The Arc of the 30th Meridian North of the Equator

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SUMMARY

This paper covers three countries – Uganda, The Sudan and Egypt – which between them have more than half of the 608 stations on the Arc of the 30th Meridian. Work on the Arc here took place over a period of 50 years. The various parts of this are summarised to illustrate how a jigsaw finally came together to realise David Gill's dream.

Four distinct periods are noted: 1908-1909, the 2º arc in Uganda; 1800-1930 in Egypt; the Sudan before 1950 and 1952-1954 closing the gap in the arc in Uganda and Sudan A summary is given of the baselines on this section of the arc.

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1. 1908-1909 2º ARC IN UGANDA

At the beginning of the 20th century there were three colonial powers in the central part of Africa, namely Belgium, Germany and Great Britain. There was controversy between them as to the sphere of influence in this region. "Artificial" boundaries had been established a long time before, and due to the newly discovered parts, it often led to disputes. In 1885, the 30th degree of longitude constituted the eastern boundary of the Belgian Congo. In 1894, agreement was signed between Congo and Great Britain, which met with the protest from Germany because some points in this agreement were contrary to the earlier, 1890 British and German convention. To settle the continual boundary disputes, the Anglo-German Boundary Commission was formed in 1902. This Commission, through the Colonial Office, bore the greater part of the cost of camp equipment and tools with donations from professional societies.[Thomas,1938].

The fixing of the true position of the 30th meridian between Uganda and the Belgian Congo led to a controversy as to the boundary, and in 1906 a Commission was sent to survey the territory in dispute. This joint Anglo-Belgian Boundary Commission under Lt Col Bright was operating in the region near the 30th meridian lying between Lake Albert and the parallel 1º S, and this appeared to both Gill and to Sir Herbert Read, an original member of the Colonial Survey Committee, to be a good opportunity to utilize some of the personnel of the joint Commission to measure that part of the arc of meridian which traversed the area in which the Commission had been working. This was agreed by the two Governments; Belgium appointed M Dehalu an astronomer from Liege University to assist. In the early stages the British party was under Col Bright but in August 1908 command went to Capt E M Jack who was joined by G.T. McCaw as assistant observer. The party observed an arc from 1º11' N to 1º11' S together with astronomical observations by the Belgians and a base was selected at Semiliki, at the northern part of the chain on the Lake Albert flats. Survey measurement was carried out by both parties jointly, in August and September 1908. Sixteen trigonometrical stations were fixed and permanently marked. 35 triangles in five figures were observed with a 10-inch Repsold theodolite, lent by the Transvaal Government using 5 inch helios and acetylene lamps. Using Repsold theodolites and a zenith telescope M. Dehalu observed over a period of nine months 14 latitudes using up to 49 distinct pairs of stars at a single station, and azimuths at Omunturok, NKenda and Kikerere. [Zakiewicz, 1997], [Jack. 1951]

Climatic conditions were poor, especially in the vicinity of the Ruwenzori Mountains, and each station took an average of 36 days to complete. The estimated total cost was £4750, which included the Belgian contribution, or £265 per station. [Macdonald, 1997]

British results were published in 1912 by the Colonial Survey Committee as [Colonial Survey Committee, 1912] and the Belgian results were published by Dehalu as [Dehalu, 1926]

During the same period Dehalu and Wangermée took magnetic declination observations at 58 main points of which 15 were geodetic points [Arden-Close, 1950]. In the same reference is a comment:-

> *The geodetic points are marked on the ground by piles of dry rocks, in a conical shape, around 5m diameter at the base and about 2.50m high; in the centre, following the axis is fixed an iron tube 3m long surmounted by two circular metal discs set at right angles to one another.*

The length of the Arc measured in Uganda was a little over 2º and extended from the frontier of Uganda on the south to the southern shore of Lake Albert, so that not all the meridional extent of Uganda was traversed. Thus between Lake Albert and Aswan in Egypt there was a big gap- the longest reach then (in 1929) still unmeasured. [McCaw, 1931-33]

Though relatively short, this section of the Arc possesses features of considerable interest. It necessarily followed the 30th meridian closely, and accordingly it had to climb two of the spurs of the great Ruwenzori massif, north of which it met one of the African rift valleys-that containing Lake Albert, the Semliki River, and Lake Edward. South of the equator the Arc passed close to Lake Edward and to the region known as Mfumbiro, with its great chain of extinct volcanoes. At a station (Kasunju) overlooking Lake Edward 22 small crater lakes are visible. Not only would it have been practically impossible to occupy the summit of Ruwenzori-known locally as Gambarambara- over 16 000 feet in height, but even on the higher of the two spurs occupied-Karangora-the observations were secured with difficulty, six and a half weeks being spent on the mountain for the terrestrial observations alone. Observations for latitude were made at 14 out of the total of 16 stations, and for azimuth at 3 stations. At one of the latter (Kkenda) the attraction from the west must be very considerable, yet the effect on azimuth was very slight.

In such a greatly disturbed region it might be expected that the deviations of the vertical would be marked, and they are. They rise to over 20 seconds. In order to obtain a reasonably correct value of the latitude, the measures at all stations north of the equator had to be rejected, and the latitude finally selected as standard was derived as a mean of the seven stations south of the equator.

The attractions and the geoid are shown in [McCaw, 1931-33], where the profiles on both the western and eastern sides of the chain are drawn. The attractions here are largely local and indeed, the greater deviations might have been anticipated qualitatively, being conditioned by the central mass under Margherita and the rift valley to the north, including Lake Albert. On the western line the geoid rises to the escarpment west of Lake Albert, on which stands Isura; on the eastern line, on the other hand, in the same latitudes, the geoid drops in the lake. On both the eastern and western lines the latitude of the summit of the geoid is approximately 0º 25' N.

The geoidal surface must vary considerably in an east-west direction; it will be seen that in this sense also it rises towards Margherita and climbs steeply from Lake Albert towards the

Isura Escarpment; but obviously more observations, preferably of longitude, would be required to determine its shape. It is only by making Igurua a common point of both meridional lines that any comparison in an east-west direction has been rendered possible. [McCaw, 1931-33]

The only baseline in Uganda, at Semliki, was observed August and September 1908 by G T McCaw, Capt. Jack and Dr Chevallier and had a reduced length of 16 532.37644 m. It was located in the Semliki valley in Toro to the SW of the river and to the SE of Lake Albert and was measured with 6 Jäderin invar wires of 24m each standardised at Sèvres and the NPL [Ordnance Survey, 1933] [Thomas, 1938]

2. 1800-1930 EGYPT

First surveys by British military engineers in Egypt were around Alexandria in 1801-02 by officers under General Abercromby but little more survey of note was made until the late 1800s.

Apparently it was discovered that some costly base equipment by Brunner-Ibanez had been ordered from Paris in 1858 by Said Pasha. It was used on two short bases at Giza in 1876 and 1877 but otherwise had lain forgotten in its 15 ft case. [Lyons, 1908]. It was repaired in 1885 and again returned to its box. Talbot and Lyons went in search of it and finally found it. After overhaul in Paris it was erected in 1904 at an Observatory in Helwan, 46 years after originally being ordered. [Sandes, 1937]

From 1886 to 1892 Lt.Col. H H Settle was Surveyor-General but it was not until after his time that the Egyptian Survey was reorganised by a technical expert - Capt. H G Lyons who became first Director General of Survey in Egypt when it was founded in July 1898 and stayed until 1909. He began the geodetic triangulation of Egypt along the Nile Valley in 1907 when there was a need to form a sound basis on which to tie the cadastral surveys of the country.

The main triangulation of Egypt consists of a narrow belt of braced quadrilaterals running north along the valley of the Nile from near the frontier with the Anglo-Egyptian Sudan to Cairo.

The reconnaissance survey of somewhat less than 150 km was a long strip from Cairo (lat. 30° N) to Beba (modern Biba, 1922 Bibba) (lat. 29° N), carried out by E Wande, under the charge of B Keeling, the superintendent of the Helwan Observatory near Cairo. Two baselines were chosen at this time: one near the Helwan Observatory and the second one, called Beni Suleiman (lat. 29° N), between Beba and Beni Suef.
In [AIG, 1930] it is reported that

> *A second section joining Cairo to Suez has been completely observed and computed. This is the first stage of a junction of the Egyptian geodetic chain with the Palestine triangulation*

The baselines were measured with six, 24 m long, Jäderin invar wires and base measuring apparatus designed by Benoit and Guillaume; made by Carpentier of Paris. Four of the wires were purchased new in 1920. These wires were standardised on a 24 m base at Helwan Observatory, measured with a 4 m invar bar. [Cole, 1944]

The primary standard bar was calibrated in France and later was kept at Helwan Observatory. Eight arcs of angles were observed with the 10-inch Repsold theodolite on concrete pillars. At the end of 1909, the reconnaissance was carried southwards to Assiut (lat. 27° N), where the third baseline was selected. In the following years as the work extended further south other baselines were measured at Luxor (lat. 25°40' N) and Aswan (lat. 24° N). The angular observations on the section, between these two latter baselines, and the determination of astronomical latitudes, were carried out by J H Cole, and for the first time since 1907, by an Egyptian, Ibrahim Azzam [Survey Dept. Egypt, 1928].

In the 1920s, a chain of triangulation was observed southwards along the Nile Valley in Egypt as far as Luxor under the direction of Captain (later Sir Harry) Lyons RE. This was soon extended to Aswan under the direction of Hussein Sirry Bey and thence to Adindan, across the border from Wadi Halfa in the Sudan. This triangulation followed the course of the Nile from Cairo southwards and the survey teams were transported by cargo sailing boats until they were as close to the station as possible. Then camels were hired to move them up to the station from the river. Observing standards were high and, because ‘broken transit’ theodolites were used, latitudes were observed at every station. Considerable thought went into devising procedures which accelerated progress without compromising accuracy.

The average length of first order side was 40-50 km. with a maximum distance between baselines of about 200 km. Angular and astronomical observations were by Repsold or Breithaupt theodolite of just under 10 inches diameter read by two microscopes at 180º apart. Horizontal angles were observed to 5 inch helios or to electric lamps driven by accumulators. At most stations at least 8 rounds of angles (i.e. face right and face left = one round) were observed on different zeros. [Cole, 1944], [Murray, 1950]. The eyepieces were fitted with micrometers having a single fine vertical travelling hair. In addition there were six fixed hairs; four vertical and two horizontal. The Repsold was graduated to 4′ intervals with the microscope reading to 2″. The Breithaupt had 5' intervals with 2″ by microscope. The vertical circles of both were divided to 10' with 10″ direct by microscope.[Cole, 1944]

Various details of how the circles were tested are given in [Cole, 1944]. It is interesting to note that, when Hotine started to work in Western Tanganyika in 1931, he was still being exhorted to use acetylene lamps by his superiors and had to work hard to convince them that electric lamps were a better solution. [Macdonald, 1997] Practically all stations built in the desert were on rock. They were beaconed with iron cylinders 60 cms. diameter and 110 cms. high filled with concrete and cemented in the top was a tribrach to automatically centre any instrument or signal. This structure was initially centred over a brass stud set at ground level in a metre square of concrete. [Cole, 1944]

The geodetic triangulation from Cairo to Aswan- some 550 miles- was of a very high order. The p.e. of an angle about 0.3 sec of arc. At the time of starting this work the latest available figure of the earth was that by Helmert (a = 6 378 200 1/f = 298.3) of 1906, and the domestic geodesy of Egypt, including lower order triangulation continued to be based on that figure. This figure was used in preference to those of Clarke. When the Madrid Conference of 1924 accepted the figure of Hayford 1910 it was too late to change as the mapping was so far advanced although for scientific use the triangulation was computed on both figures. The positions of the arc have been recomputed on Hayford figure, but judging from the printed report of 1927, the result may increase the A-G differences. The positions of all trig. points were also given on the Transverse Mercator. [Winterbotham, 1928]

When the geodetic triangulation started there was only one point of fixed longitude in Egypt. This had been achieved at the time of the 1874 transit of Venus at Moqattam Hill near Cairo by the exchange of telegraph signals with Greenwich Observatory and at the same time with Suez similarly determined by Sir David Gill in 1874. Subsequently it was thought to be in error by about -3.45″ due to deflection of the plumb line. The Helwan Observatory was connected, through subsidiary triangles, with the transit of Venus station on the Moqattam Hill.

For latitude, the mean discrepancy between the astronomical and geodetic latitudes of the first eight stations south of Cairo was made zero. The Egyptian chain, between Cairo and Adindan (north of the Sudan border), was adjusted in blocks. Laplace azimuths were used only for the southern section, between Aswan and Adindan. A chain from Cairo to Suez, was established with a view to a future connection with the parallel Indian Arc. The Suez and Adindan bases were measured in 1929-30 with the new invar wires re-standardised in Paris in 1929 and wireless longitudes were made at five stations. [Survey Dept. Egypt, 1928], [Zakiewicz, 1997]
In 1930, the Egyptian portion of the Arc of the 30th meridian was already completed. It ended at a measured baseline near the Nile at Adindan (lat. 22°10' N). Later, in the 1930s, the geodetic network Cairo-Adindan was extended from Cairo through Alamein (100 km west of Alexandria) and Mersa Matruh to the western boundary of Egypt. [Zakiewicz, 1997]

3. PRE 1950 IN THE SUDAN

The first Royal Engineer to survey in the Sudan was Col. Charles Gordon who landed at Suakin 25 February 1874. His work consisted mostly of rapid exploratory work and detail survey.

In 1893 Major M.G.Talbot went to Wadi Halfa and began a small triangulation after fixing his position by telegraphic comparison with Cairo. Subsequently he went into the Nubian desert and determined the position of the oasis Murrat Wells. During the winter of 1893-4 he commenced triangulation from Suakin, in 1896 completed a triangulation survey from Halfa to Kerma, in 1898 he fixed Merowe telegraphically and began a small triangulation between there and Abu Hamed. On January 1st 1900 Talbot was appointed to the newly created post of Director of Surveys and then resumed mapping the country.

In 1901 C.W.Gwynn was detailed to mark the frontier and as a result the position of the Blue Nile as shown on previous sketch maps proved to be in error in longitude by up to 50 miles. Gwynn later resurveyed the Eritrean frontier from Kassala to the Red Sea, closing on the Suakin triangulation. He measured a base at Kassala and began triangulating northwards in December 1901, completing it at Suakin in March 1902. In 1903 the Butter-Maud Expedition was to survey the country east of Lake Rudolph and to carry triangulation to the north end of the lake. They measured a base of 3 ½ miles near Lake Rudolph.

Capt H.D.Pearson succeeded Talbot as Director of Surveys, with Lieut. A.E.Coningham as Assistant Director. During 1905 and 1906 Coningham became proficient at triangulation covering 5000 sq miles in one season and in 1907 he started triangulation south from EI Obeld. [Sandes, 1937] .

In 1908, presumably as a result of a resolution passed in that year by the International Geodetic Association favouring the continuation of the Arc, A. E. Coningham presented a short note to the Director of Surveys, suggesting a rough line for the measurement of the Arc through the country. He suggested three different routes for traversing the swamp belt lying between latitudes 6º and 10º North (the Sudd) which presented the greatest difficulty. Large detours could be made to the east or west of it, or else it might be possible to “slog" straight through the area, erecting signals at carefully selected points.

From then until 1928, there was silence but in that year a similar though more detailed resolution was passed at the first Conference of Empire Survey Officers and this led to the reopening of the work by an imperial party in Tanganyika Territory, who were to connect the existing parts of the Arc in Northern Rhodesia and Uganda, whence the chain was to be continued northward into the Sudan.

In 1929 discussions about the most economical way of dealing with the Sudan gap made considerable headway. Better knowledge of the Sudd region indicated the possibility of taking the triangulation across this area on dry land with the help of portable steel towers. E. K. G. Sweeting was able to confirm this and suggested a feasible route, east of the Bahr ez Zeraf, linking up the hills north of Juba with the Nuba Mountains.

Then unfortunately the world economic crisis intervened to create a further delay. The Sudan was badly hit and was slow to recover, so it was natural that the problem of the Arc was shelved. In 1933 the question was reopened by the International Union of Geodesy and Geophysics, at their 5th General Assembly at Lisbon, and the following proposal was made:

> *L'Union Géodésique et Géophysique Internationale confirme le voeu qu'elle à adopt, a l’Assemblie générale de Stockholm en 1930 relativement ... l’arc du 30-iéme Méridien en Afrique. Elle appelle attention des Gouvernements intéressés sui, la nécessité de compléter cet Arc et d`entreprendre la mesure de deux Arcs de paralléle, l’un voisin de l’équateur, du Sénegal ... la Somalie, l’autre le long du parallèle de latitude sud* 6º

The state of the finances of the Sudan still precluded any large contribution but, with the far-sighted support of the Governor-General, Sir Stewart Symes, £E.1,000 was allotted for 1935 with the promise of further annual allotments of not less than this amount. This sum was sufficient only to maintain a party in the field but they were able to loan a Geodetic Tavistock theodolite from Tanganyika and had the promise of base-measuring apparatus as soon as it was free. The fact that a single reconnaissance cum beacon building party was put in the field in October, 1935, was largely due to the energetic efforts of S. L. Milligan who had kept the idea of the scheme alive since the depression of 1930.

Egypt had completed its part of the Arc to the Sudan border in 1930 and, as the gap south of the Sudan had not been closed by 1935, the obvious decision was made to begin in the north. The field party started from Wadi Halfa with few fixed ideas.

The Egyptian part of the Arc ended at a measured base line near the Nile at Adindan (lat. 22º 10' N). No detailed reconnaissance had been made of any part of the Sudan Arc, nor did sufficiently good maps exist of the northern half for even a preliminary layout to be settled in the office. In the early years of the century some rapid triangulation had been done but basically it was starting from scratch again.

As a result of negotiations with the G.S.G.S a request for the loan of the "Macca" base measuring apparatus from the Department of Lands and Mines of Tanganyika met with a favourable reply in December, 1935. The gear for use on the Amentego baseline reached Khartoum two months later and was examined rather superficially before being taken into the field.

This apparatus has been described in detail by M. Hotine [Hotine, 1935] It included the three standard 100ft. invar tapes Nos. 1, 4 and 5 and the two working tapes Nos. 2 and 3 used on the Kate base. Standard tape No. 1 was not received with the rest of the apparatus and reached the field party after the initial comparisons between the working and standard tapes had been made. The rotten condition of the straining cord was not discovered in Khartoum and this was later to have serious consequences.

The small aligning telescope, which was used for measuring the vertical angles of each bay, was fitted with a vernier system of reading. This was found unsatisfactory as gross errors of a degree or ten minutes were liable to occur and it was not realised, until half way through the first measurement, that it is essential to record each angle of slope as an elevation or depression; this would not be necessary for a circle fitted with a micrometer reading system. To change face, the telescope must be removed from the wyes, which becomes very tedious on continuous slopes exceeding 1º. Work lasted from March 18th to May 1st, 1936, a total of 45 days.

The Quleit base was 6.2 miles long in latitude 13º 50' N. in the *qoz* country of Northern Kordofan. The distance from Amentego is 600 km. measured along the median line of the chain. Every effort was made during reconnaissance to get its direction as nearly at right angles as possible to the prevailing winter winds from the north

The site for the base at the southern end of Section 1 was found by R. C. Wakefield in December, 1935. The line is 6.4 miles long, with its western terminal about two miles from the nearest point on the east bank of the Nile and five miles approximately N.N.E. of the village of Amentego. The area is rough flattish stony desert with isolated hills. The only obstacles in the line were an isolated sand-dune, 30 m. wide and 5 m. high and a few steep rocky knolls.

The centres of the helio screws of the terminal pillars are marked with cross cuts and protected by brass caps. This simple arrangement demands filing down half the helio screw to allow for the slope of the tape.

With vast desert areas on both sides of the Nile Valley in these latitudes, it was obvious that the chain would follow the valley as far as Debba; for not only would there be a better chance of arranging a good lay-out, but the river and the motor track alongside it would be the main line of communication. The previous triangulation along the river would also provide the necessary control for the exploration of the desert on either side.

In general, and except for the area lying close to the river north of 'Abri, the country west of the river provides no obstacle to mechanical transport. It is the friendly type of desert country, where numerous small sandstone hills and ridges give a pleasant relief to an otherwise endless plain of uneven hard sand, covered with fragments of eroded sandstone.

On the east bank the picture was very different. As far as 'Abri there is no freedom of movement for mechanical transport, and the rough road is the only way through this barren mass of broken hills.

The natural route for triangulation was astride the river, but ease of inter- communication was an important factor in the lay-out with a single observer and inexperienced native light-keepers. The only two places at which any facilities at all existed for ferrying the cars across the river were Wadi Halfa and Dongola, and those at Dongola were very primitive. A third ferry was later organized at El Ghaba just north of Debba, where the bank was so steep that a block and tackle was needed. [Wakefield, 1950]

Due to the Second World War all survey activities were stopped and work on the Arc in Sudan was resumed only in 1947. Then, most of the pillars for the third section of the Arc were built. The observations at the 25 stations of this section were carried out during the observing seasons, until April 1952. D. T. F. Munsey was in charge of the field party in the first seasons of 1949 and 1950.

The angles of the primary chain were observed, sometimes on 32 zeroes, with meticulous care and analysed so thoroughly that a systematic error in the theodolite circle was tracked down and eliminated. It was found that the same angle observed from an even graduation to an odd one was 2" larger than when observed the other way round, due to an engraving fault which became apparent as soon as contact was made with Cooke Troughton & Simms works where the small and geodetic Tavistock theodolites were built. The dividing engine only cut the 20-minute divisions for the smaller instrument, to cut the intermediate 10-minute ones for the geodetic model the circle was turned, in theory, through exactly 10-minutes. but in the Sudan instrument this was 9'59", hence the anomaly. The average triangular misclosure of the chain was 0.60".

For the baselines, measured with 100-foot invar tapes in catenary, a large party was required particularly to hold and move the windscreen required in the open desert. The Abu Qarn base site was selected in 1951-52 by Munsey and Mason at the southern end of the chain (lat. 10° N) and Mason started its measurement and that of the expansion figure in November 1951 and completed it in January 1952. Unfortunately it was to be the most inaccessible of all the base lines in Sudan. From clearing the line to its completion took 39 days. The difference in length between the outward and reverse readings for all the 336 x 100 ft bays was but 0.002 ft. For this section of about 4º the closure on the Abu Qarn base from a triangle near Quleit was -1:150 000 in length and 2 seconds in azimuth.

The Sudan portion of the Arc was computed on the Modified 1880 Clarke ellipsoid. It was the recommendation of the Colonial Survey Committee to have all African surveys based on the same ellipsoid. One of the Adindan base terminals was chosen as the origin of the Sudan part of the Arc. Its geographical co-ordinates were computed on the Hayford 1909 figure of the earth. The longitudes required a correction of +3.45". [Zakiewicz, 1997]

4. 1952-1954 CLOSING THE GAP IN THE ARC IN UGANDA AND THE SUDAN

With the completion in 1940, of that part of the 30th Arc between Wadi Halfa and El Obeid in the Sudan, there remained only a gap of some 630 miles (1000 km) to make the Arc complete from near Port Elizabeth northwards to Cairo. Half of this 630 mile (1000 km) gap was probably the most difficult section of the whole Arc from the surveying point of view, involving as it did, the crossing of the vast Sudd area of the Southern Sudan. [Anderson, 1956]

This gap extended from the Semliki flats, at the southern end of Lake Albert (now Lake Mobutu Sese Seko) in Uganda and the Belgian Congo, to the Nuba Mountains in Sudan. There was a distance of about 315 miles (500 km) crossing the Sudd region in Sudan, with no hills and floods occurring during the rainy season. This area was for a long time considered impassable for survey. It was stressed that the triangulation south of the Nile bend, at latitude 18° N, where it left the Nile Valley, was of very little value to Sudan and to the development of this region. From Juba to Abu Qarn along the Nile valley it crossed such flat country that 33 m towers were required throughout. This section of the Arc was carried out mainly in the interest of the international geodesy. [IUGG, 1954]
With the possibility of the "Cold War" the United States Government decided that a more accurate figure of the earth was essential for the calculation required for long range rocket warfare. However, to survey a 630 mile (1000 km) chain of geodetic triangulation over some of the roughest terrain in Africa, in a short space of time, was an undertaking calling for a large survey organisation with full State backing. [Anderson, 1956]

At the Conference of Commonwealth Survey Officers in 1951 [Rainsford, 1951] discussions led to a request that a resolution be passed to encourage the execution of the necessary work. The American observer, Mr Floyd Hough, indicated that he would be making a proposal on these lines to his superiors and Conference duly passed the resolution proposed by Martin Hotine and seconded by Colonel Baumann of South Africa. Soon afterwards, a proposal by the United States Army Map Service, which had available the required equipment and the necessary skilled personnel, either of their own, or on secondment from the Coast and Geodetic Survey, for the completion of the work was submitted to the governments of the Sudan, Uganda and the Belgian Congo. This was quickly accepted and, by mid-December 1952, a large United States team was in position in Juba in the southern Sudan.

The party formed up in the Sudan in 1952 and by their first entry into Uganda in April 1953, had observed a large part of the chain across the extremely difficult Sudd region using Bilby towers as “stepping stones” and bulldozing some of the taller parts of the scrub, to get as long lines as feasible. Even then, assuming level ground between them, the stations could only be sited a maximum of 18 miles apart. With 18 mile diagonals on braced quadrilaterals, this meant that side lengths could only be some 12 miles long at their maximum if forward movement was to be maintained without expense to figural strength. [Anderson, 1956]

The party from the A.M.S. cooperated with the survey departments of the other countries. All operations in Sudan were carefully planned with the assistance of the Director of the Sudan Survey Department, Mr Wakefield. Due to the short, four months dry season in Sudan, it was decided to complete the triangulation work during two seasons. The operations started in December 1952 from Juba (the Luluba base) and proceeded northwards to the Ayod base [Mills, 1955].

The team consisted of seventeen Americans, in addition to about 100 staff of the Survey Department. The majority of the party were in fact USC&GS personnel, who had volunteered for this one job, and they had been working to similar standards in America. The equipment included 24 four-wheel drive vehicles and even two bulldozers. The steel towers were of the Bilby type and consisted of inner and outer towers of heights between 50 and 103 feet. Sudan provided twelve towers and five were brought from America. Due to the hard-baked clay soil it took about a week to install four towers with a team of nine people. All observations were made at night and the visibility was poor due to the grass fires.

Among the array of equipment was a De Havilland “Beaver”, seating four passengers, plus pilot and mechanic; it could be used to drop mail, messages and spare parts to the observing teams. This type of plane was able to take off from a short runway carrying a heavy payload and was very popular for survey work in Canada, their country of origin.

The Semliki base had been measured in 1908, when another section of 150 miles of the 30th Arc was surveyed southwards along the eastern side of the Ruwenzori, and down into Tanganyika- then German East Africa. With a probable error of better than 1 in a million, the base was regarded as being sufficiently accurate for carrying the Arc northwards for some 300 miles (480 km) to the new Luluba base near Juba in the Sudan.

The Semliki base had not been visited since the early 1930s, but reasonably adequate description cards were obtained from the Entebbe office, and both Kibuku and Makoga were easily found with the old beacons (steel pipes with round petrol drum tops as signals) still standing, but with considerable slant. Isura and Omunturok, the two western expansion stations, were both in the Congo, and it is of interest to note that at the time the Semliki base was measured, both of these stations were in British Territory – the land lying to the west of the River Semliki in this area, was not agreed to be Belgian until 1911.

Before any observing commenced the Arc stations were reconnoitred right up to the line Zeu (302) – Erusi (303), on the Uganda –Congo border, to the north-west of Lake Albert. The approximate positions of stations were provisionally selected from the existing map of the area, with due regard to shape of figure but the map could not of course be relied upon for checking inter-visibility, this was done by plane. In four hours flying from Fort Portal, proposed stations for 110 miles of Arc were positively identified, inter-visibility checked, and best methods and routes of ground approach studied by the observer who would later be occupying the particular station.

When there was any doubt about a line being clear closer flying was employed. In these cases – the line Zeu to Erusi was one, for example, the pilot having flown along the bearing to the new station, and identified its proposed position, would then goa mile or two further with one of the passengers keeping the hill in view, and then turn the plane round sharply and fly back along the back bearing. As he approached the hill, with the plane on bearing, he would cut airspeed to its minimum and come down low over the ground, and then fly up the side of the hill, and as the plane flew a few feet over the top, the observers would crane forward to see if they could see the back station ahead on line- if so, well and good- but if not the pilot would repeat the process and sometimes even go back and try the line again from the other end, until the chief observer was sure that a satisfactory ray would, or would not, go through.

Observing parties were all equipped with Wild T3 theodolites which had been found to be robust, accurate and yet comparatively light in weight, and all the observers were at home with them, as also with the Parkhurst theodolites that were the standard geodetic instruments in the United States at that time.

All observations on the Arc were done at night to signal lamps, following USC&GS practice, and thereby obviating the need for beacons, which would have been troublesome to build at many of the remoter stations due to the poor accessibility, labour and often lack of suitable local materials.
Sixteen rounds of horizontal directions were laid down for geodetic triangulation, and these were observed on both faces. The rejection limits for a single observation was 4″ from the mean. Extra rounds were taken until a full set of 16 rounds was obtained with a spread of less than 8″.

On July 8th 1953 the next 50 miles of Arc up to the latitude of Arua were reconnoitred by the plane from the Arua airstrip, and one alteration to the preliminary diagram was found desirable. By the end of July, observations had been completed up to and including the line Oyii – Kuching.

The remaining Uganda lines up to the Sudan border were flown on August 3rd and marking of these stations then went ahead whilst the observers were moving up two figures behind. By the end of August all the stations in Uganda had been completed, including a triangular fix to Koboko for the Ugandan Survey Dept. so that it could tie on a few local surveys in that area, and also the link up figure Oyiena, Isi, Meliale, Arawa, Lilak.

For the entire Arc between the Semliki and Luluba bases:-
Distance 263miles 84 triangles closed
Max triangle misclosure 1.81″
Average triangle misclosure 0.52″ [Anderson, 1956]

In October, the party reached Juba in Sudan. When roads were declared open in December 1953, the party moved to the Ayod base to tie the existing triangulation in the Nuba Mountains. Now towers were erected at the rate of one a day and progress was rapid. The gap in the Arc, between the Semliki base and the Abu Qarn base, was closed on the night of 27 January 1954. Sir David Gill's dream of having a continuous meridional Arc, extending from the Cape to Cairo and even to the North Cape, became a reality. [Zakiewicz, 1997]

Overall, 109 stations (63 on towers), with 253 triangles had been observed in 13 months. Astronomical azimuths were observed at six stations. The maximum triangular closure was 2.11 secs with an average value of 0.58 secs. [Mills, 1955],[Zakiewicz, 1997]

But why were the Americans willing to mount such a costly operation? The answer given to the Conference of Commonwealth Survey Officers in 1955 [Mills. 1955] was that

> *truly and simply … … we are interested in obtaining more accurate information on the size and shape of the Earth.*

Base line details

Name	Country	Date	Observer	Length (m)	Method
Helwan (Saqqara)	Egypt	1908	Keeling & Wade	7 946.0433	8 x 24m invar Jäderin wires
Beni Suleiman	Egypt	1908	Keeling & Wade	6 390.8397	8 x 24m invar Jäderin wires
Assiut (Abnûb)	Egypt	1920	Cole	9 686.77095	4 x 24m invar Jäderin wires
Luxor	Egypt	1922	Cole	8 668.76169	4 x 24m invar Jäderin wires
Aswan	Egypt	1927	Cole	7 014.9969	4 x 24m invar Jäderin wires
Adindan	Egypt	1930	Cole	7 865.777	4 x 24m invar Jäderin wires
Amentego	Sudan	1936	Wakefield & Munsey	10 306.1022	Macca
Quleit	Sudan	1939	Wakefield & Munsey	9 904.5724	Special equip:
Sabaloka**	Sudan	1944-45	Wakefield & Munsey	11 790.221	100 ft tapes
Abu Qarn	Sudan	1951-2	Mason	10 230.3720	100 ft tapes
Ayod	Sudan	1953	Mason	8 101.9062	100 ft tapes
Kwidok	Sudan	1953	Mason	6 807.1327	100 ft tapes
Luluba	Sudan	1952-3	Mason	10 324.7917	100 ft tapes
Semliki	Uganda	1908	Jack & McCaw	16 532.37644	6 x 24m invar Jäderin wires

** the Sabaloka base is not strictly on the 30th Arc but on an eastwards chain.

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BIOGRAPHICAL NOTES

Jim R Smith has been involved in various aspects of FIG since 1968 including Secretary to Commission 6 from 1979 to 1987 and Secretary since 1984 to the International Institution for the History of Surveying & Measurement, a body within FIG. In this last position he has been one of the lead figures in the submission to UNESCO of a case for the Struve Geodetic Arc to be designated as a World Heritage Monument. He was on the Land Survey Council of RICS from 1967 to 1996 and Hon.Secretary to the Division from 1968 to 1980.

He took early retirement from the University of Portsmouth in 1989 and acts as Editor of the *Survey Review*. He is author of 7 books, mostly on topics related to the history of surveying, and numerous technical papers since 1967.

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