of the Himalaya and otherwise, for it to be included in a general world-wide adjustment, whereas the observations on the parallel, somewhat subsidiary in his programme, have proved their value (see Section 3).

Everest suffered from ill health on a number of occasions and on the first of those he was sent to the Cape Colony to recuperate. While there he re-examined the survey of de la Caille which appeared discrepant with surveys elsewhere and concluded that the attraction of Table Mountain had disturbed measurements of latitude nearby (Everest 1822). He later made similar calculations in India to attempt to account for anomalies in the Indian survey. His initial measurement of the arc between Damargida (18deg 3min) and Kalianpu (24eg 7min), with a central astronomical station and base at Takal Khera, appeared to show that the radius of curvature of the meridian in the northern section was less, not greater, than that of the southern section. Everest calculated the attraction of a table-land to the north of Takal Khera and shewed that it could account for the anomaly.

The survey of the Damargida-Kalianpur arc was however as a whole unsatisfactory, with relatively large errors in the sums of the angles of triangles, and Everest therefore repeated it with better instruments, including Colby's compensating bars for base-line measurements. He then extended the arc northward to Kapianpur at 29deg 31min and did not go further because he considered that the disturbance of the Himalayan mountains would be too great.

Everest subsequently repeated some of Lambton's survey to the south and set up new stations where Lambton's could no longer be found. He paid careful attention to the measurement of bases. Astronomical latitudes and longitudes were observed throughout the arc of the meridian, especially at Kalianpur (24deg 7min) where many observations were made.

When he came to publish his final report on the Indian arc, Everest had available the results of a number of other surveys, namely that from Spain through France to Scotland, the arc measured by Struve in western Russian, and the short arc in Peru. He seems to have been the first to drive a figure for the Earth by combining the results of surveys in different parts of the world, as distinct from calculating the radius of curvature in a given latitude from a single survey, so setting the pattern for all future investigations of the size and shape of the Earth. He combined the results by a method that falls short of true least squares, and indeed introduces internal correlations, and obtained the following results (Everest 1847):

Equatorial semi-axis:	3 486 817.08 fm	= 20 920 902.48 ft
		= 6376 691 m,
Polar semi-axis:	3 475 607.00 fm	= 20 853 642.0 ft
		= 6356 190 m

The polar flattening is then 1/311.0

Those elements were used for some years for the reduction of Indian surveys and for map projections.

3. THE INFLUENCE OF EVEREST'S WORK

As was pointed out in the Introduction, the Indian arc is important because it lies in much lower latitudes than those of Europe and when combined with them should have enabled much better values for the elements of the figure of the Earth to have been obtained than from any of them separately. The care with which the operations were carried out also seems to have been a model for subsequent work. Everest's own values for the elements of the figure of the Earth are however very different from modern values and indeed from contemporary estimates, and the reasons for that are now considered.

The first reason is that the standard of length for Lambton's southern arc was in error. Only after Everest had sent the Indian standard (B) to the Ordnance Survey Office for comparisons in 1830 was the value of that standard well established, the data for an earlier comparison having been deficient (Everest 1847). In consequence, only the northern section of the whole Indian arc, that for which Everest was entirely responsible, was securely based upon the Ordnance Survey standard. In the course of the extension of the geodetic surveys in India by Everest's successors, the southern section of the arc was revised and referred to the Ordnance Survey standard. In 1866 Clarke published the results of comparisons of the standards of length of countries with major geodetic surveys and also the results of an analysis of all the important data for the figure of the Earth.

Clarke (1880) gives the following values for the equatorial and polar axes, in feet of the British standard yard; Everest's values are those already given.

	Clarke	Everest	Difference
Equatorial axis	2092 6202	2092 0902	5300
Polar axis	2085 4895	2085 3642	1253
Polar flattening	1/293.5	1/311.0	

The second reason for the discrepancy between Clarke's results and those of Everest is that, as Clarke points out, the Indian arc, being in low latitudes, has a strong influence on the estimation of the polar axis but a relatively weak one upon the estimation of the equatorial axis; the radius of curvature of meridian at the equator is $c(1-e^2)^{1/2}$, whereas at the poles it is $a/(1-e^2)$[illegible] .

Later analyses of more recent observations (Jeffreys 1948) have given yet different elements. Jeffreys in fact rejected the data from the Indian meridian because he considered that the uncertainties of the attractions by the Himalayas were too great; his final result was

equatorial semi-axis:	6378 100km,
polar flattening:	1/297.10

Clarke's value of the equatorial semi-axis corresponds to 6378.306km and Everest's to 6376.691km.

The values for the polar axis, the one best determined from the Indian arc, are

Everest:	6356 190 km
Clarke:	6356 572 km
Jeffreys:	6356 632 km

Everest's value for the polar axis is indeed much closer to later estimates than is his value for the equatorial axis, but it is clear that the effective radius of curvature over the Indian meridian is too small.

In the years since Jeffrey's study, triangulation has been superseded or supplemented by direct measurements of length by electromagnetic means and surveys have been adjusted taking into account the effects of variation of the gravitational potential. Most recently, observations to artificial spacecraft have been added. The consequence has been that the following values were derived in 1963 (Cook, 1965) using radar data for the distance of the Moon but not satellite results:

equatorial radius:	6378.144 km
polar flattening:	1/298.26

the latest values, with results from ranging to space craft are

equatorial radius:	6378.137 km
polar flattening:	1/298.257
	(Marsh and others 1989)

The corresponding polar radius is 6356.752 km.

One reason for the lower values that Everest found for the equatorial and polar radii is that the radius of curvature over India is less than the average spheroidal value. Satellite results show that the geoid is depressed by about 80m over most of the sub-continent (Marsh and others 1989) but that does not entirely account for the difference between the Indian survey and others.

Although the Indian meridional survey is now seen to depart appreciably from the mean spheroid Everest's work had a great influence on geodesy by calling attention to the importance of combining surveys made in different places, and especially over different ranges of latitude, if properly representative values of the parameters of the figure of the Earth were to be estimated.

Everest's work was very influential for another reason. The discrepancies between geodetic and astronomical angels in the Indian surveys are not great, implying that the gravitational equipotential surfaces in India are close to those of a common spheroid. Everest had earlier, in 1822, studied the triangulation of de la Caille in Cape Province in south Africa (Everest 1822) and had found that an anomalous result could be accounted for by the attraction of Table Mountain. He consequently expected that the Indian deflexions would be larger, especially in the south where the deficit of mass in the southern seas might have given a deflexion of the vertical to the south; and close to the Himalaya where the attraction of the mountains might again have deflected the vertical to the south. The deflexions at those extremities were in fact little more that 3 sec.

The explanation for the small deflexions was provided by Archdeacon Pratt of Calcutta who shewed that if the average density of material beneath the Himalayan mountains was less than that below the Indo-Gangetic plain, the net deflexion of the vertical would indeed be quite small. That was the first indication of the principle of isostasy whereby extra mass above sea level, as in high mountains, is compensated by a corresponding deficit below sea level. Similarly, the lower mass of the water of the oceans is compensated by extra mass below them. Sir George Airy devised a somewhat different scheme of compensation from that proposed by Pratt and later observations of gravity in India and survey operations in the mountainous regions of the United States amply confirmed the prevalence of isostatic balance. Gravity measurements at sea in the last half of this decade have shewn that over very large areas of the the Earth, isostatic balance is maintained to within about twenty parts in a million of the attraction of gravity, or about one part in twenty of the difference of attraction between oceans and continents. Isostatic balance is one of the most important features of the structure of the outermost parts of the Earth and the ways in which it comes about, not yet fully understood, are closely related to tectonic processes in general. Everest's surveys were the first to bring out clearly the existence of isostasy, for the European surveys covered ground with comparatively minor tectonic features which would not in any case cause great deflexions of the vertical.

4. CONCLUSION

Everest's work in India was seen at the time, and has been recognised ever since, as major advance in geodesy, both in applying the most precise methods and apparatus of the day outside Europe and by recognising the world-wide scope of geodesy through his combination of results from a number of meridional arcs. The Royal Astronomical Society awarded him a testimonial, equivalent to the Gold Medal of the Society, and in presenting it, the President of the Society, Sir John Herschel, said

> "The Great Meridional Arc of India is a trophy of which any nation, or any Government of the world, have reason to be proud, and will be one of the most enduring monuments to their power and enlighten regard for the progress of human knowledge."

So it has proved to be.

REFERENCES

Delambre and Mechain, 1821-1845, Base du Systeme métrique. 4 vols. (Paris)

Clarke, A R, 1866 Comparison of the Standards of Length of England, France, Belgium, Prussia, Russia, India and Australia. (London, HMSO)

Clarke, A R, 1880 Geodesy (Oxford: Clarendon press)

Cook, A H, 1965 Geodetic Constants and the Motion of the Moon. Bull. Astronom. Obs. Paris, **25**, 33-65

Everest, G, 1822 The Triangulation of the Cape of Good Hope. Mem. Roy. Astronom. Soc, **1**, 255-270

Everest, G, 1829 Remarks on Errors likely to arise in the determination of the length of the Pendulum from the false position of the fixed axis. Mem.Roy. Astronom. Soc. **4**, 25-38

Everest, G. (1847) An Account of the measurement of two sections of the Meridional Arc of India (London: W H Allen)

Jeffreys, H, 1948, The figures of the Earth and Moon. Mon. Not. Roy.Astronom. Soc. Geophys. Suppl. 5, 219-47

Marsh,J G, Lerch, F J, Putney,B H, Felsentreger,T L, Sanchez,B V,Klosko, S M, Patel, G B, Robbins,J W, WIlliamson,R G, Engelis, T E, Eddy, W F,Chandler,N L, Chinn, D S, Kapoor,S, Rachlin,K E, Braatz,L E,Pavlis, E C, 1989, The GEM-TL Gravitational Model. NASA Tech. Mem. 100746