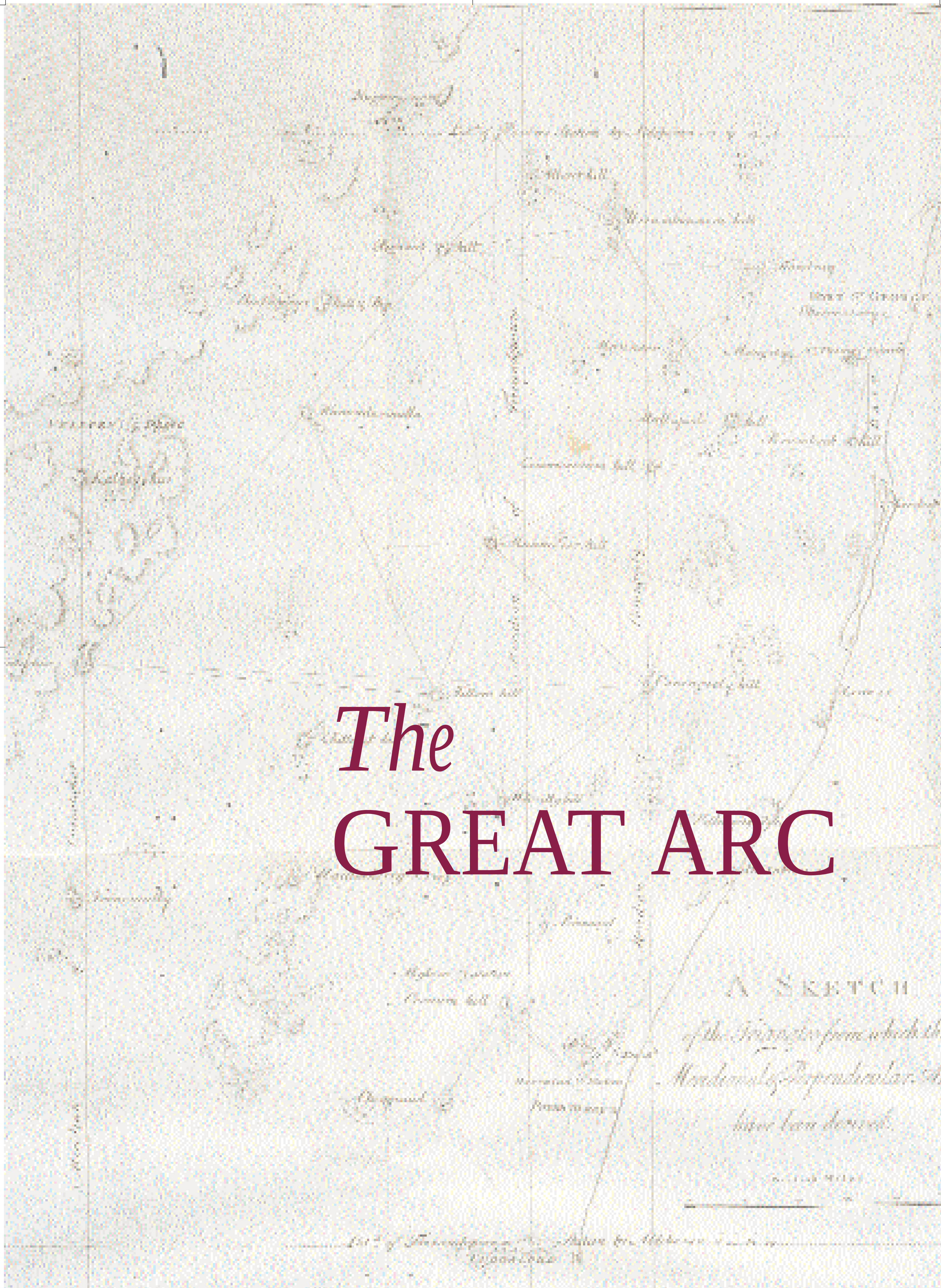
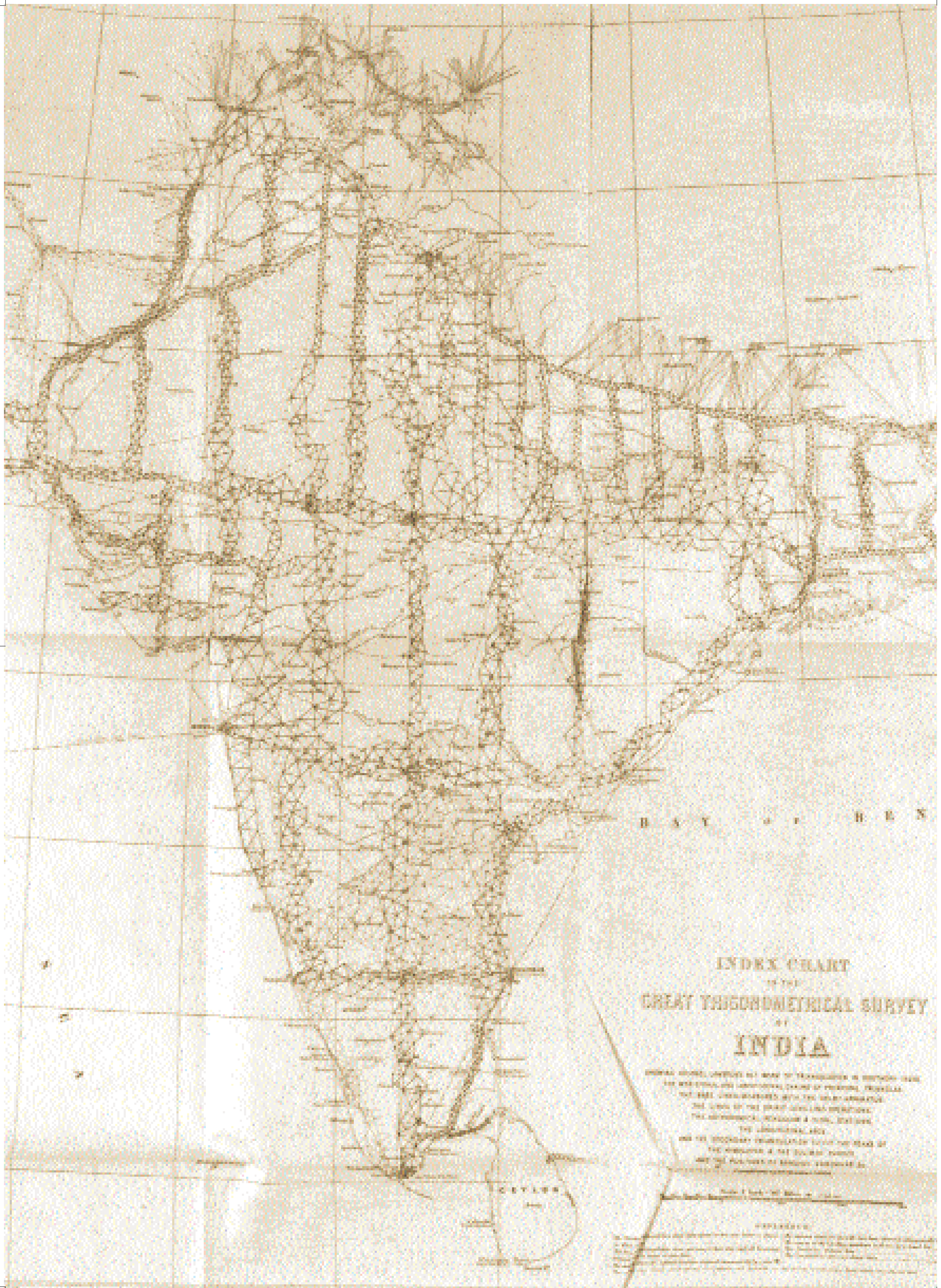


The
GREAT ARC



SURVEY *of* INDIA

AN INTRODUCTION

Dr. Prithvish Nag, Surveyor General of India

The Survey of India has played an invaluable role in the saga of India's nation building. It has seldom been realized that the founding of modern India coincides with the early activities of this department, and the contribution of the Survey has received little emphasis - not even by the department itself. Scientific and development initiatives in the country could not have taken place without the anticipatory actions taken by the department, which played an indispensable pioneering role in understanding the country's priorities in growth and defense.

The path-breaking activities of the Survey came, of course, at a price and with immense effort. The scientific measurement of the country, which was the Survey's primary task, had several ramifications. Surveyors had to traverse from region to region, waiting for an opportune time, free from natural, man-made and logistic problems in order to continue with their efforts. Resistance from local people, dacoity, diseases, snakebites, battles and other hazards came in the way of their mission. Despite this, the surveyors penetrated the jungles, climbed mountains, crossed rivers and fixed poles, stations and control points all over the country. There was no respite, whether on the slopes of the Western Ghats, the swampy areas of the Sundarbans, ponds and tanks, oxbow lakes or the meandering rivers of Bengal, Madurai or the Ganga basin. Neither were the deserts spared, nor the soaring peaks of the Himalayas, the marshlands of the Rann of Kutch, rivers such as the Chambal in the north and Gandak to the east, the *terai* or the *dooars*. With purpose and dedication the intrepid men of the Survey confronted the waves of the Arabian Sea and Bay of Bengal, dust storms of Rajasthan, cyclones of the eastern coast, the cold waves of the north and the widespread monsoons and enervating heat.

It was against this price, and with the determination and missionary zeal of the Survey's first participants that the mapping of the country was done. The information collected over the years with whatever technology then available proved to be invaluable. The process has reaped rich results in that new information packages, based on the latest technologies, such as aerial photography or global positioning systems, are able to benefit from the data generated by these pioneers. No piece of information lies unused; all of it has relevance even after decades. How was such an empire of knowledge built up?

Not only are its technological achievements significant, but the work of the Survey stands testimony to the pursuit of one of the longest scientific experiments carried out in the world, that is, mapping the nation against all odds.

The legacy and traditions of the Survey continue but it is a matter of great interest to know how such a superstructure of information was built. How did these scientific experiments continue to be undertaken for so long? What were the compulsions and apparent benefits? Why did the colonial rulers and later the independent government, with limited resources, continue their interest in this expensive exercise? These are some of the questions that will continue to baffle those who are interested in the scientific history of this country.

MAPPING KNOWLEDGE

The basic concepts of map-making, that is, scale, generalization of features, etc, were known in India from ancient times, as is evident from the *Puranas*. Various references in the *Vedas* testify to this: *Chatvaraha prithvi naga dharayanti chatur disham Vardhamana suvri-dhrishcha ativridha prithishrava* (Garga Samhita quoted in Adbhut Sagara).

The art of surveying or the technique of mensuration of areas was well developed in ancient India as is established in the manual *Sulva Sutra* (science of mensuration). In Vedic literature, *sutras* (formulae) are provided for the measurement of angles, distances and areas. Our ancient knowledge of astronomy, astrology, rocketry and geography is well known and it is apparent to Indian scholars that the *Vedas* and later Sanskrit works contain these truths. In the *Vedas*, *Upanishads*, the great epics *Ramayana* and *Mahabharata*, the *Puranas*, the *Manusmriti*, works of Panini, Patanjali and Kautilya, and even in the poems of Kalidasa, there have been references of geographical accounts of India. The Vedic concept of the motherland, mentioned in the *Prithvi Sukta* of the*Atharvaveda* has no parallel in any other literature written outside India.

The science of map-making could have not been possible without a knowledge of the shape and size of the earth. This was, and is required for determining the coordinate of points on the earth's surface, which are used for map-making. Efforts were made from the very beginning by various philosophers and scientists to determine the shape and size of the earth. Man's first conception of the earth's shape was that it was a plane. Greek philosophers thought it to be a sphere. Sir Isaac Newton proved that it was spheroid. The actual development of the science of surveying and mapping of the earth's surface in an orderly manner is, however, ascribed to Eratosthenes (276-198 BC) who based the compilation of his comprehensive map of the world upon his famous determination of the circumference of the earth. Claudius Ptolemy, a mathematician, astronomer and geographer produced a map of India in the 2nd century AD.

The golden age of India's scientific renaissance started in the 5th century, when the genius Aryabhat calculated the earth's circumference to be 25,080 miles and wrote the *Surya Sidhanta*. Indian astronomers and mathematicians such as Aryabhat, Baraha-Mihir and Bhaskaracharya discovered several truths such as the shape of the earth, its rotation around the sun, and even the force of gravitation. In their contribution to Indian geography they were followed by Chinese and Arab travellers who left many interesting detailed accounts of their journey. It is no wonder that this mystic land attracted so many adventurers.

Although the foundations of geographical knowledge and their subsequent developments were laid from the very beginnings of civilization, that is the domain of history. The knowledge of mapping as a science grew with time and even religious thinkers started delving into its mysteries. The age of great exploration started with the quest for absolute

truth. Major exploration got underway at the end of 15th century with Columbus crossing the Atlantic in 1492 and Vasco da Gama circumnavigating Africa in 1497. Magellan's expeditions circumnavigating the world took place between 1519 and 1522. The Dutchman Snell (1591-1626) carried out the first measurement of angles and distances and made the rigorous study of refraction. In 1670 the French clergyman Picard, measured the size of the earth. His result of 6,275 km for the radius of the earth was the first improvement on Eratosthenes' determination.

Newton's theory that the earth should be oblate because of the centrifugal force caused by the spin was validated by the measurements of two meridian arcs, one at the equator and the other closer to the pole, measured by two survey expeditions by the French Academy of Sciences.

The dissemination of geographical knowledge was limited till the 15th century, before the invention of printing techniques, due to the labour and skill involved in duplicating graphic data. Once lithographic techniques were discovered, map-making got a stimulus, particularly in Europe, where adventurous men went out to conquer new worlds for religion and commerce. Father Monserrate, a Jesuit, brought out a map after a visit to the Mughal Emperor Akbar's court. This was the first of those maps based on measured routes and astronomical observations. Akbar's revenue minister Todar Mal's maps and those of the brilliant administrator Sher Shah Suri, based on regular land survey systems, were well known in their time and continued to be used in the mid-18th century. Information is available on the surveys instituted by Akbar during the 16th century, measurements being made by a hempen rope which was replaced by a 'jarib' of bamboos joined by iron rings. Other noted cartographers of the time also published their versions of maps of India. In 1752 the French geographer, Jean-Baptiste Bougigon d'Anville published a map that put Indian geographical knowledge on a definitive scientific footing.

Pioneering work by French expeditions showed that terrestrial measurements (angles and distances) are the main tools for the task of relative positioning. The techniques of triangulation - astronomical determination of positions and azimuths - as well as levelling were started in the mid-17th century.

A landmark in mathematical and geographic determination was the establishing of five astronomical observatories by the Jaipur Maharaja Sawai Jai Singh II (1693 - 1743) at Jaipur, Delhi, Mathura, Ujjain and Varanasi to calculate the position and movement of celestial bodies and forecast relevant information. In the early days of the imperial powers in India, the geographical knowledge of the southern parts of the country was greatly increased during the wars of political supremacy between the colonial powers, but information about the north remained sketchy. Nevertheless, attempts were being made from very early times to establish the geographical locations of important places.

During the middle of the 18th century, latitude could be easily determined by observing the meridian altitude of the sun or stars. For longitude determination, one had to wait for favorable phenomenon such as an eclipse of the sun, moon or satellites in clear sky, with similar observations being made at several known places. In 1787, astronomical observations for latitude and longitude at various places were made covering India, and proper centres of astronomy were established in due course of time using sextants, chronometers and telescopes. The results of these instruments were, however, inaccurate because of faulty mathematical tables. An interesting observation is that because of the difficulty in determining longitude, early maps of India do not indicate longitude with reference to the Greenwich meridian but to the arbitrary meridian passing through Madras or Calcutta.

Most early maps were based on local surveys carried out by a cursory method. In 1776, comprehensive instructions for preparing maps on the scale of two miles to an inch were formulated in which distances were measured by parambulators rather than with chains and bearing to conspicuous hills. Short base lines were laid and measured and distant points were fixed by triangulation.

SURVEY OF INDIA

The Survey of India traces its birth to Major James Rennell's appointment as the Surveyor General of Bengal on 1 January, 1767. In those days, there was an urgent need for pictures of the country showing the general course of main rivers and the location of principal towns. This task was taken up with speed and the result was that serviceable maps of the area of Bengal and Bihar were produced in less than twelve years. These maps, however, could lay no claim to accuracy of details but were sufficient to meet the needs of the time. Rennell also produced the 'Map of Hindoostan' in 1783 after relinquishing the post of Surveyor General.

The progress of topographical surveys in Madras and Bombay presidencies was a more or less independent exercise and not coordinated with the work of the Bengal presidency till the beginning of the 19th century. This was not a satisfactory state of affairs and retarded the progress considerably. It was only in 1787 that an accurate survey of the sea coast from Madras to the southernmost extremity of the peninsula was taken up by running a 300-mile line of triangles along the coast with the aim not only of ascertaining the actual line of the sea coast but undertaking a complete survey of peninsular India. This survey was the first Indian survey based on the system of triangulation.

Towards the close of the 18th century, theodolites, now considered primitive, had been brought in use. Angles and bearings were measured with theodolites, with pocket compasses for determining the direction of the road, etc. The technique of plane tabling was first used in 1792. Plane tabling survey was subsequently developed into an art and has been used extensively down to present times for topographical surveys in all types of terrain. Even now, with the emergence of modern techniques of surveying, this simple technique is widely used in various surveys such as large-scale mapping, engineering surveys, cadastral surveys, and the like.

BEGINNING OF SCIENTIFIC SURVEYS

The period of piecemeal surveying came to an end by the close of the 18th century. A new era began with William Lambton and George Everest, which signalled the consolidation of coordinated efforts. The foundation of a truly scientific Survey of India was laid, the beginning of a period of stupendous work, which occupied the lifetime of scores of noble and devoted surveyors. A network of primary triangles was established by the trigonometrical surveys. It was a magnificent scheme, timely conceived and brilliantly executed. Although techniques of triangulation, astronomical determination of positioning and azimuths as well as levelling were started in the mid-17th century, scientific procedures started only by the end of the 18th century when a project for the measurements of an arc of the meridian through a network of trigonometrical surveys covering the Indian peninsula was formulated.

The actual work of the Great Trigonometrical Survey was commenced on 10 April, 1802 by the measurement of a baseline near Madras. This baseline was established using a steel chain which consisted of 40 links of 2½ feet each, measuring in total 100 feet. The baseline was measured with the aid of coffers (long boxes) as it was required for the triangulation of the 'Great Arc' where utmost possible accuracy was the aim. From this baseline, the

measurement of a series of triangles was carried out up to Mysore and the second base was measured near Bangalore in 1804. The station of origin was the primary reference station of the Astronomical Observatory at Madras. Having connected the two sides of the peninsula, Lambton devoted much of his labour to the measurement of an arc of meridian. The series measured for the purpose is known as the 'Great Arc Series'. In addition to the measurements of this series, webs of triangles were extended in order to establish the positions of main cities. This idea of the web was replaced due to cost effectiveness by an all-India grid composed of criss-crossing 'chains' or 'bars' of triangles centered on the Great Arc. The holes on the grid could be filled later by cheaper and less rigorous topographical surveys. The idea gave birth to the term 'grid-iron'.

The grid-iron layout generally consisted of an outer frame of two extreme meridional and two longitudinal series closing at each junction on a measured baseline. To bring the Great Arc across the plains, masonry tower stations were built which were about 50 feet high. The first essentials of every observation station, whether on hill top or tower or otherwise was the stability of the instrument and immovability of the mark over which the instrument and signals were centred. These marks were established after great effort, and were then handed over to the civil authorities when all corrections had been completed. In 1866, it was ordered that all stations of the Great Trigonometrical Survey should be placed under the official protection of district magistrates and visited periodically. This practice still exists today for all primary GT stations and bench marks.

Lambton's main instrument was referred to as the Great Theodolite which was a marvel of workmanship in those days. The horizontal circle was 36 inches in diameter and the vertical circle 18 inches; each was read by two microscopes. This theodolite was used by Lambton and his assistant and then by Everest and others till 1866. Various other theodolites were used for observations for the meridional series, namely, the 36-inch theodolite, which was built up from Lambton's great theodolite, the 34-inch theodolite, 24-inch, 18-inch and 15-inch theodolites. For the purpose of laying out the series and running secondary and minor triangulation, small theodolites were used, that is, 14 inches, 12 inches and 7 inches. For baseline measurements, compensation bars and other baseline apparatus were used. The compensation bars remained, however, the only means available for measuring the baseline of the main triangulation framework. Vizagapatnam and Cape Comorin bases were measured between 1862 and 1869. In 1856 standard yard arrived from England and the following year a special room at Dehra Dun was set aside where subsidiary standard could be laid off or compared by microscope as and when marking of staves for levelling operations required. Standard spirit levels were used during those days.

Triangulation or levelling computation was made to a regular routine, adapting rules and formulae to the requirements of the department. Computation forms were lithographed at Calcutta under the direction of the Chief Computer. One of the greatest contributions which Radhanath Sickdhar, Chief Computer, made to the Great Trigonometrical Survey was the preparation and publication of a set of tables to be used with departmental formulae and computation forms. The first official list of geographical coordinates was published in 1842 and the first edition entitled 'Tables to Facilitate the Computation of a Trigonometrical Survey and the Projection of Maps' was published in 1851. Auxiliary tables to facilitate the calculations of the Survey department were published in 1868.

For the dispersal of triangular error, the method followed by Everest was tested against the new method devised by Gauss. Radhanath first tried two simple figures and obtained results closely agreeing with the old method. He tested this on complicated figures that occur in the trigonometrical survey. The results were highly satisfactory, showing that the greatest discrepancy between Gauss's and Everest's methods would not exceed 0.14 arc seconds.

The final distribution of errors and reduction of results of the triangulation of the Great Trigonometrical Survey was carried out under the direction of General James Walker whilst he was superintendent of the trigonometrical survey. For this purpose the whole triangulation was divided into five zones - Northwest, Northeast, Southwest, Southeast quadrilaterals and the Southern trigon.

Lambton and Everest did not go deeply into the subject of heights above sea level. Lambton first connected to the sea at Madras in 1802, but for his great Central Arc he preferred the connection made at Cape Comorin in 1809. From this he brought up his height by vertical angles from station to station. At that time surveyors in India had no professional interest in the measurement of the vertical rise and fall of tides along the coast except to find the level of the sea from which to calculate their land heights. Lambton followed the practice of his time by calculating his heights from low water. It was only in 1837 that the mean between high and low tide observations for at least half a month were proved to match closely between one place and another. Self registering tide gauges had been invented during 1830-33 and were established at the Colaba observatory, Bombay in 1842. Tide gauges at various other places were also connected through spirit level during 1851 to 1860.

Levelling was initiated on scientific lines in 1858. It was General Walker who was the founder of this activity and initiated the field work.

Waugh took over in 1843 from Everest and during the seventeen years of his administration, the triangulation series was advanced eastward to the Ganga valley up to Calcutta and all the way to Assam. Regular observations of the Himalayan peaks were recorded. It was under Waugh that the highest mountain in the world, 29,002 feet above the sea, was discovered and he recommended that it should be named after George Everest, who had built up the triangulation system by which the discovery was made possible.

Regular astronomical observations for azimuth and meridian were continued along both meridional and longitudinal chains of triangle as a check against accumulation of errors in direction. Both Lambton and Everest had been well aware that their observations were influenced by visible mountain masses and variation of density. Various other mathematicians and geodesists worked on this subject and attracted wide attention. They suggested the value of pendulum observations for the determination of variations of gravity and introduced the theory of compensation or isostacy.

DEVELOPMENT OF THE GREAT ARC

The measurement of the Great Arc from Cape Comorin to the Himalayas was completed by 1843. The grid-iron system consists of meridional chains of triangle tied together at upper and lower ends by longitudinal chains. This ambitious scheme of triangulation commenced with the Great Arc Series, based at Dehra Dun in the north and Sironj in central India as the southern end. The Northwestern Himalayan series was further extended from the Dehra Dun base while from Sironj the Calcutta longitudinal series was extended up to a base at Karachi. In 1887, the Kashmir series was started as an extension of the Northwestern Himalayan series. The height of stations averaged 17,000 ft in this series. The second highest peak, next to Mount Everest, was found during this triangulation to be 28,290 ft high and this was named K2.

The Great Trigonometrical Survey Triangulation Network of India and adjacent countries was started in the year 1802 and by about 1880, a number of triangulation series had been observed to warrant their simultaneous adjustment. This triangulation network was first adjusted to form a self consistent whole in 1880. Adjustment of this horizontal network was based on the Indian Geodetic Datum. Here, the Everest ellipsoid is used as the reference surface (Indian Geodetic Datum) in India. This reference surface has been named after Sir George Everest. A reference ellipsoid is defined by various components, namely, semi-major axis (a), flattening (f), and coordinates, namely, latitude, longitude and deflections of the vertical: meridional and prime vertical, and geoidal undulation at the origin. Everest adopted Kalianpur in central India as the point of origin. Various components of the Everest ellipsoid or spheroid and its orientation at origin were worked out in piecemeal manner in various campaigns.

In the year 1937, another adjustment was attempted, incorporating the new triangulation series observed after 1880: the Laplace stations to control directions and new baselines measured with invar wires between the year 1930 to 1934 to control the scale of the triangulation series. In this adjustment, instead of resolving the simultaneous normal equations formed after incorporating new data, the graphical technique of adjustment was employed. However, this technique was not considered appropriate and the adjustment found to be of no practical use.

The adjustment of 1880 has remained the basis of Indian triangulation and mapping except for a constant change of -(2’27”.18) in longitude. This change was essential as the longitude of the Madras observatory was revised in 1905.

Early mapping activities of the Survey were scientifically executed and based on the triangulation series adjusted in 1880. Most of the maps were on the scale half inch or larger. Mapping activities opened up new possibilities with the introduction of aerial photographs in the early years of World War I. The science of photogrammetry had not developed but the immense value of aerial photos impressed the surveyors. Air survey techniques were not, however, used very much in the department up to 1939 except for training for military survey purposes and for the survey of inaccessible areas. The primary map scale 1 inch to a mile was adopted by the Survey of India in 1905. It was also decided that these maps be produced in colour and that the relief be shown by rigorous contourings.

The requirement for printed maps increased greatly during 1939 but the main printing organization at Calcutta was unable to meet the demand. The present site at Dehra Dun was therefore selected and printing machines installed here and by mid-1943, printing was in operation with three large high-speed machines. At the time of Independence (1947) mapping of about 60 per cent of the country had been completed on the primary scale of 1 inch to 1 mile.

PRESENT SCENARIO

After Independence, there was an immense increase in developmental activities and this drive continues till today. It was only the Survey of India, as the premier organization engaged in surveying and mapping, which could take up survey work for developmental schemes, because of which normal topographic surveys became secondary.

During the First and Second Five Year Plans, the department was faced with demands for survey which required far more survey infrastructure than it had. During the First Five Year Plan (1951-6), nearly 70 per cent of the department was employed in developmental surveys and in the Second Five Year Plan about 60 per cent was directed towards this purpose. The department had diverted the work load with the switching over to the metric system in 1956 and the basic map scale having been changed to 1/50,000 from 1 inch to 1 mile. It was during the Second Five Year Plan that various advanced techniques of mapping became available and there were pressing demands for maps needed for development work. Since that time, the Survey of India has kept pace with modern technologies of surveying and mapping and continues to adopt various activities in the field of geodesy and geophysics, topography, photogrammetry, cartography and printing, manpower development, and so on.

GEODETIC AND GEOPHYSICAL SURVEYS

The responsibility of establishing geodetic and geophysical control in India lies with a separate directorate known as the Geodetic Research Branch. With the introduction of modern instruments in improving the precision and accuracy of all geodetic and geophysical surveys, the activities of this branch have been diversified and today it is engaged in a number of research and developmental programmes.

Theodolites used in the past were replaced by glass arc theodolites in the late forties of the 20th century, which made it possible to read directly to an accuracy of 0.2 second of arc. Geodetic bases of length 10-12 km, established during the period 1831-82, have been measured with Iridia 10 ft bars, while modern baselines were measured with invar wires. In order to check the scale of Indian triangulation, these baselines have been measured with great care. Accuracy of baselines was of the order of 3 part per millennium (3 mm per km) or better. Astrono-mical azimuths have also been measured at a few stations to keep a check on the orientation of the triangulation series. In order to provide first order control by a chain of primary and secondary series every 4° (about 400 km) apart the triangulation network was completed by the year 1956. The work for densifications to bring control at 2° (about 200 km) apart and upgradation of the existing series classified as 'secondary' has been taken up by the Survey of India. There has been tremendous growth in the field of space geodesy in the last couple of decades.

The TRANSIT system was adopted by the Survey of India in the seventies to establish geodetic control. A more rigorous system called NAVSTAR GPS (navigation satellite with time and ranging global positioning system), or simply GPS, a satellite based radio navigation system providing three-dimensional positions, navigation and time information to suitably equipped users all over the globe at any point of time, was introduced in the year 1980. The GPS technique was adopted in the Survey of India around the year 1990 and enormous work has since been done in this area. Electronic distance measuring devices have been introduced since 1962 and a number of bases have been added to the principal Indian triangulation system.

There is a growing realization that Indian geodetic datum needs to be redefined and Indian triangulation readjusted afresh. This is because of the inherent weakness in the geodetic datum and triangulation adjustment of 1880. These inherent weaknesses are: ill fitting of the ellipsoid, inadequate bases and non application of various geodetic corrections like deflections, skew normal, geodesics, etc, in the observed directions. Enormous amounts of data have been collected after the first adjustment of 1880, namely, baselines, Laplace stations and several new triangulation series in the Great Trigonometrical Survey. After incorporation of this data in the Indian triangulation net, simultaneous adjustment of the primary and secondary series has been taken up to redefine the Indian Geodetic Datum.

Various geodetic and geophysical modern instrumentations are being put in use for geodetic, gravity and geomagnetic observations. Glass arc theodolites, astrolab, chronograph, crystal clocks for geodetic work, Frost, Worden, Lacoste Romberg and Automated (CG-3M) gravimeters for gravity measurements and QHM (quartz horizontal magnetometer), BM (zero balance magnetometer), Proton magnetometer for geomagnetic observations, all are in use for geodetic and geophysical surveys. Computers are extensively used for better and more homogenous adjustments and data processing.

TOPOGRAPHICAL MAPPING

After establishing the ground control points either by conventional ground method or by space-based techniques, the subsequent steps include: survey of ground details and verification, annotation and introduction of names of rivers, roads, villages, towns, etc, and depiction of topographic features by contour and other suitable symbols. The SPOT, IRS and Landsat imagery for topographical mapping on small scale are also used. Digitally generated data is used to create a cartographic database in various scales, namely, 1:250,000 and 1:25,000. In addition to this data base for district planning a map series on scale 1:250,000 is being carried out. Digital terrain model (DTM) is being generated for developmental activities in the country.

With the completion of the 1:50,000 Topo-graphical Survey of the entire country by 1982 and mapping by 1985, India has joined a select group of countries which have completed map cover on the national scale. The department now has an ambitious programme of covering the whole of India by maps on 1:25,000 scale. The country covers 394 maps on scale 1:250,000 and 5,106 sheets on scale 1:50,000.

PHOTOGRAMMETRY

Aerial photographs made their appearance in the early years of World War 1 when sephotographs were extensively used for preparation of large-scale maps in India. 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 survey. After 1955, with the acquisition of analogue instruments of high precision, photogrammetric and plotting machines from stereo models were adopted and became the standard procedure for topographical large-scale mapping in the department. The Survey of India now has analytical/digital photogrammetric instruments which are being used for map-making and for generating digital data.

In the Survey of India the process of map-making with aerial photographs starts with the planning of the aerial photograph. The Ground Control Points (GCPS) at selected locations are connected with existing geodetic control by field survey and their positions are captured. With photographs and minimal ground control and their position identified, the stage is set for undertaking Independent Model Photogrammetric Triangulation and subsequent computation provides requisite control points in each model. The models, properly oriented, are then used for generating cartographic data which is verified on the ground before preparing the final map.

DIGITAL CARTOGRAPHY

As a part of its activities to keep abreast with the latest technologies in the science of map-making, the Survey of India adopted the digital mapping programme in the early eighties. It adopted the Computer Assisted Cartography (CAC) system, the 'Automap' in 1981. In this system geographical and other data are stored in digital form and processed on demand to draw the required map output by using a computer operated drafting table. The Survey of India took a giant leap forward in 1986 when integrated digital map production systems were installed at three locations: (a) Modern Cartographic Centre (MCC), Dehra Dun, (b) Digital Mapping

Centre (DMC), Dehra Dun, and (c) Digital Mapping Centre (DMC), Hyderabad. Having overcome the initial difficulties of new technology induction in the early nineties, the department aimed to achieve flexibility in satisfying users' demands by establishing a structured Nations Cartographic Data Base (NCDB) and Geographic Information System (GIS). In the year 2000 the Survey of India brought out a digital cartographic data base on 1:250,000 scale for the entire country. Digitization on scale 1:50,000 and 1:25,000 is in progress. This activity is likely to take some time as the volume of work is high.

PRINTING

Conventional map printing activity is a fairly cumbersome process in which map manuscripts are colour separated and press plates are prepared through a chain of intricate reprographic processes. The final printing is carried out on rotary offset multicolour printing machines. Map printing activities started in the Survey of India when the printing machine at Calcutta became fully operational in 1852. One of the tasks of this new office was the printing of postage stamps of India. The first stamp was printed on 4 May, 1854. By 1865 another printing press had been established in Dehra Dun.

The requirement for more printing machines increased considerably during 1940 and a full-fledged printing press was now installed at Dehra Dun which started functioning by the middle of 1943.

Reproduction techniques have undergone revolutionary changes over the years. With the availability of information from digital cartographic data bases it became imperative for the organization to install compatible printing machines and the Survey of India now has five printing groups located at Kolkata (Calcutta), Dehra Dun, Hyderabad and Delhi with the latest map publishing system and machines, making them compatible with digital data and capable of producing the highest quality.

SURVEY TRAINING

Over the years, officers and staff of the Survey of India have ventured into unmapped territory for others to follow and record as they surveyed the deepest forests, deserts and swamps, the lowest coastal belts and highest mountains. All this has been possible because of the basic training they received, either on the job or through for the purpose of carrying out specialized survey tasks.

India's colonial rulers had established a centre at Abbotabad (now in Pakistan) for the training of officers and surveyors of other ranks. Immediately after Independence, a training directorate was established at Dehra Dun for the officers and staff of the Survey of India. The training directorate was subsequently shifted to Hyderabad in 1962. With advances in the field of computers, electronics, satellite techniques and remote sensing, the technology of surveying has undergone a qualitative change necessary to catch up with modern trends. With the assistance of the UNDP, the training directorate was reorganized as the Survey Training Institute (STI) and came into existence in 1970. This institute, apart from catering for internal training needs, also imparts training to other organizations in India and also to students from developing countries. With the introduction of sophisticated hardware and software, staff members have been trained in collaboration with the International Institute of Aerospace Survey and Earth Sciences (ITC) in the Netherlands.

Being a premier institute in survey education in Asia, the Survey Training Institute is geared to meet the sophisticated training needs commensurate with fast changing technologies required not only by students from within the country but from neighbouring countries as well.

RESPONSIBILITIES AND CHALLENGES

In its assigned role as a national mapping agency, the Survey of India, as the premier national survey and

mapping organization in the country bears a special responsibility to ensure that the country's vast territory is explored and mapped suitably to provide base maps for the expeditious and integrated development of the nation. In the process, the Survey of India has been producing all purpose topographical and various other series maps required by defence, by civil administration, internal security, for developmental needs, irrigation, watershed management, resource management and various types of engineering projects. It is also responsible for establishing precise planimetric control, heights above MSL, gravity, geomagnetic and tidal prediction as prerequisites for mapping activities and other scientific applications. The department is committed to provide technical expertise to other countries in the fields of geodesy, surveying, cartography and survey education.

With the introduction of digital technology in the department, a digital topographical database for the entire country is being created in various planning processes and for creating GIS. Its specialized directorates such as the Geodetic and Research Branch, Research and Development Directorate and Survey Training Institute have been further strengthened to meet the growing requirements of users. The department has also been contributing immensely to a number of multi-institutional scientific programmes related to the field of geophysics, remote sensing, glaciology, study of seismicity and seismotectonics. scientific expeditions to Antarctica and digital data transfer.

The Survey of India has taken up a major programme related to technological development in the field of mapping activities with the initiatives of the Department of Science & Technology. Under this programme the National Spatial Data Infrastructure (NSDI) and a new series of maps have been initiated.

India is fast moving into an information and knowledge based society. Emphasis is increasingly placed on IT driven 'transparent' e-governance. The nation has been generating voluminous field/ digital data, that is, information through systematic topographical surveys, geological surveys, soil surveys, cadastral surveys, etc. Access and availability of such information to the citizen, private enterprises and government are of immense importance. As a part of this vision, NSDI, a national system, is being involved through a partnership approach among various data generating agencies to facilitate integration, easy access and networking of databases with the power of IT. This enables information support for decision making in government, industry, academia and other organizations and serves the needs of the public.

The strategy and action plans of NSDI have been formulated through a multi-institutional approach involving the Department of Science & Technology (DST), Survey of India (SOI), Indian Space Research Organization (ISRO), Geological Survey of India (GSI), and National Atlas & Thematic Mapping Organization (NATMO), etc.

In order that maps in analogue and digital form are available to users all over India for the sustainable development of the country, a new series of maps on WGS 84 datum is planned and the work on various components involved in this proposal has already begun.

In over two and half centuries the Great Trigonometrical Survey of India has collected invaluable information and its resources continue to be utilized in the development of the nation. Geodetic and geophysical information such as planimetric and height control, gravity, geomagnetic and sea level data are being continuously collected with the aim of serving humanity by forewarning them about natural disasters and by making information and resources available to earth scientists.

The PRELUDE

In a time long gone, about 3000 years before the birth of Christ, somewhere in the sweeping expanse of land known today as India, Man stood beneath the vast emptiness of the sky and gave shape to the infinity of the cosmos.

And so was born the concept of *sunya* - in itself nothing, a void, but having infinite potential.

Later, much later, in the 7th century AD, Bramagupta became the first person to integrate this concept into mathematics by treating the *sunya* as a number.

When *sunya* is added to or subtracted from a number, the number remains unchanged; when multiplied by *sunya* it becomes *sunya*; when a quantity is added to *sunya* the result is that which is added.

Mathematicians in India were already working with a base 10 system that had unique symbols for the numbers one through nine and a place value notation.

As early as 2500 BC, the Harappan civilisation had adopted a uniform system of weights and measures that were decimal in nature. Both weights and scales have been discovered, and measurements of excavated ruins reveals that these units of measurement were used in the planning and construction of that extraordinary city.

The introduction of *sunya* perfected the writing of numbers in decimal arithmetic, and, thus, were made simpler infinite calculations of reality.

Known in different places at different times as *sifr, zephirum, tziphra, zenero, zero, sunya* gradually came to be assimilated by the Arabs and from there, over four centuries, into western mathematics.

At that time knowledge, whether in science or technology, dealt primarily with the abstract and carried, therefore, a strong essence of timelessness. This was further strengthened by the Indian tradition of oral learning and communication of knowledge as *sutras*.

A *sutra* is the encoding of thoughts into compact word-capsules or formulae that contain a very high density of expression and is often set to metre.

Between the 6th and the 4th century BC, the grammarian Panini put down a sophisticated language theory - a masterly achievement of logic, analysis and classification.

An epigrammatic *sutra* on the rising of the planets: in the 6th century astronomical treatise *Pancasiddhantika*, Varahamihara uses consonants to define a simple numeral value and a vowel to give the place value.

"From the R sine anomaly of conjunction of Jupiter, Mars and Venus subtract one fourth of itself. From that of the rest, (viz. Mercury and Saturn) add an eight. Add both algebraically and note the direction, north of south. Multiply this by R (i.e. 120') and divide by the hypotenuse got in the last step. The latitude is got, its direction being that of the noted direction."

The sciences, including mathematics, of Vedic times were closely related to philosophy and religion. The complicated geometry that was developed in 800 BC in Baudhyana's *Sulbashastras* for instance, related to the rules for measuring and constructing the sacrificial fire altars. They are religious works, but extraordinary in terms of mathematical content - the problem is stated in geometric terms, the solution given in a combination of geometry and algebra.

The use of Pi, the ratio of the circumference of the circle and its diameter resolved difficulties arising of the need to circle a square or the square a circle. Also laid down by Baudhyana as the means to identify the perpendicular (north-south) direction in the east-west line of altar settings, was the logic better recognised today as Pythagoras's theorem.

The belief that cosmic energy sources are the procreators of the entire manifest world was central to Vedic philosophy. Sages studied the sky and tracked the movement of heavenly bodies to define, within the logic of infinity, a point in time and space.

The sun was regarded as being the most important heavenly object and its path, the ecliptic, was considered sacred. The moon was next in importance and its cycle provided the basis for a working calendar. The length of the year was known and calculated as also the lunar month.

In all seven planets were identified - the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn. Records of celestial phenomenon are found in the Vedic *Samhitas*, *Vedanga Jyotisa* and *Surya Siddhanta*, dated between 2500 BC and 400 BC.

Aryabhata, author of the earliest preserved work dealing with mathematics and astronomy dated to the 5th century, has given a systematic treatment of the position of the planets in space. He calculated the circumference of the earth. The axial rotation of the earth, radius of the planetary orbits in terms of rotation around the sun, elliptical orbits of the planets and the causes of eclipses of the sun and moon, all have been considered.

A cyclic concept of time, rooted in n the idea of a *yuga* or cycle, was the basis of Indian astronomy. A *mahayug* was identified as a period at the beginning of which all the planetary bodies are in conjunction. It ends when each of these planets has completed an integral number of revolution and they are in conjunction again.

The number of revolutions made in this period by the planets was also calculated. The sun, it was worked out, would make 43,20,000 revolutions and the moon, 5,77, 53,336 revolutions in one period of the *mahayuga*.

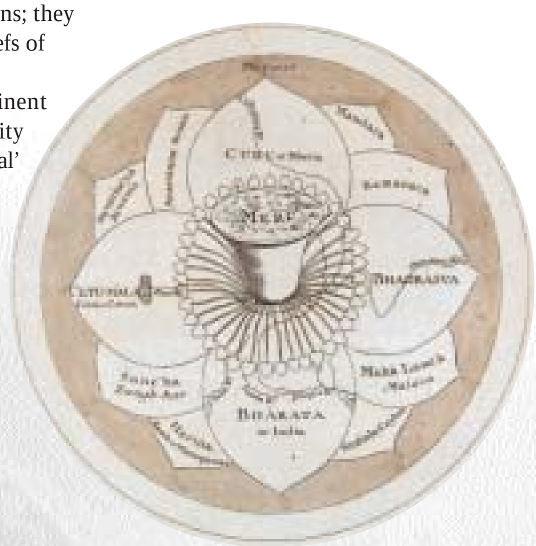
Varahamihira also referred to the sphericity of the earth in his treatise *Pancasiddhantika*, which plots the ancient view of the world.

This located Mount Meru, the highest point on earth on the North Pole. Surrounding it are four island continents aligned to the four points of the compass. Four rivers flow down from the mount. The southern island is Jambudvipa where humans reside.

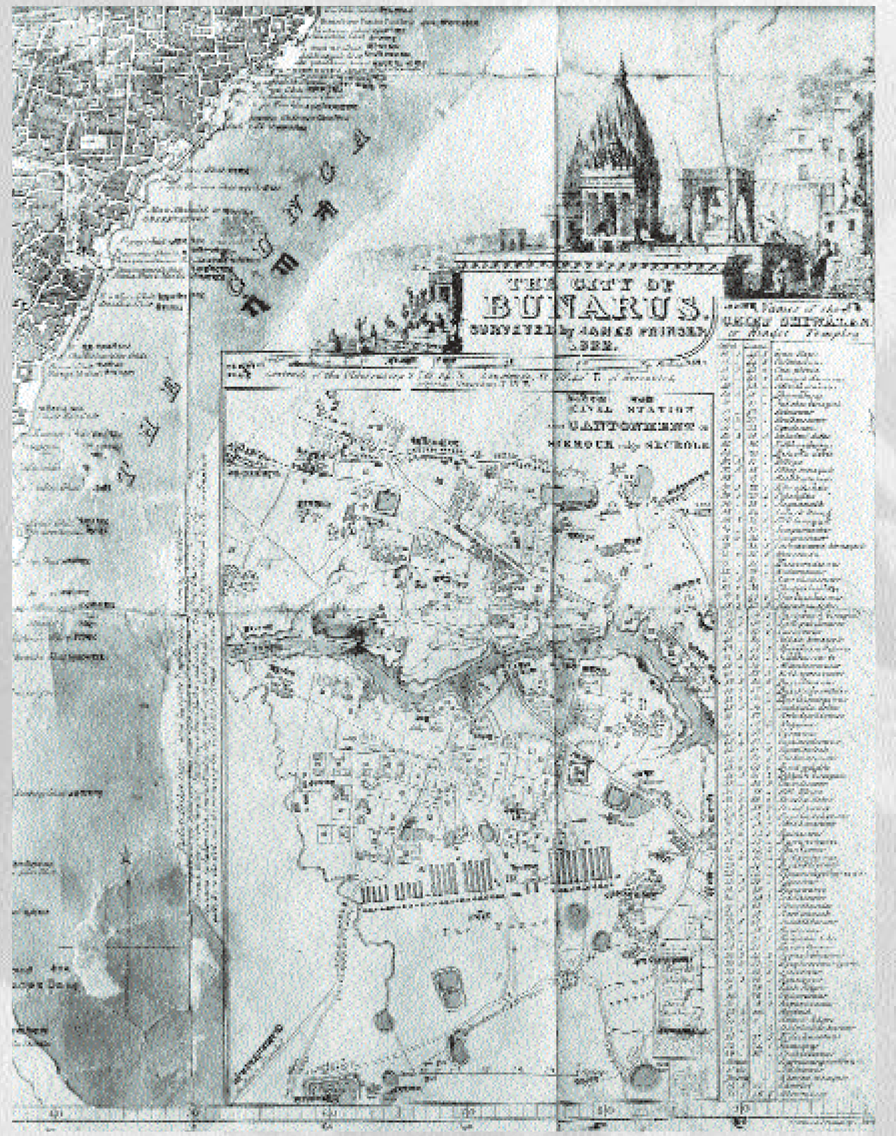
Thus, from a time in the distant past when our understanding of the universe seamlessly integrated both the physical and the metaphysical, the subcontinent has been bound in the North by mountains from which the waters that nourished life flowed all the way down to the sea.

But these were subjective depictions; they incorporated the culture and beliefs of the observers, just as much as the scientific tradition of the subcontinent did. In the 19th century, subjectivity had no place within a new 'rational' empirical science the West was awakening to.

Early Indian Globe
This 18th Century globe shows the earth in two parts. The upper half are the heavens and the lower the earth.



Right: Buddhist concept of the Universe
In this cosmographic conception, Mount Meru is shown as the centre of the Universe.



Below: The City of Bunarus
The city plan of Varanasi surveyed by James Princep in 1832.

The PLAN

The plan
A plan to survey the subcontinent of Hindoostan, ascending the 78th meridian…

This is the story of a scientific endeavour of Herculean proportions to be launched on the vast expanses of Hindoostan.

The enormous peninsula will be surveyed on the most precise and "correct mathematical principles" by Brigade-Major William Lambton, an officer in His Majesty's 33rd Regiment.

The venture has the full support of the East India Company who sees the Indian subcontinent as a highly desirable territory. For Lambton, however, this is a great space for geodetic investigation. The subcontinent is a large, curved surface of the earth close to the equator, a continuous global detail, that can be accessed, mapped and mathematically computed.

Lambton is a mild-mannered man of extraordinary scientific passion. A self-taught astronomer, geographer and mathematician, it is his "desideratum most sublime…to determine by actual measurement the magnitude and figure of the earth, an object of the utmost importance in the higher branches of mechanics and physical astronomy."

A man of his times, Lambton shares the 19th century obsession with the figure of the earth. His imagination is fired by similar investigations in Lapland and Peru.

Lambton joins the British army as an ensign in the 33rd Regiment and is sent to Canada. Enlisted as a surveyor, he spends 13 years in the wilderness applying himself to surveying and mathematics - and foregoing promotions. He finally moves with his regiment to India, almost 50 years of age.

"The presence in India of a man of Lambton's genius and character, knowledge of mathematics and interest in geodesy, was entirely fortuitous…"

The proposal : politically correct, geographically precise and scientifically sublime
Lambton's Plan of a Mathematical and Geographical Survey talks about "the great advantage to general geography that would be derived from extending a survey across the Peninsula of India for… determining the positions of the principal geographic points… ascertaining the great geographical features… upon correct mathematical principles…"

George Everest is the brilliant executor of Lambton's scientific legacy. He will join the Survey when it reaches central India and take the Great Arc forward to its conclusion at the foothills of the Himalayas. A scientist, engineer and astronomer and above all, a man of indomitable will and character, he will raise the accuracy of the Survey to the highest possible level. Restless experiments and innovations will earn him the epithet of "Neverrest".

The survey plan is quite audacious. It seeks to explore the territories of Tipu Sultan in Mysore, the Nizam of Hyderabad in the Deccan, the Maratha confederacy of the Peshwa, Holkar, Scindia, Bhonsle and Gaekwad stretching from the Deccan to Delhi, the Nawab of Awadh...

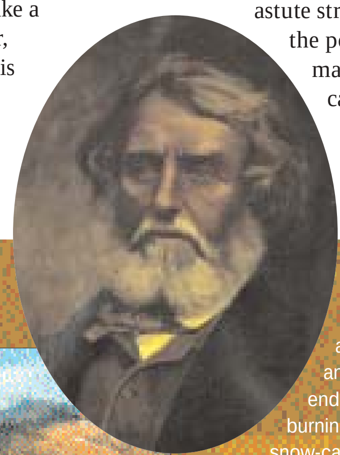
In its agenda, it is much like a military campaign. However, Lambton, who has proved his soldierly qualities in the last battle of Seringapatam, is interested in nothing except his scientific dream.

Maps are power
The British Army is still smarting under a defeat with Tipu Sultan, misled by a map that had shrunk the land and changed the topography. The Governor General's brother, Arthur Wellesley (better known later as Duke of Wellington), therefore supports Lambton's grand proposal. An astute strategist, he understands the potency of an accurate map in a military campaign.

Maps merit great attention, specially as the geographical knowledge of the Indian princely states is not for sharing. Most maps are guarded, safe from an envious neighbour or would-be conqueror.

Even the most assiduous surveys till now have resulted in maps more enthusiastic than accurate. Large areas are left blank or detailed imprecisely. To the dismay of the powers, the widely acclaimed Map of Hindoostan by James Rennell will soon be revealed to have gross errors, with all principal places "considerably out of position", and "an error of no less a quantity than 40 miles in the breadth of the Peninsula".

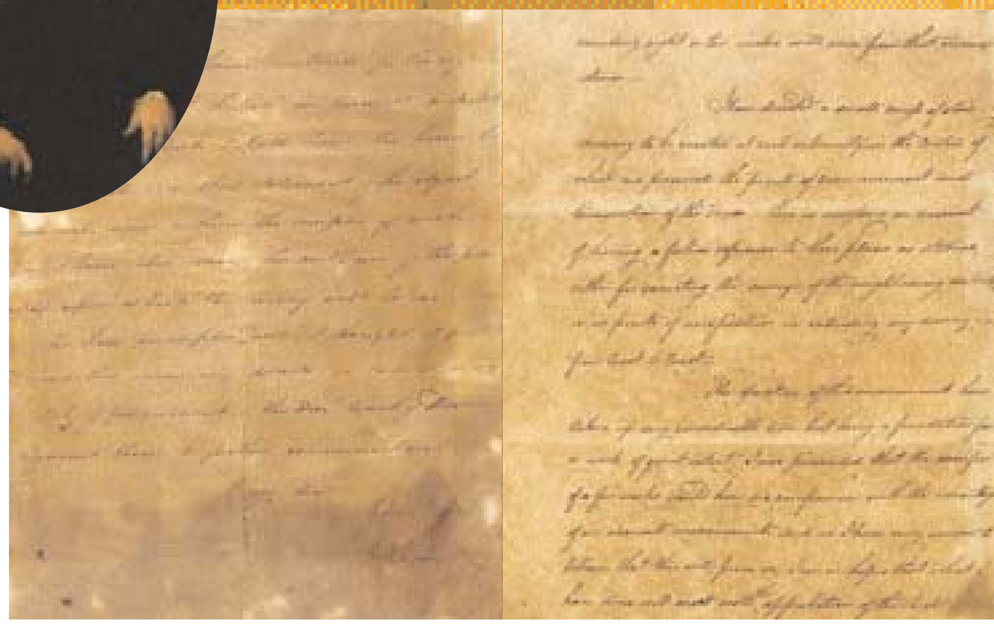
Coat of Arms of the East India Company



George Everest
A worthy successor to Lambton who made the Arc his life's work. The loftiest peak in the Himalayas and, consequently, in the world, was given his name: an acknowledgement of the painstaking scientific endeavour that crawled through the subcontinent's vast burning expanse to mak possible the measurement of the snow-capped Himalayas.

Park Estate in Hathipaon near Mussorie
The Estate was bought by Everest in 1829. Here he set up both home and office and many of the operations of The Great Arc were conducted from here.

William Lambton
Initiated into higher mathematics early in life; joins the British army as an ensign in the 33rd Regiment; moves to Canada, enlisted as a surveyor; spends 13 years in wilderness applying himself to surveying and mathematics - and foregoing promotions; finally moves with his regiment to India, aged almost 50 years.



Lambton's Proposal
The original letter dated 10th February 1800, from W. Lambton to the Secretary to the Governor of Madras forwarding his proposal for a mathematical and Geographical Survey to be extended across the presidency.

Rennel's map of Hindoostan

James Rennel
The first Surveyor General, was commissioned by Lord Clive in 1760 to survey the country.

The first step of the greatest geodetic measurement ever undertaken

Inch by inch, over grains of sand, to crystals of snow

Slowly, and with great deliberation, the Survey will journey in a great arc from the sands of Marina Beach in Madras to the towering Himalayas, taking half a century to reach its goal. From start to finish, it is the scientific determination of the first step that will steer the Survey in a relentless pursuit of precision.

The flag-off is the measurement of the baseline at Madras, on grounds Lambton has chosen carefully "the country best suited for this measurement…St Thomas' Mount…an entire flat, without any impediment for nearly eight miles, commencing at the race ground and extending southerly".

The region selected is politically friendly and supportive of the endeavour: Fort St George in Madras has been a British base since 1640. The surrounding countryside is perfect for the exercise, dotted with *droogs* (hills) that offer convenient vantage points so essential for triangulation.

The Survey will begin by determining the length of a degree, between two latitudes and two longitudes - measuring north-south and east-west.

Two seas will be connected by actual measurement, the Bay of Bengal in the east and the Arabian Sea in the west.

Triangle by triangle, a mathematical mesh will cover the entire subcontinent. This will become the base for all other surveys, which can then be accurately extended in any direction and to any distance.

The first triangles: "as perfect a thing of the kind as has yet been executed…"

10 April to 22 May 1802:
The base of the first triangle is measured - a stretch of 7½ miles (12 km).

The Chain
The 100 ft chain that was used by Lambton, to measure the first baseline. This British-made chain was intended for the Emperor of China, but by circumstance, ended up in the possession of Dr. Dinwiddie, who then sold it to Lambton.

Astronomical observations are taken to fix the latitudinal positions at each end of the baseline.

27 September 1802 to 13 April 1803:
The penant at St Thomas' Mount is observed from each end of the baseline, thereby forming the first triangle.

The penant at Perambauk Hill is observed from each end of the baseline, forming another triangle.

The hypotenuse of the second triangle becomes a base for the next triangle.

In this way the triangulation moves hilltop to hilltop, over 36 stations. Lambton reports that the work has "been conducted with every possible attention".

The foundation

At Madras, Lambton fusses over the baseline operations, supervising every detail as the 100 foot measuring chain is stretched 400 times to cover the distance of 7½ miles (12 km). Each time it is spread in its special housing, levelled, aligned with elevating screws, and anchored against the high winds. Because metals expand, a new chain is kept as a standard and elaborate expansion and tests are conducted regularly.

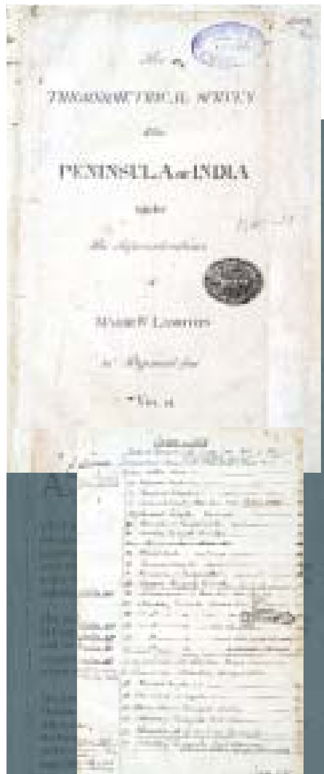
No scope for error

The Great Theodolite, the main instrument with which the angles are observed, receives special attention. Each and every aspect is tested: the semicircle; line of collimation; values of revolutions; divisions on the micrometer in the eyepiece of the telescope.

A triumph of precision

Measurements and observations of the chain, the angles, the stars, are taken twice, thrice, four times. This systematic check-countercheck precision will become the hallmark of the Great Trigonometrical Survey.

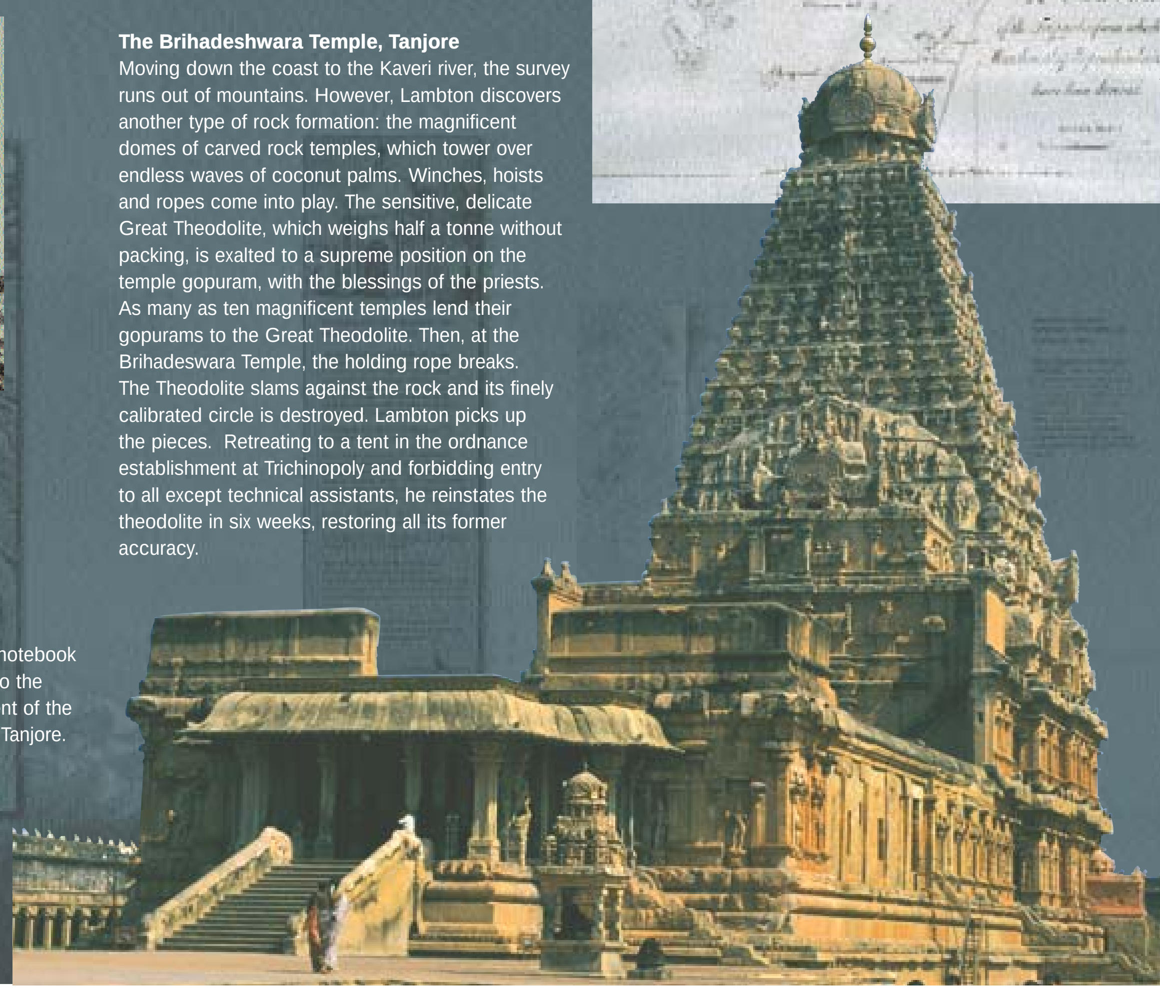
Early Triangulation Map
On April 10 1802, Lambton began his first triangulation, starting at the Marina Beach in Madras. He carefully laid the baseline for the measurement of the length of a degree of latitude along a longitude in the middle of peninsular India, at St Thomas' Mount in Madras.



The Trignometrical Survey of the Peninsula of India under the Supertendence of Major W Lambton 33rd Regiment foot.

Fort St. George Madras
The earliest British settlement in India

Page from Lambton's notebook pertaining to the measurement of the baseline at Tanjore.



The Brihadeshwara Temple, Tanjore
Moving down the coast to the Kaveri river, the survey runs out of mountains. However, Lambton discovers another type of rock formation: the magnificent domes of carved rock temples, which tower over endless waves of coconut palms. Winches, hoists and ropes come into play. The sensitive, delicate Great Theodolite, which weighs half a tonne without packing, is exalted to a supreme position on the temple gopuram, with the blessings of the priests. As many as ten magnificent temples lend their gopurams to the Great Theodolite. Then, at the Brihadeswara Temple, the holding rope breaks. The Theodolite slams against the rock and its finely calibrated circle is destroyed. Lambton picks up the pieces. Retreating to a tent in the ordnance establishment at Trichinopoly and forbidding entry to all except technical assistants, he reinstates the theodolite in six weeks, restoring all its former accuracy.

The great THEODOLITE

So dear to Lambton, no one else may handle it.

Specially commissioned by Lambton from Cary of England, instrument makers par excellence, the 36" theodolite is a machine of many enthralling parts. It is fitted with a 36" horizontal circle, 18" vertical circle and 5 verniers. The readings are so fine, they have to be read through microscopes fitted on each circle.

"A very noble piece of workmanship"

The circle of the theodolite is divided with great accuracy. In almost all respects it is a replica of the instrument made by Ramsden for the famous Ordnance Survey of Great Britain.

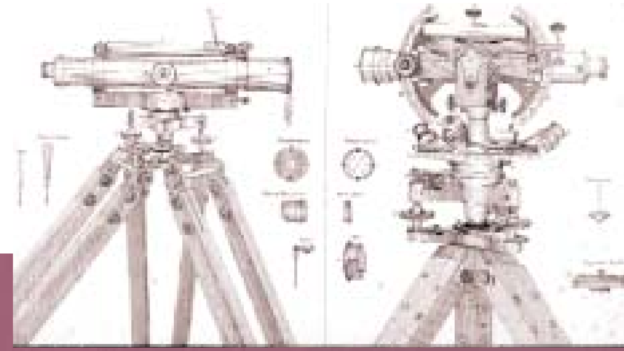
The theodolite is shipped to India at a time when England and France are competing for territory in the East and the ship carrying it is captured by a French frigate but released, "in the interests of science".

The Great Theodolite is a giant, weighing half a tonne. When Lambton takes delivery of the equipment at Pondicherry in, he needs more than 12 coolies to port it.

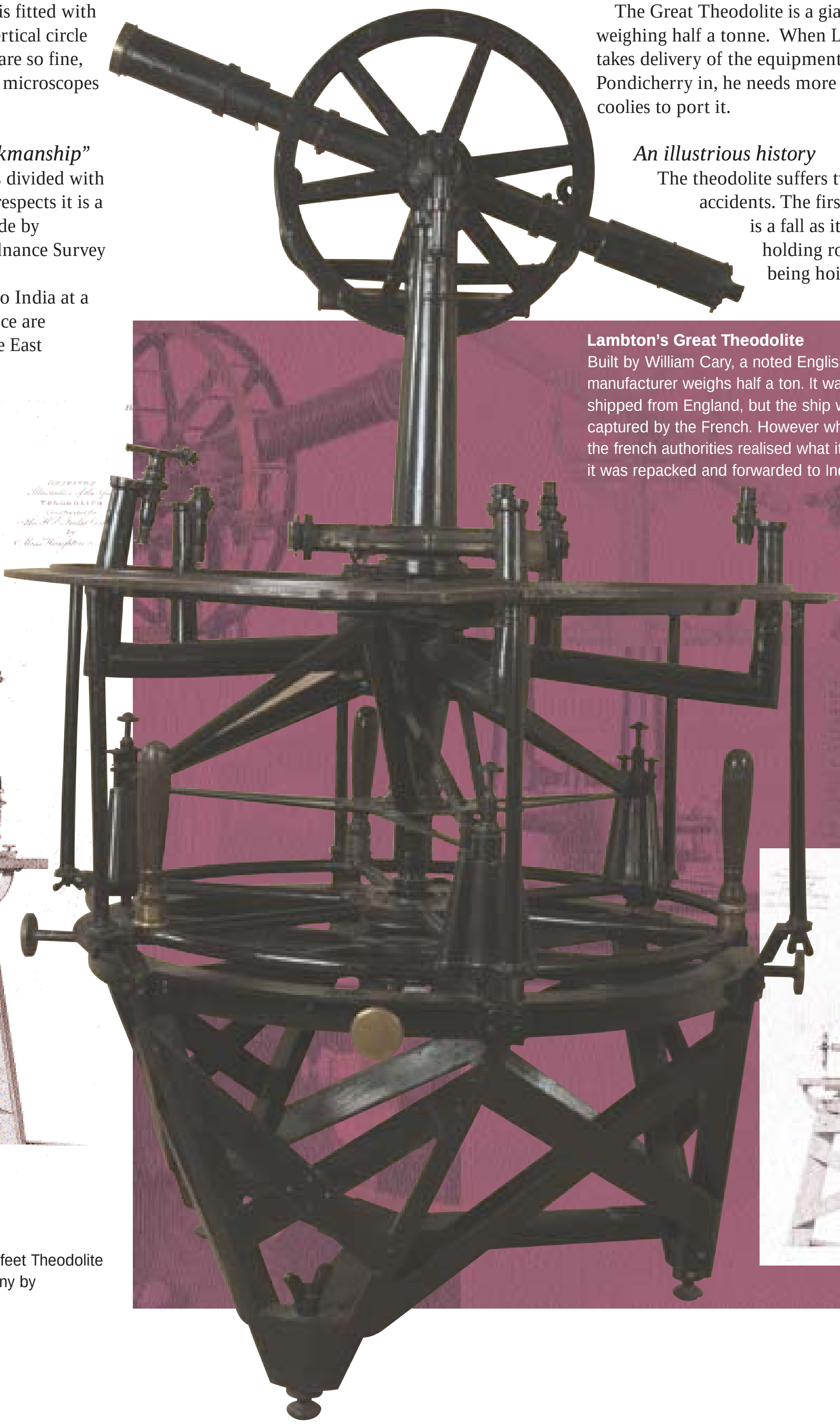
An illustrious history

The theodolite suffers two accidents. The first accident is a fall as it breaks its holding rope while being hoisted to the top of the Brihadeswara temple, Tanjore. Lambton restores it to its original accuracy. The second is a sudden storm that sends the tent crashing down on the instrument. In its 28th year, Everest finds "the delicate screws of the levels are all more or less out of order from continual use", and it is badly in need of rest and repair. The grand old instrument is sent for renovation to the workshop in Calcutta.

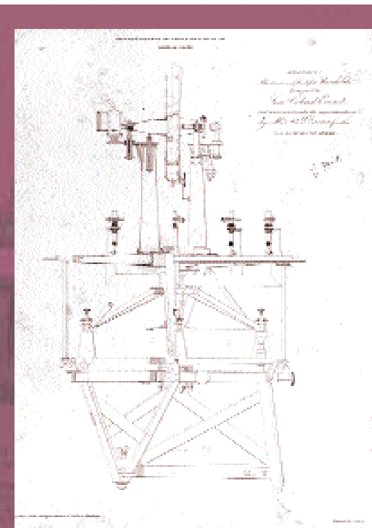
And put back on the field for principal triangulation for another three decades.



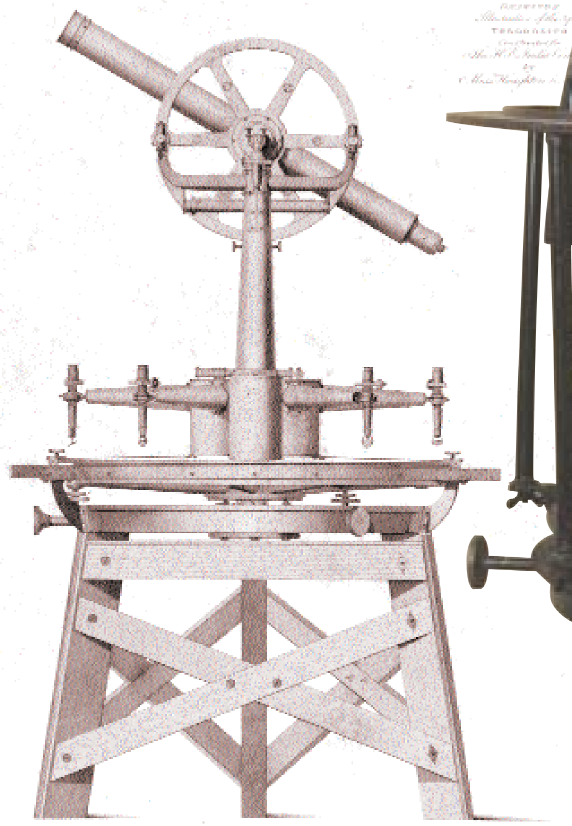
Levelling Instuements
Incorporating a spirit level and telescope, were used for the measuring the rise and fall of the ground along the baseline. Distances could be roughly measured by pushing a perambulator equipped with a milometer.



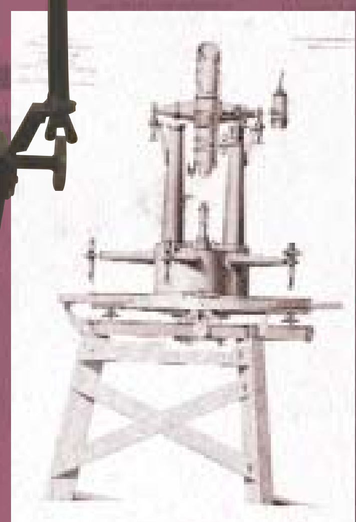
Lambton's Great Theodolite
Built by William Cary, a noted English manufacturer weighs half a ton. It was shipped from England, but the ship was captured by the French. However when the french authorities realised what it was, it was repacked and forwarded to India.



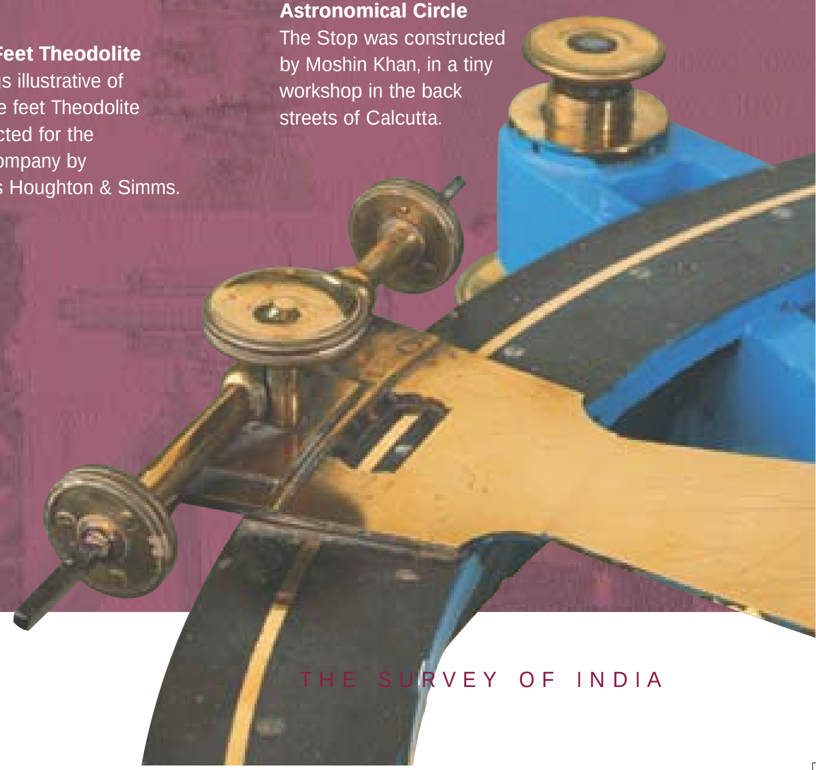
Theodolite designed by Everest
The legend on this drawing reads: Drawings illustrative of the 3 feet Theodolite designed by Lieut. Colonel Everest and constructed under his superintedence by Messers H. Barrow for the G. T. Survey of India.



Three Feet Theodolite
Drawings illustrative of the three feet Theodolite constructed for the H. E. Company by Messers Houghton & Simms.



Three Feet Theodolite
Drawings illustrative of the three feet Theodolite constructed for the H. E. Company by Messers Houghton & Simms.



Astronomical Circle
The Stop was constructed by Moshin Khan, in a tiny workshop in the back streets of Calcutta.

Inspired INSTRUMENTATION

Lambton's genius
Nothing appears to daunt the survey. Dramatic solutions and inventions are the order of the day. Lambton's genius in this respect has already become folklore - of a larger-than-life figure who could resurrect even the Great Theodolite. Everest, the more flamboyant inventor and innovator, creates and improvises on the field.

The uphill task of ensuring hairline precision
The surveyors are passionate about their instruments as these are ported from height to height. The instruments must be maintained in mint condition, despite rocky journeys, by palanquin, bullock cart, camel or elephant back.

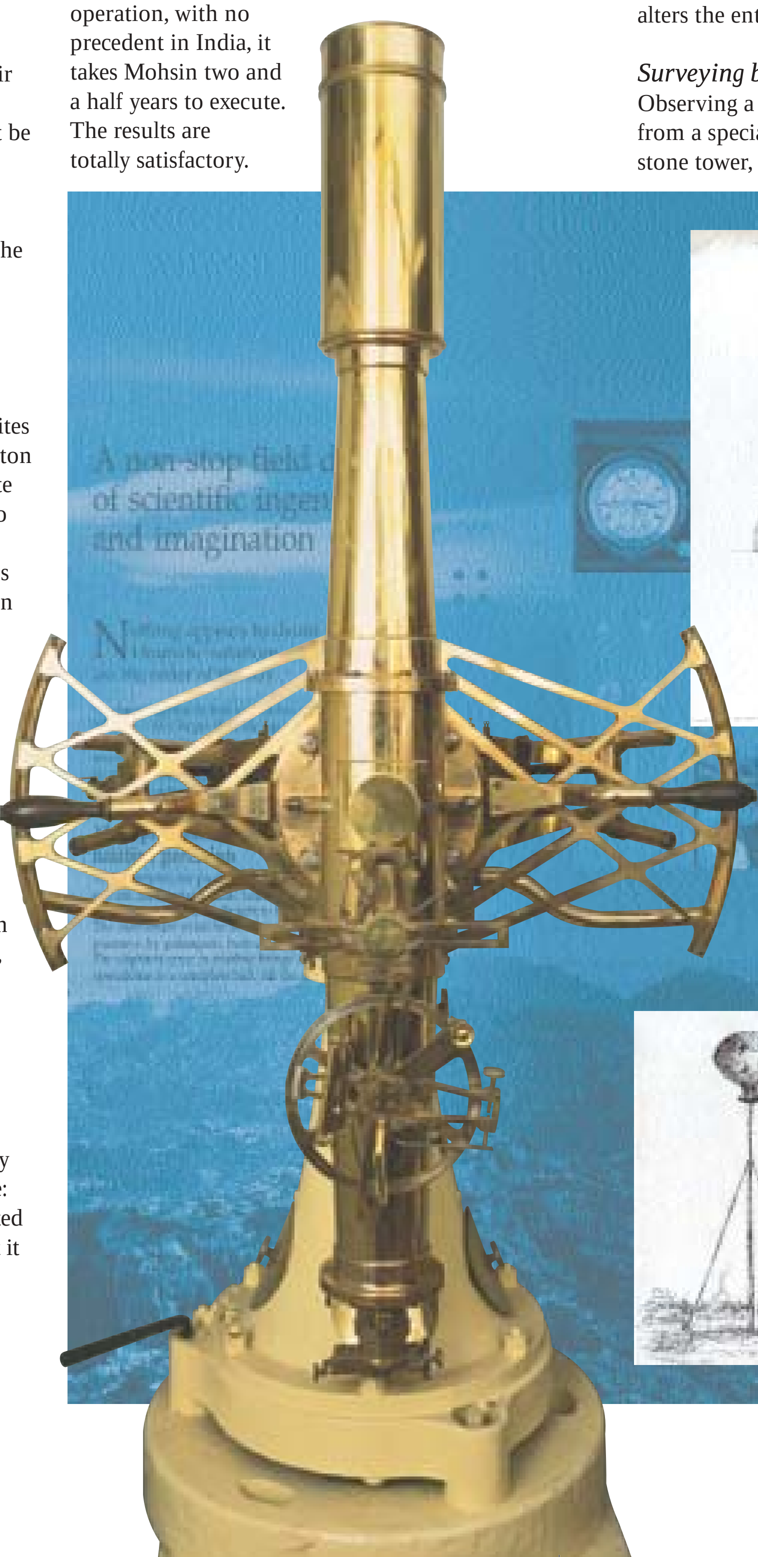
By 1832, Everest has begun to carry the workshop with him, consisting of the "artist" Mohsin Hussain, the carpenter Ram Dheen and a blacksmith.

The Everest theodolites
Everest modifies and improves theodolites continuously. He prevails upon Troughton and Simms to make a 14 inch theodolite based on his design, a stable and easy to handle instrument, ideal for revenue surveys. He also gets 18 inch theodolites manufactured from London, in addition to the one Mohsin Hussain makes, almost wholly with local materials.

The uphill task of ensuring hairline precision
The surveyors are passionate about their theodolites, zenith sectors, measuring chains, transits, watchful and protective as these are ported from height to height. No error is tolerated. The instruments must be maintained in mint condition, despite rocky journeys, by palanquin, bullock cart, camel or elephant back.

The indispensable Mathematical Instrument Maker
Mohsin Hussain, a watch maker from a jeweller's shop in Madras, is game for any challenge. Everest is gushing in his praise: "Whenever any portion of the complicated base-line apparatus was deranged he put it to rights. When the large theodolite by Troughton was found at first trial unfit for work, he rectified its defects. When the cranes were unavailable for…raising large theodolites to the summits of the observing towers, he constructed others…"

Mohsin's greatest achievement is dividing the horizontal circles in 1839, a job refused by Barrow, the Mathematical Instrument Maker at Calcutta. A delicate operation, with no precedent in India, it takes Mohsin two and a half years to execute. The results are totally satisfactory.



Strange's Zenith Sector No. 1
Though similar to the Zenith Sector used by Everest and Waugh, it is smaller in size. (It was manufactured in 1866.)

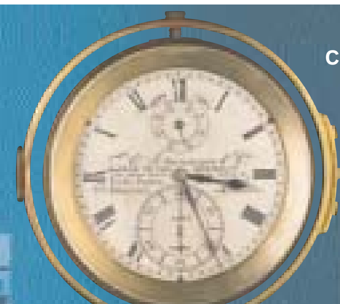
A view that changes the entire schedule of operations
Despite innumerable difficulties, Lambton has always insisted on working during the rainy season. The rain settles the usual haze of the atmosphere, clearing vision. But this is also the time for pestilence, malarial and deadly. On his first assignment in the flat treeless Deccan plateau, Everest arrives at a solution that alters the entire schedule of operations.

Surveying by the clear light of night
Observing a torch lit at a distant station, from a specially constructed 20-feet high stone tower, Everest is delighted to find that the atmospheric properties of the night are better for vision. The atmosphere is much clearer and, what's more, light is visible over greater distances, enabling the sighting of longer angles.

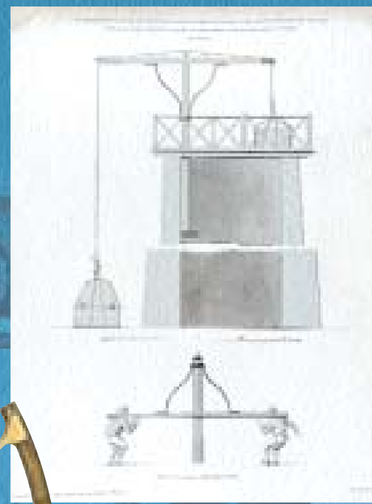
From here onwards, Everest prefers the night to day. Taking advantage of the night air, the Survey begins to work in the healthier dry season. This means eight months in the field as opposed to the earlier four. And, a greater chance of survival.

Tall orders all over the countryside
The lack of natural elevations leads Lambton to use the tops of towering temples - and Everest to construct heights. Despite the substantial additional expense, towers are constructed in various sizes and shapes depending on the terrain and availability of materials. At the extremities of the Calcutta baseline, towers are built 75 feet high to match the elevations of the telegraph towers which are used for observation. For the flat Gangetic plains, Everest deploys his civil engineering skills to design 14 towers, down to the smallest detail.

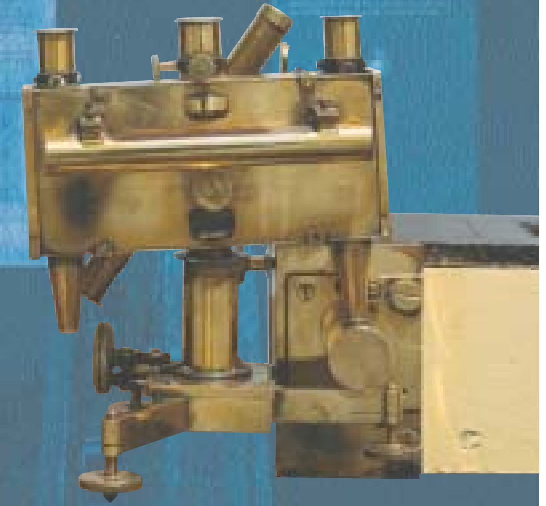
For hoisting the theodolite to the tops of towers, Everest designs and fabricates his own crane. The ones available are not good enough...



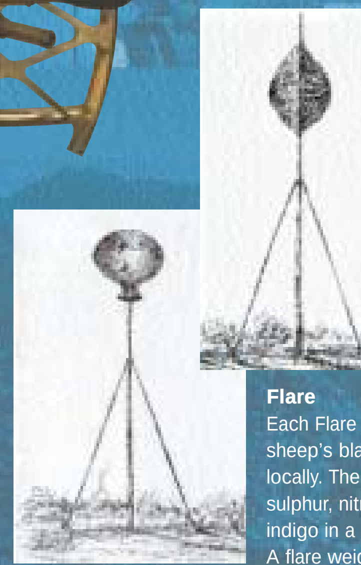
Chronometer
Manufactured by A Johannsen & Co, makers to the admirality of the Indian Government and Royal Navies of Italy, Spain and Portugal, 1894, Minories, London.



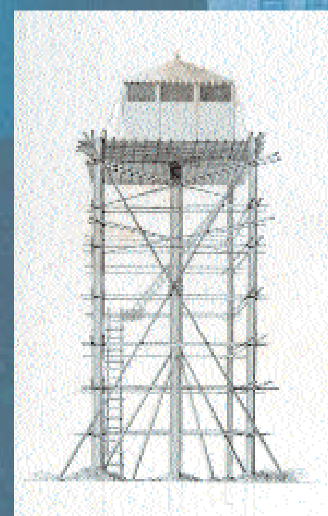
Crane
Drawing descriptive of the crane constucted for raising the Theodolite to the tops of the station towers of the Great Trignometrical Survey of India.



Micrometer
This was attached to the Colby's compensation bar to measure fire variation in length. The Compensation Bar was introduced by George Everest to replace the chain. It was developed by Thomas Colby, the Ordanance Survey's Surveyor General who was entrusted with the surveying of Ireland.



Flare
Each Flare was sealed into a sheep's bladder and was made locally. The recipe involved sulphur, nitre, arsenic and indigo in a specified ratio. A flare weighed upto 3 pounds.



Scaffolding
Perspective drawing of scaffolding used in the approximate operations of the Great Arc Series in 1833-34.