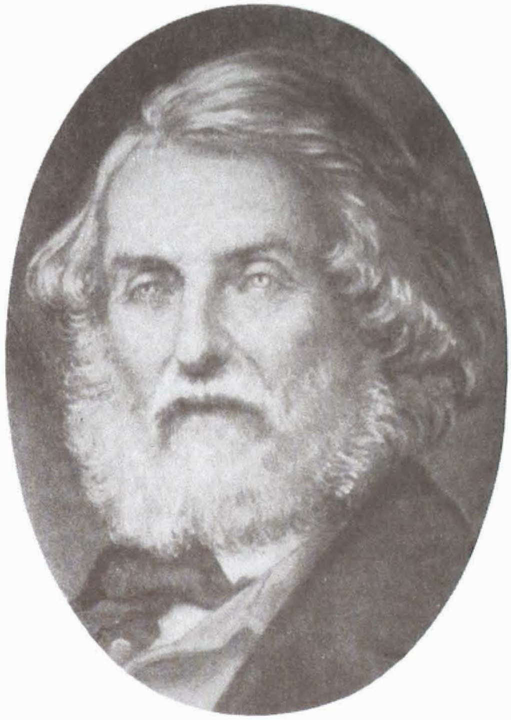

Colonel Sir George Everest CB FRS

Proceedings of Bicentenary Conference at the Royal Geographical Society

8th November 1990

R·I·C·S

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

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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

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.

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 <u>map</u> 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 <u>Improved Map of India</u> 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 <u>par excellence</u>, 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 <u>A Bengal Atlas</u>.(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 <u>Atlas of South India</u> and a single-sheet <u>Sketch of the Outline and Principal Rivers of India</u>.(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 <u>Atlas of India</u>, 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

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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.

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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).

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COL. SIR GEORGE EVEREST, CB, FRS

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Early life

The ancestors of George Everest (pronounced Eve-rest) can be traced back to a marriage in 1682 of his great great grandfather Tristram Everest to Anne Fisher, both of whom were from Greenwich. Both he and his son, of the same name, were butchers but by the next generation John Everest is recorded as an Attorney in Greenwich and in his will of 1769 described as John Everest, Gentleman.

The father of George Everest, another Tristram, was a solicitor with addresses in Greenwich and Crickhowell in Co. Brecon. Born in 1747, he married Lucetta Mary Smith on 2 August 1786. One of a family of 10, Tristram had 6 children of his own of whom George was the third. Of these, two graduated at Oxford and one at Cambridge but George had none of this Oxbridge background.

Where George was born on 4 July 1790 is open to some doubt. Some reference works suggest Gwernvale House near Crickhowell, but it is more likely to have been Greenwich, where he was certainly baptised some six months later. In August 1804 George was nominated as a Gentleman Cadet and joined the Royal Military Academy at Woolwich on 30 March 1805 after a preliminary spell at the R M C Marlow. Courses were not of great length and he left the Academy on 31 November 1805 with a recommendation to the East India Company. On 4 April 1806 he was gazetted as a Lieutenant in the Bengal Artillery and on 11 July, the same year, aged 16, he arrived in India.

India 1806-1820

Little is recorded of his early years there other than that he was at the siege of Kalinjar in 1812. It is known however that from about 1813 he served some time in Java and part of this was in a survey capacity. It was in 1811 that Java - then a Dutch territory - had been overrun by the French and this did not please the East India Company because of its nearness to their interests. To redress this a large force of mostly Madras troops captured Batavia in August 1811.

Sir Stamford Raffles was Lieutenant Governor at that time and in 1814 he selected Everest, because of his mathematical and scientific background, to map the island, and particularly the coast and mountains, prior to its return to the Dutch - which took place in 1816. The return came earlier than perhaps was expected so that Everest was rushed into a rapid survey of the strategic sites before the country was evacuated. For his work in Java Everest had a double armed perambulator, a large ship's compass, a theodolite and a micrometrical telescope.

On 28 September 1816 Everest was embarking at Batavia in the Lady Barlow for his return to Calcutta via Malacca, but not before he experienced his first bout of fever. As yet he was not full time on survey and his next posting was to devise methods of clearing obstructions to navigation in the rivers Ichamati and Matabhanga which connect the rivers Ganges and Hoogly.

Although his methods could not give a permanent cure because of the nature of the problem, they were 100% successful when applied. The ingenuity employed on this by Everest brought him to the notice of the Government in India and subsequently to Col.Lambton.

By Order of 21 October 1817 he was detailed to survey the tower positions for a telegraph line over the 400 miles from Calcutta to Chumar near Benares. Intervals between towers were to be as long as possible consistent with an endeavour to have a 30 feet clearance for intervisibilty, but these were limited both by the terrain and the low power of the telescopes at their command. Despite this, in the forested areas they reached some 9 miles and where it was clearer, 13 miles. On occasions, to achieve this necessitated towers of 70 feet. Measured distances were not so critical and could be obtained by perabulator or by observing the angles contained between the telegraph and conspicuous points.

Within a few days of the Order regarding the telegraph line, Everest was appointed by the Marquis of Hastings as Chief Assistant to the Trigonometrical Survey of India although he completed the prior task before moving to Hyderabad.

By October 1918 Everest was able to leave Chunar to join Lambton at Hyderabad and embark upon the work that took him the rest of his working life to complete. In 1799 Col.William Lambton, following earlier ideas of William Roy, had put forward the suggestion of a "Mathematical and Geographical Survey" right across the peninsula, as a foundation for a general survey of the whole country. Government approval was given in February 1800 and thus was born, but not in name until 1818, the Great Trigonometrical Survey (GTS) of India. By September 1800 Lambton had left Calcutta to measure the first baseline near Bangalore.

His particular aim was the observation of a meridian arc through the centre of India from Cape Cormorin - at the southern tip of the country - to the Himalayas, some 22 degrees in extent more or less up the 78th meridian. This would be a length far in excess of any previous arc measure.
On his 10 week trek from Chumar to Hyderabad Everest voluntarily made a route survey as he went but the plotting of this did not materialise until 1840.

By the time Everest joined him Lambton was around 65 years old - give or take a few years as his date of birth is uncertain. Realising that a younger man would be needed to complete the arc measurement he was ready to let a successor phase himself in.

Early in 1819 Everest was given field instruction by Lambton, and no doubt had his techniques critically appraised at the same time by the man he was later to succeed. His initial observations were at three of the arc stations near Bidar, 70 miles N W of Hyderabad but by April 1819 he had started on the triangulation from the Ceded Districts to the river Goodavery. Starting in the deep end would be an understatement. There were thick forest, swollen rivers and all the ingredients of malaria. Forests of 90 feet high teak trees, thick undergrowth, infested with tigers, boa constrictors, without water or provisions, and jungle fever everywhere imminent. Within four months he and 150 of his men had fever and retreated to Hyderabad, but 15 succumbed on the journey.

Not to be beaten, Everest went out again the following June to complete the interrupted triangulation but was once more struck down. This time it was deemed that he must have sick leave to recuperate and for this he sailed to the Cape of Good Hope on 1 October 1820.

The Cape. 1820-1821

With the journies - 7 weeks each way - he was away just over a year but had instructions from Lambton to put at least some of that period to good use. In 1752 l'abbé LaCaille had observed a meridian arc near Cape Town but his results contradicted the theories of Newton and supported the prolate theory for the figure of the Earth originally propounded by the Cassinis. By then however other measures in Peru and Lapland had confirmed Newton's thoughts so what was wrong with LaCaille's work? His reputation as a good observer was second to none so there must be another explanation. It was not until June 1821 that Everest was able to acquire a copy of LaCaille's Journal from England. It is not known what Everest did in the intervening six months but he is unlikely to have been idle. After study of the sites used for the triangulation stations, and in particular the terminal ones where astronomical observations were made, Everest concluded that the effect of deviation of the plumb line was the likely cause of the apparent discrepancy. The result of this conclusion was a complete remeasure and extension of the arc by Thomas Maclear starting in 1840.

India 1821-1825

By the end of 1821 Everest was back in India and started on the 760 mile trek from Madras to meet up with Lambton at Takal K'hera, which he did in 13 days march. Only to find that the news of his coming had not reached Lambton and just two days before his arrival the equipment had been packed away. With insufficient supplies a further 360 mile trek was then required back to Hyderabad. An unfortunate restart to his labours on the Arc, Everest then set out on a westward chain at about 18ºN that went towards Poona and Bombay.

Here the terrain and climatic conditions were more amenable - no jungle, no mosquitos, no bandits, and generally more acceptable open terrain. However for triangulation purposes the isolated hills were of insufficient height to give long sight lines and he had to resort to towers. Refraction was a particular problem he had to get to grips with. On numerous occasions targets appeared at night that were invisible by day and on one occasion he recorded the upward 'movement' of a target from a depression of 7 1/2' to finally only 3'.

This phenomena hastened the change from using flags as daytime targets to the use of lamps by night. Whereas Lambton had always done his observing by daylight in the worst season of the year from the point of view of weather, Everest was now able to observe in the better seasons. The type of lamp required was the reverberatory sort but this was not obtainable within India. A local version - the vase light - consisted of a six inch diameter cup, filled with cotton seed that was steeped in oil and resin. This was put under a large inverted earthenware vessel that had an aperture in the side. When lighted it could be used, in good conditions, to over 30 mile range. Other forms included the cylindrical blue lights consisting of paper, cotton cloth, sheep's bladder and a concoction of chemicals. The

range could be 50 or more miles. Each weighed some 3 pounds and 22 were needed at each station. The capacity for a camel was 160 such lights.
Everest had only completed around half of the Bombay Longitudinal Series when news reached him on 3rd February that Col. Lambton had died on 20 January 1823 at Hinganghat. He immediately took it upon himself to cease work, return to Hyderabad, and assume control of the Great Trigonometrical Survey although he was not officially confirmed in the post until 7 March.
At this time the idea of continuing the Great Trigonometrical Survey was re-appraised by the East India Company. On this occasion it was championed by the Surveyor General elect, Valentine Blacker. Later, in 1827, N B Edmonstone of India House, sent a long memo to the East India company outlining the advantages of the work, its importance to science and the need to see it to completion.

> "Surely it is no more than becoming the character, the situation and dignity of the Court of Directors to show to the world that they duly appreciate the magnitude and importance of these objects of Science and are disposed to afford to the prosecution of them their liberal patronage and support unclogged by a strict adherence to Official Rules and Form when they interfere with that which ought to be the sole object in view, the successful prosecution of this great <u>National</u> undertaking". "This Arc...<u>will be the grandest monument of practical Science that has ever been or ever can be exhibited in any age or nation."</u>

Everest resolved to continue where Lambton had finished and was hoping to be back in the field by October but fever overtook him yet again in August 1823. Among the cures was one involving the taking of mercury pills and to go riding regularly. This was all very well until on one such ride he was caught in a very heavy storm and was soaked through. His pains became even more violent and with the fever he was wracked with aching bones and convulsions for six months. It caused him great discomfort.

But the surveyors of that time were made of stern stuff and as soon as he could bear the motion of his palanquin he set off for the field again. Neither fever nor agonising pain were going to prevent him completing the Great Arc. So much so that when it came to using the zenith sector for his astronomical observations at Takarkhera he had to be raised and lowered into position. Then at the large theodolite his arm had to be supported in order to manipulate the vertical circle. Much of the time he could not stand unaided.

It might be asked why he did not get others to do the observing but he just did not have staff upon whom he could rely. Repeatedly it is recorded that he carried out every aspect of a project himself, not leaving anything for others. He was very much a stickler for accuracy and for always following the stipulated routine in observing. Woe betide those who digressed at all - his letters were very sharp and to the point.

> "I suppose you are still directing it (the light) to Bahin, but you might as well turn it to the moon".

> "You are certainly most irregular. Who but a half-crazy person, would have chosen a time when it was blowing great guns to burn his lights in utter defiance of my orders, and you certainly did this..."

"Be pleased...instead of wasting time in committing your impertinence to paper, to employ your whole energies in endeavouring to put the instruments into working order....."

After carrying the chain over the Gawilgarth Hills he reached 23 1/2° north by May 1824. Then yet again he was stricken with fever and confined to bed for more unpleasant treatments. He had an abcess on his neck, another on his hip, from both of which fragments of decayed bone had been repeatedly extracted. He also refers to sundry incisions and other surgical operations of an unpleasant kind. With repeated relapses he was so dangerously ill that he applied for leave in England.

He struggled on for a further six months until November 1824 when the triangulation reached Sironj and he measured another baseline of about 38410 feet with a steel chain supported on coffers. The chains had been calibrated against Cary's 3 foot brass scale, which in itself was a major exercise. Everest constructed a 120 feet long polished stone surface supported on 15 pillars each 3 feet high and having brass marks set in it. He personally did everything connected with the measurement from supervising the driving of every peg to keeping watch over the ten thermometers. He would tolerate no inferiority in execution and if there was any reason to suspect a defect or imprecision of any sort that could not be accounted for the whole was rejected and an entirely new set of observations taken. This applied whether it was astronomical observations, baselines, or triangulation.

By the time he had completed the astronomical observations at Kalianpur he finally succumbed once again and had to take leave in England. He sailed on 11 November 1825 and it was to be five years before he returned.

England 1825-1830

To Everest sick leave did not mean putting your feet up and taking it easy. Much of the time was spent studying improvements that could be made to the various instrumentation and superintending the construction of new instruments founded on the latest developments. He was determined that India should have the best available and persuaded the East India Company accordingly, aided and abetted by the letter from Edmonstone mentioned earlier.

Prior to leaving India the best instrument had been the great theodolite with a 36 inch circle but that had been damaged twice and was in need of replacement. What the damage had introduced however was the idea, first practiced by Lambton, of reading angles on many zeros to overcome variation in the circle division. Everest continued this idea but nevertheless obtained an aditional large instrument of similar diameter by Troughton and many smaller theodolites.

What he was particularly interested in studying while on leave was the new idea put forward by Col.Colby of the Irish Survey, for measuring baselines with compensating bars. At the time Colby was measuring a base in Ireland and Everest visited him there in 1829 and made a special study of the system. He reported very favourably on the method and the means of carrying it out and was able to obtain a set of bars to take back to India with him. The Lough Foyle base measured by Colby with his bars was remeasured in 1960 with a Tellurometer, with a difference of only one inch in 41641 ft.

It is known that during 1829 Everest visited Rome and possibly other European centres but there are no details. In addition to his efforts to acquire new equipment Everest also took an active part in the scientific life of London. On 9 February 1827 he was elected to the Council of Astronomical Society and on 8 March of the same year became a fellow of the Royal Society. Among his sponsors were Henry Kater, Francis Baily, F J W Herschel and Henry Foster.

His pen was also not idle during the five years. He compiled *An Account of the measurement of an arc of the meridian between the parallels of 18°03' amd 24°07'* which was published in 1830. Besides containing all the observations and calculations for the arc to that time it also had the dirivation of his first set of parameters for the figure of the earth. These were a = 20922931.80 ft b = 20853374.58 ft and e = 1/300.80. They were based upon the arcs Punnae to Kalianpur and Formentera to Greenwich.

On 12 August 1829 Everest was informed that he had been nominated as Surveyor General of India in addition to his existing post as Superintendent of the GTS. Whilst this was obviously a great honour it did put a considerable extra strain on his time for field work. While his primary interest was the Great Arc he now had the added problems of controlling work on the revenue and general mapping surveys.

India 1830-1843

On 30 October 1830 he arrived back in Calcutta on board the Cornwall. It must have been extremely frustrating for him to have to spend the first year after his return pushing the paper of administration around rather than being out in the field. However by November 1831 he was in a position to measure the first baseline in India with the Colby compensating bars. It was on the Barrackpore road at Calcutta and took about 45 working days to cover the 33959.9174 feet.

Work on the Great Arc was then able to restart after a break of 7 years and another 9 were to elapse before its completion with the Bedar base in 1841.

Survey headquarters were in Calcutta but this was most inconvenient for work on the Arc since at its nearest point it was some 600 miles away. Thus it was that Everest arranged to move his office to a more convenient location. On Christmas Eve 1832 he left Calcutta and aimed northwest towards Upper India. His first target was to visit those already engaged on extending the Arc and then he headed towards the Himalayas. Since this was to be the future route of the Arc he noted all of interest on the way such as possible station and baseline sites. His choice of location for his headquarters was near Mussoorie which he reached in May 1833. He purchased the Park House Estate near the peak of Hathipaon with the idea of using it as both office and residence.

However such a suggestion came unstuck as it contravened existing rules and regulations. Whilst he was allowed to keep his residence there he was obliged to move the office elsewhere and this he established a few miles away in Dehra Dun - where it has remained to this day.

The Estate was of considerable extent although different references give conflicting areas. It was in a well wooded area at over 6000 feet elevation. Besides the main house there was the Bachelor's Hall - built in 1833, Logarithmic Lodge - built in 1835 and an Observatory built in 1839.

The area around Dehra Dun lent itself to a baseline site and after much reconnaissance Everest found a suitable location and in 1834-5 it was measured with the compensating bars as 39183.783 feet. 177 comparisions were made between the compensating bars and the standard bar to ensure as reliable a result as possible.

The country around this baseline site was plentifully supplied with tigers and very long grass so that transport was essentially by elephant. When he again moved south to Muttra to carry on the triangulation it must have been an impressive sight to see his cavalcade of 4 elephants, 42 camels, 30 horses and about 700 followers.

The problem now was to connect the bases of Seronj and Dehra Dun by triangles but this was across the smoke filled Jumna Plain where there was no hill in sight. Scaffolding masts became an essential element and he required 13 of these at over 70 feet high. Such structures were not known to his men so he found it once again necessary to supervise every aspect of the work since "....at that time there was no person at my disposal to whom I could depute any portion of the work..."

It was at this time that he developed what was called the ray tracing method of locating stations. This was a form of perambulator and theodolite traverse that proved to be far more rapid than minor triangulation and just as effective. Mention should also be made of his introduction of the grid iron system of triangulation coverage which is such a distinctive feature of a map of the Indian network.

From May to October 1835 he was again laid low with serious illness and for much of this time was confined to bed and on the verge of death. It is recorded that on one occasion he was bled to fainting by 1000 leeches, suffered 30 or 40 cupping glasses and numerous doses of nauseating medicine. Of the four attacks he had each was worse than the previous one and they caused alarm in the East India Company since there was no appointed deputy.

The country through which the arc was going now warranted 14 masonry towers, mostly 50 feet high and with foundations as deep as 20 feet. Portable cranes were required to hoist the theodolites to the top. By the end of May 1836 half the gap between the Seronj and Dehra Dun bases had been filled and the remainder was completed the following season.

Astronomical observations were then required at Kaliana but he soon discovered that his instruments were faulty. The astronomical circles were top heavy and unstable and it took until October 1839 to complete the modifications. This was partly due to the inadequate service given by Barrow, the Mathematical Instrument Maker from Calcutta, that led Everest to transfer the task to his Indian assistant Mohsin Hussain but under his own direct supervision.

In the interim the Seronj base was remeasured by Waugh as about 38413 feet. Everest himself was again struck down with fever that nearly proved his end but which also led to an unpleasant exchange of correspondence. The East India Company became further alarmed at the continuing severe bouts of fever that hit Everest and decided to make the provisional appointment of a successor. Thomas Jervis was the chosen candidate but the appointment was conditional on either the resignation or premature death of Everest.

Now on the one hand, Everest had not been consulted and Jervis would never have even reached his shortlist. Then on the other hand Jervis knowingly or otherwise, misinterpreted the conditions and considered himself as already in the post. This he used when presenting a paper to the British Association and his ideas contained in that paper were endorsed by many eminent scientists. Everest was so furious that there was a long and biting series of letters to the Duke of Sussex as President of the Royal Society. These were all subsequently published in book form in 1839.

The outcome was in Everest's favour because not only did he survive to see the completion of the Arc but Jervis retired from India before Everest and so did not get the coveted post. This was to go to Alexander Waugh whom Everest considered to be a most able man.

It was Waugh, who assisted in the 1839, 1840 exercises of trying to obtain simultaneous astronomical observations initially between Kaliana and Kalianpur and then between Kalianpur and Bidar. Waugh it was who fitted the last piece to the jigsaw of the Arc by reobserving the Bidar base in 1841. Although it was some 425 miles and 85 triangles from Seronj the agreement between the observed and computed length of the Bidar base came out to be only 4.3 inches or 0.36 feet in a line length of 41578 feet.

By the 1840s Everest saw much of India covered by triangulation but of even more importance to him as a personal triumph was the completion, against all odds, of the measurement of a meridian arc of over 20° extent. It took two further years to write up all the reports, complete the computations and lay safeguards for the future of the Survey of India before he retired on 16 December 1843.

Retirement

He had sold his Park estate in September of that year prior to trekking down to Calcutta and sailing in the Bentinck for England and a new life. Various tributes were paid to his great work in India and among these was the following on his nomination for honorary membership of the Asiatic Society of Bengal.

> "By the light it throws on researches into the figure and dimensions of the earth, it forms one of the most valuable contributions to that branch of science which we possess, whilst at the same time it constitutes a foundation for the geography of Northern India, the integrity of which must for ever stand unquestioned."

One of his first tasks upon retirement was to compile *An Account of the Measurement of two sections of the Meridional Arc of India*...in two volumes, published in 1847. In this he gave his second set of parameters for the figure of the earth as: a = 20920902 ft b = 20853642 feet and e = 1/311.044. For this he was awarded in 1848, a testimonial (medal) of the Royal Astronomical Society. It was presented to him by Sir John Herschel who said it "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 of their power and enlightened regard for the progress of human knowledge".

Yet there was one who later said "the name Everest which the English gave to the mountain has served to confere undying fame on a mediocrity". What then does one have to achieve in that person's eys to be worthy of recognition?

Early on in his retirement he was a keen rider with the hounds in Leicestershire. At that time he lodged at Claybrooke Hall but he seems to have had many addresses during the last 23 years of his life. However his prime residence, purchased in 1846, was 10 Westbourne St, Hyde Park Gardens.

Between July and November 1845 it is known that he was in the USA and a year later he married. Emma Wing, at 23, was the eldest daughter of Thomas Wing, a solicitor of Gray's Inn and Hampstead, and Mary Ann Wing. Sir George was 6 years older than his father-in-law.

They had six children: Emma Colebrook (1849-52); Winifred Crew (1851-1910); Lancelot Feilding (1853-1935); Ethel Gertrude (1855-1916); Alfred Wing (1856-1928); and Benigna Edith (1859-60). Only Lancelot had children and both of those died without issue so the direct family line ended in 1935.

It is interesting to note from the names above that "Fielding" referred to the godfather who had been a good friend to Everest in India. Can it be inferred that "Colebrook(e)" came from a similar source since they were a south coast family with several connections to India and the East India Company? Winifred married her cousin Vincent Wing. Then what of the name Benigna? Surely that has an Indian connection of some sort?

Were the Wings at all related to the two Wings who published survey books- Vincent Wing in 1664 and J Wing in 1700? That lends itself to further investigation. Then Everest's niece Mary married George Boole the renowned mathematician. With the descendants of Boole there are four Fellows of the Royal Society among the descendants of Tristram Everest.

Obviously his young family would have kept him busy but nevertheless Everest found time to be active in the Royal Society, the Royal Geographical Society, the Royal Astronomical Society and the Royal Institution - where he was a Manager from 1859 until his death. Lady Everest was elected a member of the Royal Institution in 1863 and the Rev. Robert Everest in 1857. Everests's sons A W and L F Everest became members in 1878.

In February 1861 he was made a CB and on 13 March that year was knighted. He died on 1 December 1866 in London but is buried in St Andrews (old) churchyard, Hove. Three neighbouring granite headstones record the burial of Sir George and six other members of the family but not of Lady Everest.

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.

Various alternative values have been given over the years and one of the latest even queries whether Everest is the highest peak, but it seems unlikely that the value of 29028 feet (8848m) will be amended or challenged again since it is probable that all other values quoted in the range would have to be changed as well.

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"INSTRUMENTS OF A VERY BEAUTIFUL CLASS" - GEORGE EVEREST IN EUROPE 1825-1830

J E Insley, Science Museum, London SW7 2DD, UK.

At the end of 1825, George Everest left India for England after a severe bout of food poisoning had come close to killing him. For two years he had been successor to Col W Lambton, the Superintendent of the Great Trigonometrical Survey, and his visit to England can be seen as a watershed between two very distinct periods in the history of the Survey of India. He returned in 1830, fighting fit, Fellow of the Royal Society, nominated Surveyor General as well as Superintendent of the Trigonometrical Survey, with a large consignment of the most modern equipment that he could persuade the Honorable Court of Directors of the East India Company to allow him to buy, and with a revised streamlined method of observations designed to eliminate as many errors as possible. The meridional arc that he and Lambton before him were aiming to determine was the largest that it was possible to measure in a single country and was the subject of considerable interest in the scientific world. This paper focuses on the time he spent in Europe, and the way that he set about acquiring instruments of sufficient quality to do justice to the work.

A collection of papers at the India Office Library and Records in London includes a deluge of correspondence written by Everest during this time.(1) It is clear that Everest was still very weak when he arrived in England, as he wrote from Ramsgate in May 1826 to say that he was still

> "not ready as yet to do business in a regular way",(2)

but indicating that he had brought details of observations back with him which he would work on as he recovered, possibly with the help of assistants, and that he would write occasionally on matters to do with the GTS. He also asked permission to have further documents sent from India, and for information regarding the measures taken respecting an indent for instruments.

In fact he had already started to write. The first memoir in the collection is a full 130 paragraphs, drafted between April and June 1826, and consists of a comprehensive description of

> "the Survey Establishment in India, particularly the Great Trigonometrical Survey."(3)

It discusses the inaccuracies of the route survey methods in use up to that date, the problems of determining longitude and latitude, a description of how to carry out geodetical operations, and the need for instruments to be as accurate as possible. The core instruments of the GTS were a zenith sector by Ramsden, a 100 foot steel chain by the same maker, a levelling instrument and a chronometer, which were part of a presentation collection of scientific instruments turned down by the Emperor of China. There were also a large theodolite by Cary, similar to that used by General Roy in Britain, and an altitude and azimuth instrument by the same maker, which had arrived in India in 1801. Everest went on to describe the progress of work so far, and indicated the calculations he would be able to complete with the material he had in hand. He also pointed out a perceived weakness in the system of dispatch of data, as there were areas that had been surveyed but the results of which had never reached the India House. He commented on the disadvantages (for him) of the lack of knowledge of geodetical work on the part of the Surveyor General, and made various suggestions to make the procedures more efficient. He detailed the problems with the principal apparatus - the chains for baseline measurement had increased in length over a period of use of 25 years, the standard scale had not been checked in 20 years, the Cary theodolite had been damaged in an accident at Tanjore and its woodwork was

> "falling fast to pieces",(4)

and the micrometer screw on the zenith sector was worn with wear and could not be repaired in India. What had made things worse, his proposals for sending these to England for expert attention had been rejected without official reason (on grounds of cost). He argued again that it would be of interest to the world of science to allow at least the chains to be sent home

> "Since my arrival in England the scientific gentlemen with whom I have conversed have expressed the greatest regret that the chains at least had not been sent home. It is still not too late to rectify this omission and I trust that the Court of Directors will upon a mature view of the case see the propriety of causing them as well as the other instruments to be immediately dispatched under the charge of some officer whose acquirements are such as to render him fully alive to their delicacy and value.
>
> In truth too much attention can hardly be bestowed upon a matter which trifling though it may appear to the superficial observer is on a closer view obviously of great moment for the Honorable Court have long been looked up to by all the civilised world as the patrons of the greatest scientific undertaking of the kind that has ever been attempted."(5)

Work could continue in his absence in the connecting of the positions of Bombay and Calcutta with respect to Madras by triangulation. He recommended using half-castes to do computation, as

> "Persons of this tribe compute steadily they are plodding and painstaking they have a great fund of patience they generally write clearly and legibly they bear exposure to the climate better and are more temporate and sober than the European."(6)

He outlined the disadvantages to Europeans of attempting to make a career in the service. He asked again for the original documents, in case of copying errors, and for two assistants to help. He finished with a recommendation that the new instruments indented for should be constructed by Troughton, Jones or Dollond. The implication of this last remark is that he had already identified with top makers in London, but had yet to make a firm decision between them.

This memoir did not have the desired results immediately. But in March 1827 Everest was elected to Fellowship of the Royal Society, an event which was to prove of great use to him. The Royal Society sat in the centre of intellectual activity of the time, and through its resources Everest would have been able to be in very direct contact with other scientists, and indeed geodesists, from all over the world. This was invaluable in the situation where a letter to England might have to wait for up to a year for a reply. He was for a short time in the perfect place to discover just what work was going on elsewhere, and to read the reports of earlier attempts at meridional arc measuring. In May 1827, he wrote again to the Board of Directors to request that the instruments and documents should be sent home. This time he received support, from Edmonstone of India House (7) on the basis that the astronomical and mathematical work of previous years could not be verified, and as the chains were known to have changed in length they should be compared again with standards in England as a matter of urgency. This appears to have worked, as the next document in the sequence is a letter Everest wrote from Rome nearly a year later (April 1828) where he was engaged in inspecting observatory instruments. He also enclosed a certificate for an extension of his sick leave for a further twelve months - he was described as having ulceration of the ileum from which several exfoliations had taken place. Notwithstanding his health problems he was able to visit Naples Observatory and other places where

> "I have met with some vertical circles by Reichenbach of a construction which appears to be admirably adapted to remedy the defects of the zenith sector. Two of these are in the possession of Signori Brioschi Astronomer Royal at Naples who speaks most highly of them."(8)

Rome was a very suitable place to visit for this purpose. The Greenwich List of Observatories (9) shows that transit circles and zenith instruments made between 1810 and 1825, by Reichenbach and others, were installed in a large number of places. In addition to the British ones with which Everest would have been familiar, there were seven in Italy alone, several in Germany and a fair number in the Baltic countries. Struve's work at Dorpat (now Tartu) was reported to the Royal Society, and Everest would have been ideally placed to choose where to visit.

By November 1828 Everest was obviously on the mend, and wrote more fully acknowledging permission given by the Court of Directors to employ assistants to help with the calculations, and naming two employees of the Royal (Greenwich) Observatory that he had persuaded to start on the work in his own house until such time as suitable accommodation became available at India House.(10) A month later he requested permission to send a gravity pendulum and an astronomical clock which he had discovered were ready for dispatch to Bombay over to the Royal Observatory so that he could experiment with them and establish that they were in proper working order, and could be strictly compared with other invariable pendulums used by Hall, Sabine and Foster. He also asked for the opportunity to allow several cadets from Addiscombe to attend the experiments as a training exercise.(11) Permission having been granted, he would appear to have done the same to the altitude and azimuth instrument being made by Troughton and Simms which he described in a somewhat self-satisfied manner in May 1829 as being ready for dispatch, but only after Troughton's partner Simms who had also been present during the experiments had carried out some small but necessary repairs.(12)

But before the experiments could take place, Everest had to attend to another matter concerning the new zenith circle under construction at Troughton and Simms' London workshop. He clearly wished to introduce some features he favoured from Reichenbach's pattern, in particular to have the vertical circle engraved on both sides, and to add another pair of micrometer microscopes. The estimate for this work was £157-10-0, and the fitting of the microscopes necessitated a new arrangement of the centrework which had already been finished, and which would be charged for separately. The total cost of the new instrument would therefore be an extra one-third above the original, at which the Honorable Court of Directors clearly baulked. So Everest mobilised his contacts at the Royal Society, and three wrote to him with their comments after visiting the workshop and inspecting the incomplete instrument. Bailey thought the second set of divisions would be "most advantageous and useful," F L W Herschell thought that and the microscopes would more than double the reading power, and that the extra expense though 'serious' might not be too great for the chief instrument of an operation of so grand a scale, and South claimed that if the instrument were for his own use, he should consider it little less than two-thirds complete. All three had signed his petition for Fellowship of the Royal Society just over two years before. This lobbying was successful, and the work continued.(13)

In March and April 1829 three groups of cadets were released from Addiscombe to attend the experiments. By this time the scope had increased again, to include compensation bars for measuring baselines and a transit instrument. The groups were joined at the Observatory by Lieutenant Murphy of the Royal Engineers, who had worked with Colonel Colby in Ireland on the measurement of the Lough Foyle base, and who therefore was able to give practical tips in using the bars.

> "It will be in your recollection that in March last with consent of the Chairman and at my suggestion Colonel Forrest sent to the Royal Observatory a set (consisting of three of these bars and their standard). My objects were to try these bars in Greenwich Park and see whether they where (sic) complete. To get all the practical information I could respecting their use. To explain the construction and use of them to the Young Officers from Chatham; and to give Mr Pond an opportunity of measuring a base line of such length as would be sufficient to determine the distance from the Royal observatory to Lavendroog Castle.
>
> The first three points have been accomplished the last did not succeed, but it was attempted by myself and the Assistants of the Royal observatory and only given up because the idle people at Greenwich Fair pulled up the Astronomer Royal's marking stones and so showed the inutility of further proceeding without the usual formality of a guard of Soldiers."(14)

Another set of papers relating to the pendulum experiments ends with a letter from the Military committee authorising the bill for accommodation at the Green Man in Blackheath, but commenting that at £64 for 11 days it seemed to be rather high.(15)

By May Everest was ready to present the cost of the computations carried out by Richardson and Taylor, and admitted that the experiments on the pendulum though incomplete because of bad weather would be finished shortly afterwards, and indeed the results were published subsequently. Experience in Ireland had shown that baseline work proceeded twice as fast if a double set of six bars were used instead of three, so in June Everest recommended that the two sets of bars under construction for Bombay and Calcutta for geographic surveying should be combined to form one set for the great Trigonometrical Survey, and supplied a copy of the bill to the Irish Survey for the additional instrumentation that this entailed.

Everest set off for Ireland on 5 July 1829, to vist Colonel Colby and to see for himself how the survey was organised,

> "The damp and rainy weather which has continued through the whole summer, and the foul air of the bogs in Ireland brought on an attack of fever"(16)

but by the end of October he had drafted a 70 paragraph memoir comparing the Irish and Indian establishments for submission to the Court of Directors. One set of problems had been resolved already, as in August he had been nominated Surveyor General of India as well as Superintendent of the Trigonometrical Survey.

The main points he noted about the Irish Survey were firstly that all surveying work was subservient to the trigonometrical work, and determined from it. Field notebooks were kept on a daily basis, and used as active means for justifying increases in pay and tracing the causes of accidents. The status and salary of the officers involved were high compared to the norm, and of the instruments described, including two theodolites and compensating bars, any problems could be fixed automatically by direct recourse to the instrument makers Troughton and Simms.

Turning to the Indian situation, Everst argued again for improvements in the organisation of the establishment, for the increased use of mertizas or half-castes to carry out the work in a disciplined way.

> "European soldiers cannot stand the climate and are besides generally given to drinking and other irregularities, and native soldiers can seldom or never read or write English and consequently would be unfit to draw up field books."(17)

He put forward the case for a Mathematical Instrument Maker to be sent to India to facilitate repairs, and he reminded the Court of his wish to use two zenith circles simultaneously for determining arc amplitudes. Finally, as the idea was to found observatories at the Presidencies of Bengal and Bombay as well as to appoint a successor to Mr Goldingham, the astronomer at Madras, he put in a word on behalf of the two computers from the Royal Greenwich Observatory who were working on the calculations of the observations so far. Indeed Mr Taylor was subsequently appointed to the Madras post.

A month later he returned to the problem of establishing these new observatories, and in a letter to Col Salmond described in great detail the instruments which would be needed.(18) It is also clear from this letter that he knew the details of observatory instruments in Naples, Palermo and Milan, most probably from his visit to Rome the previous year. The zenith circles from the GTS would of course be available after the work on the meridional arc was over. He made recommendations concerning the observatory buildings, and the type of person who would make a good astronomer.

> "The astronomers must not be fine gentlemen, nor need they be first rate mathematicians because the object of such observatories being to record facts and observations, a good methodical system, abundance of perseverance and habitual integrity are most likely to advance it not that I mean to undervalue other literary or scientific or social qualities, but when Mr Goldingham speaks of establishing the place of astronomers in

society I deduce that his arguments are directed against a very different sort of person to what I have in my mind's eye. To admit the astronomer to the levee of the Governor General on occasions of ceremony is all that could in reason I think be asked. His place in society after this he must make for himself but the sort of person whom I should recommend would not be one for whom balls and fetes would hold out much gratification and we all know these are the only occasions and that the ladies are the sole sticklers for such questions of precedence."

Everest still wanted his instrument maker though, and by December 1829 had marshalled a summary of repair and replacement costs for the Survey of India. He was able to demonstrate an immediate cost of £2000 per year which could be partially recouped by an instrument maker on the spot, before even considering the problems of rebuilding the Cary theodolite and fixing the zenith sector, both of which were unusable.(19)

"It is not that I contemplate any accident, it is in my humble opinion no excess of prudence to guard against an evil which may occur and to stare that evil full in the face. The Honorable Court will I trust forgive my earnestness if I state to them that I hope to be placed on a par with my contemporary Colonel Colby in respect of the advantage he possesses of instantaneously repairing the slightest injury which his bars might sustain. I should feel myself deeply responsible to my Honorable masters where I to hesitate to bring to their full notice the urgency there is for this measure..."

Again, he was successful. Henry Barrow was appointed, and travelled out to India in 1830, followed by his family, for a stay of nine years. Although he and Everest failed to see eye to eye, it is clear that Barrow did an excellent job, repairing the Cary theodolite to such an extent that it worked better than the item made by Troughton and Simms. Everest acknowledged this in his book of 1847.(20)

"I must do that artist (Barrow) the justice to say that for excellence of workmanship, accuracy of division, steadiness, regularity, and glibness of motion, and the general neatness, elegance and nice fitting of all its parts, not only were my expectations exceeded but I really think it is as a whole as unrivalled in the world as it is unique."

The last document in the collection is the indent for the instruments, and a covering letter with dispatch instructions. A paragraph of this letter gives the earliest reference to what later became known as the Everest Theodolite, and so is here quoted in full.

"I have devoted some consideration to the improvement of the common theodolite which are both more cumbersome and expensive than they need be and after frequent examination of all the best devices I could meet with in the shape of the various makers in London Mr Simms has at my suggestion designed an instrument which contains all the useful parts of the old construction, is quite free from superfluous apparatus and is cheaper by one-fourth. I beg to suggest the propriety of keeping one of the 7 indented for at the India House as a model and sending two to each of the Presidencies.

> The model has only 5 inch diameter but the principle is so perfectly applicable to all instruments for secondary triangles that I should respectfully recommend the propriety of adopting this as the Honorable East India Companys form for all small theodolites not exceeding 12 inches diameter and preserving on all future occasions the strictest uniformity."(21)

The first six theodolites of the Everest pattern left for India with their inventor in June 1830.

ACKNOWLEDGEMENTS

My grateful thanks go to Matthew Edney for providing me with the original reference; to Jim Smith, Andrew Cook and Peter Clark for countless discussions; to Anita McConnell for nuggets of information concerning the instrument-making activities of the firm of Troughton and Simms; to the Survey of India for inviting me to their own celebrations in India; and to the British Council for enabling me to accept that invitation. The staff in the Science Museum Photographic Studio performed miracles on my behalf, not only for this conference but also for the accompanying exhibition here at the Royal Geographical Society.

NOTES AND REFERENCES

1. India Office Library & Records, L/MIL/5, 402, Collection 205.

2. Letter dated 29 May 1826.

3. Folios 358 to 406.

4. Paragraph 88.

5. Paragraph 92 & 93.

6. Paragraph 103.

7. India Office Library & Records L/MIL/5, 407, Collection 263, folios 191-200.

8. L/MIL/5, 402, Collection 205, folio 417.

9. Journal for the History of Astronomy, Vol.17, Part 4, November 1986.

10. L/MIL/5, 402, Collection 205, folio 419 et seq.

11. Ditto, folios 423-426.

12. Ditto, folios 454 et seq.

13. Ditto, folios 427-431.

14. Ditto, folios 325-328. However, there is conflicting evidence as to the exact form the experiments took. In the 'Asiatic Researches of Bengal' for 1833, Everest wrote in a paper dated March 1831 that the instruments had been set up in Lord's Cricket Ground in April the previous year, and giving a different list of people attending - Taylor is recorded as being Company's Astronomer, which appointment was made in early 1830, and Drummond from the Irish Survey was there as well as Murphy. There may have been two sets of experiments.

15. See note 7.

16. See note 1, folio 296.

17. Note 1, folios 310 and 311, part of paragraph 49.

18. Note 1, folios 340 to 352.

19. Note 1, folios 447 to 453 - paragraph 13, folio 450.

20. Everest, G. An account of the Measurement of two sections of the Meridional Arc of India, 1847.

21. Note 1, folios 458-464, paragraphs 12 and 13.

GEORGE EVEREST ON THE TRIANGULATION OF THE CAPE OF GOOD HOPE

including an extract from the Memoirs of the Astronomical Society of London, Volume 1 Part II, 1822 (Reproduced here by kind permission of the Royal Astronomical Society).

C G C MARTIN
Department of Surveying, University of Cape Town

Abbe de La Caille

From April 1751 to October 1752, the French astronomer, Abbe Louis Nicholas de La Caille was occupied at the Cape of Good Hope carrying out astronomical and physical measurements, mapping nearly 2000 stars of the southern hemisphere and taking observations for parallax (of the Moon, Sun, Venus and Mars), pendulum movements, meteorology, mercury barometer altimetry, geomagnetism, tides, etc. This work was endorsed by the Academy of Sciences, Paris, as was also his task of measuring an arc of a degree of latitude, which he did during September to October 1752. It was expected that the results of the latter work would support the hypothesis that the figure of the earth was an oblate ellipsoid, as had the measurements of the Peruvian and Lapland arcs. De La Caille's map of the Cape is included in the attached extract.

He used as his observatory a house sited at Number 7 Strand Street in present-day Cape Town from where he carried out most of his astronomy and which he also used as the southern extremity of the arc. His northern station was at Klipfontein, near present-day Aurora, where he observed for six successive nights with his 1.8 metre zenith sector, deducing the latitude difference to be 1 degrees 12′ 1.55"

In October 1752, on the Swartlands Plains north of present-day Darling, he measured a baseline 12.605 kilometres long using four iron-tipped wooden rods (each 3 toises, or 5.847 metres long). He then linked the baseline to the northern and southern extremities of the arc by triangulation extension to derive the length as 68 469 toises. From this, it could be concluded that a degree of latitude centred at 33 degrees 18′ 30" South was 57 037 toises (or 111 169.1 metres), which suggested that the southern hemisphere rather took the form of a prolate ellipsoid. Perplexed by this anomalous figure and to eliminate the possibility of gross error, he then remeasured the baseline with a 30 toise cord confirming the validity of the earlier figure.

> "This conclusion excited the surprise of astronomers, being totally at variance with the theory of gravitation, which assigns the same elipticity to both hemispheres. On the other hand, the high celebrity of the astronomer upon whose authority it rested, served only to render the question still more perplexing." (Grant)

George Everest

On 25 November 1820, Captain George Everest arrived in Table Bay having been granted a year's leave of absence from Hyderabad for health reasons. His senior officer had requested him to examine the terrain over which de La Caille measured his arc (suggesting that the reason for the anomaly was suspected early on in British circles).

On 26 July 1821 he started to visit the stations, recovering the sites of all with little difficulty, but only finding one artificial mark i.e. at the house in Strand Street. At Riebeck's Castle, Everest found an old pile of stones with half-burned wood in a state of partial decay, de La Caille having used blazing fires at night for signals, which were remembered by an aged resident at the time of Everest's visit. He remarked that not only would such fires have made ill-defined signals; but the reported simultaneous observations at Kipfontein and Riebeck's Castle meant that these centres for observations, supposedly on that line, would have been a likely source of inaccuracy of angular measurement. Also, Everest had doubts about the stability of the roof of the house in Strand Street.

He also inspected the baseline, again finding the sites of the terminals but not the marks, and felt that the intervening terrain was unsuitable for rigid rod measurements, but that catenary apparatus should have been used.

Such were Everest's reservations about de La Caille's methods of survey and he then tried to quantify the effect of the neighbouring mountain masses, Piketberg in the north and Table Mountain in the south. He compared de La Caille's length of the arc and the flattening of the ellipse, with that of Bouguer and de La Condamine (1738), with that of Cassini (1740) and finally Bouguer and de La Condamine with that of Cassini and reasoned that if an oblate ellipsoid of elipticity 1/300 could be assumed from those arcs measured in the northern hemisphere, then using the same terrestrial length and mid-latitude as de La Caille, the latitude difference would be 1 degrees 12' 10.54" which exceeded the previous determination by 8.99".

With Piketberg being generally to the northeast of Klipfontein and Table Mountain being to the west and south of the observatory, Everest contended that gravitational attraction could so affect the plumb-line to make the zenith appear further north at the northern station and further south at the Cape Town end, resulting in a smaller deduced amplitude of the arc than the true by an error equal to the sum of the zenith errors. Because de La Caille did not appear to apply any corrections for gravitational attraction, (though they were known by 1738), Everest deduced that the greater part of the 8.99" difference was due to this attraction.

Concerning the base-line and triangulation measurements, Everest reported: "The irregularities which may have attended the terrestrial measurements .... are likely to have tended to increase as to diminish the length of the arc; but still the very uncertainty under which they labour is sufficient to throw doubt upon the whole operations...."

He concluded his report by suggesting that instead of reobserving de La Caille's arc, new triangulation should be extended over four degrees of latitude, from the new observatory then being built in Cape Town to Namaqualand, and that the old stations be connected to it to finally resolve the matter.

Thomas Maclear

In 1837, Thomas Maclear the Astronomer Royal at the Cape reported that he had done just this, with a triangulation network including a station near de La Caille's at Klipfontein, and was able to reconcile the elipticity derived from the greater coverage of his work with that derived in the northern hemisphere. He was also able to conclude that de La Caille's error could be reduced by half by remeasurement of the base-line and the triangulation, the remainder being the result of gravitational attraction. Furthermore, latitudes of those triangulation stations sited away from mountain masses matched the adopted figure of elipticity. Everest's assessment had been vindicated.

A July 1990 Postscript

In July 1990, two amateur astronomers from Cape Town, Alan Cameron and Keith Graham, reached the culmination of their research by being the first to successfully recover, by resection to surrounding peaks, Maclear's station at Klipfontein which the latter had sited 100 yards distant from de La Cailles' northern station of the arc. Maclear reported that a message in a quart bottle, sealed and tarred was buried three and a half feet deep, surmounted by a stone slab, carved '1838' and covered with soil. The subsequent excavation this year, under the supervision of H Deacon, professor of archaeology at the University of Stellenbosch, verified the correctness of Maclear's description. The bottle was left undisturbed and the seal not broken.

Coincidentally, this took place during the period 2 to 5 July, the operation being delayed by one day due to heavy rain. Otherwise, it would have been a fitting commemoration in the Cape of George Everest's birthday.

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XXI. *On the Triangulation of the Cape of Good Hope. By Captain G. Everest, of the Bengal Artillery, &c.*

Read May 10, 1822.

Sir, East India House, Jan. 10, 1822.

THE Court of Directors of the East India Company having received from Captain GEORGE EVEREST, an officer in their service in the Artillery on the Bengal establishment, a copy of a letter which he lately had occasion to write to Colonel WILLIAM LAMBTON, Superintendant of the Trigonometrical Survey of India, upon the subject of the geodetical operations which were carried on at the Cape of Good Hope during the last century, accompanied by the request of Captain EVEREST, that a copy thereof might be furnished to you as President of the Astronomical Society; I am accordingly commanded by the Court to transmit to you a copy of the said letter.

I have the honour to be,

Sir,

Your most obedient humble servant,

JOSEPH DART, *Secretary.*

Sir WILLIAM HERSCHEL,
President of the Astronomical Society.

To JOSEPH DART, *Esq. Secretary to the Honourable the Court of Directors.*

Cape Town, Cape of Good Hope,
September 3, 1821.

SIR,

I take the liberty to solicit that the inclosed paper may be submitted to the notice of the Honourable the Court of Directors by as early an opportunity as may be convenient; with a request from me that, should it be deemed unobjectionable, it may be forwarded, under their auspices, to Sir WILLIAM HERSCHEL, President of the Astronomical Society.

It is the copy of a letter which I have lately had occasion to write to Colonel W. LAMBTON upon the subject of those geodetical operations which were carried on at the Cape of Good Hope during the last century; and they are particularly important from their furnishing the only data the scientific world is in possession of respecting the compression of the southern hemisphere. We have in fact meridional arcs, determined in several different parallels of latitude in the northern hemisphere, but all leading to results very different from those of M. DE LA CAILLE; and as the most splendid of these, whether we regard its accuracy or extent, is beyond doubt that which owes its origin to the patronage of the Honourable the East India Company, it is a fair presumption that the Honourable the Court of Directors will not view the present, my humble attempt to clear up this serious anomaly, with indifference. I rest persuaded that I shall not be considered as unnecessarily intruding myself upon the time and attention of that Court, in whose service I have passed the prime of my life and youth, and under whose patronage, if the effects of climate do not blast my prospects, I look forward to the cheering hope of taking an ample share in the measurement of the arc now in progress towards Agra and Hurdwar; which, if it be completed, will exceed every other the world has yet witnessed, in the ratio of nearly 3 to 1, and be sufficient in itself to establish the compression of the globe independently of any other data.

The apparent informality of transmitting a copy of my letter directly to you, will I trust be overlooked by the Honourable Court. The matter of it, concerning the scientific world at large, has no more reference to India than to England, France, Italy, or America; it has been sent in this channel, therefore, purely to avoid the loss of time which would arise from travelling by a circuitous route: and I know the liberality of my friend Colonel LAMBTON sufficiently well to be convinced that such a procedure will be attributed by him to the right motive, and cannot be unpleasing to him.

The matter and manner of my report are I believe perfectly original; as far as concerns me, they certainly are; for I am not aware that any attempt has hitherto been made to reconcile the contradictory conclusions which it relates to. A gentleman, who was formerly assistant to Lieut.-Colonel LAMBTON, (Captain WARREN, of His Majesty's 33d Foot,) was some years ago, when he passed the Cape of Good Hope, extremely desirous to obtain information relating to the subject, and left a memorandum to that effect with the Colonial Secretary, by which it appears, that he was authorized to communicate to the Royal Society any discovery he made: but the records of the Colonial Government and all the public and private libraries at the place were searched at my request in vain; and I know perfectly well, that the country now described has not, within the memory of any individual residing there, been subjected to a scientific examination since the year 1752.

With many apologies for intruding thus largely upon your valuable time, permit me to subscribe myself,

Sir,

Your most obedient and very faithful servant,

(Signed) GEORGE EVEREST,

Capt. Bengal Artillery, Chief Assistant of the Geod. Trig. Surv. of India.

To Lieutenant-Colonel WILLIAM LAMBTON, *H. M. 33d Foot.*

Cape Town, Cape of Good Hope,
August 31, 1821.

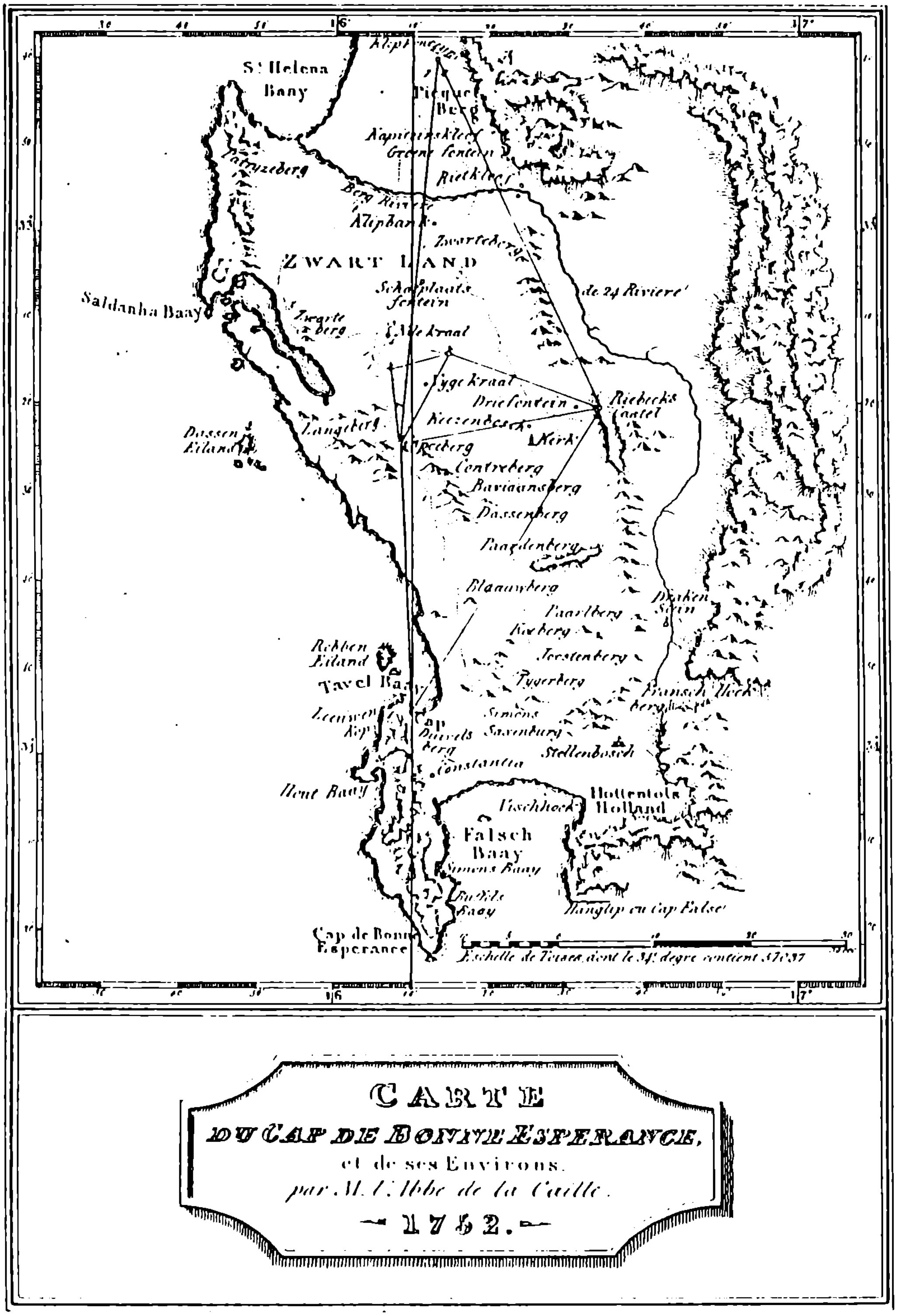
SIR,

It will be in your recollection, that on my departure from Hyderabad in August 1820, you expressed a desire that I should, in the event of my proceeding to the Cape of Good Hope, examine the tract of country in which the geodetical operations of M. l'Abbé DE LA CAILLE were conducted; and I now proceed to acquaint you with the fulfilment of your wishes.

You are already aware that I arrived in Table Bay on the 25th of November 1820; immediately on which I commenced my inquiries; but as no information could be obtained on the spot, I directly applied to a correspondent in England for such papers as related to the object of my search; and, in effect, by the latter end of June of this year, a journal of M. DE LA CAILLE's Travels reached me, so that I was enabled by the 26th of July to visit the places described as the sites of his stations, and in fact to traverse the whole theatre of his labours.

It will appear from the plan in the margin *, that besides the two extremes of the base, there were four principal stations forming two large triangles united together by a common side; the celestial observation having been made at the two vertices, which are separated from each other by a distance of about 79 miles. The two middle stations terminating the common side are Capok Berg and Riebek's Castle, lying nearly east and west of each other. The station forming the northern termination of the arc is Klip Fonteyn, and that to the southward, was I conclude the site of M. l'Abbé's Observatory at Cape Town. The base appears to have passed in a direction a little northward of East, the southernmost point lying near Klip Berg, and the northernmost near an estate called Coggera. This being premised, I will now proceed to describe the existing condition of the station, and what decisive marks I have been enabled to trace on them.

Capok Berg is a rounded hill, of easy ascent, belonging to a range of granite, which runs at the back of the Moravian Missionary Settlement at Groene Kloof; and I should estimate its height at about 600 feet. At the highest point of the level of the hill, and at the western side, is a solid rock of considerable area, with a smaller one on the northern side, as described in page 173 of the Journal; and as the angles taken from this correspond with those in the



Lithog.d by C. Hullmandel. For the Memoirs of the Astronomical Society of London plan of triangles, I consider the identity of this station to be satisfactorily established, though it is to be regretted that no artificial marks now remain there. Its particular features are specified in page 173 of the Journal now in my possession, under the Mem. of 6 Aoust 1752.

Riebek's Castle is the next station in order to be described. The mountain so called, whose height I should think cannot be less than 1500 feet, is a lofty chain of sandstone, running nearly N.W. and S.E., of about two miles and a half in length at the summit, and divided into several different peaks, on the second of which, reckoning from the N.W., there are the remains of an old pile of stones, having (about five feet to its N.W.) a considerable quantity of half-burned wood in a state of partial decay. As this is the peak particularly adverted to in the Journal, and we know from other certain information that the signals were made by blazing fires, I think no doubt can remain of its identity.

In reference to the base, the following remark is extracted from page 174 of the Abbé De la Caille's Journal:—"Aoust 11, 1752. J'allai à cheval dans la plaine qui est au nord de la montagne appellée Contreberg, pour chercher un terrein propre à mesurer une base; cette plaine est très étendue et fort unie, mais un peu embarrassée de broussailles; j'ai pris pour terme sud de la mesure une roche qui paroit être de marbre blanc, et qui est sur un petit tertre; elle est très remarquable; j'ai trouvé qu'en élignant la base au nord on la pouvoit prolonger autant qu'il étoit nécessaire."—Hence, therefore, and from knowing nearly the angles subtended at the south end of the base between Capok Berg, Riebek's Castle, and the detached mountain at the back of Klip Fonteyn, with the distant appearances of which I had taken care to make myself acquainted, it became a work of no great difficulty to detect the approximate site of the point to be sought; and in effect, after frequent measurements, I at last came to a spot between the estate of Klip Berg and another estate bearing also the name of Klip Fonteyn, where a ridge of quartz rock, somewhat resembling marble in whiteness and lustre, protrudes itself through the soil, and where the angles answered the given conditions.

This therefore, it appears to me, is doubtless the spot alluded to in the description; for though neither the quartz rock in question is so remarkable as might be expected, nor are there any artificial marks remaining to denote it, yet a constant exposure to the atmosphere for a lapse of seventy years is probably sufficient to account for the obliteration of the latter, as well as any distinguishing features which the rock itself may formerly have borne.

The northern extremity of the base, viewed from the southern, is in the Plan at an angle of 27° with the station of Riebek's Castle; so that by assuming a distant point, and proceeding in a straight direction towards it, I was enabled, after several trials, to reach a small mound of raised earth in the vicinity of Coggera, where the angles between Riebek's Castle, Capok Berg, and the hill behind Klip Fonteyn, nearly corresponded with those taken from the Plan; and though here there are neither artificial nor natural marks to designate the site of the station, yet so little doubt remains in my mind of its being the point to be sought, that I consider myself warranted in offering the following remarks as drawn from an actual inspection of the tract of land through which the base line passed.

The soil is throughout a mixture of sand and clay, rather light than otherwise, but still sufficiently solid and substantial. The surface is undulated and irregular; and though there are neither rivers nor deep ravines, nor large forests, yet it is covered thickly with small bushes and brushwood; and there are at the present day inequalities enough to render such a measurement at least dubious, if it were performed by any of the means then in common use. The Abbé De la Caille's biographer does not in the Journal (and I regret to say this is the only work upon the subject yet in my possession) enter into any of the scientific details; but we know that the more refined corrections were introduced into practice at a period long subsequent to the year 1752; and the fact seems to me to be beyond doubt, that the plain to the north of Capok Berg and Contre Berg is no where sufficiently level and even to admit of an operation so delicate in its nature, unless indeed the chain were supported by Coffer's tripods and such other apparatus, as there is every reason to conclude M. De la Caille was not supplied with, since no hint leading to such a supposition is any where thrown out in the work before me. I speak of course of the face of the country as it at present stands; what it may have been seventy years ago is another affair, though I do not find on inquiry any individuals now in existence within whose remembrance any considerable change has taken place.

It would seem by the following extract from M. De la Caille's Journal, page 144, that he had originally intended to establish the northernmost station of his triangles at the summit of a mountain detached from the great range of Piquet Berg:—September 7, 1751. "J'ai été sur une des montagnes de la première chaine, dont je viens de parler. Cette montagne s'appelle Capok Berg, &c. &c. . . . . .; j'ai vu une montagne fort éloignée dont une des extrémités étoit presque dans le nord, et fort propre pour terminer la mesure d'un degré. Depuis cette montagne en allant par l'est vers le sud, l'horizon est bordé de hautes montagnes." He however mentions afterwards, page 180, that his sector was erected in an old granary belonging to Klip Fonteyn for the following reasons:—14th September, 1752. "En général on y voit tout ce qu'on eut pu découvrir du sommet du Piquet Berg ou de la montagne voisine; c'est pour cela que je n'ai pas placé des signaux sur ces montagnes pour terminer mes triangles; mais que j'ai marqué un point pris à 36 toises à l'ouest de mon observatoire à fin d'y faire des feux pour former mon dernier triangle." Now in reference to this matter, it may not be amiss to mention, that the daughter of the quondam proprietor of Klip Fonteyn, now an aged lady named Letchie Schalkeveck, is still in existence, and not only gives a narration perfectly agreeing, but has pointed out the very platform on which the granary once stood; and states further, that the signal-fires were so large and brilliant, that those of Riebek's Castle were visible from Klip Fonteyn, a distance of more than forty-five miles, with the naked eye at night. The same lady relates also, that the Abbé De la Caille observed the stars with his instrument (the sector I suppose) in the granary (an aperture having been made in the thatched roof for the purpose), until the day when the fires were lighted; when, having previously sent M. Poitevin his assistant to make simultaneous observations at Riebek's Castle, he placed it, or some other, at some paces in front of the fire: and as this account tallies with what I have before observed in my remark respecting Riebek's Castle, it leads directly to the extraordinary conclusion, that not only the signals in these operations were ill defined, but that the instrument for measuring the horizontal angles was not placed over the centres of the stations. The above remarks relate particularly to the terrestrial measurements: we come now to the subject of M. De la Caille's celestial observations, which, from their superior delicacy and the important consequences attending any errors committed in them, will demand a more minute investigation.

The granary at Klip Fonteyn, which is beyond doubt the northern termination of the arc, is in the immediate vicinity of a very extensive range of sandstone mountains called Piquet Berg, some of the peaks in which I should think cannot be less than 2000 feet in height; and it is at the foot of the detached hill at the back of Klip Fonteyn, already so often alluded to, which rises, I should conclude, to the height of 700 feet, so that the whole horizon from the N.E. to the S.W. is completely inclosed by mountainous masses; whilst on the opposite quarter is an open country without any counterbalancing matter whatever. The masses are so irregular, that it would be a work of extreme difficulty, if not of absolute impossibility, to calculate the attraction which they would be likely to exert upon the plumb-line; but it will be evident from what has preceded, that if any such lateral attraction did exist, it would lie all on one side, and principally in a N.W. direction.

The last station to be noticed is that at the southern termination of the arc, which I have been enabled satisfactorily to trace to a particular house in Strand Street, Cape Town, adjoining the one in which I reside; and as this may be an interesting subject for you hereafter, I shall particularize the grounds which have led me to this conclusion. The Abbé De la Caille's Journal, page 140, contains the following passage bearing immediately upon the question:—21st April, 1751. "Nous logeons chez M. Bestbier, Capitaine de la Cavalerie Bourgeoise, chez qui je trouve un endroit propre pour observer, en y faisant batir un observatoire pour y placer mes instrumens." Now, as the house of M. Bestbier was in the memory of a person* living in No. 7, Strand Street, the present residence of Mr. De Witt, this circumstance would almost be sufficient to establish its identity with the point in question; but there is a mark in existence which furnishes another corroborating fact, namely, that a brass plate perforated with a small hole, and fixed horizontally in a vertical wall, with a black line traced immediately below it, for the obvious purpose of determining the sun's passage over the meridian, still stands at Mr. De Witt's house, and is said to have been placed there by the Abbé De la Caille.

The erection of M. l'Abbé's observatory is stated in the Journal to have been commenced on Monday subsequent to the 24th of April, and to have been finished on the 17th of May following; and as it was performed by the Government workmen, it could not have been a very substantial fabric. The probability is, that he took advantage of Mr. Bestbier's house having a flat roof; and if that were the case, it is very easy to imagine that extensive errors may have arisen from placing his instrument on so frail a basis.

But were it even admitted that the observatory had been unobjectionable in respect to stability, still its situation must have rendered it highly ineligible for the delicate operation depending on it. It is well known that Cape Town lies at the very base of Table Mountain, a vast formation of sandstone in hori-

* A female slave belonging to Mrs. Hertzog is the person alluded to.

zontal strata rising above a sienitic or granitic base for the upper half of its height, like a mighty wall, quite bare, towering and precipitous; the lower half of the mountain being formed apparently of debris, which slopes gradually till it reaches the ocean. This immense mass, including the Devil's Hill, which forms in fact part of the same land as the Table, though the continuity of the upper strata is broken through by a considerable intervening chasm, occupies the horizon between S.E. 22¾° and S.W. 27°, and averages between 13° and 14° of elevation from the house in question; further southward it extends with various heights for the distance of about thirty-five miles, and ultimately forms the peninsula of the Cape of Good Hope. The mountain called The Lion occupies the horizon from N. 72¾° W. to S. 66° W., and is distinct from the Table; for though it was probably in the origin of the same formation, yet it is now quite different in its features, being rounded off, of easy ascent, and covered with soil; the small part, called The Lion's Head, is however formed of horizontal strata similarly disposed with those of Table Mountain, and the bases of the two run into each other, the uniting ridge being about 800 feet high, and apparently formed from the debris of each.

The Abbé De la Caille, when he was here in 1751 and 1752, had taken the heights of all the different eminences in the environs, and left a record at the request of the Colonial Government, in the Secretary's office, of which a copy being still in existence, I have made use of it to ascertain the relative approximate distances of the peaks by observing the angles of elevation and azimuth from the roof of the house adjoining that on which was the site of the observatory, considering the distances as radii to be determined by the heights as tangents. This method of course is rough, and admits of no great nicety; but it is sufficient to convey a general notion of the localities of this vicinity, and with that view I subjoin the following table.

Names.	Height.*	Elevation Angles.	Dist.*	Directions with the True Meridian.
Devil's Hill	3106	13° 55′	12,350	22¾° S.E.
Table { Eastern Extreme .	3302	13 12	13,880	2° S.E. } The surface included between these two rays is very solid and compact.
Table { Western Ditto .	3353	13 26	13,850	27° S.W. }
Lion's Head	2085	10 39	10,850	66° S.W.
Lion's Rump . . .	1102	10 24	5,760	72¾° N.W.

* The heights and distances are all in Paris feet, which are to English feet as 4.263 to 4.000.

Now it appears to me, that so vast a quantity of matter could not have existed so near to the site of the observatory without affecting the plumb-line of the instrument used by M. De la Caille in 1751, 1752. The lateral force exerted by mountains was certainly known to the scientific world at that period; for in the year 1738, MM. Bouguer and De la Condamine had attempted to calculate the attraction of Chimboraço: perhaps, indeed, M. De la Caille may have made some calculation to this effect; for I must candidly avow, that I have never been so fortunate as to read any of his papers in the Memoirs of the Academy of Sciences; but if he did, it is a great chance, considering the failure of the celebrated geodists who measured the arc near Quito, that he did not arrive at any accurate conclusion. For the present, therefore, I shall suppose that there was no correction applied on this account, but that the plumb-line of his sector was drawn out of the vertical by a lateral force at the southern extremity of the arc, in a direction of S.W. A°, and that the resolved part of this force parallel to the plane of the meridian was such as to cause the zero to stand at a'' too much to the southward; by which means his zenith would be affected in the opposite direction, and would appear more to the northward than was due by an equal arc. Similarly, if the resolved part of a lateral force exerted by the mountains at Klip Fonteyn caused the zero to stand b'' too much to the northward, the zenith of that place would have appeared b'' to the southward of the true place, and thus the whole apparent arc of amplitude would have been less than the true one by the sum $a''+b''$ of the two arcs of error, or, what is the same thing, the measure of the arc would have been too great.

If this reasoning be admitted (as I think it must), we may perhaps be able to reconcile some considerable discrepancies to which the geodetical operations in question have given rise; for if the earth be an ellipsoid of revolution, whose meridional arcs increase in a certain ratio as we advance from the equator to the poles, it is evident that, on comparing the measurement in this latitude with that made nearer the equator, the ratio of increase would be too great; and, on the contrary, if the comparison be made with a more northerly arc, the ratio of increase would be unduly diminished. In the first instance, the calculated figure of the elliptic meridian would have a greater compression; in the second, a less compression than would be found to result from a comparison of the two extreme measured arcs with each other. And that this really occurs in the case before us I shall now proceed to demonstrate.

To this end I shall first compare M. De la Caille's arc with that measured by MM. Bouguer and De la Condamine in the year 1738; I shall then draw a comparison between M. De la Caille's arc, and that measured by M. Cassini in the year 1740; and lastly, I shall compare the arcs of M. Bouguer and M. Cassini with each other. The formula I shall adopt is the common elliptic one of $\frac{c}{d} = \left(\frac{m\,\frac{2}{3}\sin^2 C - M\,\frac{2}{3}\sin^2 L}{M\,\frac{2}{3}\mathrm{Cos}^2 L - m\,\frac{2}{3}\mathrm{Cos}^2 L}\right)^{\frac{1}{2}}$, where c and d represent the major and minor axes L and l, the middle points of latitude corresponding to the measures M and m; and the calculations here follow at full length.

1st Comparison, where $L = 1°\ 30'$ N.; $M = 56749$; $l = 33°\ 18'\ 30''$ S.; $m = 57037$.

L = 1° 30′ Log.	Sin. $\bar{2}$ 417919	....	Log. Cos. $\bar{1}$.999851
	2		2
M = 56749 Log. 4753958			
2	Sin.² $\bar{4}$.835838		$\bar{1}$.999702
3)9507916	3.169305		3.169305
M ⅔ Sin.² L = 1.012 Log.	0.005143	M ⅔ Cos.² L = 1475.731	Log. 3.169007
l = 33° 18′ 30″ Log. Sin.	$\bar{1}$.739687	....	Log. Cos. $\bar{1}$.922064
	2		2
m = 57037 Log. 4.756157			
2	Sin.² $\bar{1}$.479374		$\bar{1}$.844128
3)9.512314	3.170771		3.170771
m ⅔ Sin.² l 446.833	Log. 2.650145	m ⅔ Cos.² l 1034.902	Log. 3.014899

M ⅔ sin.² l—M ⅔ sin.² L=445.821 m ⅔ Cos.² L=m ⅔ Cos.² l=440.829

1st Comparison continued.

445.821	Log. ...	2.649160
440.829	Log. ...	2.644270
		2)0.004890
$\frac{c}{d}$=1.0058	Log. ...	0.002445

$\frac{c}{d} - 1 = \frac{1}{173}$ Compression.

2d Comparison, where L=33° 18′ 30″; M=57037; l=49° 22′; m=57074.

l=49° 22′	Log. Sin. 1̄.880180		Log. Cos. 1̄.813725
	2		2
m=57074 Log. 4756438			
2	7.760360		1̄.627450
	3.170959		3.170959
3) 9.512876			
$m\ \frac{2}{3}$ sin.² l 853.726	Log. 2.931319	$m\ \frac{2}{3}$ Cos.² l 628.651	Log. 2.798409
M $\frac{2}{3}$ sin.² L 446.833		M $\frac{2}{3}$ Cos.² L 1034.902	
$m\ \frac{2}{3}$ Sin.² l − M $\frac{2}{3}$ Sin.² L = 406.893	Log. 2.609481	M $\frac{2}{3}$ Cos.² L − $m\ \frac{2}{3}$ Cos.² l	
M $\frac{2}{3}$ Cos.² L − $m\ \frac{2}{3}$ Cos.² l = 406.251	Log. 2.608795		
	2) 0.000686		
$\frac{c}{d}$ = 1.0008	Log. 0.000343	$\frac{c}{d} - 1 = \frac{1}{1250}$ Compression.	

3d Comparison, where L = 1° 30′; M = 56749; l = 49° 22′; m = 57074.

M $\frac{2}{3}$ Sin.² L	1.012	M $\frac{2}{3}$ Cos.² L	1475.731
$m\ \frac{2}{3}$ Sin.² l	853.726	$m\ \frac{2}{3}$ Cos.² l	628.651
$m\ \frac{2}{3}$ Sin.² l − M $\frac{2}{3}$ Sin.² L 852.714	Log. 2.930803	M $\frac{2}{3}$ Cos.² L − $m\ \frac{2}{3}$ Cos.² l = 847.080	
M $\frac{2}{3}$ Cos.² L − $m\ \frac{2}{3}$ Cos.² l 847.080	Log. 2.927925		
	2)0.002878		
$\frac{c}{d}$ = 1.0033	Log. 0.001439	$\frac{c}{d} - 1 = \frac{1}{300}$ Compression.	

Here, therefore, we have $\frac{1}{170}$, $\frac{1}{1250}$, and $\frac{1}{300}$, which vary *inter se* in a manner very similar to what might have been expected; but we may yet pursue the inquiry further, by considering the quantity $\frac{1}{300}$ as derived from the last comparison to be constant, since it is not very different from what has been derived from the best accredited modern operations. Making, therefore, always M and L apply to the lower latitude, m and l to the higher, we shall have two well known formulæ $m = \left(\frac{\frac{c^2}{d^2}\text{Cos}^2 L \times \sin^2 L}{\frac{c^2}{d^2}\text{Cos}^2 l \times \sin^2 l}\right)^{\frac{3}{2}} \times$ M or else $M = \left(\frac{\frac{c^2}{d^2}\text{Cos}^2 l \times \sin^2 l}{\frac{c^2}{d^2}\text{Cos}^2 L \times \sin^2 L}\right)^{\frac{3}{2}} \times m$, in which, substituting as before, we shall know of what length the arc measured in this latitude must be in order to give a compression of $\frac{1}{300}$ when compared with each of the other two.

1st Comparison *m* determined for De La Caille's Arc from Bouguer's.

Sin.^2 L 1° 30′ Log. $\bar{4}$.836838 N. N. 0.0006852	$\text{Sin.}^2\, l$ (33° 18′ 30″) Log. $\bar{1}$.479374 N. N. 0.3015604
$\frac{c^2}{d^2} = \overline{1.0033}^2$ Log. 0.002878	$\frac{c^2}{d^2} = \overline{1.0033}^2$ Log. 0.002878
Cos.^2 L 1° 30′ Log. $\bar{1}$.999702	$\text{Cos.}^2\, l$ (33° 18′ 30″) Log. $\bar{1}$.844128
$\frac{c^2}{d^2}$ Cos.^2 L . . Log. 0.002580 N. N. 1.0059583	$\frac{c^2}{d^2}$ Cos.^2 L . . . . . Log. $\bar{1}$.847006 N. N. 0.7030823
$\text{Sin.}^2 L \times \frac{c^2}{d^2}\text{Cos.}^2$ L. Log. 0.002875 N. N. 1.0060435	$\text{Sin.}^2\, l \times \frac{c^2}{d^2}\text{Cos.}^2\, l$ Log. 0.002012 N. N. 1.0046427

$\text{Sin.}^2\, l \times \frac{c^2}{d^2}\text{Cos.}^2\, l$ Log. 0.002012

0.000863
3

2) 0.002589

0.001295

M = 56740 . . . . . Log. 4.753958

m = 56918.4 . . . Log. 4.755253

These measures, excepting those of the Quito Arc, are taken from a very old edition of Dr. Hutton's Philosophical Dictionary; for the principal part of my library being in India, I have by me very few books of reference. The comparisons are sufficient for my present purpose; but I shall hereafter compare the more modern measurements of De Lambre, Colonel Lambton and General Mudge with De la Caille.

2d Comparison, M determined for De la Caille's Arc from Cassini's.

$\text{Sin.}^2\, l$ 49° 22′	Log. $\bar{1}.760360$	N. N. 0.5759173	
$\frac{c^2}{d^2} = \overline{1.00331}^2$	Log. 0.002878		
$\text{Cos.}^2\, l = 49° 22′$	Log. $\bar{1}.627450$		
$\frac{c^2}{d^2}\, \text{Cos.}^2\, l$	Log. $\bar{1}.630328$	N. N. 0.4269020	
$\text{Sin.}^2\, l \times \frac{c^2}{d^2}\, \text{Cos.}^2\, l$	Log. 0.001223	N.N. 1.0028193	
$\text{Sin.}^2\, L \times \frac{c^2}{d^2}\, \text{Cos.}^2\, L$	Log. 0.002012		
	$\bar{1}.999211$		
	3		
	2) $\bar{1}.997633$		1st Result 56918.4
			2d Result 56918.7
	−1.998817		Mean 56918.6
$m = 57074$	Log. 4.756438		
$M = 56918.7$	4.755255		

The mean of these results, or 56918.6 toises, is what would belong to a degree in latitude 33° 18′ 30″ south, upon the hypothesis that the earth was an ellipsoid of revolution with a compression of $\frac{1}{300}$; and had the arc measured in this latitude been found to be of that size, the three arcs introduced into these calculations would have led to the same conclusions. Now as the whole measure of the Abbé De la Caille's arc was 410814 feet* = 68469 toises, if we divide it alternately by 56918.6 and 57037 toises, the difference of our two quotients in degrees will be the approximate sum of the small angles of error, which I have above supposed to exist under the form of $a \times b$.

* Vide Hutton's Philosophical Dictionary, page 233.

Now, $\frac{68469}{56918.6} = 1^\circ\ 12'\ 10''.54$ on the meridian by hypothesis.

And $\frac{68469}{57037} = 1^\circ\ 12'\ 1''.55$ Ditto by De la Caille. The difference therefore is 8″.99, to be divided between both stations of observation; and perhaps this will not appear too great, when the localities described in the foregoing pages are duly taken into consideration. We know that Schehallien did exert a lateral attraction sufficient to cause a deviation of 5″.8*. We know further, that MM. Bouguer and De la Condamine had found by experiment that 7″½ was the effect of Chimboraço; and I think I have made out undeniably that in no part of the globe is this disturbing force more likely to have prevailed than at Cape Town, whilst the site of observation at Klip Fonteyn could hardly have been free from its effects. The irregularities which may have attended the terrestrial measurements cannot here of course be taken into consideration, because they are as likely to have tended to increase as to diminish the length of the arc; but still the very uncertainty under which they labour is sufficient to throw doubt upon the whole operations; and at least I think it must be admitted, that the measurement in this quarter of the globe is by far too dubious to establish the theory which would assign to the southern meridians a different ellipticity from that found to obtain in the northern hemisphere.

Were the operations in themselves of sufficient importance, it might indeed be an object to measure them again; but as it would be impossible perhaps to place an instrument over the centre of the site of the Observatory at Cape Town, or indeed at any one of the stations, excepting Riebek's Castle, I see not what would be gained by such a procedure. It might be interesting, no doubt, to ascertain the exact latitude of both extremes of the arc by a series of triangles connecting them with the Observatory now about to be erected in this neighbourhood; and this, which will doubtless be hereafter done, may in able hands furnish a *new* datum respecting the attraction of mountains; but as to the arc itself, it seems to me to be too small to be of any weight, even were all other objections removed; and the labour of correcting the old results, except for the mere curiosity of the matter, would therefore be much better expended on a perfectly new series of triangle.

Such a series, instead of terminating at Klip Fonteyn, might very easily be

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* Vide Vince's Astronomy, pages 99 and 100.

carried through the country of the Namaquas to the northern boundary of the colony, which would furnish a very pretty arc of nearly four degrees in amplitude, and I doubt not set for ever at rest the anomalous hypothesis of the different form of the two opposite hemispheres of the globe.

In no country indeed could a datum of this nature and of equal importance be obtained with less personal toil and suffering to the individuals engaged in it; for the climate is perhaps without a parallel on earth, the face of the country presents no appalling difficulties, and there is a degree of hospitality and readiness to oblige on the part of the colonists in general, which would render a sojourn amongst them highly pleasing and satisfactory.

In the hope that the description above offered will meet your expectation, I shall now bring my report to a close; but I shall at all times be happy, after we meet, to enter into any further explanation of such points as you may consider to require elucidation. In the mean time, allow me to subscribe myself

Your very obedient servant and sincere friend,

George Everest,
Capt. Bengal Artillery, Chief Assistant to
the Geod. Trig. Surv. of India.

THE ACHIEVEMENTS OF SIR GEORGE EVEREST IN GEODESY

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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 $c(1-e^2)^{\frac{1}{2}}$, whereas at the poles it is $a/(1-e^2)^{\frac{1}{2}}$.

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.

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THE DEVELOPMENT OF SURVEY OF INDIA FROM THE TIME OF SIR GEORGE EVEREST TO MODERN DATE

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Everest, during his tenure in Survey of India, brought a technical revolution in survey work, by bringing it on a sound scientific system. He set out new procedures for day-to-day working in taking observations and laid down accuracy standards in respect of quality of observations. Instrumentation was improved to such an extent, that even the observations taken then are comparable with the observations taken with the modern instruments. Survey of India owes a lot to Everest for laying the foundation of a high quality trigonometrical control work based on which detailed topographical maps were produced subsequently.

The base, which Everest provided has taken a giant leap in shaping the Survey of India as it exists today. It has grown up many folds since the time of Everest. With the advent of scientific advancement in survey technology, many new branches have come up and blossomed such as geophysical sciences, photogrammetry, cartography, etc; all these have given a new shape to the organisation. The progress of Survey of India over a span of about 150 years since Everest, can best be assessed by the following account.

Base Measurement

The scientific measurement of base line by Colonel Everest replacing the Ramsden's steel chain started in 1830. The base line was measured in terms of Indian standard Bar 'A' by using Colby's apparatus. During 1930, 4 metre and 24 metre comparators, standardised against 1 metre Nickel Bar, were installed at the observatory in Dehra Dun for calibration of working invar wires. The Nickel standard bar is standardised in terms of International Metre kept at the National Physical Laboratory, Teddington. However since 1960 EDM/EODM instruments are being used for base measurements. A long base line has recently been measured from Delhi to Kalianpur, in the form of diamond chains (zero-order traverse) consisting of triangulation, trilateration observations using T-3 theodolite and geodimeter, to check the scale for the Doppler Satellite Surveys. India had accepted conversion factor from feet to metre as 0.3047996 in terms of 10 feet 'A' Standard Bar.

Geodetic Triangulations

The measurement of Great Arc from Cape Comorin to Himalayas was completed by Everest following his 'gridiron' system which consists of meridional chains of triangles tied together at the upper and lower extremities by longitudinal chains. As per Everest's plan the work was carried out by his successors, Colonel Waugh and others. Indian Triangulation was first adjusted in 1880. The inherent weaknesses of the triangulation were soon discovered by J de Graff Hunter and Captain G Bomford in 1916 and 1917 respectively. These were (i) the ill-fitting nature of the ellipsoid (ii) inadequate bases (iii) lack of laplace observations and (iv) non-application of various geodetic corrections like deflection, skew normal etc.

Captain Bomford classified the Indian triangulation into primary and secondary order according to their accuracies superseding the early criteria of assessment based on the accuracy standards given by Hunter. He pin-pointed the weak points of Indian triangulation, and accordingly Survey of India had taken up the revision of secondary series under upgradation and densification scheme.

There is a growing realisation that Indian geodetic triangulation needs an immediate review as also the redefinition of Everest Datum. However, since 1927, International Spheroid is being used for scientific purposes. Many bases along with Doppler vectors and Laplace observations have since been added to the principal Indian Triangulation and the origin of Indian Triangulation, ie, Kalianpur has been thoroughly studied and redefined. Efforts are being made to find a suitable program which could simultaneously adjust about 5000 stations of Indian Triangulation at a time. The finalisation of the technique to be followed for the adjustment of triangulation data for the country, is in hand.

For the time being the transformation parameters between Everest's Spheroid and WGS-72, have been worked out, so that the coordinates of stations as derived from Satellite observations could be converted into Everest terms. Recently we have also procured few GPS receivers which would help us to connect our islands with the mainland and also carry out various geophysical studies.

Discovery of Mount Everest

The discovery of Mount Everest as being the highest peak in the world was made by making observations on the snowy peaks of Himalayas. The observations were excluded from Nepal and thus the observations had to be carried out at a distance of about 160 km from the peaks in jungle covered plains of Bihar and U P and infested with malaria. The observations were carried out in 1847 and calculations were ready by March 1856. Subsequently the observations were also made in 1950 and the revised value of the height arrived at.

Gravity

The importance of gravity/pendulum operations was felt during the time of Colonel Everest, while studying the effect of local attraction and attraction due to the Himalayas, on the measurement of 'Great Arc'. Everest contemplated on such investigations and while in England during 1826-30, he obtained two pendulums of Kater's inversible type and sent them to India. But the pendulums were never used and the idea of making pendulum observations a part of the survey, seems to have dropped out of his mind, until it was revived in 1864 at the suggestion of Major General Sir Edward Sabine, President of the Royal Society.

Pendulum observations were started in India in 1865 by Captain Basevi and Captain Heaviside at Dehra Dun and then at Kaliana, the northern most station of the 'Great Arc'. Captain Heaviside carried out observations with Russian pendulums. Major Herschel (SOI) tried to establish criteria for the vertical attraction of irregular mountain masses but Archdeacon Pratt (1860-61) set himself to calculate the actual amount of attraction of the Himalayan masses and of the deflection/deviation of the plumb line, at the three stations of the 'Great Arc', and as such propounded the 'Theory of Isostasy' in 1852; later G B Airy gave another theory taking into account the work of 'Great Arc'. Thus India is the birthplace of the theory of Isostasy, which is a significant contribution to the geophysical sciences.

The need for these gravity observations/operations was more and more felt to study the figure of the earth, ie, geoid. The various branches of earth sciences viz Geophysics, Geology, Geodynamics, Seismotectonics and 'Prospecting' for the economic development of the country - all require gravity data and as such Survey of India is systematically covering the whole country with a mesh of gravity stations, 15 km apart. These provide valuable information as regards various gravity anomalies, gravity deflections and undulations. We have also plans to start helicopter gravity survey in the Himalayas and also intend to make earth tide observations at a few places around the country and also establish absolute gravity stations with foreign collaboration.

The contributions of Dr Hunter, Burrard and after independence of Shri Gulatee and Dr J C Bhattacharjee are held in high esteem amongst the scientific community. Shri Gulatee has determined gravimetric geoid in the high Himalayas and also corrected the height of Mount Everest.

Standard gravity stations were established at Palam Airport, Delhi in the '50s by taking repeat observations with absolute gravity instruments in terms of Potsdam standard gravity station by various foreign agencies. Afterwards this station was connected to Dehra Dun by repeating observations. Subsequently, almost all airports of the country were connected (by air) for establishment of sub-standard gravity stations using Lacosta-Romberg gravimeters.

<u>Magnetism</u>

Magnetic operations were started in India by Captain Boileau in 1840, during Everest's tenure as Surveyor General. The magnetic operations were kept in abeyance until 1896 when it was proposed to set up Magnetic Survey of India by Sir John Eliot, a meteorological reporter to the Government of India and General C Strahan, RE, Surveyor General of India. The proposal was also recommended by W H M Christie and Sir J Norman Lockyer, who visited India in 1859 in connection with the total eclipse of the sun.

The first determination of the values in respect of each element of the earth, ie, Dip, Declination and Horizontal force etc, were made in 1901, with instruments like Dip circle and conventional magnetometer etc of Survey of India pattern.

The magnetic observatories were also established in various parts of the country during 1902-1904. Alibagh (Colaba) observatory, was shifted to its present site in 1904 though it was established in 1940 and the value of base line of five magnetic observatories was determined in 1920. Studies of secular and diurnal variations was continued in addition to analysis of data in respect of various abnormalities/disturbances.

The magnetic observations with conventional magnetometer was continued until 1940 and after independence rapid strides were made for advancement in the field of magnetism in Survey of India in particular and in the country in general. The magnetic operations were not given much attention during World War II, as the complete strength was deployed on topographical surveys.

The procedures of magnetic observations were switched over to modern methods with the advent of QHM, BMZ, Vector Magnetometer, etc. Our local observatory at Sabhawala, which was commissioned in 1964, is recording continuously observations with Kew pattern magnetometer. Askania and Lacour magnetic instruments were also installed in the observatory. Continuous photographic recording of the three geomagnetic elements is being done. Magnetic instruments are calibrated in our Sabhawala observatory and also are standardised at Alibagh observatory, before and after the field observations. There are about 182 repeat stations, spread over the entire country, on which observations are taken at an interval of five years for the preparation of epoch charts.

Recently in 1979-80, data of Magsat, to measure earth magnetic field on global basis, pertaining to Indian sub-continent in collaboration with NASA and USGS were taken for analysis and the regional model of the main field was computed and co-related studies were made. Magnetic observations were also carried out with two geomagnetic elements viz HF and VF at 5-km apart in connection with deep seismic sounding in Peninsular India.

Tides

Tidal observations in India did not form part of survey operations during Everest's time. Though the earliest recorded tidal observations was observed by James Kyd at Hooghly River (1806-27) but a breakthrough was made in 1871-2 by Major B R Branjill of Survey of India, who introduced a self-registering tide gauge at Tuticorin and the observations were reduced by simple Harmonic analysis. However on 4 July 1877, Survey of India was entrusted with tidal observations under Captain Baird.

Tide Predicting Machine, with 24 components, was brought to India in 1921 and in 1953 a latest tide machine with 42 components was set up and first predictions with this machine was published in 1956. Survey of India made many headways in this field and covered many standard and sub-standard ports, which were earlier not done (until 1947) for harmonic analysis and synthesis. Survey of India has now started replacing the old and irrepairable tide gauges by the ones indigenously produced in Survey of India itself.

Since 1978, the synthesis and prediction of tidal data has been switched over to electronic computer device.

The predictions of each port are based on data produced by the analysis of a sufficient series of tidal observations. The predictions take into account the effects of seasonal changes in the meteorological conditions and deduced by analysis from observations but do not include the effects of temporary and unpredictable meteorological conditions.

The predictions of river and shallow water ports are calculated by the harmonic method with harmonic shallow water corrections. Predictions are made for 76 standard ports, 44 ports between Suez and Singaport, 32 ports along the Europe, Africa, China, Japan, S E Asian coast etc, 17 shallow water ports and 16 secondary ports along the Western coast of India. Determination of M S L based on tidal observations is a continuous process for the vertical datum of the country. Under world activity programme, monthly mean sea level data of 24 ports is being supplied to the permanent service of Mean Sea Level (PSMSL). A project of modernisation of existing tide gauges, which are of old designs, is being formulated under the GLOSS (Global Sea Level Observing System) and Tropical Oceans and Global Atmosphere (TOGA) programme of Intergovernmental Oceanographic Commission (IOC) of UNESCO for quick collection of the sea-level data and processing of these for long term climate predictions and allied objectives of crustal movement sutdies, flood forecasting, storm surge warnings, etc.

Astronomy

Astronomy became an increasingly active and popular discipline during Everest's time, since observations of azimuth for control of direction was made at the start and close of every series of triangles, whether meridional or longitudinal. Intermediate azimuth was observed along the 'Great Arc' mostly with 36 inch and 24 inch theodolites known as great theodolite and astronomical instruments. Everest introduced modifications for azimuth observations with circumpolar stars. He used zenith sector for determination of amplitude of arc, modifying earlier procedures of observations as used by Lambton.

The astronomical observations played a significant role for determination of astro-geodetic geoid and to improve upon the triangulation network by basing on the Laplace azimuth. As such in this discipline of surveying, a dramatic change came after Everest because positional astronomy became an important tool in the field of geodesy. Since 1848 to 1957-58, the instruments used were Barrow's 24 inch theodolite No.1, Strange's Zenith Sector No.1, Transit telescope No.1, 60 Astrolabe (Geodetic Model); Zenith telescope, Motor Transit, Hunter's Shutter Transit, Wild T-3 with Astrolabe attachment, Wild T-4 and Danjon Impersonal Astrolabe.

For astronomical observations, three types of instruments are required:

i) Observational

ii) Time Keeping

iii) Time Recorder.

In time keeping and time recorder, the following instruments were/are used:

Crystal clocks
Wireless set National/Telefunken
Chronograph Mercer/Favag
Time Recorder-2 and
Chronochord etc.

Different observatories were established after 1884 viz Hennessey observatory, which was built for sun photographs. In 1924 Shortt clock and Riefler clocks were installed in this observatory. The observatories were/are:

i) Hunter Observatory built in 1925 for housing the transit instruments for high class time determination

ii) Haig Observatory for latitude observations, built in 1886. An old zenith telescope No.1 and in 1928 a large zenith telescope were installed in it. This is still being used for latitude variation studies.

iii) Danjon Astrolabe Observatory established in 1972, used for determination of time and latitude. This is connected to crystal clock.

India started taking part in various scientific studies in respect of international projects on polar motion and earth rotation, when some world observatories began emitting time signals in 1920. India took part in International Longitude project of 1926-29 and Latitude project of 1930-33 and in Geophysical Year 1957 for latitude variation and polar motion studies etc.

Since space techniques are gradually replacing astronomic methods, India is trying to catch up with the technology in a modest way having already acquired GPS and is on the threshold of procuring SLR and VLBI.

Levelling (A Vertical Control)

Levelling was not started during Everest's time. Before 1858, the heights were determined only trigonometrically. The first levelling operations in India was planned and carried out by General Walker, known as the Father of Indian levelling. The first level net which forms the part of levelling operations from 1858 to 1902 was adjusted by Colonel G S Burrard. The present system of fore and back levelling was introduced in 1913-14. Wooden staves were used up to 1933 and invar staves were brought in from 1929-30 and gradually a procedure for data acquisition has continuously been improved since 1930.

The first level net consisted of 86 levelling lines of about 20,000 linear kilometers and was based on mean sea level of 9 ports. The second level net comprising of 99 lines after upgrading some of the previous lines, consisting of about 26,500 linear kilometers and was also adjusted based on 4 ports.

The third level net has been taken up as the second level net:

i) did not differentiate between geologically stable and unstable areas

ii) used normal gravity values instead of standard gravity values

iii) adopted an arbitrary system of weighting and constrained the adjustments to fit the local mean sea level at 4 ports.

Therefore the third level net has been divided into two portions:

The Phase I consists of stabler peninsular Indian portion and has been adjusted using standard gravity based on 1 port, ie, Bombay, using Wassef's formula for weighting. It comprises 50 lines.

The Phase II, consisting of remaining India, is in hand, which will be adjusted based on the values of Phase I when the standard gravity values of the standard benchmarks are available.

Geodetic control for Engineering Projects

The rapid advancement in the country to meet the increasing demand of water and power supply and the industrial boom posed many new challenges on the Survey of India. The execution of such projects etc including the construction of large structures which are safe over a longer period of time calls for greater accuracies in the surveying operations. Survey of India has carried out all such surveys including grid layout for installations of various plants, tunnel alignments for survey in dams and thus paving the way towards progress.

Deformation and Seismotectonic Studies

Deformation studies in respect of large structures, ie, dams etc, is a continuous process as a routine. India has taken up the seismotectonic studies at places situated in different parts of the country which are prone to seismic effects, basing the analysis of data on high precision levelling, triangulation, gravity anomalies, magnetic anomalies etc, along with the geology of the area. Survey of India intends to use latest instruments like GPS, VLBI, SLR etc in connection with plate-tectonic studies etc. Verticality of large structures is also being measured in addition to crustal movement studies across the fault zones of the country.

Instrumentations/Repair Workshops

Survey of India has gone a long way since the first repair workshop of surveying and mathematical instruments was opened at Calcutta during 1830 by Everest, which manufactured astronomical circles. This was continuously developed to a great organisation and is now known as National Instrument Ltd. It was separated from Survey of India in 1941.

Survey of India had however established its own repair workshop at Dehra Dun and after Independence opened another at Hyderabad to meet the ever increasing demand of repair of surveying instruments. The workshops were continuously upgraded to meet the challenge of repairs of modern sophisticated electronic, photogrammetric, geophysical and optical instruments.

Survey of India had the credit of designing and developing simple survey instruments such as Abney Level, Clinometers, Sight Rule and Plane Table and has more recently developed Traverse Targets, Electric Signals etc.

It has also fabricated a prototype of E D M instruments known as 'Doori Mapak'. R&D activities towards development of Auto Set Level, Solar Battery Charger, Metallic Staves etc (Invar etc) and Alap Dori Mapak based infra-red are continuing.

Topographical and Photogrammetric Surveys

During the Everest time mostly revenue surveys were undertaken on priority. The topographical and geographical surveys were authorised for limited areas only. The compilation of 1/4" maps of the whole country was, however, taken on a priority basis.

Since then Survey of India has made tremendous progress in this field. The entire country has now a cover of topographical maps on 1/50,000 scale, which is one of the rare achievements.

The use of photography as a tool for survey operation dates back to 1899, when a photo theodolite was procured for valuation of its mapping potentiality (Bridges-Lee). But the recorded systematic photography came in 1927 on scale 4 inches to 1 mile. Since then, over the years, the entire country has been systematically covered by photographs on various scales. The ground survey method employed in the past up to 1930, were very time consuming due to unfavourable weather conditions, in addition to hazards to the surveyors. The introduction of photogrammetry simplified the work of ground surveyors to a considerable extent. The first plotting instrument was installed in 1950. Since then rapid strides have been made in the field of photogrammetric surveys replacing the graphical method. After 1955, with the acquisition of analogue instruments of high precision, photogrammetric plotting from stereo models was adopted. Now Survey of India has analytical photogrammetric instruments available in many of the Directorates.

Computer Assisted Cartography

Though developments in Computer Assisted Cartography started in the mid-1950s the first prototype of semi-automated Carto system was displayed in the second conference of ICA in 1964. The necessity of introducing Computer Assisted Cartography was well understood by SOI and in 1981, an automated Cartography Cell was raised under R&D mode. The cell developed necessary softwares to meet the various demands and has successfully developed a system for large scale urban/rural mapping from aerial photographs without the aid of any photogrammetric plotter.

SOI soon recognised that normal digitizing was an expensive road block. Action was therefore initiated to establish the Digital Mapping Centre at Dehra Dun and Hyderabad and the Modern Carto Centre at Dehra Dun which are now fully operational. The introduction of digital equipment has resulted in the automation of various phases of conventional mapping processes apart from creating data for GIS.

Remote Sensing

During the last decade, SOI has been preparing itself to develop the necessary knowledge to exploit the satellite imagery for cartographic purposes. Geodata base which is a combination of Remotely Sensed data with thematic and cartographic information is being created with the help of Land Sat and TM Imageries in certain specified areas and has been evaluated for generation of thematic maps. Some of the data received through IRS-1A has also been utilised for updating of 1:250,000 maps.

Realising the importance of remote sensing, SOI has recently procured two image processing and analysis systems.

Fair Drawing

Conventional methods of fair drawing are being replaced by the latest scribing techniques.

Reproduction and Printing

Much of the Surveyor General's printing work was handed over to private firms and it was not until 1841 that a branch of the Government Lithographic Press was placed at its service. The departmental press was not established until 1852. It was a great step forward when machines and staff were transferred to the Surveyor General's Office in 1852 at Calcutta. The first important task of the new office was the printing of Postage Stamps of India during 1854-55, pending supply from England. The first stamp was printed on 4 May 1854. Over the years, the reproduction techniques has undergone revolutionery changes and Survey of India is now well equipped with the latest printing machines.

Exploratory Boundary Surveys

Survey of India in the remote past has produced great explorers for transfrontier exploratory surveys. Two of the earliest Indians who made a name in this field were Pandit Nain Singh and Kishen Singh, who did exploratory surveys in Tibet which is adjudged as a remarkable feat. Survey of India has also undertaken various jobs of demarcation of International boundaries viz Bangladesh, Parkistan, Burma, Nepal etc.

Training

The Centre for Survey Training and Map Reproduction, Hyderabad, is a premier training establishment in surveying and mapping in this part of the world. The centre imparts training both at the technician as well as professional level to departmental, extra-departmental and foreign trainees. It also conducts post graduate level courses, and is in the process of being recognised for carrying out doctoral level studies. Before the establishment of Survey Training Institute the surveyors had to be trained in survey training parties.

Establishment

After Independence, Survey of India has multiplied manifold and at present is one of the largest Governmental departments in the Government of India. Its strength during 1988-89 is as follows:

Group 'A'	367)	825
Group 'B'	458)	
Group 'C' (Div.I	1724)	7030
Group 'C' (Div.ii)	5306)	
Ministerial Est.	1378	1378

Survey of India extended survey support to Indonesia, Nigeria, Bhutan, Bapal and Iraq etc.

Conclusion

Survey of India has kept apace with the rapid advances in science and technology and has made many headways in the field of geodesy and map making since the time of Everest. The department has contributed significantly in the development projects in the country. The post-Independant period has brought forth an upsurge of activities for defence, development and administration. There has been continued effort in Survey of India to adapt itself to the new technological developments in the fields of geodesy, photogrammetry, Computer Assisted Cartography, remote sensing and map reproduction and to make innovations as an inhouse effort.

The field of survey has developed from topographical map making to complex multi-disciplined structures and is fast developing especially with the advent of high speed computers. Our R&D directorate has been entrusted with the job of keeping ourselves abreast with the pace of development in the various fields of cartography, geodesy, map printing etc.

In the field of instrumentation we are trying to make instruments for import substution. Mention has to be made for GPS, Orthophoto mapping system, digital terrain mapping system, Interactive Cartographic system, and we in Survey of India have taken a note of these developments and brought them in use as relevant to our situation.

THE NEW 1:50,000 MAP OF MOUNT EVEREST

Dr W Altherr, Swiss Air Photo Survey, Obstgartenstrasse 7, PO Box 288, CH-8035 Zurich, Switzerland.

"Survey by air has a prominent place on its own merits as the swift and sure instrument for topographical mapping, although hitherto it has seldom, if ever, been used except at comparatively low altitudes".

Pilots of the 1933 British flight of a pair of bi-wing aircraft over the summit of Mount Everest (Fellowes et al., 1933).

1. INTRODUCTION

What seemed to the pilots of the 1933 Mount Everest flight a novel technology - aerial photogrammetry, then only occasionally used - has grown in the meantime to be a standard procedure as a first step in topographical map production.

As well as the many standard applications there are now and then projects evolving which require, because of political, economical, logistical and/or topographical constraints imposed upon them, a well-balanced combination of conventional techniques and new, partially unproven approaches.

The recent mapping of Mount Everest at a scale of 1:50,000 was such an ambitious project. This project was relentlessly pursued by Bradford Washburn after his retirement in 1980 as Director of Boston's Museum of Science, and sponsored by the National Geographic Society together with the Museum. In the National Geographic Magazine, Vol.174, No.5, November 1988, a report was given both about some of the technical aspects and about the tremendous organisational efforts which were necessary to make such a project a success.

In (Washburn, 1990) a more detailed description of these organisational hazards and the inspiring personal involvement of Bradford and Barbara Washburn and other persons concerned with the project will be given. This contribution focusses on the technical procedures, and is as such based on three earlier reports (Altherr, Grün, 1989; Jeanrichard, 1989; Grün, 1990).

2. PREPARATION OF FLIGHT OPERATION

2.1 Selection of aeroplane

The flight planning shows our flight lines on an elevation of 43,000 ft and therefore the use of a jet plane became a necessity. With a maximal altitude of 45,000 ft, the Learjet was a natural choice. Futhermore, the modifications for installing our RC-10 camera were minimal.

2.2 Navigation concept

As frequently found in remote places like the Himalaya, no useful maps were available for a visual nagivation. Therefore, a navigation system was needed which allowed for an accuracy of +/- 200m for the flight lines.

The Learjet was equipped with a global navigation system GNS 500A (VLF/Omega). The cockpit crew foreseen for the mission in Nepal had already tried out this sytem successfully over flat terrain for small scale applications in Africa, but never before in places like the Himalaya. To be on the safe side some kind of visual navigation would be needed as additional control of the Omega system.

At the end of 1981 it came to our knowledge that during the next Space Shuttle Mission a Zeiss Metric Camera RMKA 30/23 photography out of 244km above ground was foreseen. We decided that an enlargement of 1:100,000 would be an ideal navigation help for this mission. Brad Washburn contacted NASA to make sure that the East Himalaya would be included in the next Space Shuttle Mission.

2.3 Films

It was planned from the very beginning to shoot the photography with minimal snow coverage in order to get a good and realistic ground coverage corresponding to the summer season. In Nepal, this is usually the case in November and December which happens to be a time of stable weather. Even if the Himalaya is on the same latitude as Cairo, the shadows are extremely long due to the large height differences and extremely hard due to the clear and crisp air.

For practical reasons, film and developer had to be chosen previously to the mission in Nepal. Over the Swiss Alps, a Kodak Plus X 2402 film was successfully tested, using always the same filter. The developer Kodak DK50 was tested in two different compositions, to find out the best solution for developing large snow areas and at the same time hard shadows.

3. FLIGHT OPERATION IN NEPAL

On 13 December the Learjet chartered at Swedair arrived in Zurich and the camera was built-in for a flight test. Unfortunately, a navigation test with the Omega system was not possible due to bad weather over the whole of Europe. After landing in Nicosia, Dubai and Karachi, the Learjet landed on 16 December at 10.00pm in Katmandu.

20 December was to be the day. At 11.50am, after the morning fog had lifted from the Tribhuvan airport, the Learjet took off and reached the Everest region 20 minutes later. We were back at 3.20pm in Kathmandu. In this short time hard work had been done by the Learjet team (Fig.1).

The calibration of the Omega system at Kathmandu airport as well as the calculated and registered geographical coordinates of the beginning and end points of the flight lines and the first pictures proved to be very accurate.

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Erratum page 68.

Prof. Dr A Gruen, Institute of Geodesy and Photogrammetry,
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The calibration of the Omega system at Kathmandu airport as well as the calculated and registered geographical coordinates of the beginning and end points of the flight lines and the first pictures proved to be very accurate.

Adapting to the planned flight lines (16km before taking the first picture) functioned very well, with the time indication given by the Omega system being very useful for the navigator. The cockpit crew was also grateful for smaller and larger corrections given by the navigator through the use of the enlarged Space Shuttle pictures. The Omega system was not accurate enough to guarantee the accuracy of +/- 200m for the flight lines having a length of up to 65km.

The usual, alternative pattern of flight coverage was not possible due to the very strong jetstream blowing with approximately 240km/h from west to east. The Learjet could not get below 900km/h over ground in a west-east direction, which would have caused problems with the sharpness of the pictures.

At these elevations the temperatures were -50 to -56 degrees Celsius, so that a large ice-shell was built up around the outside camera parts (Fig.2 and 3).

All films and some 100 copies were made at the Survey Department lab. On 22 December, a second flight covered the whole colour program (Fig.4).

4. AERIAL TRIANGULATION

After aerial photography a major problem consisted of the determination of control point coordinates for block triangulation. Because of the high map standard requirements the graphical extraction of control points from existing maps would not have been appropriate. The application of terrestrial surveying methods, even in their most efficient form - via GPS - was not feasible for several reasons. Therefore a novel approach was required. Fortunately, photogrammetric cameras had been carried on two Space Shuttle missions a short time before and metric photographs taken of the Mount Everest region. Experiments with the NASA Large Format Camera (LFC) were carried out on a Challenger mission between 5 October and 13 October 1984. However, the photographs from ESA's Spacelab Metric Camera (MC) experiment on the Space Shuttle STS-9 Columbia mission between 28 November and 7 December 1983 did show the region of interest with less disturbing clouds and were thus selected for processing. The basic idea was to derive the control points needed for the triangulation of the aerial block from a stereopair of space photographs.

4.1 Control point determination from ESA Metric Camera photographs

On 2 December 1983 at 3.30 Greenwich Mean Time (9.30 Local Time) the astronauts on Space Shuttle STS-9 Columbia produced a series of excellent cloud free colour infra-red Metric Camera photographs over the Mount Everest region. A suitable stereomodel with 60% overlap was selected from this strip (photograph nos.01-0013-01 and 01-0015-01). Table 5 shows the project parameters of the Metric Camera photographs.

Flight:	ESA Spacelab 1 on board NASA Space Shuttle STS-9 Columbia
Mission duration:	28 November - 7 December 1983
Exposure time:	2 December 1983, 3.30.58 GMT
Flying time:	244km
Speed over ground:	7.6km/sec

Sun position:	Elevation 29º, Azimuth 140º
Camera:	RMK A 30/23
Camera constant:	305mm
Photoscale:	1:800 000
Film material:	Colour infra-red KODAK 2443

The processing of this stereomodel was done on the WILD AC-1 analytical plotter at the Institute of Geodesy and Photogrammetry of ETH Zurich.

The control points for the absolute orientation were taken from the topographical map 1:100,000 of the Royal Geographical Society, which is based on the British Survey of 1921-36, the Austrian Survey of 1957 and Chinese Surveys of 1960 and 1975.

After determination of the map sheet deformation from 15 grid points, which turned out to be less than 0.3mm, 45 full control points and 14 planimetric control points were digitised on a WILD Autograph A8 plotting table. These control points were all natural features and their coordinate accuracy was estimated to +/- 25m.

For the orientation of the stereomodel on the AC-1, the control point coordinates were transformed into a local orthogonal tangential coordinate system, in order to make them compatible with the orthogonal image space systems of the photographs. The orientation was performed with the two-step procedure (relative-absolute orientation) and was, after deletion of erroneous points, finally based on 18 full control points and 1 planimetric control point.

Figure 6 shows the control point distribution for the absolute orientation of the MC-stereomodel.

The RMS errors for the spatial similarity transformation of the absolute orientation resulted in σ_{xy} = 45m in planimetry and σ_z = 31m in height. Here it is obvious that the a priori planimetric accuracy of the digitised control points was not as good as expected. Inaccuracies in digitisation, problems with point definition and errors of the original mapping accumulated to errors larger than +/- 25m. As was shown in (Grün, Spiess, 1987) the inherent geometrical accuracy of this kind of space photography is much better; with well defined control and check points the processing of an LFC-stereomodel gave accuracies of μ_{xy} = 8m in planimetry and μ_z = 11m in height. However, through the use of the two-step orientation procedure the good internal stability of the photogrammetric model is preserved and not distorted by low quality control points. In addition, through the use of a highly redundant number of control points the model orientation could be considered sufficiently good.

After orientation, 102 natural points were measured in the MC-stereomodel in order to serve as control points for the block adjustment. Figure 7 shows the distribution of the MC-control points within the aerial photogrammetric block.

4.2 Aerial triangulation by model block adjustment

The measurement of model coordinates and the adjustment of the model block was made by Swissair Photo + Surveys Ltd, Zurich. The aerial block was flown with 80% forward overlap and 35% sidelap. The average photoscale was 1:35,000. For the model block adjustment 77 models were used, which were arranged in 8 strips with 60% forward overlapping photographs. To the 102 control points from the MC-stereomodel other height control points were added, which were taken from the 1:50,000 map of Mount Everest of the German and Austrian Alpine Club and the German Research Foundation. The peak height of Mount Everest was fixed at 8848m. After a few initial computer runs the gross erroneous points were deleted and the final adjustment was executed with 99 planimetric control points and 92 height control points.

Statistics of aerial triangulation

Mount Everest:	N = 27º 59′ 16" E = 86º 55′ 40" Z = 8848m/29028 ft.
No. of models:	77 within 8 strips
No. of control points from MC-stereomodel:	87
No. of height control points from map 1:50,000:	29
No. of tie points:	148
RMSE at tie points:	σ_{xy} = 3.3m; σ_z = 2.5m
RMSE at control points:	σ_{xy} = 17.5m; σ_z = 10.6m
Estimated a posteriori accuray of model coordinates:	σ_o = 6.0m

These results indicate that a major part of the error budget is due to inaccurate control points. However, with its considerable height differences the block has a very good internal stability. An accurate datum (position, orientation and scale) is guaranteed through the use of a great number of control points.

5. PHOTOGRAMMETRIC PLOTTING

It was originally planned for scientific purposes to map in a larger scale than 1:50,000. 1:10,000 was chosen with a height interval of 20m between contours for photogrammetric plotting (on 10 plotting sheets). This was also to be the base for the future one-coloured 1:10,000 map. The plot covers an area of 2.10m to 3.65m and resulted in 2,660 hours of plotting. Plotting was done on a WILD A8 with RAP-system and a TA-2 table (Fig.8).

A comparison of this plot with the maps 1:25,000 of Erwin Schneider or with the 1:100,000 map of the Royal Geographical Society (RGS), one finds many differences in various cartographical elements. This is not surprising as these maps are a conglomerate of data of variable quality and background. The differences are most remarkable on glaciers and crests and with contour lines.

6. CARTOGRAPHIC WORK

It was planned from the very beginning to print a 1:50,000 map according to the same standards of the Swiss national map. Therefore, the cartographic finishing was done by the Swiss Institute of Cartography in Berne.

6.1 Documents

The cartographic work was done at the same map scale as the published map. In order to get the cartographic base of the documents, a reduction of 1:10,000 to 1:50,000 was necessary. This showed not to be practical, as this reduced document could not be interpreted. It was, therefore, decided to base the work on a 1:20,000 reduction. The cartographic drawing was realized on a diazoique copy in blue colour for the ground coverage adjusted on the film with the contour lines. The cartographic work includes the following steps (Fig.9):

- A differentiation of the ground coverage (glaciers, rocks, etc) with coloured plates and a generalization of the perimeter

- An ink drawing of the main contour lines (400m)

- A drawing of the glacier surfaces, the crevasses and the séracs for the final graving.

All the names have been given using the National Geographic Society's conventions.

6.2 Cartographic details

The usual graving method for the 1:50,000 Swiss national map has been chosen. It allows for accurate adjustment of the various levels and for very good quality of line drawing.

The main difficulties were the cartographic representation of the relief due to the enormous height differences, representation of the glacier surfaces and the rocky sites. Glacier characteristics which are unique to the Himalaya are the enormous séracs and crevasses and the large rocks lying on the glaciers.

Rock drawing had also to be adapted for the Himalayan environment. Light and shadow challenge the 3-dimensional effect according to the hypsometric graduation principle, meaning an accentuation proportionally increasing with height.

7. PRINTING

As the National Geographic Magazine of the National Geographical Society is printed monthly in an edition of 11 million copies, the Everest map had to be printed in the same edition. All the National Geographic Society maps are printed on a six-colour offset printer with an hourly capacity of 30,000 sets.

Precisely on the date foreseen in 1986, namely on 22 August 1988, the National Geographic Society received the six printing films for the final printing. Shortly after, on 6 September 1988, the map was printed double-sided with the new Everest map on the front page and a birds' view map on the back side. At the end, the paper was dried out, cooled and cut (Figs.10 and 11).

<u>Printing statistics</u>

- 20,000 maps/h
- 20 days, 24 hour shifts
- 11 million maps
- Simultaneous six-colour printing, front
  five-colour printing, back
- 662 paper rolls with a weight of 747 kg/roll.
- 16,987 kg printing colour
- total length of the paper band = 10,560km.

8. CONCLUSIONS

For the Everest region, this is the first time that a map with such a high homogeneity has been produced. The printing of the 1:50,000 map was not the last step. Since 1988 Swissair Photo + Surveys Ltd has plotted a 1:5,000 map with a contour interval of 5 meters over an area of 102 km2. This map was used by the Rauda Company in Seattle to establish a relief 1:2,500 model. It is foreseen to publish the 1:5,000 map in black and white and in four sheets.

The Boston Museum of Science and the Swiss Foundation of Alpine Research will publish in spring 1991 a second edition of the Mount Everest map. The reverse side will be totally new, showing on an enlarged 1:25,000 map all first ascents in the Everest region. In addition, short expedition reports on these ascents will be printed (Fig.12).

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Figure 1   The Learjet on the Tribhuvan Airport/Kathmandu

Figure 2 Mt. Everest, Lhotse, Nuptse from the Nepal side

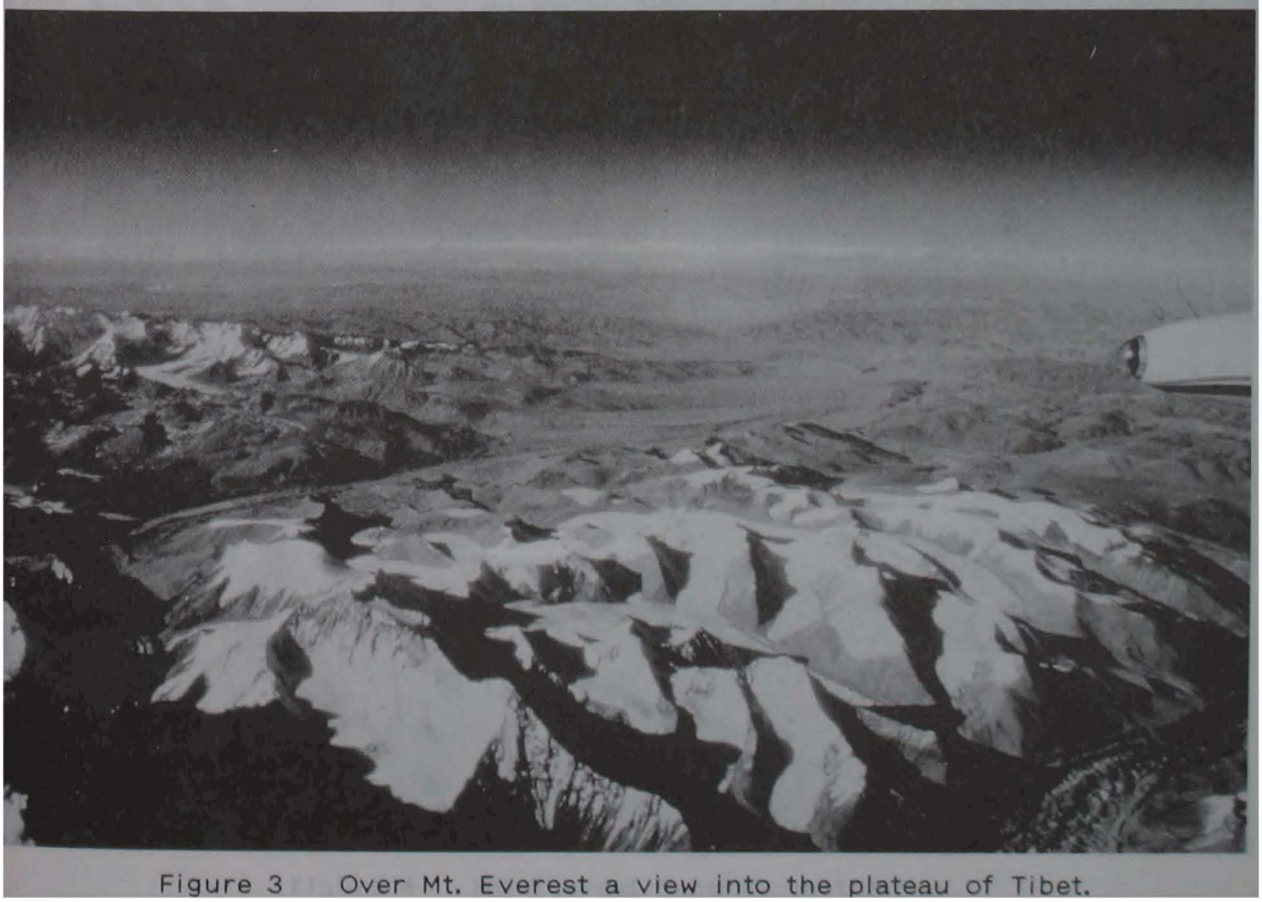

Figure 3 Over Mt. Everest a view into the plateau of Tibet.

Figure 4   Mt. Everest hanging on the line

Figure 5 Project parameter of the Metric Camera photographs

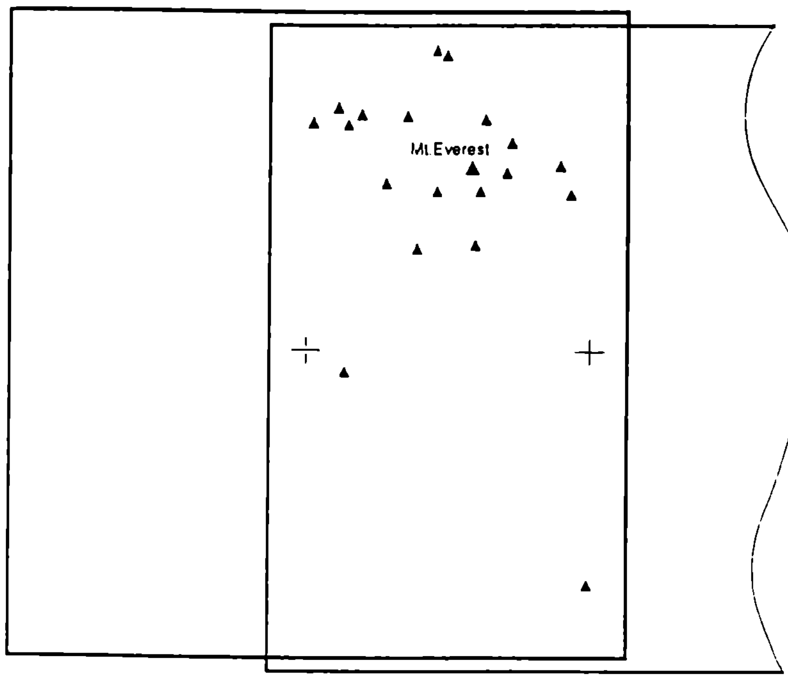

Figure 6   Control point distribution for the absolute orientation of the MC-steremodels.

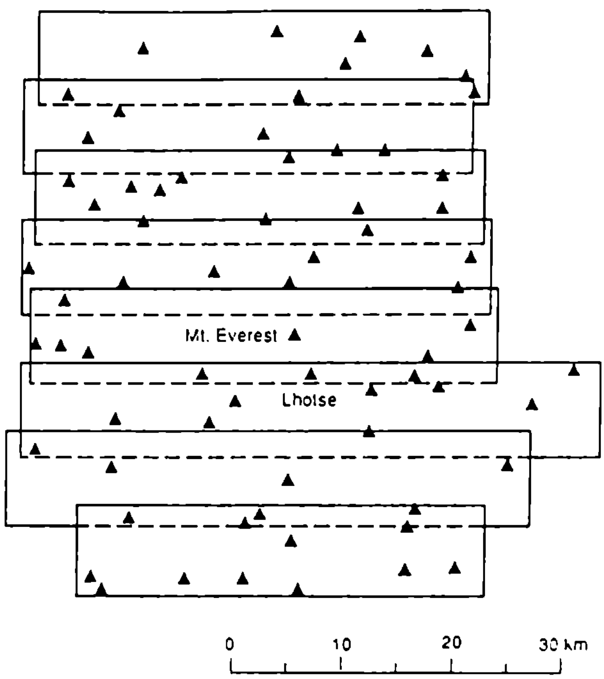

Figure 7   Distribution of the MC-control points within the aerial photogrammetric block.

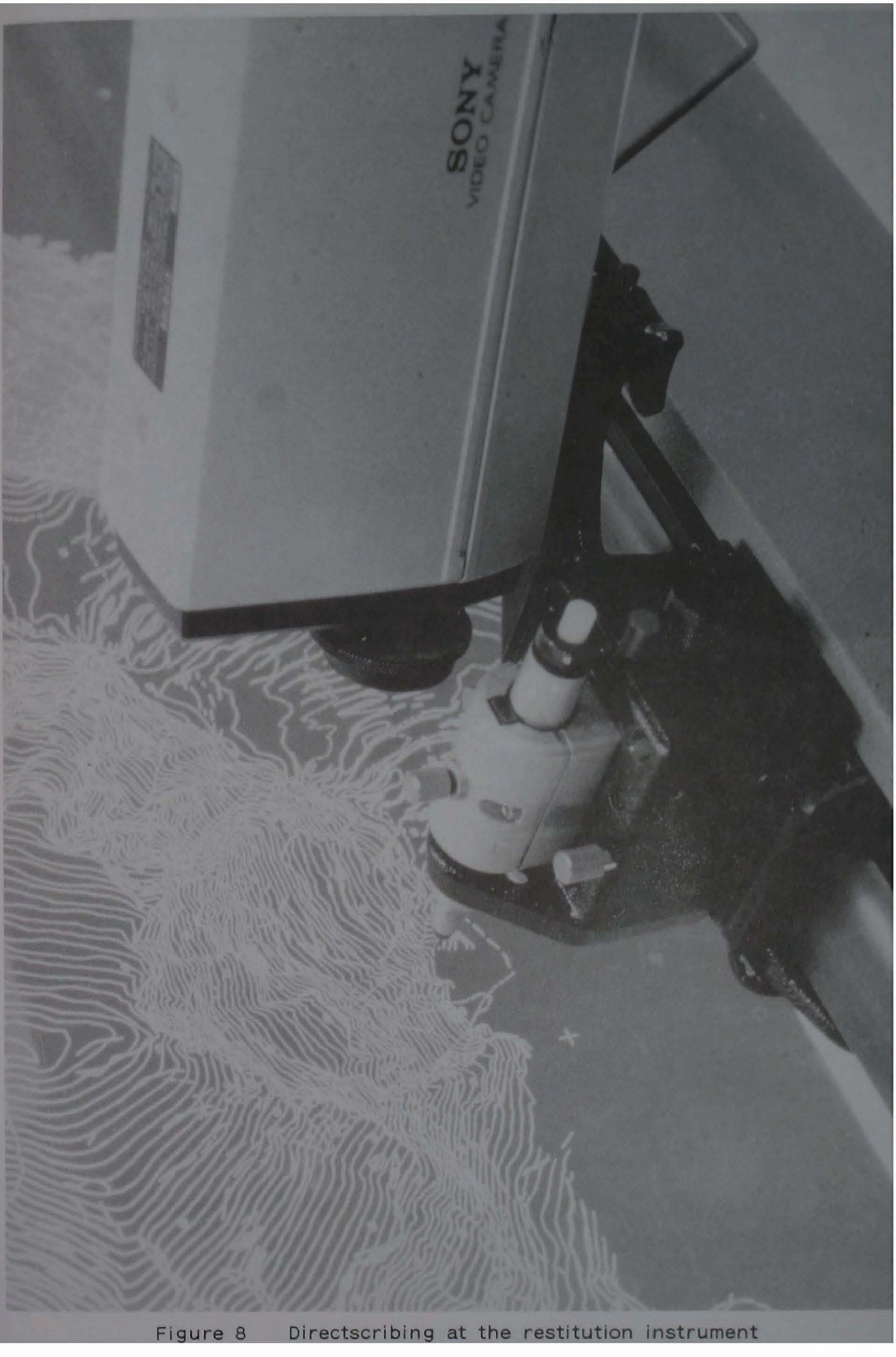

Figure 8   Directscribing at the restitution instrument

Figure 9 Editing of 1:20'000 as base for the cartographer

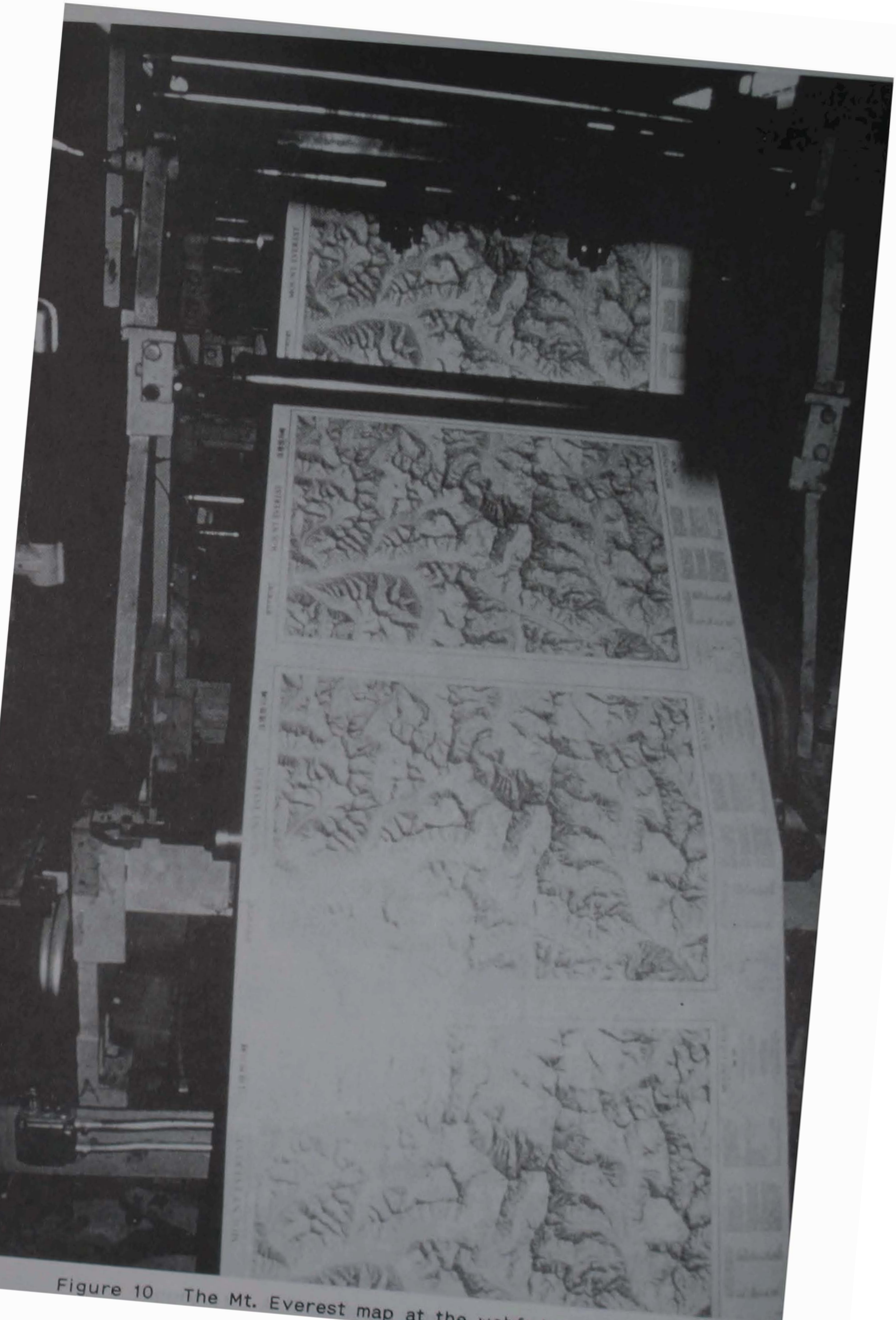

Figure 10 The Mt. Everest map at the webfed offset press

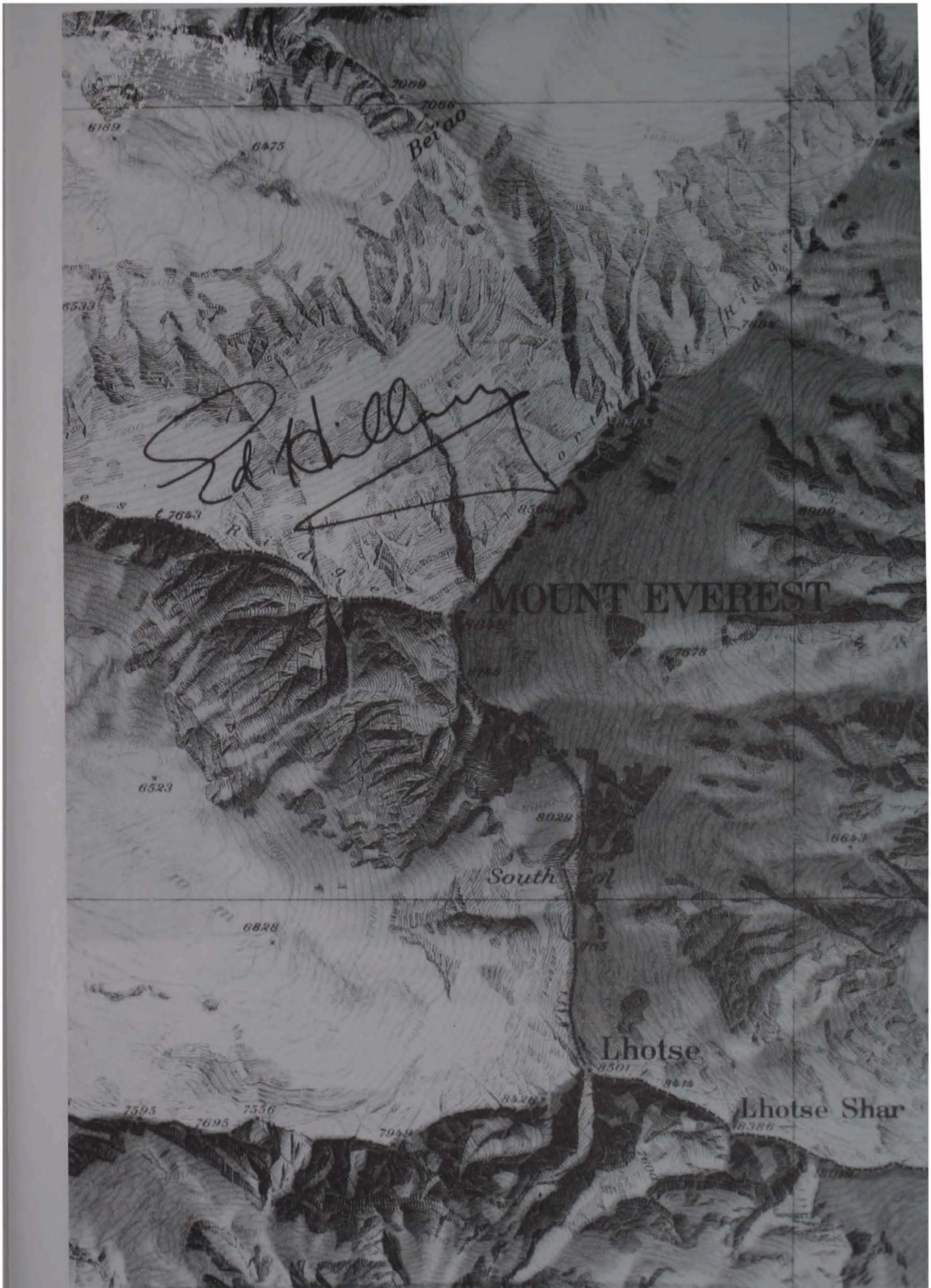

Figure 11 A final print signed by Ed. Hillary

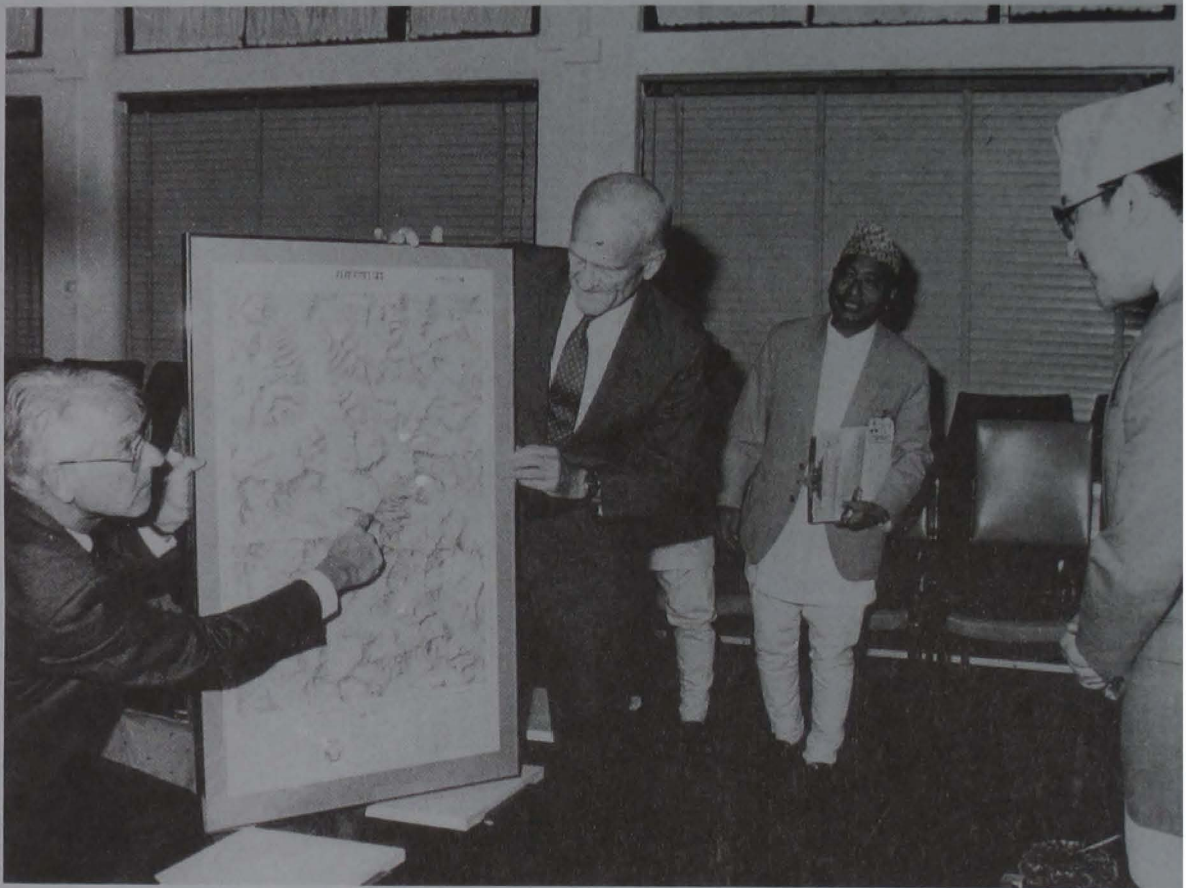

Figure 12 Presentation of the first final map to the King of Nepal H.M. Birendra Bikram Shah Dev.