The Cape Geodetic Standards and Their Impact on Africa

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SUMMARY

The Cape Geodetic Standards consist of two ten-foot iron bars, brought from England in 1839, and used by Sir Thomas Maclear, during the years 1841/42, for the verification of Lacaille's Arc of 1752. Forty years later, when Sir David Gill, having commenced the Geodetic Survey of South Africa, initiated the measurement of the Arc of the 30th Meridian, the "Cape Bar A" was still in existence and kept as a standard reference. In 1886, in Paris, the bar was standardized in terms of the international metre. However, due to the implications with the legal and international metres, it appeared later, that the results of the geodetic triangulation were computed not in English feet but in terms of the fictitious unit now called the South African Geodetic foot. This caused the reference ellipsoid to be renamed to the Modified Clarke 1880 ellipsoid. Later, as a consequence of an extension of the Cape Datum, the 1950 ARC Datum was established, giving a uniform framework of triangulation from the Cape to the Equator. Until the present, some countries, along the 30th Meridian, use the 1950 ARC Datum, thus, the Modified 1880 Clarke ellipsoid, or, its revision, the Arc 1960.

The paper gives an outline of the development of the English and metric systems, which have, without doubt, influenced the establishment of the "commercial" Cape units, used for everyday purposes, and, also, of the unit of the Geodetic Survey of South Africa. The paper describes the reference geodetic standards of this Great Survey, and produces a brief summary of the history of the measurement and computation of the Arc of the 30th Meridian. It will also focus on the Cape Datum, as well as on the 1950 Arc Datum and their influence on Africa.

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1. STANDARD UNITS OF LENGTH MEASURE

Measurement means the determination of any extent in terms of a suitable unit. Usually, it is not so significant how long a particular unit is, but it is crucial that it means the same for everybody. Therefore, measurements must be standard and all units must be accordingly related.

1.1 An outline of ancient standards of length measurement

Distance measurement was presumably expressed initially by means of paces, stone's throw, days taken to travel, etc. Pictures in Egyptian tombs, 5000 years old, show priests with wooden rods, about three metres long. Already around 1700BC, Babylonians used the length of a human foot as a unit of measurement. The Greek units of length were derived from the Egyptian and Babylonian units, which in turn were adopted by the Romans, whose measures, during the Roman Empire, originated the European systems of measurement.

1.2 Development of the English and metric systems

Two systems of measures, widely used and recognized, are the English (or Imperial) and metric. The fundamental length units of these systems are yards and metres, respectively. In England and France measures developed in rather different ways.

In the 1100's a foot of modern length, the "foot of St. Paul", was inscribed on the base of a column of St. Paul's Church in London. From 1300, at least, to the present day there appears to be little or no change in the length of the foot. Henry I (1068-1135) ordered the construction of 3-feet standards, which were called "yards", thus establishing that unit for the first time in England.

In 1824, the English Parliament legalised a new standard yard, constructed in 1758. The same law, the Act of 1824, defined relation of the metre to the English foot (Hendrikz, 1944) as:
1 Metre = 39.37079 English inches = 3.280899167 English feet
Hence,
1 English foot = 0.3047945 Metre (the "Legal metre")

In France, the metric system was adopted in the 1790's, during Napoleon's time. In 1799 the metre was required by law to be used in the Paris region. At first the new metre, as a measure of length, proved confusing so Napoleon finally was forced to abandon the metric system. However, in 1837, France again went back to the metre, hoping to make it global unit.

The metre was intended to be one ten-millionth part of the distance from the North Pole to the Equator, when measured on a straight line running along the surface of the earth through

Paris. It was soon found that, not only was the determination of this natural standard an extremely laborious undertaking, but the accuracy attainable was less than that possible in the comparison of material standards. Here, it must be stressed that, initially, the metre did not physically exist in a form of any bar. The “Toise of Peru” remained the national material standard in France. It was an iron bar, reconstructed from an old “Toise” standard for the measurement of the Peruvian arc in the 1730s. The law defined the length of metre, that is its relation to the “Toise of Peru”, hence the adoption of the name “French Legal metre” (McCaw, 1932).

In about 1795, the French Academy of Science instructed Borda, the Guardian of Standards, to make a physical standard. Borda made two: the platinum “Metre of the Archives”, and, the so called, “Module”, of the length of two “Toises of Peru”, being one of four “Rules”, which he produced. [8] It was Borda’s “Module” that was regarded as the French standard of length, not the “Metre of the Archives”. Subsequently, the duplicates of the “Module” were issued to the European countries. Thus, up to 1880, the whole of Europe, except England, where a copy of the “Metre of the Archives” was kept, referred its linear standards to the “Toise of Peru”.

In 1866, Colonel Clarke determined the relation of the “Toise” to the “Imperial Standard Yard”, from various copies used in Europe. He arrived at the length of the metre:
1 Legal metre = 39.370432 British inches = 3.28086933 British feet
Hence,
1 British foot = 0.3047972654 Legal metre.

In 1875, the International Bureau of Weights and Measures was established in Paris, and it was decided to adopt an “International metre” (McCaw, 1932). In about 1883, the sample of the metre was prepared and issued, having caused a great implication to the geodetic community in Europe, as the standard of the “International metre” was produced from the “Metre of the Archives”, and not from the Borda’s “Module”, then in use in Europe. Definitely, “*the difference between these metres has affected the whole civilized world*”.

In 1896, Benoit and Chaney compared the new “International metre” with the British yard, and determined the relation:
1 International metre = 39.370113 inches = 3.28084275 British feet.
Hence,
1 British foot = 0.3047997348 International metre.

Therefore, comparing Clarke’s and Benoit’s values, it is obvious that the “Legal metre”, determined from the “Toises”, was longer than the “International metre” in a ratio of 1.0000081: there is difference of 8 microns between these two metres.

It is to be underlined that, the history of the metre, and the metric system, with its “Legal” and “International” metres, is not as simple as it might look from the above summary – it is, in fact, very confusing. As was once observed: “*To understand thoroughly the true relations between the old standards is beyond the reach of human endeavour. To gain considerable* *knowledge in regard to them, the principal standards themselves must be described*" (McCaw, 1932).

1.3 Early measuring system in South Africa and an Old Dutch unit of measure

The history of the Cape Colony, thus of South Africa, goes back to 1652, when Jan van Riebeeck arrived at the Cape and the Dutch East India Company settled there. The Dutch pioneers brought their own measures, then in use in Holland. The "Rhynland rood", comprising twelve "Rhynland feet", remained the official unit of length in the Cape for two centuries, until 1859, when a new unit of length, the "Cape foot", was instituted.

During the 18th century the standard of the Rhynland measure was generally regarded as the length of an iron bar, placed in a vertical position in the wall of the Courthouse at Leiden, Holland. It was deemed to be a true copy of the "Rhynland rood", used by Willebrord Snellius for his famous survey of the triangulation chain in the 1620's. In 1808, resolution of the King of Holland defined relation of Snellius' rod to the "Old French Legal metre" as being:
1 Metre = 3.1852560866 Rhynland feet.
Hence,
1 Rhynland rood (consisting of 12 Rhynland feet) = 3.767358 Legal metre (Hendrikz, 1944)

Thus, by comparing the ratio of the British Act of 1824 and that proclaimed in Holland in 1808, it brings, that the true Rhynland foot is equal to 1.030 British feet.

1.4 Establishment of the "Cape foot"

Between 1685 and 1800, ten Government Surveyors performed surveys in the Cape and Stellenbosch districts. In 1800, Thibault succeeded Wernich, and the latter Leiste. Their time of office overlapped and their rods were equal. However, although there was continuity in surveyors' standard, there was no official standard. This situation led to significant discrepancies in surveys. Only in 1813, the Chief Justice of the Court brought this problem to the attention of the Governor Cradock, advising him of the differences, between old units of measure used in Cape Town, before and after 1800. The Court dictated that "*an additional of four inches to the sixty-feet measure of Mr. Thibault, was the difference, and that this difference should be observed at every resurvey of old-granted erven in Cape Town*".

No further action occurred until, in 1844, the Surveyor-General Michell instructed his Deputy to investigate the state of the land measure of the Cape Colony. Hertzog's findings and his proposals were partially repeated, in 1858, by the Commission, appointed by the Governor Sir George Grey "*for the purpose of ascertaining and fixing the unit of land measure in the Colony of the Cape of Good Hope*" (Report of the Commissioners, 1859).

Thibault's two rods, each 6-foot long (intended to be a total of one "Rhynland rood"), regarded as the only standards for reference in the Cape Colony, were subjected to precise checking, at the Astronomical Observatory. The five-member working group, under

leadership of Sir Thomas Maclear, confirmed what Hertzog exposed in 1844: Although the "true Rhynland foot" was equal to 1.030 British feet, this ratio looked different in the Cape:
1 Rhynland (Cape) foot = 1.033 English feet,

Finally, in 1859, the recommendations of the Commission were lawfully declared by the Act No 9, which established the "Cape foot" - a unique, and truly South African entity, used, except Natal, in the whole country. Since then, the ratio: 1 Cape foot = 1.033 British feet was binding on all surveys, and was the legal relation between the "Cape foot" and the "British foot". This ratio was in use for a period of over 60 years, and, in 1922 was slightly modernized, in terms of the International metre, by the "Weight and Measures Act", No. 32.

The following table (Zakiewicz, 2004) summarises the Units of Length, as discussed above.

LEGAL METRES 1824	**LEGAL METRES 1866**	**INT. METRES 1896**	**INCHES**	**ENG. FEET**	**CAPE FEET**	**CAPE ROODS**
1	1.0000091	1.0000172	39.370 79	3.280 899 17	3.176 0884	0.264 6740
0.9999909	1	1.0000081	39.370 43	3.280 869 33	3.176 0591	0.264 6716
0.9999828	0.9999919	1	39.370 11	3.280 842 75	3.176 0339	0.264 6695
0.304 7945	0.304 7973	0.304 7997	12	1	0.968 0542	0.080 6712
0.314 8527	0.314 8556	0.314 8581	12.396	1.033	1	0.083
3.778 2326	3.778 2669	3.778 2972	148.752	12.396	12	1

2. GEODETIC STANDARDS AT THE CAPE

2.1 Sketch of the Geodetic Survey and of the Arc of the 30th Meridian

The achievement in determining ellipsoids from various arcs, and from Struve's in particular, has, without doubt, influenced the imagination of its promoter, Sir David Gill (1843-1914). Gill's idea was to extend a chain of triangles from the Cape to Egypt, and even further north to the Arctic Ocean. When connected with Struve's arc, the whole arc would terminate at the North Cape, and would then have amplitude of 105° (Gill, 1896). Gill visualised this project as very important for practical as well as for scientific purposes. Soon after his appointment, as Her Majesty's Astronomer at the Royal Observatory at the Cape of Good Hope, in 1879, Gill designed the gridiron network of trigonometrical chains to cover the then four states of South Africa. Gill intended that the chain of a triangulation, along the 30th degree of longitude, would constitute the backbone of the African Arc. To begin with the Arc took Gill a lot of effort and three years of correspondence with many governments and institutions.

In 1883 (Gill, 1896), the Geodetic Survey of South Africa, thus, the measurement of the 30th Meridian Arc, commenced, thanks to Sir David Gill, its promoter, inspirer and scientific adviser. Nine years later, in 1892, the survey of the Cape Colony and Natal, under Captain Morris, was completed. The continuous triangles were of sides averaging 50-80 km in length, with the longest line 160 km, across the Karoo. Sir Thomas Maclear's arc, of 1841-48, 4°37' in length, and its Zwartland base were incorporated into the scheme. Three new baselines were measured, with five iron bars (3.05m long); at Pietermaritzburg (3.3km), Port Elizabeth (5.2km) and Kimberley (4.5km).

A chain of triangulation through the Orange River Colony was still required to complete the scheme, but Gill's effort in this direction failed. To continue with an extension of the Arc further north, Gill managed to get the interest of Cecil Rhodes in this project. Between 1897 and 1901, Alexander Simms executed the triangulation of Southern Rhodesia (now Zimbabwe). Two bases, the Inseza, near Bulawayo, and Gwibi, near Salisbury (now Harare), were measured. Due to various difficulties, Simms's party was disbanded after the four years of fieldwork, during which a distance of about 4° of the Arc, almost to the Zambezi River, was measured (Gill, 1905).

Between 1902 and 1906 (Gill, 1908), Col. Morris carried out the geodetic survey of the Transvaal and Orange River Colony. Five extra baselines were established: at Belfast (19.0km), Ottoshoop (17.4km), Wepener (21.7km), Kroonstad (19.8km) and Houts River (34.0km). They were measured with the nickel-steel brass and "invar" Jäderin wires, 25m long. The steel bars, the same as previously used during the Cape-Natal Survey, were employed to measure ground standard bases (146.3m long), which were erected at every baseline, to serve as a check for the Jäderin wires, and were measured both with the wires and the steel bars.

Finally, the South African network formed a gridiron system of triangles arranged in eight circuits. From 1906 to 1907, Captain Gordon surveyed a gap of 2 degrees in the Arc, between Simms's chain in Southern Rhodesia and the newly completed triangulation in the Transvaal. The Transvaal triangulation was joined at points Pont and Dogola, and Simms's chain was connected at Standaus and Wedza. In the meantime, thanks to Gill's further effort, funds were obtained to continue Simms's chain northwards. Between 1903 and 1906, Dr Rubin carried out this work (Gill, 1933). The large difficulties, experienced by Rubin's party, were similar to that of Simms's: problems with haze and light, strong winds, lack of roads, transport and labour. In spite of these problems, Rubin managed to extend the chain of triangulation for almost 800 km; from Manyangau, in Southern Rhodesia, to Mpange, in Northern Rhodesia (now Zambia).

When Sir David Gill retired, in 1907, the Geodetic Survey of South Africa was completed, and the Arc of the 30th Meridian extended from the Cape to the southern shores of Lake Tanganyika.

Between 1908 and 1909, a section of 2 degrees in amplitude was measured in Uganda: from the Semliki baseline, at latitude 1° North, across the Equator, to latitude 1° South (Thomas, 1938). The work on the southern portion of the Arc was resumed only in 1931 (Hotine, 1934), when Major Hotine, picked up Rubin's points in Northern Rhodesia and, in 1933, brought the triangulation, through Tanganyika (now Tanzania), up to Urundi (now Burundi). Later, the Tanganyika's Survey Division continued the survey of the 400 km of the Arc (Rowe, 1938), between Kigoma and Uganda, across Urundi and Ruanda (now Rwanda). Since 1937, the Arc extended from the Cape to the Equator.

The northern segment of the African Arc began in Egypt. In 1907, the geodetic triangulation, along the Nile Valley, commenced near Cairo, and in the following years was extended southwards to Wadi Halfa. Six baselines were measured in Egypt: near the Helwan Observatory, Beni Suleiman, Assiut, Luxor, Aswan and Adindan (Union of Geodesy, 1928). In 1930, the Egyptian portion of the Arc of the 30th meridian was already completed. In the 1930's, the geodetic network was extended from Cairo to the western boundary of Egypt (Ministry of Finance, Egypt). Due to the economic crisis and poverty of Sudan, the survey of the Arc across this territory started only in 1935 (Wakefield, 1950). From Wadi Halfa, the chain followed the Nile Valley as far as Debba, where the first baseline, the Amentego base was measured. South of Debba, the Quleit baseline was chosen, and measured with specially designed apparatus, which had electrically illuminated gear for working at night, when the strong wind stopped. The Abu Qarn base was selected at the southern end of the chain, and was measured in 1952 (Munsey, 1959). In 1953, the US Air Force joined the African Arc with the European triangulation, by an electronic trilateration carried out through the Mediterranean Sea, from Greece. There was also an alternate connection, of the African and European geodetic networks, through the Middle East. The entire African Arc was now completed, except the 1000 km gap between the Abu Qarn base, in Sudan, and the Semliki base, in Uganda. From 1952 to 1954, the United States Army Map Service closed this difficult gap. The Luluba, Kwidok and Ayod baselines were then measured (Mills, 1955). On the night of 27 January 1954, Sir David Gill's dream of having a continuous meridian Arc, extending from the Cape to Cairo, and probably even to the North Cape, became a reality (Zakiewicz, 1997).

2.2 The Standard of the Geodetic Survey

In 1752, Abbe de Lacaille performed the first measurement of an arc of the meridian in the Southern Hemisphere, at the Cape. Lacaille's base (12.6 km long) was surveyed by means of four iron tipped wooden rods, compared with the iron standard rod, which he brought from France (Smith, 2001). In 1841-1848, Sir Thomas Maclear undertook the verification and extension of Lacaille's arc, and proved that, contrary to Lacaille's result, both hemispheres were equal in shape, as Newton had predicted (Maclear, 1866).

When Maclear started the verification survey, he did not have any standard of length at his disposal, because, as already noted, no such standard was in existence in the Cape Colony at that time. In 1838, authority was given in England, on the recommendation of Sir George Airy, Astronomer Royal, for the construction of "*two iron 10-feet bars, similar in size and general arrangement to those used by Colonel Colby, for reference in his measure of the base near Lough Foyle, in Ireland*". The bars were produced by Messrs Troughton & Simms and compared with the Astronomical Society's standard. They were sent to Maclear in July 1839.

Quoting Maclear's words (Maclear, 1866):
"*These bars being alike, a description of one will serve for both. Bar B is wrought iron, 122.22 inches long, 1.46 inch broad, and 2.6 inches deep, supported at one-fourth and three-fourth of its length on brass rollers, secured to the bottom of its wooden enclosing box, and prevented from moving longitudinally by a pin attached to the box, which enters a small hole*

in the centre of the under surface of the bar. At each end, about 2 inches in length and 1.3 inches in depth, are cut away, leaving surfaces which are supposed to coincide with the neutral axis of the bar: into each of these surfaces a gold pin is inserted, to carry the punctures or dots, meant to define the length of ten feet of the British Imperial Standard. A spirit level, in length about 9.5 inches, is attached to the middle of the upper surface of the bar by adjusting screws....At each end, about two inches of the bar, projects through a hole in the case, for the purpose of exposing the dots to the microscopes. A brass ring surrounds the hole, to which a cylindrical brass cap screws on when the bar is not in use.".

In 1840-41, during the measurement of the 13km long Zwarland base, the "Standard Bar B" was used, in the field, for comparison with the Colby compensation bars, lent by the British authorities. ("Bar A" was left at the Observatory). In 1842, the "Standard Bar B" and the compensation bars were returned to England. Then, Bar B was calibrated against the British standards.

Sir Gill commenced the "Geodetic Survey" forty years after Maclear's measurements. "Cape Bar A" was still kept at the Cape Observatory as a standard reference. Gills provides another description of the "Cape Standard Bar A" (Gill, 1896):
"*This standard, which was used by Sir T. Maclear, is a rectangular iron bar 64.5 millimetres deep and 38 millimetres broad. For a distance of 50 millimetres from its extremities it is cut down to half its height, exposing two plane rectangular surfaces coincident with the neutral axis of the bar. In the centre of each of these surfaces is embedded a circular surface of gold and upon each circular surface is a small dot.*"

Hence, during Maclear's survey, the length of the standard bar was deemed to be the distance between two dots in small surrounded round surfaces of gold. However, Gill was not satisfied with the accuracy he obtained, while comparing the "Standard Bar A" with the bars of the newly acquired Troughton and Simms base-measuring apparatus. He was of the opinion that the centres of two dots of the bar, between which the original standard was defined, were difficult to recognise. Therefore, in 1884, he brought the bar to England and requested "*Messrs. Troughton and Simms to engrave a fine line beside each dot; the distance between the centres of these lines represents the present standard*" (Gill, 1896).

In August and October 1886, Benoit performed standardisation work, at the International Bureau at Sevres, near Paris, and produced results in the "International metres". Hendrikz's findings proved that there was no difference, between the provisional, of 1883, and final, of 1888 (Rüther, 1977), version of the prototype of the "International metre", and, hence, that the "Cape Standard Bar A" was standardised in terms of the "real" International metre.

To conclude, it must be observed, with great satisfaction, that, at present, the 167 years old "Cape Standard Bar A", the monument of the Geodetic Survey of South Africa, is still in a good condition, and is preserved, for viewing, in the museum of the Chief Directorate: Surveys & Mapping, Mowbray.

2.3 Unit of length of the Geodetic Survey

As described above, the “Cape Bar A” was standardised in terms of the “International metre”. Thus, in turn, all the lengths of the base measuring bars and, consequently, all the geodetic baselines, were expressed in terms of this unit. In order to reduce his results, and define them in English units, Gill used Clarke’s 1866 ratio, the only metre-foot ratio available at that time. However, because Clarke’s relation connected the British foot with the ”legal metre”, instead of the ”international metre”, the metric lengths of the Cape standards could not be converted to British feet. This confusion caused the introduction of the untrue unit (McCaw, 1939), named the “South African Geodetic foot” (S.A.G. foot). Therefore, all results, which were published in feet, in the Report on the Geodetic Survey of South Africa, were expressed in S.A.G. feet (Hendrikz, 1944).

The following ratio connects the “South African Geodetic foot” with the “International metre”:
1 S.A.G. foot = 1 Int. metre : 3.28086933 (*Clarke*) = 0.3047972654 International metre

Another relations can be stated:
1 British foot = 3.28086933 S.A.G. feet : 3.28084275 (*Benoit*) = 1.00000810158 S.A.G. feet
1 S.A.G. foot = 0.99999189849 British feet

At the commencement of the Geodetic Survey, Gill adopted “Clarke 1880 ellipsoid”. Because all the results of the Geodetic Survey of South Africa, including baselines, were published in the “South African Geodetic feet”, it was necessary to re-define, and rename the ellipsoid (Hendrikz, 1944). As a result, the ellipsoid became the “Modified Clarke 1880 ellipsoid”, with parameters:

a = 20926202 S.A.G. feet = 6378249.145326 International metres
b = 20854895 S.A.G. feet = 6356514.966721 International metres

The following table summarises the Geodetic Measure:

INT. METRES	ENG. FEET	S.A.G FEET
1	3.280 842 75	3.280 869 33
0.304 799 734 8	1	1.000 008 101 58
0.304 797 2654	0.999 991 898 49	1

2.3.1 Reflection on the Introduction of the Geodetic Survey Unit

A chronological summary of the previous statements (Zakiewicz, 2004):
1795 - Material metre was produced (“Module” & “Metre of the Archives”)
1824 - English Parliament Act defined the ratio of the Legal metre to the English foot

1866 - Clarke found the ratio of the Legal metre to English foot (from Toise standards)
1880 - Clarke determined the parameters of his new ellipsoid
1883 - Sample of the "International metre" was produced
1883 - Geodetic Survey commenced
1886 - "Cape Bar A" was standardised by Benoit, in terms of the "International metre"
1896 - Benoit found the ratio between the "International metre" and the "English foot"

At the time of Gill, the "Cape foot", related to the "English foot", was a legal unit of measure, used beyond the Cape Colony as well. The "Clarke 1880 ellipsoid", adopted by Gill at the commencement of the Geodetic Survey, was defined in "English feet". Thus, due to circumstances, and the above facts, it seems to be justified that Gill intended to use the "English foot", instead of the "metre", as a unit of measure for presentation of the results of the Geodetic Survey. Yet, Gill had no option but to use Clarke's ratio for converting "metres" to "English feet". Of course, he could wait until a new, and accurate ratio, between the "International metre" and the "English foot" had been defined, maybe by himself – if he had had more time, and funds, or, by Benoit – if had been prepared to start his work earlier. One must bear in mind that Gill was committed to the issue of the outcome of the Geodetic Survey as soon as possible, so there was not much time left for the experiments. As a consequence, a new unit, the "S.A.G. foot" was launched.

While it is inappropriate to "blame" Gill for the "inadvertent" use of Clarke's ratio for the reduction of the results, on the other hand, one can think that all the inconvenience caused by the introduction of an extra unit to the Geodetic Survey could have been avoided if Gill would have determined the relation of the "International metre" to the "English foot" himself – especially, since such a possibility existed. It is certainly of interest to note that, in the 1940s, D.R. Hendrikz, from the Trigonometrical Survey Office, Mowbray, calculated the ratio, between the "International metre" and the "English foot" based, entirely, on the data delivered from the "Cape Standard Bar A" (Hendrikz, 1950). As described before, this standard bar had two sets of marks. In 1839 and in 1844, Sir George Airy determined the original distance, defined by two dots, and later, in 1886, Benoit measured the distance, in terms of the "International metre", between lines engraved at Gill's request.

Hendrikz measured the small distances, of about 0.2 mm, flanked by the dots and the lines, by means of the precise pillar micrometer microscope. He wrote: "*... two sets of sixty independent readings were made of 'e', the distance between the line and dot at the east end of the bar, and of 'w' the corresponding distance at the west end...The smallness of the probable error of the measurement would seem to confirm our contention that Gill was not strictly justified in stating that accurate readings to the dots cannot be made easily*".

Hendrikz used the statistics of the previous Airy's and Benoit's measurements. He applied the difference (0.043mm) to Gill's standard:
Cape Bar A (lines) = 3.04800832 Int. metres at 62°F
and obtained:
Cape Bar A (dots) = 3.0479653 Int. metres at 62°F

Finally, Hendrikz arrived at the ratio: 1 International metre = 3.2808451 British feet, which is very close to Benoit's of 1896 (1 International metre = 3.28084275 British feet) and almost identical to Sears of 1928 (1 International metre = 3.28084558 British feet). Thus, according to his finding, the "Legal metre" is 7.4 microns longer than the "International metre", as compared to 8.1 microns from Benoit's value, and 7.2 microns from Sears.

Without doubt, Gill, scientific adviser to the Geodetic Survey, and man of genius, could have done this determination as well. If this would have happened, the somewhat confusing history of the South African measurement system would have been less complicated.

3. ADJUSTMENT OF THE ARC FOR PRACTICAL PURPOSES

3.1 The origin of the South African geodetic system

The geodetic station Buffelsfontein, situated near Port Elizabeth, was adopted as the initial point of the geodetic system - the Cape Datum. The geographical co-ordinates of Buffelsfontein were derived indirectly from the astronomical observations carried out in Port Elizabeth, during the geodetic survey of the Cape Colony. The adopted geodetic latitude of Buffelsfontein (33°59'32",000 S) was the mean astronomical latitude, derived from many nearby situated astronomical stations (Gill, 1896). The centre of the Cape Transit instrument of the Royal Observatory in Cape Town is the origin of all longitudes of the system. The adopted geodetic longitude of Buffelsfontein (25°30'44",622 E) was transferred from the Observatory in Cape Town. The difference of geodetic longitude, between the Cape Observatory and Buffelsfontein, was computed from the triangulation chain using the elements of the "Modified Clarke 1880 ellipsoid".

Thus, the Cape Datum defined by the parameters of the Modified Clarke 1880 ellipsoid and the initial point of the datum, Buffelsfontein, became the origin of the geodetic survey in South Africa, hence, also, the origin of the Arc of the 30th Meridian.

3.2 Local adjustments up to 1950

3.2.1 In South Africa:

The main network of the geodetic triangulation established under the direction of Gill was adjusted at the Cape Observatory. The geographical co-ordinates of the station Buffelsfontein were adopted as the origin for the computation of latitudes and longitudes of all other beacons. Maclear's triangles, which were incorporated into the geodetic circuits, were corrected and recomputed using Clarke's parameters, instead of Airy's. The adjusted values of the stations of the Cape Colony and Natal (Gill, 1986) served as a base for the adjustment of the Transvaal and Orange River Colony surveys (Gill, 1908). The stations of the two quadrilateral chains were held fixed, and only co-ordinates of the stations of the loose chains (Hanover-Kimberley and King Williams-Newcastle) were affected by the adjustment. The four baselines controlled the system originally and another five were measured during the Transvaal and Orange River Colony surveys. A number of astronomical observations were also made. These values, however, were not used in the adjustment of the triangulation. They provided an indication of the differences of the geodetic and astronomical positions. The whole of the adjusted triangulation was geometrically harmonious, and the computed lengths of the baselines, corresponded to their measured lengths.

3.2.2 North of South Africa:

The origin of Simms's survey in Southern Rhodesia depended on the astronomical determination of the station at Salisbury (Gill, 1905). Thus, this triangulation was entirely isolated, at that time, from the rest of the geodetic survey in South Africa. Gordon connected Simms's chain with the Transvaal system. The results, based on the side Dogola-Pont, showed a difference of 8",87 in the orientation of the two systems. The latitude and longitude differences, at the common points (Standaus and Wedza), were very small (3",5 and 0",6 respectively). Gordon's connection made it possible to reduce Simms's system, together with Dr Rubin's work, to that of the geodetic survey of South Africa (Gill, 1933). Hence, the triangulation system from the Cape to Lake Tanganyika became homogeneous.

In 1946, Simms's chain and the Simms/Rubin connection were strengthened. Then, in the same year, two geodetic circuits in Southern Rhodesia were finally adjusted (Bradford, 1952). A new datum, called the Circuit Datum was instituted. The computation was based on two fixed sides, common with the South African triangulation, namely: Dogola-Pont and Dowe-Madimba. (Its co-ordinates became available after the adjustment of the Northern Transvaal geodetic network was completed in 1942). From that time, all local origin systems in Southern Rhodesia (Simms's Datum and Union Datum) were abandoned. All co-ordinates were superseded by Circuit Datum values. The triangulation in South Africa and Southern Rhodesia became uniform again.

The Uganda section of the Arc had been adjusted in Uganda. The section in Tanganyika, between latitudes 5° S and 1° S, had never been computed (Rainsford, 1955).

3.2.3 Northern Section of the Arc (Egypt, Sudan)

The origin of the Egyptian chain was the transit of Venus station on the Moqattam Hill near Cairo. For latitude, the mean discrepancy, between the astronomical and geodetic latitudes of the first eight stations, south of Cairo, was made zero. For longitude, the result obtained, in 1874, at the transit of Venus station, was adopted (it appeared later to be in error of -3",45). The Egyptian chain, between Cairo and Adindan, was adjusted in blocks. Laplace azimuths were only used for the southern section, between Aswan and Adindan. Geographical positions were computed on the Helmert ellipsoid 1906 and later recomputed on Hayford 1909 ellipsoid (Munsey, 1959).

In accordance with the recommendation of the Colonial Survey Committee, to have all African surveys based on the same ellipsoid, the Sudan portion of the Arc was computed on the "Modified 1880 Clarke 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 longitude was corrected by the already mentioned +3",45.

3.3 1950 Arc Datum

Before the Second World War, the Arc still consisted of the two portions. The northern section of the Arc extended from Egypt southwards to latitude 10° N, in Sudan. The southern part was from the Cape to Uganda. Due to a growing numbers of surveys in the developing territories, the necessity of basing them on a rigidly adjusted framework became an urgent matter. It was, therefore, decided to adjust the Arc in two portions, one to the north and one to the south of the Equator. Already in 1937, this task was allocated to the War Office in England. As a result of an extensive correspondence with the Trigonometrical Survey Office, Mowbray, (Chief Directorate: S&M), the War Office agreed to maintain the geodetic triangulation in South Africa as fixed, so that final adjustment could not have any effect upon cadastral, topographical and engineering surveys already done in South Africa.

It was only in 1949, when the computation of the southern portion of the Arc commenced, under the direction of H F Rainsford, of the newly formed Directorate of Colonial Surveys. Prior to that, Rainsford recomputed the main triangulation in Uganda. The adjustment of the Arc was completed in December 1951. It was based on the fixed line Manyangau to Tondongwe. The junction points with the Southern Rhodesia circuits were also held fixed. In this computation, the lengths of all measured bases (Luangwa, Kate, Kasulu) were fixed, as well as the azimuth of the Uganda Arc at Kicherere (observed in 1908). All other astronomical azimuths were ignored. The 445 angles were adjusted and 98 points were fixed, on a 2000 km long chain. The misclosure on the astronomical azimuth of the line Kicherere to Karamrani was 13",95 (Rainsford, 1955).

The adjustment, carried out on the “Modified Clarke 1880 ellipsoid”, established the datum known as the 1950 ARC Datum. It was done for practical purposes, to give a uniform framework of triangulation from the Cape to the Equator, to which other adjacent triangulations could be tied.

4. CONCLUSION

Due to the implications with the Legal and International metres, the metric lengths of the Cape standards were converted to a fictitious unit now termed the “South African Geodetic foot”, what, subsequently, caused the reference ellipsoid to be renamed to the “Modified Clarke 1880 ellipsoid”. Although all this complications could have been avoided, if Gill would have determined the relation of the International metre to the English foot himself, but, on the other hand, thanks to such circumstances, South Africa obtained, not only a superb triangulation network but also, a unique geodetic unit, which nowhere else in the world could be met.

Later extension of the Cape Datum, along the 30th Meridian, up to the Equator, established the 1950 ARC Datum, thus, also resulting in the “spread” of the “Modified Clarke 1880 ellipsoid" over the African continent. It has been noticed that, even in our time, there is confusion around the world, as to which Clarke 1880 ellipsoid is in use: either the original 1880 figure (with values specified by Clarke himself), or its South African version: the "Modified Clarke 1880 ellipsoid". (To prevent any uncertainty in this regard, one should always refer to the ellipsoid parameters in use).

Until now, there are several African countries, which have their co-ordinate system based on the 1950 ARC Datum, and its "Modified Clarke 1880 ellipsoid": Botswana, Burundi, Democratic Republic of Congo, Lesotho, Malawi, Swaziland, Zambia, Zimbabwe (NIMA, 1997). The Sudan portion of the Arc, while being on the Adindan Datum (NIMA, 1997), was also computed on the "Modified Clarke 1880 ellipsoid". In Kenya and Tanzania, the 1960 Arc Datum – revision of the 1950 Arc Datum – is in force (NIMA, 1997).

The adjustment of the 30th Meridian Arc, for scientific purposes, related all the Arc data to the European Datum (Chovitz, 1956). The computation, completed in 1957, established the Extended European Datum (Corps of Engineers, US AMS). It also showed that, though the European Datum was not a suitable datum for the entire African continent, it could be adopted successfully in some countries, as it was then the case in Egypt (NIMA, 1997).

The 1950 Arc Datum was regarded as the first step to a common geodetic datum for Africa. Satellite geodesy led to the development of the global geodetic reference systems and its latest version: the well-known WGS84. In South Africa the geodetic network, based on the Cape Datum, served well for a century, and was superseded, on 1 January 1999, by the Hartebeesthoek94 Datum, based on the World Geodetic System 1984 ellipsoid. The AFREF project has been already initiated in order to unify all the geodetic datums in Africa and to create a uniform co-ordinate system, positioned on the International Reference Frame (ITRF). It is well advanced, especially for the Sub-Saharan region, comprising of the Southern African Development Community (SADC) countries and Madagascar. However, until the long desired aim, to implement a common, geocentric datum, has been finally achieved, the "remains" of the Cape geodetic standards will still be visible in the Africa.

NOTE

This paper should be regarded as a short version of the author's two previous papers, listed in the "References".

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BIOGRAPHICAL NOTES

Tomasz Zakiewcz, born in Warsaw, Poland, graduated from the Faculty of Geodesy and Cartography, of the Technical University in Warsaw, in 1971. In 1975, after three years with the government enterprise in Warsaw, he went to Libya, where he worked for six years in the "Polish Consulting Engineers – Polservice Company", engaged on various engineering, topographical and cadastral surveys. In 1982 he emigrated to South Africa, and, in 1987, was registered, with the South African Council for Professional and Technical Surveyors (PLATO), as a Professional Land Surveyor. He is a public servant, with 23 years of service. Previously with the Departments of Water Affairs (Dam Deflection Division) and Development Aid, in January 1990 he joined the Chief Directorate: Surveys and Mapping, Mowbray, a component of the Department of Land Affairs, where he holds a position of the Deputy Chief Land Surveyor, in the Directorate of Spatial Information and Professional Support. Besides the technical aspect of his daily activities, he has keen interest on the history of surveying in Africa, particularly in South Africa. He has presented two papers on the topics connected to the Geodetic Survey in South Africa, one of them being "The African Arc of the 30th Meridian" (Consas 97).

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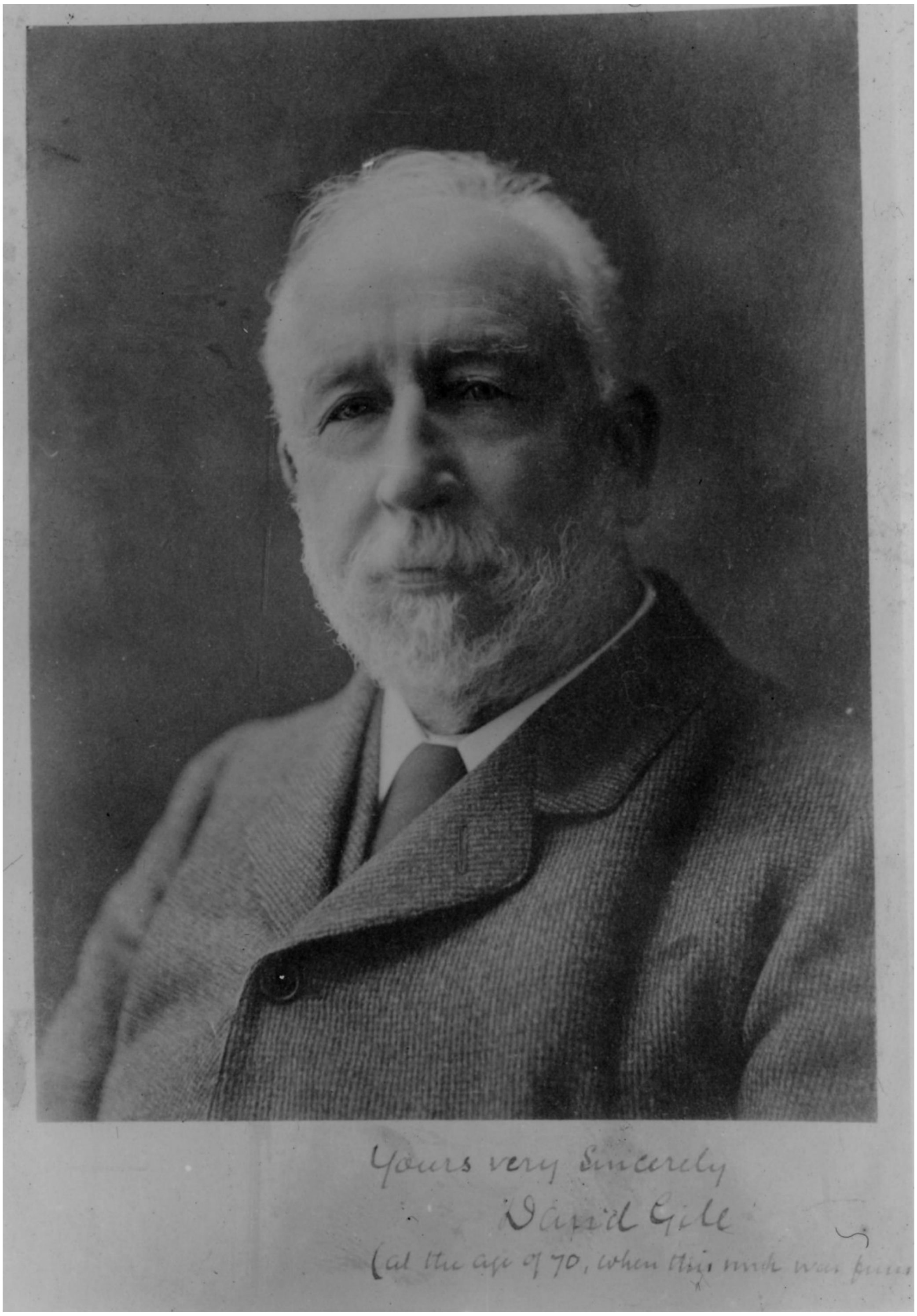
Yours very Sincerely
David Gill
(at the age of 70, when this work was

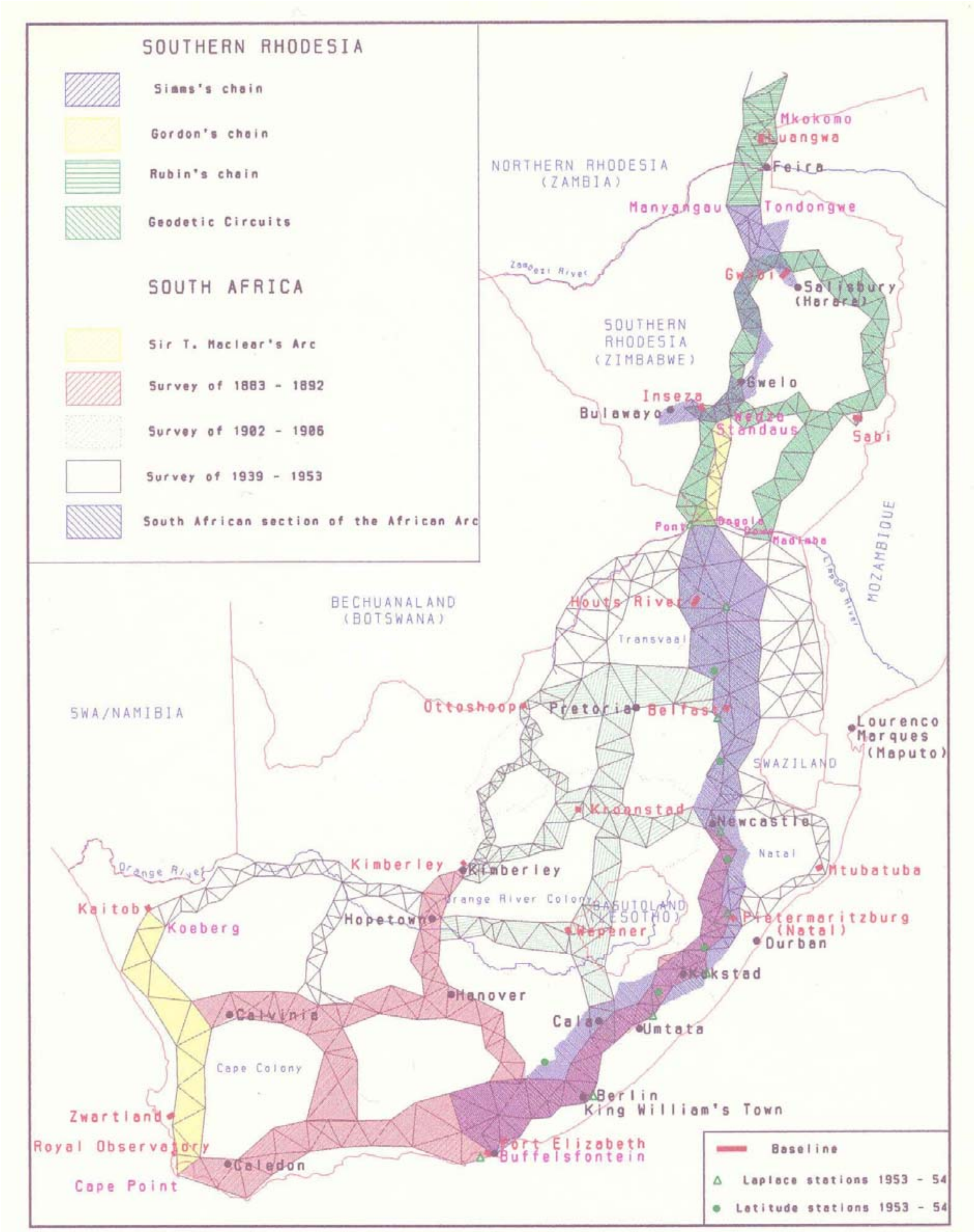

Figure 2. Geodetic Triangulation in Southern Africa

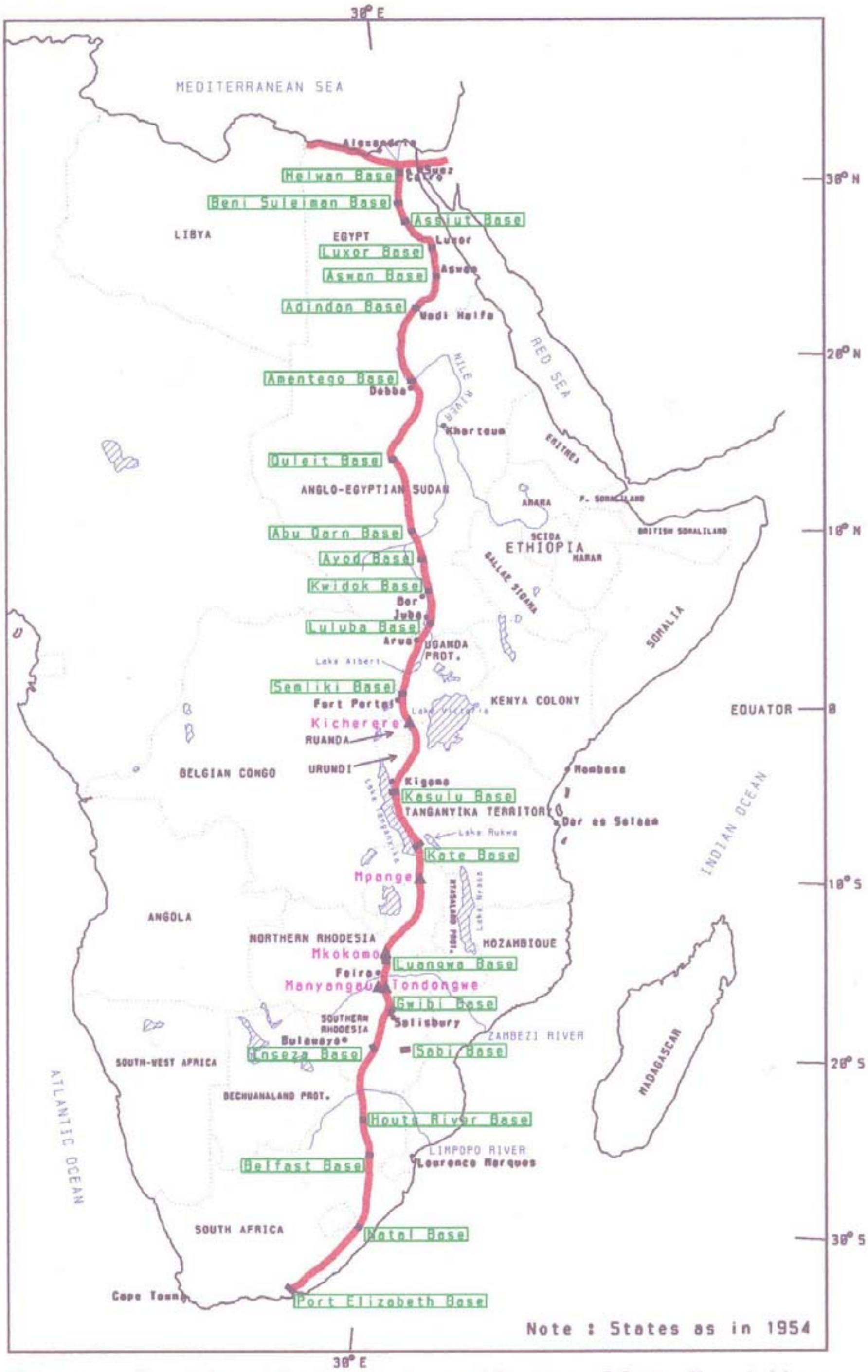

Figure 3. The African Arc of the 30th Meridian (1883 - 1954)

Approx. Scale 1:35 000 000
1cm = 350km