THE STRUVE GEODETIC ARC

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(A body wholly within FIG)

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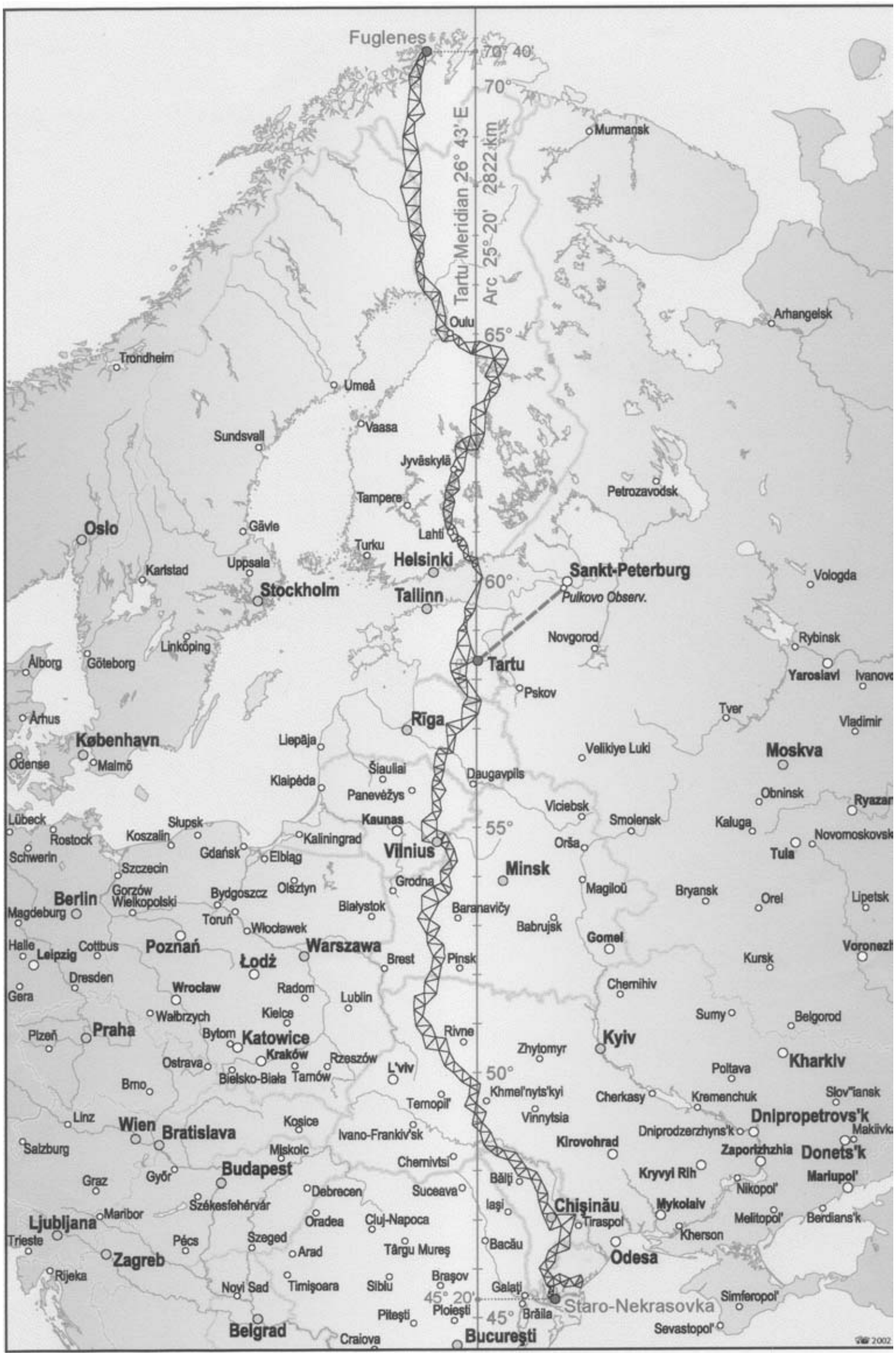

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ABSTRACT

Surveyors cannot readily point to a structure and say that "I made that". All they can do is say "I did the survey for that". In other words, they have nothing obvious that they can point at as their achievement except a few concrete pillars or pegs in the ground. Whilst this situation has not changed certainly the perception of the surveyor's craft should be enhanced through the acceptance of the Struve Geodetic Arc as a World Heritage Monument.

The text below is a modified and extended version of that used in the submission document to the UNESCO World Heritage Committee. It has been made reasonably comprehensive so that readers, both lay and professional, should find most of the answers to any questions there. In addition an extensive bibliography is included. It must however be remembered that many of the records either no longer exist or their location is unknown, or if known, not necessarily accessible. The best sources are the two volumes published by Struve in 1857,1860 but they are now very rare and difficult to find.

INTRODUCTION

On 15 July 2005 the World Heritage Committee of UNESCO (United Nations Educational, Scientific and Cultural Organisation) inscribed 17 new cultural sites on its World Heritage List to make a total of 812 sites. Among the 17 successful bids this year was The Struve Geodetic Arc.

This is unique as it is the first surveying site to be accepted and in addition it crosses ten countries –namely Norway, Sweden, Finland, The Russian Federation, Estonia, Latvia, Lithuania, Belarus, The Republic of Moldova and The Ukraine. During the preparations to submit this project the Republic Moldova ratified the decision to become member of UNESCO and so this was that country's first heritage monument. In addition it is the first such scientific monument to be on the World Heritage List.

The International Federation of Surveyors (FIG) news item on this monument referred to it as follows:-

> *The Struve Arc is a chain of survey triangulation stretching from Hammerfest in North Norway to the Black Sea, through ten countries and over 2820 km. These are points of a survey carried out between 1816 and 1855 by the astronomer Friedrich Georg Wilhelm Struve and others, which represented one of the early accurate measurements of a long segment of a meridian. This helped to establish a value for the size and shape of our planet and marked an important step in the development of earth sciences and topographic mapping. It is an extraordinary example of scientific collaboration among scientists from different countries and of collaboration also between monarchs for a scientific cause. The original arc consisted of 258 main triangles with 265 main station points. The listed site includes 34 of the original station points, with various markings, i.e. a drilled hole in rock, iron cross, cairns or built obelisks.*

The Road to Becoming a World Heritage Monument

Following on his researches from the 1960s into the 1980s Aarne Veriö of Finland prepared a paper to present at a scientific conference in Tartu in 1993 [**11**] but due to sickness he was unable to be there. However the paper was presented on his behalf by Seppo Härmälä of the National Land Survey of Finland who included mention of Veriö's idea for seeking a UNESCO declaration to preserve a selection of the remaining points of the Struve Arc as a World Heritage site.

The Scientific Conference in Tartu took forward the idea and on August 28, 1993 agreed the following
Resolution No 1:

> *Considering the scientific, historical and practical importance of the measurement of the arc of meridian through Tartu, made by F.G.W. Struve,*
> <u>*Urge*</u> *the governments of those countries that still possess relics of that enterprise to take all possible steps to preserve those relics, including an approach to UNESCO to declare them to be World Heritage sites.*

A corresponding resolution 1/2 1994 was then made at the FIG Congress at Melbourne in 1994

> *Considering the great historical value of the measurement of the arc of the meridian, and that an inventory exists of land monuments marking the arc of the meridian, called Struve, which extends over 9 countries and 25º of latitude from the Black Sea to Hammerfest situated on the north coast of Norway, Commission 1* <u>*recommends*</u> *that FIG should present a request to the United Nations that the remains of this arc of meridian be added to the World Heritage List of Historical Monuments*

and as resolution No. B10 by Commission 41 of the International Astronomical Union (IAU) at its General Assembly in The Hague in 1994 -

> <u>*Considering*</u> *the scientific, historical and practical importance of the measurement of the arc of meridian made by F G W Struve*
> <u>*Urges*</u> *the Executive Committee of the IAU to approach the governments of the following countries: Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Ukraine, Belarus, Poland and Moldova, which still possess relics of that enterprise, with a view to taking all possible steps to preserve those relics, including an approach to UNESCO to declare them to be world-heritage sites.*

NB It will be noticed that the drafters of this resolution mistakenly included Poland and omitted Russia.

The IAU resolution was reaffirmed on 10 January 2003 by the General Secretary of IAU

> *Dear Dr Smith,*
> *This is to confirm that at its 22nd General Assembly in The Hague, August 1994, the International Astronomical Union passed a Resolution, proposed by Commission 41 for the History of Astronomy, in support of the efforts that are still under way to have a selection of points of the Struve Geodetic Arc recognized by UNESCO as World Heritage Monuments.*
> *With best regards, Hans Rickman. IAU General Secretary.*

In an e-mail of March 1996 The International Association for Geodesy (AIG) also expressed its support.

IAG Letter No. 6/96 dated March 51 (sic) 1996,
Dear Dr Smith,
Your letter dated March 13 1996 directed to the IUGG was transferred to IAG by the general secretary, Dr Balmino.
I can inform you, that the issue of the preservation of the Struwe arc was not brought up in Boulder. However, IAG welcomes any effort to preserve the monument, and would very much like to support a proposal send to UNESCO.
Yours sincerely, C C Tscherning, Secretary General.

A similar conference to that of 1993 was held in Tallinn and Tartu from 25 to 28 September 2002 under the title “Struve Arc 150”. 50 delegates from 10 countries attended- namely Norway, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Belarus, Ukraine, Moldova, Belgium and UK. Essentially it was commemorating the 150th anniversary of the completion of the Struve Geodetic Arc, but was an ideal opportunity to discuss the arc in detail and to progress the efforts of the International Institution for the History of Surveying & Measurement to have selected points in each country recognised by UNESCO as a World Heritage Monument. At that time the Republic of Moldova was not a member of UNESCO.
Four resolutions were passed, of which the following two were the most important:-

Resolution No. 1.

Following Resolution No. 1 from the International Scientific Conference held in Tartu in August 1993 and resolution No. 1 of FIG, Melbourne Congress in 1994 the participants in the International Scientific Conference held in Tallinn and Tartu, Estonia, on September 26-28 2002 to honour the scientific achievements of F.G.W.Struve,
considering the scientific, historical and practical importance of the measurement of the arc of meridian through Tartu which stretches from near North Cape in Norway, through Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Belarus, Ukraine and Moldova to the Danube Delta made under the guidance of F.G.W.Struve,
urge the authorities in the 10 countries through which the Struve arc passes, to complete the preservation of the arc of meridian and the documentation in their countries as soon as possible, so that in their turn the national representatives to UNESCO may be urged to put them on their national provisional list of World Heritage Monuments.

Resolution No. 4

The participants in the International Scientific Conference held in Tallinn and Tartu, Estonia, on September 26-28 2002 to honour the scientific achievements of F.G.W.Struve,
considering the historical importance of the measurement of meridian arcs encourage the International Institution for the History of Surveying & Measurement to continue its investigation into the connection between the Struve Meridian Arc and the Arc of the 30th Meridian in East Africa,
urge the authorities of those countries concerned to assist in all ways they can to preserve selected points in their countries so that it is possible to achieve the aim of a World Heritage Monument stretching from near the North Cape of Norway at latitude 70° 40′ 11" N to latitude 33° 59′ 32" S in South Africa, making it the longest monument in the world.

Subsequently the International Institution for the History of Surveying & Measurement (at that time a fledgling permanent body within FIG) worked in conjunction with the ten countries to achieve the preservation of the Struve points and to get the aforementioned declaration of UNESCO. From 2002 The Survey of Finland took on the major task of compiling and publishing the final document.

The desired World Heritage declaration required that the included Struve stations are already protected in those countries where they are situated. This task was not easy because the legislation deviates from one country to another. For instance in Finland it was unclear whether to apply the rules of planning or nature conservation. Similar problems arose elsewhere. However, co-operation between all ten countries and the International Institution for the History of Surveying & Measurement resulted in the formulation of the case to be put to UNESCO.

Progress was slow but steady considering all the parameters – not least of which were language and general communications- that affected the ready accumulation by the National Land Survey of Finland of the necessary documentation, maps and photographs.

Despite the set backs a final document of 270 pages was produced in time for presentation to the UNESCO in January 2004. The 18 month period of scrutiny within UNESCO and ICOMOS (International Council on Monuments and Sites) seemed endless but at last a decision was made on 15 July 2005 at the UNESCO annual meeting in Durban, S Africa. World Heritage status had been achieved.

After submission of the document to UNESCO all concerned took a deep breath and sat back to await the outcome. Some may have thought that once the result was heard that was the end of the matter but that was far from the correct picture.

In the remote hope of future success various Resolutions had been passed at conferences in Tallinn, 2002, Minsk, 2003, and Chisenau, 2004 and these now required implementing.

In summary they are:-

1. Ensuring the maintenance and management of all 34 sites.
2. Determining the location of all surviving Struve material on the subject, cataloguing, preserving and archiving it for use by future generations. Translation and reproduction of the two Struve tomes. The tomes in French by Struve where the Arc was documented [**5**], are valuable and interesting and belongs to the history of surveying. Unfortunately the books are now a rarity, and seldom found in libraries. It is uncertain whether they are even available in all of the ten countries involved. It is true, some chapters from it have been reprinted in Russian in 1957 in Moscow but even that must now be out of print there. [**8**] It would be a cultural achievement to reprint the tomes. In French it could be a facsimile product, but still better if it could be in English to reach more readers.
3. Pursuit of the idea of a Struve museum or home in Tartu.
4. Consideration of possible scientific schemes over the 34 points as a data base for future use.
5. Extension of the accepted scheme via the territory between Belarus and Crete to embrace the Arc of the 30th Meridian through E Africa. This would result in an overall arc of 105º.

But how then does all this fit into the concept of a World Heritage monument? Such monuments approved to date have all been very large structures or features for which the area is often measured in many hectares. With the arc, the area covered by the chain of triangulation is large but the actual survey stations defining it are essentially point positions only and even with any cairn that covers some of them the area taken up is but a few square metres per point. That did not appear to present a problem to the authorities who rather saw the unusual concept as a challenge.

Today the Struve arc passes through ten countries - Norway, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Byelorus, Ukraine and Moldova. Each of these countries contain a good number of the Struve stations except Russia which has only two-on the island of Högland in the Gulf of Finland.

The arc in total consists of about 265 points plus some ancillary ones in base extension networks. Of these a few are already permanently monumented such as those at Fuglenaes in North Norway and Staro-Nevassowka in the Ukraine where there are inscribed obelisks.

The aim was to select three or four points in each of the nine countries, other than Russia where there are only two, that were recoverable as definite Struve positions and to have them marked in some commemorative manner. Those selected are in positions of reasonable access to the public and spread throughout the country. (Some in North Norway for example, would require a helicopter to achieve access or alternatively several days trek)

The structure of the selected points varies from country to country but each will in due course bear a similar plaque giving the briefest of information about the arc and the particular point.

Each of the countries involved was required to first of all identify a selection of points and then to indicate how they would see them being permanently marked and maintained in good order and access. The authority for this came from the national government department concerned. Considering the age of the points, the difficult access to the vicinity of many of them and the difficulty of recovering the ground mark, the task of compiling a summary for submission to UNESCO was obviously hard work and took much time to complete.

This was coordinated by Pekka Tätila of the Survey Department of Finland. The arc passes through that country, and much of the material necessary is available there. As UNESCO has look favourably upon the idea and has granted the arc World Heritage status, it is hoped to mount a re-measuring exercise by GPS at the selected points and to use that to investigate the accuracy of the original work. That could then lead to further investigative work relating to the original observations and form an historical data bank for any future scientific work relating to movements of parts of the land mass over which the arc goes whether that be due to tectonic plate movements or as a result of volcanic activities. However because of the very limited resources available at present, progress is one step at a time rather than opening up on several fronts at once.

BACKGROUND

Since the time of Eratosthenes, (c276 BC- c195 BC), the dimensions of the earth have been determined by surveying techniques in the measurements of arcs of lines of longitude (See figure 1). In fact the theory developed by Eratosthenes remained in use until the era of satellite geodesy. This is the use of orbiting satellites to refine the determination of knowledge of the size and shape of the earth.

Many famous names in the fields of astronomy, mathematics and surveying have been involved in the gradual improvement in techniques, equipment and results. Among these one might mention Fernel, Picard, the Cassinis, Newton, Bouguer, La Condamine, La Caille, Maupertuis, Gauss, Delambre, Mechain, Airy, Everest and many others. Notice how many of these were Frenchmen.

The focus of this paper is another name, that of F.G.W.Struve, who made an important contribution during the 19th century. Such was the importance of the work by Struve and his collaborators (particularly Tenner, Selander and Hansteen) that it was the hope that some of his survey points that still remained could be designated as world heritage monuments. But more of him later. To put his work in context some background detail is necessary.

THE PROBLEM

Prior to Eratosthenes, back to the time of Pythagoras around 500 BC, it had been known that the earth was not flat but of some spherical shape. Why spherical was the next step after flat and not some other shape is open to conjecture. At the time however the sphere was considered to be the perfect shape, perhaps because of its regularity in all directions, and could well have been selected in this case just on that assumption. The fact that it turned out to be a correct choice would then, have been pure luck.

The problem over the intervening centuries has been to determine its exact shape and size. This is no easy problem when considering the huge size involved. While it was considered to be a true sphere the problem resolved itself to one of just determining its size, but by the time of Isaac Newton in the second half of the 17th century even the idea of a true sphere was being questioned. (By 'true sphere' and other terms mentioned later, is meant the sea level surface assumed continuous around the earth. In relation to the overall size of the earth the topography is insignificant).

Why was knowledge of these parameters of importance? This can be illustrated simply by saying that if Christopher Columbus had known the true size of the earth, he would not have gone where he did. By working with a figure that was much too small he had a distorted idea of the earth he was navigating upon. It was almost as if he thought he was going round a tennis ball when in fact he was on a flattened football. Not only would he be using incorrect distances but incorrect directions as well. [**1**]

THE MEASUREMENT DIFFICULTY

The problem of measuring accurately an object the size of the earth is not an easy one yet the principle, first deduced by Eratosthenes around 230 BC, has remained the basis of all attempts until the advent of satellites. Although the method devised by Eratosthenes was based on the mathematics of a sphere it was later possible to modify it to apply also to shapes that were not quite true spheres.

Whatever one is measuring it is advantageous to determine by direct measurement as large a part of it as possible before resorting to extending a value by calculation. One has however to keep within the bounds of practicality. For example, if you wanted to measure the circumference of a football that would be done by putting a tape measure around it. If on the other hand it was required to measure the circumference of a large traffic circle it might be more practical to measure the length of an estimated quarter of it and multiply the result by four, or alternatively determine the diameter and multiply up by π. When the structure or figure involved becomes the size of the earth then a small fraction, say 1º, might be the more practical amount to measure and then multiply up by 360. This is in effect the basis of the method used.

WHY A GREAT CIRCLE?

As is well known, a line of longitude circles the earth and goes through both poles. Such a line is called a great circle of the earth. All lines of longitude are of that form but in latitude the only line that is a great circle and of comparable size is the equator. Thus to get the full circumference in as simple a way as possible it was necessary to measure (or calculate) the length of a circle or arc of longitude or of the equator. (This is rather an over simplification but can be accepted as the basis of what is required). As theory later developed so it became possible to use arcs that were not sections of great circles or which did not exactly follow any one line of longitude.

Assuming a spherical earth, Eratosthenes said that if you measured the linear distance between two points on a particular line of longitude (also called a meridian line as, for example, that of zero longitude through Greenwich), and were then able also to determine the angular distance subtended at the centre of the earth (see figure 1) between the same two points then the radius and other parameters of the earth could be easily determined. Such an angle is not as inaccessible as it might at first appear as it can be found from star observations at each of the two points. The angle determined represented some fraction of the 360º circumference and its length was also known. A simple calculation would then give the circumference or radius.

For example, if the angle was 6º then that would represent 6/360 or 1/60th of the circumference. If in turn the distance between the same two points was 600 km then the circumference would be 600 x 60 = 36 000 km. (of course they did not use kilometres at that time but the idea is the same).

Unfortunately there are many sources of error inherent in such observations, particularly in the angle and distance measurements. These in turn were functions of the inaccuracies of the equipment and methods of the time. Despite gradual improvements even by the late 15th century calculated values of the earth’s size varied considerably and unfortunately the value selected by Columbus was incorrect by about 25%.

MEASURE LONG LINES

One of the difficulties in all the early measurements was that the linear distance required had to be physically measured from end to end by whatever method was felt the most appropriate at the time. Each distance had to be of the order of at least 60 miles (100 km). If only much shorter distances were used the accumulation of errors in the results would have been unacceptable. There were no tape measures then as we know them and the methods were pacing, knotted ropes, camel days journeys, the distance travelled by horsemen in a given time and variations on these.

As far as the angular value was concerned this could be found by observing the stars or the shadows of obelisks but in either case the results were crude.

THE ADVENT OF TRIANGULATION

It was not until the early 17th century that a more convenient method, triangulation, was developed in Holland and better measuring equipment became available. While it still kept to the basic principle of Eratosthenes for measuring a very long distance now an element of computation entered the method. It required a much shorter line to be measured as accurately as possible (a baseline) and the longer distance calculated by simple geometry. The angles were measured by instruments such as quadrants and later, theodolites.

Essentially the solution revolved around the fact that from a chain of triangulation it was possible to determine the distance between a point at each end of the chain. (figures 2 and 6). [**1**]

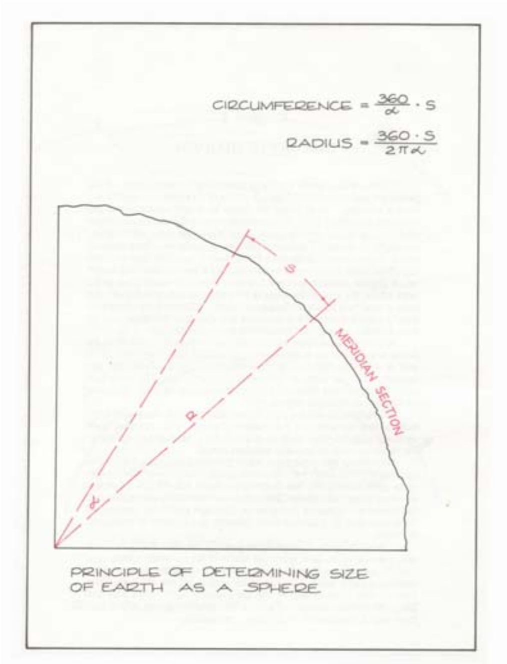

Figure 1. Principle of Determining Size of the Earth as a Sphere.

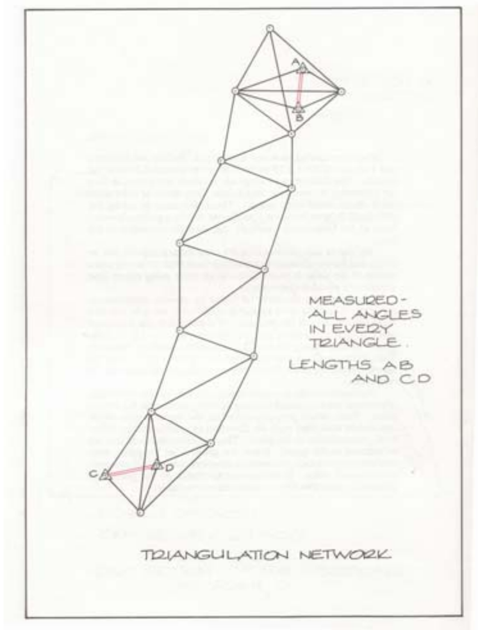

Figure 2. Triangulation

PERTINENT TRIANGULATION DEFINITIONS

Station point
These are marks at each observation position within a triangulation system. They can take a variety of forms as indicated in the section on monumentation.

Station witness marks
Around each station point it is general practice to have several witness marks each a few metres from the main station point and in different directions (see Figure 3). Then when it is required to recover a buried or hidden station point finding one or more of its witness marks can greatly assist in the full recovery.

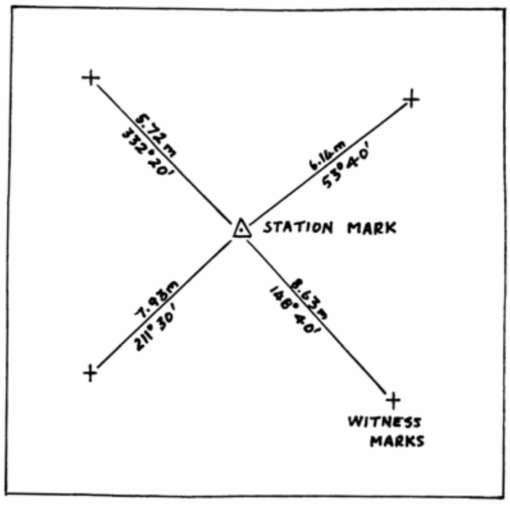

Figure 3. Station witness marks

Offset station point

(Often called a satellite station until the advent of artificial satellites and possible confusion of terminology). Observing with a theodolite to a point 40 kms away requires a very distinct target. This may be, for example, the spire or flagpole on a church as with point 11 at Tornio. The problem arises when it comes to setting up the theodolite at that point to sight back to where the theodolite was previously. It would obviously be impossible to set over the spire so an offset point would be used and be connected to the spire through several ancillary observations as shown in Figure 4 below.

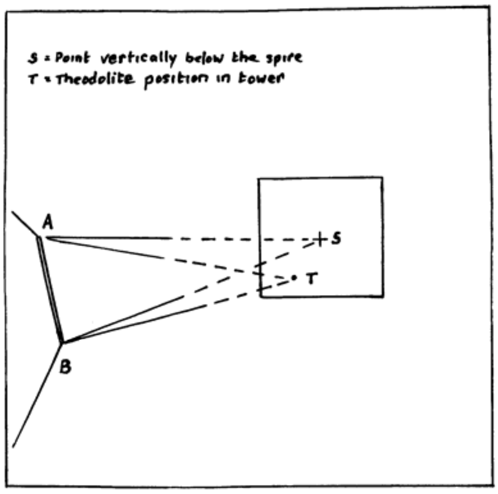

Figure 4. Principle of offset measurements

A, B = two pegs say 10 m apart at ground level such that from each it is possible to see both the top of the spire (S) and a position in the tower (T) where it is possible to set the theodolite. By determining the coordinates of A and B in the survey system and measuring the angles at A and B to each of S and T it is possible to calculate the relative positions of S and T and the direction between them. From this information appropriate corrections can be applied to the observations to make them appear as if the theodolite were set over S rather than over T.

Base line

Triangulation in its simplest form is a chain of triangles spanning maybe several hundred kilometres of countryside with each of the sides of the triangles many kms in length. See Figure 2 above where AB and CD are baselines within the triangulation. Depending on the topography a main triangle side could be as much as a 100 kms long.

To determine the relative positions of each successive triangle corner (= station point) all the angles within the chain of triangles are measured as accurately as possible with, for example, a theodolite. So that coordinate geometry can be used it is also essential for at least one side (e.g. AB) to be measured to give scale to the whole chain and to allow the coordinates of each station point to be computed. Extra baselines such as CD in Figure 2 are often added to control the accumulation of errors. However if a side was 40 kms long it would have been impossible to measure it directly prior to the advent of electronic technology. There were though methods designed to measure lines of some 10-15 kms very accurately indeed (e.g. 2 or 3 mm per km. of length).

Base extension

To calculate a triangulation chain it is necessary to have a separate network of triangles to initially extend a measured baseline of 10 km to the 40 km. or more of a triangle side. Such a network is called a base extension and Figure 5 illustrates that used on the baseline at Romankautzi. There the measured baseline is between Grubui and Tschubutinzi and the required triangle side is Britschani to Gwosdautzi. By measuring all the angles in the figure the computation of the required side is readily possible.

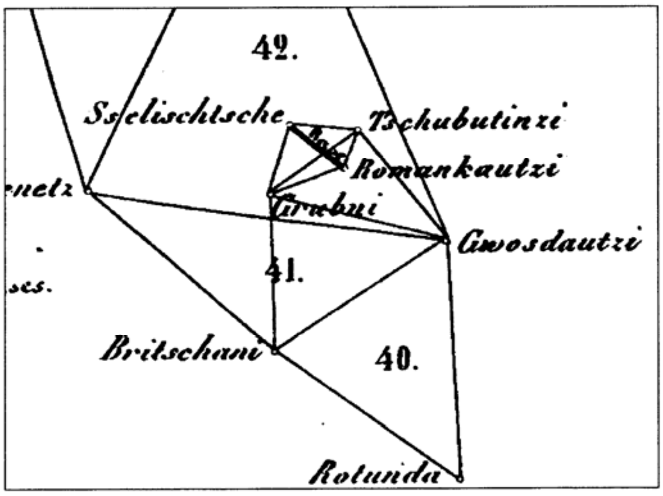

Figure 5. Base extension network at Romankautzi in The Ukraine

THE 'TRUE' SHAPE

Both theory and, as methods improved in sophistication, the practical results, suggested that the earth was probably not a true sphere after all but some slightly distorted shape. Ignoring the land elevations and sea bottom depressions around the world, sea level forms a sensible datum surface to which everything can be referred and can be treated mathematically.

Various long triangulation schemes were observed, particularly in different parts of France but by the first half of the 18th century also in Peru, Lapland, Italy, S. Africa and Austria. During the second half of that century and the early 19th century other arcs were observed in USA, Hungary, India, Sweden, England, Spain, Denmark and Germany.

The arcs in Peru and Lapland during the 1730s and 40s settled the problem of the shape of the earth in that it was finally proved to be oblate (slightly flattened at the poles) rather than prolate (or elongated at the poles), as shown in figures 6 and 7. The full name of this figure is an oblate spheroid. The difference from a true spherical earth is small, being only some 20 km between the maximum and minimum radii in a total of almost 6400 km. (i.e. only 0.3%), but nevertheless highly significant when navigating.

But that only solved half the problem. There was still the matter of an accurate value for the size of the earth and this was complicated by the fact that it was not now sufficient to do the calculations as if it were a perfect sphere.

THE SIZE OF A NON-SPHERICAL EARTH

To determine the dimensions of an oblate spheroid (or a prolate one if it had turned out to be that shape), requires the accurate determination of at least two long arcs as widely separated in latitude as possible.

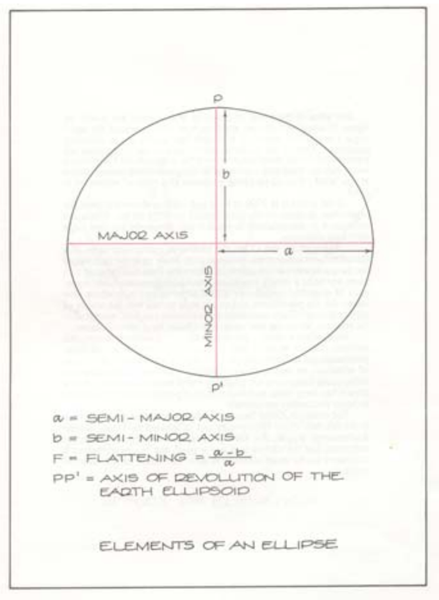

Figure 6. The elements of an ellipse

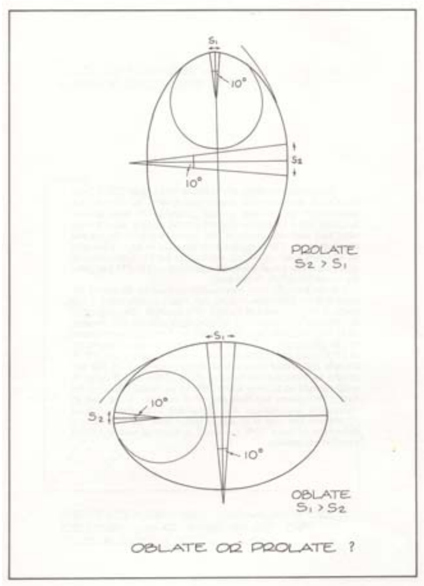

Figure 7. Oblate and prolate spheroid

The various pre 19th century arcs in the list (Table 1) were all useful but they did throw up difficulties not least of which was the effect of large mountain masses on the true position of a plumb bob, universally used to level observational instruments. It was proved during the 18th century survey work in Peru that if a plumb bob is hung in the vicinity of a large mountain mass then it is pulled (or attracted) slightly out of the vertical by that mass. If the plumb bob is not vertical then any instrument that is itself made level (horizontal) by use of a plumb bob, will also be out of level by the same amount as the plumb bob is attracted. Thus the final value of the angular distance measured between the two arc ends would become distorted.

Increasingly as further arcs were measured and the accuracy improved so the uses to which the results could be put required yet greater accuracy. The vicious circle thus required further arcs to be measured. More uses were also found for the networks of triangles that resulted, not least the basis of accurate mapping of the countries concerned.

MAUPERTUIS' ARC IN LAPLAND

The title *Lapland* although often used to describe this expedition is really a misnomer. While it represented the exotic landscape of the far north the survey was actually to the south of Lapland. *Polar Circle* is a more apt description but *Lapland* is retained here because of its wide acceptance in English language publications and because of its brevity.

A year after Bouguer and La Condamine left France for Peru to measure an arc of a meridian as near to the Equator as possible a second expedition, under Pierre Maupertuis, left for Lapland [**24**]. On the principle that if the oblate-prolate argument over the shape of the earth was to be settled once and for all, then it was necessary for an equatorial expedition to be balanced with another as near the Pole as possible.

Unlike the Peru group where there was considerable friction between the members, and maybe the terrain, length of time and conditions were enough to rouse anyone, the

Lapland one appears to have been far more harmonious. Among the scientists involved was Anders Celsius (of thermometer fame).

They arrived in the vicinity of Torneä on 21st June 1736, taking two months to travel from Paris. After looking at alternatives they selected a stretch from near Torneä in the south to Kittis somewhat less than a degree further north over which to measure a triangulation scheme (Figure 8). This straddled the River Torneä between latitudes 65º 50′ N and 66º 50′ N. Not particularly mountainous but difficult to travel over and rough living conditions.

Figure 8. The Arc measure of Maupertuis

They measured a baseline on the frozen river surface using 8 fir rods each of 5 toises length (c 10m) calibrated against an iron toise bar brought from Paris. During the measurement in mid-December the temperature fell to -37ºR (-45ºC). This, their only baseline, measured 7 406.861 toises.

The angles of the 12 overlapping triangles were measured with a quadrant (Figure 11) of 2 feet radius. The astronomical observations at Kittisvaara and Torneå were made with a zenith sector (Figure 10) where the telescope was 9 feet long. From the various observations they determined the amplitude of the arc as $57' \ 28.67''$ and its meridian length 55 023.47 toises. From which the length for 1º was found as 57 437.94 toises. When compared with other arcs of the period it was suggested that either the calculated length of the arc was too great by 200 t or the amplitude too small by about 12 seconds of arc. Investigations made in 1928 by Leinberg did in fact agree that various sources of error in Maupertuis' work could have amounted to about 12 secs.

SVANBERG'S REMEASUREMENT

Because the results of Maupertuis, whilst verifying that the earth was oblate, were rather large in comparison to others of the same century elsewhere, the Swedish Royal Academy felt further investigation was necessary.

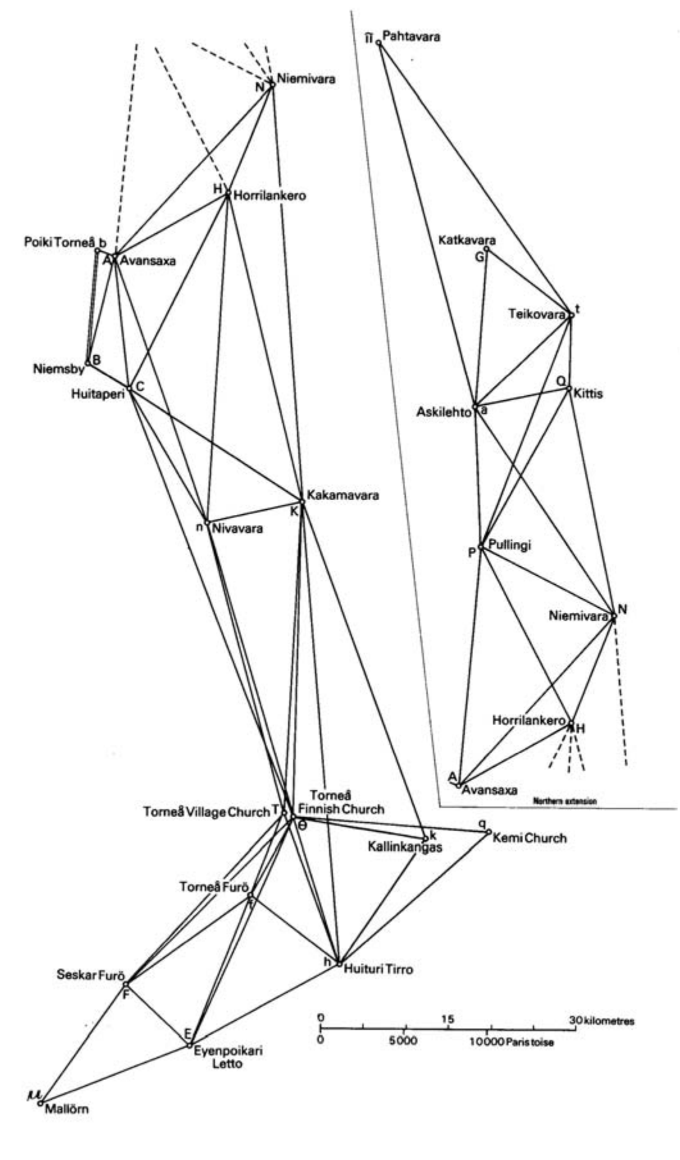

Figure 9. Svanberg´s network

Svanberg and Ofverbom, the chief engineer at the Bureau of Surveys, spent April to October 1801 in this research and the selection of station points (Figure 9). They also added several extra points to both north and south to increase the arc by some 50%. Those in the south used some of the islands that Maupertuis had first thought of incorporating but which he found unsuitable

Astronomical observations were to be taken at Mallörn, in the south- an island in the Gulf of Bothnia, and at Pahtavaara in the north.

For his baseline Svanberg found and used a mark near the south end of that of Maupertuis but not the north end. In terms of the toise of Peru it measured 7414.4919 t or some 8 t longer than that of Maupertuis.

The method of base measurement was similar in that it was done in winter-starting on 22nd February 1802, and that for much of its length it was over ice. It was completed on 1lth April 1802. They used 4 iron rods of 24.3 mm by 31.1 mm cross section and a little more than 6 m long with fine lines exactly 6m apart. They were fashioned such that they could slide together to bring their defining lines adjacent. Each bar was graduated against a 2 m standard brought from Paris for the purpose. Svanberg computed the length from Torneä to Kittis to be some 25 t less than that found by Maupertuis.

It should be noted that although the metric system had already been accepted by the time of Svanberg's measurements there was resistance and confusion at its introduction. Rather than measuring his angles to maybe 0.1 of a sexagesimal second Svanberg was using the centesimal second and quoting the very unrealistic 3 decimal places even though some of his very first triangles misclosed by nearly 9 centesimal seconds.

The angles and arc were computed by the method of Delambre to give an arc length of 92 777.981 t = 180 827.68 m and amplitude of 1º 37′ 19.56″. Whence the length of 1º computes as about 57 196 t compared with that of Maupertuis of 57 438 t

In comparing his result with that of Bouguer in Peru, Svanberg found the flattening of the earth figure as 1/329.246 whereas today the accepted figure is nearer 1/298.3

Despite the improved equipment and greater length of arc used the inherent inaccuracies in the observations were still such as to mask many of the small variations from degree to degree that the scientists were endeavouring to resolve.

OTHER EARLY MERIDIAN ARC MEASUREMENTS

The arcs by Maupertuis and Svanberg were by no means the only arc measures before Struve (see Table 1) Note that although the mean latitudes for these two arcs was the same, that of Svanberg was extended to both the north and south of that by Maupertuis.

The history of Arc measurement goes back over 2000 years but until the beginning of the 19^{th} century the accuracy of the equipment used left a lot to be desired.

During the 18^{th} century there was much controversy over the shape of the earth particularly because the results of extensive surveys by the Cassinis in France had all indicated that the earth was flattened at the Equator (i.e. prolate) whereas Isaac Newton's calculations suggested the opposite. The difficulty at that time was because the errors and inaccuracies associated with the instrumentation used were such as to be equal to, or even greater than, the small differences that it was necessary to determine. As is shown in Table 7, the length of one degree of the meridian varies in length from near the one end of the Struve arc to the other (25º 20′) by about 350m. or less than 14m per degree of arc (= 111 km) or about 1 in 8000.

Table 1. EARLY MERIDIAN MEASURES

Date	Observer	Location	Length of Arc	Mid-Latitude	Length of 1° (m)
Early Methods					
230 BC	Eratosthenes	Egypt	7° 12′	27° 40′N	128 500
724 AD	I Hsing	China	32	35 N	157 520
820	Al Mamun	Iraq	2	35 N	111 000
1525	Fernel	France	1	49 20 N	110 600
1580	Brahe	Swden	0 22	56 N	112 840
Introduction of Triangulation					
1615-1616	Snellius	Holland	1 12	52 N	107 400
1633	Norwood	England	2 28	52 49 N	111 920
1645	Riccioli & Grimaldi	Italy	19	44 34 N	119 800
1668	Picard	France	1 23	49 10 N	111 210
1681-1701	Cassini I & II	France	6 19	49 10 N	111 280
1718	Cassinio II	France	2 12	49 56 N	111 010
1736-1737	Maupertuis	Lapland	1 02	66 20 N	111 950
1738	Maupertuis	France	1 02	49 10 N	110 950
1739-1740	Cassini III & LaCaille	France	8 30	45 15 N	111 240
1734-1742	Cassini II & III	France	8 20	46 30 N	111 210
1735-1745	La Condamine	Peru	3 07	01 31 S	110 655
1751	Boscovich & Maire	Italy	2 10	43 N	111 027
1752	LaCaille	S Africa	1 13	33 08 S	111 165
1766	Mason & Dixon	America	1	39 12 N	110 670
1769	Liesganig	Hungary	3	45 55 N	110 863
1791-1799	Delambre & Mechain	France	9 40	46 12 N	111 133
1801-03	Svanberg	Sweden	1 37	66 20 N	111 475
1800-1821	Lambton	India	9 54	09 35 N	110 601
				13 07 N	110 629
				16 35 N	110 664
1820-1830	Everest I	India	15 58	13 06 N	110 634
				19 35 N	110 721
				22 37 N	110 904
1823-1843	Everest II	India	21 21	23 47 N	110 759
				26 49 N	110 837
1816-1855	Struve	10 countries	25 20	58 00 N	

THE FRENCH REVOLUTION

The seeds for the Struve Arc were sown by the Great French Revolution. Many traditional habits were replaced by new systems. Especially old measures were toppled by a new metric system. It was quite simple to stipulate that one quarter of a meridian would equal 10 million metres, but how long was the meridian? Among such measures at that time was the arc between Barcelona and Dunkerque, which, supplemented by measures in S America, yielded a prototype of the new unit, the legal Metre. However, it was based on quite inadequate measurements and calculations and within a matter of years the definition no longer held good. See Table 8.

The best possible result from the early arc measurements was derived by a Finnish astronomer H J Walbeck. He applied for the first time the method of least squares to compute the dimensions of the earth ellipsoid. However, a more reliable knowledge of the dimensions was still missing because of the limited number and limited length of measured arcs.

As another result from the French Revolution wars were raging all around Europe. The Napoleonic wars stretched from the North Cape to Cairo and from Moscow to Atlantic Ocean. The initial defeat of Napoleon resulted in the Vienna Conference but in the middle of negotiations Napoleon made a "come back" and war broke out again. When Napoleon was finally defeated the Vienna Conference reconvened and agreed in 1815 on the international boundaries in Europe and on the steps to be taken against the seeds of the revolution and against new uprisings.

At that time there was a general restlessness among the rulers in Europe. They did not trust a lasting peace and tried to be prepared for new wars. Mapping for such military purposes was a must and all steps to its promotion were advanced. [**8**]

THE NEED FOR SUCH A MEASUREMENT

The lack of a proper framework for the topographic mapping was a problem at that time. Such a framework could be likened to a human skeleton upon which the flesh (or map information) is added. At the lower order a method called framework traversing was available but the higher order was more complicated. Astronomical observations were too difficult at the density needed in traversing, especially for the determinations of the longitude which was still a very difficult problem to solve. In addition, the coordinate system required a resolution to the uncertainty of earth ellipsoid dimensions.

Especially in Russia both needs were felt deeply; that of the fundamentals of geodetic surveys and that for suitable map grids. Many professors in mathematics attempted to foster new knowledge in these areas. Top military surveyors however were interested only in better mapping. It was Colonel Carl Tenner who managed to combine both needs in the triangulation work in Lithuania started in 1816. Astronomer Wilhelm Struve's proposal to the Tzar of Russia in 1819 also combined both elements. Tzar Alexander the First, after defeating Napoleon and entering Paris felt himself leader of European politics where science was fortunately among the top priorities. Struve got all the resources he needed for his project.

The way was open for an arc measurement to develop the basis of a geodetic framework and to start the topographic mapping.

FIRST MOVES IN RUSSIA

At about the same time that the Peru and Lapland arcs were being measured Joseph Delisle published in 1737 [**2**], a proposal for an arc to be measured through the Russian empire and embracing some 22º of meridian. He stated that "...this set of degrees when determined would display in an incontestable manner, if their variations were uniform, ….. would show whether different meridians have different curvatures..." Surprisingly the Empress Anne of Russia was not frightened by such a vast proposal and gave it her backing to contribute to the progress of science.

Unfortunately in 1739, after Delisle got as far in his triangulation as measuring a base on the ice from Peterhof Castle in Kronstad to Doubni Castle on the island of

Retusri, and connecting the base to several points by triangulation, a journey to Siberia in 1740-41 interrupted his work and it was never restarted.

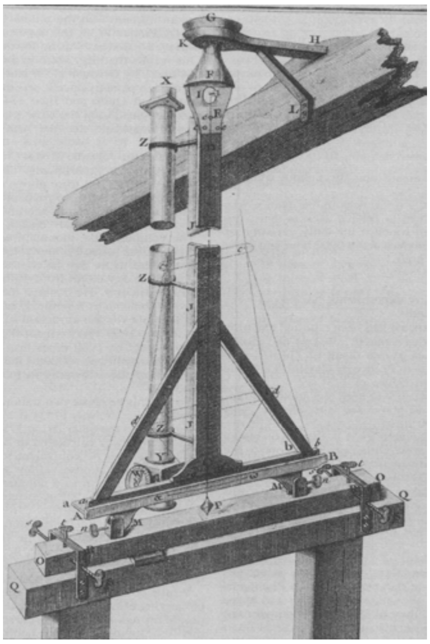

Figure 10. The zenith sector

At that time the metre had yet to be developed and the base had actually been measured at about 13.5 verstes, an old Russian unit of approximately 1.067 km per verste (or a base length of 14.4 km). The measurement itself was by wooden bars of known length placed end to end. Nothing was published on this work but in 1844 Otto Struve, son of F.G.W. Struve, did come across Delisle's manuscript in the Paris Observatory archives. [**3**]

For his angles Delisle talked of using a 30º sector of 12-15 ft radius (see figure 10) and a quadrant of 2-3 ft radius. (see figure 11)

Nothing more materialised in that region until 1814 when B.A.von Lindenau, Director of the Seeberg Observatory, an aide-de-camp to the Grand-Duc of Weimar, proposed to Prince Wolkonsky, Chef de l'Etat-Major Imperial, the measure of an arc of meridian (or section of a line of longitude) to follow the western provinces of Russia south from the White Sea. He presented the proposal to the Russian authorities. This did not progress because of a disagreement over which instruments - German or Russian- should be used. Struve's opinion however was that in any case it was not a good site for well-conditioned triangulation

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STRUVE AND HIS COLLEAGUES

The early 19th century saw the commencement of a very long arc through India by William Lambton. On the death of Lambton in 1823 it was continued to its completion in the 1840s by George Everest so that it extended from the southern tip of India to the foothills of the Himalayas. [**13**]

Around 1812 F.G.W. Struve, Professor of Mathematics and Astronomy at the University of Dorpat, was put in charge of a trigonometrical survey in Livonia. This was controlled by a baseline on the ice of Lake Werz-Jerw, measured in 1819. [**18**]

During 1820 Struve assisted Gauss in the base measure by Schumacher made near

Braack with his new Repsold equipment.

This work enabled Struve to interest officials in the idea of an arc of about 3½º between Gögland, an island in the Gulf of Finland, and Jacobstadt to the south. After getting the resources he was able to observe the arc between 1821 and 1831.

During more or less the same period (1816-1828) Carl Tenner was doing similar work further south in Lithuania but at that stage he was operating quite independently from Struve.

Once he had completed his early surveys, Struve was keen to extend the measurements further north and south so that a very long line would result and could be the basis of a sound set of values for the earth parameters as well as having other uses. He would have been aware of the work at that time in India [**13**], and that it would be an ideal partner to anything he did through Russia, to determine the earth's parameters. (As indicated above, one arc on its own is insufficient to determine the parameters of an oblate spheroid).

Selection of the Route

It is little surprise, since Struve worked at Dorpat University, that he decided any extensions of his surveys should follow, as nearly as possible, the line of longitude (meridian) through Dorpat Observatory at about 27º East of Greenwich. Looking at this line on a map it was clear that some work had already been done in its vicinity in the far north (by Maupertuis 1736-37; and by Svanberg 1802-03) from the northern end of the Gulf of Bothnia well into the Arctic Circle. Here was an opportunity to connect to that work and further extend the line. At the same time it became clear that Tenner was working more or less along the same meridian towards the south. While Struve could envisage the northward extension, Tenner similarly noticed how there could be a southern extension as far as the Black Sea. Thus the elements were present for an arc that stretched from Fuglenaes near Hammerfest in the far north over some 2800 km (1750 miles) to Staro-Nekrassowka near Ismail in the south over 25º of latitude. Today the line stretches through ten different countries.

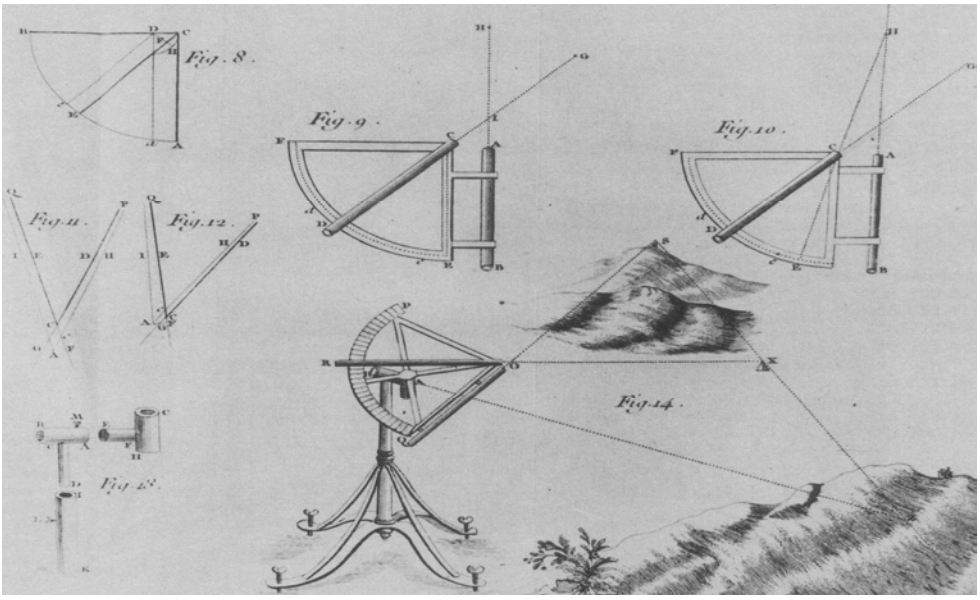

Figure 11. Use of the quadrant

It was quite natural that both Struve and Tenner assumed the astronomical positions of Dorpat (Tartu) and Wilno (Vilnius) respectively, as zero meridians of their independent surveys. Luckily these were close enough to enable a trigonometrical link. Then the observed latitudes and azimuths allowed calculation of the longitudes to the other points in relation to the zero meridians.

THE DAUNTING TASK

To even contemplate such a huge scheme of extensions and collaborations was a daunting task in itself.

Such an arc would however:

(a) build upon the previous schemes in Peru and Lapland which basically set out to prove the shape of the earth but the equipment for which was still relatively crude,

(b) allow computation of accurate figures for the earth dimensions

(c) be the first arc to feature in the Russian Empire

(d) be the longest, and most northerly extended, arc at that time,

(e) complement both the 1792-1825 meridian arc through France, Spain and England by Delambre, Mechain, Arago, Biot, Kater and others; and the l821-1823 arc of 15º along the 45th parallel of latitude across France, Austria and Italy by Brousseaud, Carlini and Plana.

(f) In the 1860s A.R. Clarke, made very extensive inter-comparisons of arcs around the world in an endeavour to get the best possible overall results for the earth's dimensions. The Struve arc featured prominently in his calculations and was the longest of the six he used.

Further extensions in the 20th century have resulted in the "Struve" arc now theoretically reaching from near North Cape in Norway to Port Elizabeth in S. Africa. It was 1954 when two quite separate arcs- that by Struve and that started by Sir David Gill around 1882 in South Africa which gradually worked its way northwards, made a link-up feasible.

UNIQUENESS

As far as is known there is no other such feature as the Struve Geodetic Arc represented on the UNESCO World Heritage List so no direct comparisons are possible. Worldwide there is a finite number of such features that might be similarly considered and probably only 5 that, should this nomination be accepted, rank as of anywhere near similar importance. These are in India, Eastern Africa from Egypt to S Africa, Peru, N. France to N. Africa and across Central Europe from Southern Ireland to the Urals in Russia.

Due to the large variety of natural and political circumstances involved, each country from the Arctic to the Black Sea presented unique peculiarities in the work, at first glance, of a purely technical kind. Norway accomplished the most northerly arc measurement in history, and the monument near Fuglenaes that marks this achievement is the most beautiful on the Arc. Swedish surveyors attempted to make the final judgment over the famous Tornea valley in Lapland being measured for the third time! – Thus they measured their principal baseline twice unlike the 9 other Struve arc baselines measured only in one direction according to the usual practice of the time. The longest arc segment in time and the second in length was measured through Finland's forests and swamps, where the large number of surviving marks are in rock. The segment was also the best connection between the monarchies of Russian Tsar and Swedish King who both contributed to the work, thus have met at quite peaceful reason, though not in fact, on the front page of the Struve final account, and acknowledged in solemn texts on the extreme arc monuments as well. Estonia gave the origin of the meridian to be measured for 40 years ahead, and famous Wilhelm Struve started as astronomer and surveyor in this country. His Baltic arc segment reached the Latvian river Daugava (Duna) and was connected in the south with the arc segment of his friend general Carl Tenner, an outstanding Russian surveyor. Latvian fields presented the first connection of measurements based on the Russian-English unit of the sajene (7-feet Tenner's standard) and the Russian-French unit of the toise (6-feet Struve's standard). The famous German astronomer Wilhelm Bessel judged on this connection and later used the combined Struve-Tenner arc for several derivations of the Earth's reliable geometry. In Lithuania the longest baseline of 11.8 km was measured with an apparatus that made the observers, Tenner among them, kneel down to read the scales of the level, thermometer and contact sliding rule. Besides, a unique triangle side stretching exactly along the meridian line was built in this country by Tenner to escape the complexity of orientation (azimuth) observations.

Table 2. PROGRESS OF THE FIELDWORK

Years	Leader	Latitude	Section of arc	Baselines	Other triangulations
1845 – 1850	**HANSTEEN**	70º 40' N 68º 54'	Fuglenaes, Hammerfest Norway Kautokeino	1850 Alta base	
1845 – 1852	**SELANDER**	68º 54' 65º 50'	Kautokeino Sweden Finland Torneå	1851 Över-Tornea base	1802-03 Svanberg 1736-37 Maupertius
1830 – 1851	**STRUVE**	65º 50' 60º 05'	Torneå Finland Gögland	1845 Uleaborg base 1844 Elimä base	1802-03 Svanberg
1816 – 1831	**STRUVE**	60º 05' 56º 30'	Gögland Baltic Jacobstadt	1827 Simonis base	1816-19 Livland Survey based on Dorpat
1816 – 1828	**TENNER**	56º 30' 52º 03'	Jacobstadt Lithuania Belin	1820 Ponedeli base 1827 Ossownitza base	
1835 – 1840	**TENNER**	52º 03' 48º 45'	Belin Podolia &Volynia Dnestre River	1838 Staro-Konstantinow base	
1844 - 1852	**TENNER**	48º 45' 45º 20'	Dnestre River Bessarabia Staro-Nekrassowka, Ismail	1848 Romankautzi base 1852 Taschbunar base	

Belarus presents a unique Struve-Tenner arc survival with the authentic endpoints of the Ossownitza baseline. Ukraine and Moldova present the longest arc segment, having entered into the northern extremes of the Islamic world. However, unlike Finland, the measurement took half the time here, thanks to the very favourable topographical circumstances. Further research will possibly reveal the highest accuracy of measurement achieved in this country. Additional search along this arc segment, still little surveyed, may also provide other interesting finds. Unfortunately, Struve's suggestion of expanding the measurement further to the south was not realized within the same century because of political unrest in the region.

THE FIELDWORK

The work on the Russian part of the arc was carried out jointly by Imperial staff officers, the Dorpat Observatory and the Central Observatory of Poulkowa. That on the Scandinavian sector was carried out by Swedish and Norwegian experts, with the assistance of astronomers and equipment from Poulkowa Observatory. Overall it was under the control of four directors – C de Tenner, W Struve, N H Selander and Chr. Hansteen. (See the Appendix for biographies).

Bjørn Härsson, speaking at the FIG Congress in Melbourne in 1994 [**4**] summarised Struve's [**5**] reported division of work on the arc in four phases totalling seven sections. Diagrammatically the various phases of the arc measurement are shown in Table 2.
Details of the fieldwork :-

FIRST PHASE Central West Russia 1816 to 1831

c 1816

The early work by Struve had baselines measured with wooden bars and angles by sextant yet even so he got good results. In 1817 Colonel Tenner who was the previous year charged with the trigonometrical survey in western Russian Provinces obtained the permission (without funds) to also carry out an arc measurement along the Vilna meridian and started it.

1820-1821

Struve obtained a grant from Dorpat University to fund further arc measurement including development of his own form of base line equipment. He consulted with Schumacher, Bessel and Gauss, and decided to adopt the observing method used by Schumacher on the arc between Denmark and Hannover. He took his reconnaissance northwards from Gögland into Southern Finland together with H. Walbeck, and investigated the country south from the Gulf of Finland.

1822 to 1827

Struve fitted surveying observations in between his lecturing duties and observing in Dorpat Observatory. Professor Paucker from Mitau (Elgava, Latvia) helped with the astronomical observations at Jacobstadt and Gögland. Struve has crossed the larger part of the Gulf of Finland although the connection was difficult: the longest side of the arc triangles he observed from Gögland to the southern shore of the Gulf. In 1827 the chain from Gögland to Jacobstadt (Jekabpils) was completed, but whilst building substantial signals there were no rocks in which to leave bolts to mark the positions.
When measuring the Simonis base in October 1827 the temperature fell to -13ºR
(= -16ºC)

1825-1827

Tenner's responsibilities extended into Byelarus. He had completed a chain along the meridian of Wilna from Belin to Bristen tied to baselines at Ossownitza and Ponedeli. As a result Tenner's most northerly point was then only 32 km west of Struve's most southerly station.

1828

The possibility of joining the two arcs brought Struve and Tenner together in Dorpat possibly for the first time. They were to fight the challenge of incomparability of their two very different units of length before connecting both chains.

Struve and Tenner managed to solve all the problems, and as a result by 1831 there was an arc of 8º 02.5' from Gögland to Belin equipped with three base-lines and five astronomical stations with latitude and azimuth observations. The results of the connecting of the two partial arcs were published by the Académie des Sciences in its Mémoires of 1832 and also in vols. VIII and X of the Annales du Dépôt topographie in 1832. It was soon used by Bessel who until 1841 was engaged in computations of improved values of the earth dimensions

SECOND PHASE Extension to the south and north- 1830-1844

This began with Struve requesting resources from the Tsar Nicholas I to extend northwards to Torneå. The idea was to connect with the earlier work of Maupertuis and the extension of that by Svanberg.

The military (not only Russian) also had the idea of connections, and Tenner secured three (in 1832, 1843 and 1853) between his, the Prussian and the Austrian geodetic networks, thence to France and the British Isles. This was the first major transcontinental European East-West geodetic framework.

1831

Struve obtained permission to extend northwards and connect with the Lapland arc. Angular measurements were performed by three Finnish officers who had been educated at Dorpat.

1833

In 1833 Struve was commissioned by Nicholaus I to build the best Russian astronomical observatory at Pulkovo

From 1835

The work was mostly led by a Finnish astronomer Woldstedt, as the officers had been called off for other Russian surveys. Meanwhile Tenner was continuing his geodetic work south of the River Pripyat passing through parts of the Ukraine. His new baseline at Staro-Konstantinow was among the longest in the whole arc. Astronomical observations were made at Kremenetz (lat. 50º 06') and Ssuprunkowzi (lat. 48º 45').

THIRD PHASE Sweden and Norway. 1844 to 1851 and Bessarabia 1846-1851

Struve had a more complicated task. The first leg across autonomous Finland was not politically difficult. Moreover, he could leave the practical implementation to Woldstedt. Later political steps were needed and the necessary agreements made.

The chain was joined in the north to that part carried out by Sweden as their share. In Sweden the responsibility for the work was given to the astronomer N. H. Selander. There the chain followed first the old Maupertuis arc of 1736, with western points on the Swedish side and the eastern ones on the Finnish side of the boundary.

Continuing further to the north there was a new political problem. Norway belonged to the Swedish realm but had her own administration. Consequently, the rest of the chain up to the Barents Sea was measured under the responsibility of Christopher Hansteen as far as the northernmost point at Fuglenaes. This finished the fieldwork.

The northern part included 4 additional astronomical stations and 4 base lines. [**8**]

1844

Struve conferred with scientists from Norway, Sweden and Russia as well as with Tenner, on the possible extension southwards to the Black Sea and for a northern extension to the Arctic. Commissioners were appointed by Sweden and Norway to assess the feasibility - Sweden from Torneå to Kautokeino and Norway from there to North Cape.

Later the same year Struve met with King Oscar I and proposed the extension to the Barents Sea. This was quickly agreed and N.H. Selander was made responsible.

A baseline was measured near Elim (lat. 60º 50').

1845

Norwegian participation was put in the hands of Christopher Hansteen (1784-1873) Director of the Christiania Observatory.

Astronomical observations were made near Torneå (lat. 65º 51'). A further base was measured at Uleåborg (lat. 65º 00').

This then allowed a readjustment of the chain from Torneå to Ssuprunkowzi, an arc of 17º 05' 33''.

13 June saw agreement between Sweden and Norway for the arc to begin. Hansteen despatched two young officers to reconnoitre the area, build signals and determine suitable sites for the baseline and astronomy.

1846 to 1850.

The field observations in Sweden and Norway.

In Bessarabia Tenner continued the triangulation chain as far as the fortress at Ismail, located near the mouth of the river Danube. Two more baselines were measured and two astronomical stations completed. He terminated in the village of Staro-Nekrassowka (lat. 45º 20')

Measurements of the Meridian Arc in the territory of Moldova started in August 1846, within the general triangulation frame of “Bessarabia Region”. General management was provided by Lt. Gen. Tenner, operational management by Lt. Col. Heldenbrand, and from August 1847 by First Lt. Napersnikov. Measurements of Moldovian points were completed in 1848. The whole triangulation of this area, including the surveying of the southern part of the meridian arc, is founded on two baselines: Romankauti and Tashbunar, both are in the Ukraine and were surveyed by means of the Struve base equipment. [**5**]. The first of them was adjacent to the border between Moldova and Ukraine and the Moldovian line Gvozdauti-Briceni. Astronomy was provided by Pulkovo astronomer Sabler at the point Vadul-lui Voda in September 1848.

1850 May.

The Alten base was measured by Klouman (1813-1885) and an astronomer, Lindhagen, from Struve's staff at Pulkovo. The area was flat but the base was only 1154.7 t. (2251.7 m) Each terminal was monumented with a stone block, and small iron bolt at the centre.

Bad weather severely delayed the astronomical observations at the northern terminal of the whole arc, Fuglenaes near the town of Hammerfest, and Lindhagen just managed to get the last boat south before the permanent winter dark set in. Unfortunately his assistant Lysander died on the long journey back to Pulkovo.

There were 15 stations between Hammerfest and the Swedish border near Kautokeino. The astronomy was at Fuglenaes because North Cape itself was unsuitable for the final station because of the weather conditions and persistent fog.

1851

A baseline was measured near Torneå and the astronomy completed at Stuor-oivi. There were 24 stations in the Swedish section which was mostly observed by Selander, Lindhagen, Skogman and Wagner.

1852

The base extension of the Öfver-Tornio (Ylitornio) was completed.

FOURTH PHASE Completion.

1852 to 1855

Some supplementary re-observation of suspect values were made during this period. To honour the completion of the arc, monuments were erected at Staro-Nekrassowka and Fuglenaes.

INSTRUMENTATION

Struve used a universal instrument (theodolite) by Reichenbach of Munich which had a 13 inch diameter horizontal circle and 11 inch vertical circle. These were graduated to 5' (= minutes of arc) and read directly by verniers to 4" (= seconds of arc). Tenner used a variety of seven instruments by a range of different makers. There were two repeating circles, one of 13 inches diameter by Baumann, which read to 4" by vernier, and the other 14.3 inches by Troughton reading by vernier to 10". A 12 inch diameter terrestrial repetition theodolite by Reichenbach read by vernier to 4" an 8 inch astronomical repetition theodolite by Ertel reading to 10"; a repeating theodolite of 10 inches made in the Etat-major and reading to 5"; and two instruments by Ertel. The first two of these instruments gave inclined angles whilst the other five used by Tenner and that by Struve gave horizontal angles direct. [**3**]

MONUMENTATION

Another remarkable item of the Struve arc is the monumentation of the stations. In Finland many were marked on the solid rock by drilling a hole. The hole was filled with lead and on the top of the lead was a plate of brass. Veriö [**11**] elaborated this point saying that nearly all stations between Hogland and Tornio were marked with small copper plates, which were soldered with lead into 5-7 cm deep holes drilled in the rock or big stones. In the course of time most of the plates have disappeared. In fact most of them were found missing already in the 1890s. Later the lead has been dug out, maybe to be made into shot for the hunters. However, nobody has been able to take along the holes in his pockets. In the Swedish-Norwegian part many points were marked directly on the solid rock or on big rocks by engraving a cross and are still unchanged. Unfortunately, Struve did not leave ground markers to mark the positions of his stations between Gögland and Jacobstadt (Ekabpils, Latvia), except for the two terminals. Within this section the centre markers were mostly placed on timbers, which have not survived. The monumentation south of Jacobstadt belongs exclusively to the merits of Tenner.

There points were marked on stones or brickwork, which were placed underground to depths of up to a metre.

In general the form of the marks can range from:-

- a small hole drilled in a permanent rock surface - sometimes filled with lead but often such a filling has been poached for other uses although the hole remains,

- cross shaped centre and/or witness marks engraved in the rock,
- to a solid block with a marker set in it,
- or a large solid structure of rocks possibly some decimetres below ground level, together with a centre stone or brick in which there is a drilled hole,
- a measuring block on top of which was a single brick on edge of which the intersection of the diagonals designated the point. This was used by Tenner on his baselines.

Essentially the marks are similar to, and serve the same purpose as, the triangulation pillars that one finds on hill tops in the many countries where there is a central mark within some larger, stable and reasonably secure structure. With the older marks these are now sometimes found 25 cm or more below ground level but on location, excavation and verification are still in their original condition.

Similar types of mark are often used to locate well-known geographical features such as various national meridians, geographical centres of various sorts and border points between countries and continents. Most of them - unlike the meridian of this paper- are not of particular universal significance or of practical use to a range of professions. They do not bear witness to such a considerable amount of international labour under various climatic, topographic and geographic circumstances, with intensive and multiple interchange of human values based on a rich historical background.

The form of conservation of those comparable properties is similar to that proposed for the selected Struve Geodetic Arc stations: i.e. special plaques or similar notice boards in the immediate vicinity. Existing linear cultural sites bear a description distributed along the lines and this is also envisaged in the case of the Arc points.

The lengths attainable between neighbouring triangulation points vary according to several factors. These include the range of height of the topography, the vegetation cover and the suitability of points to form reasonably shaped triangles. For the full Struve Arc the longest line is 81.7 km in length (from Mäki-Päälys on Hogland Island to Halljall in Estonia) and many lines are well over 60-70 km long. The shortest line is only 479.6 m in length (from Porlom 1 to Porlom 11 in Finland). The average length between points is 27.1 km.

None of the terrain over which the survey was observed could be termed mountainous as in the Peru arc of 1735 (along the Andean peaks) or the Arc of 30th Meridian (the mountains of East Africa). However the terrain varied from massive granite outcrops in the Northern latitudes, some tree covered, through low lying areas in central Finland. To the simple island of Hogland that greatly assisted the crossing from Finland to Estonia but presented poor geometry. Through thickly forested areas of Eastern Europe and the marshlands to the delta of the river Danube where long sight lines were difficult to obtain. Any hills were made use of as well as high buildings available like the tower of Alatornio church and the Observatory at Tartu.

Many chains were measured in different continents in subsequent years. Some results of these activities can be seen in the development of the computed dimensions of the earth.

UNITS AND STANDARDS OF LENGTH

Although at the time of the surveys, the metric system was well established, the base measurements were recorded in two different units of length. Struve used the old French "toise" (approx. 1.949 m) because his basic standard had come from France. Meanwhile Tenner used the Russian unit the "Sajen” (approx. 2.134 m) because his basic standard had been built in St Petersburg based on an English "foot”, as in the 18th century 1 sajen was defined equal to 7 English feet. The two units first "met" or came together on the Struve arc of the meridian. By 1830 Struve and Tenner had solved the problem of converting sajens into toises through careful examinations of their measuring bars and the respective standards, and Struve was able to present further results in toises. His final table of the length of the arc segments is computed in those units, probably for the last time in history and probably also as a sign of the merits of Frenchmen in measuring the earth.

Some complications later occurred when trying to determine the best conversion factor for relating the toise to the modern metre. Various factors will be found ranging from 1.949 to 1.949 087. Of course, with the long distances that occur in this project the last digits can make a significant difference.

The standard unit used was the toise of Paris, which was the same as the toise of Peru. Copies were specially commissioned by Struve and Bessel and constructed by Fortin. From his copy Struve had two field standards made each of about 2 toise or 1728 lignes long. (1 ligne = 1/12 inch). Tenner on the other hand used a standard of 945 lignes, which equates to the Russian sajène or 1.0946 toise. During 1850 to 1853 19 different standards were inter-compared at Pulkovo. Thus the relationships become complicated.

That used on the baselines of Simonis, Elim and Uleåborg was of 1728.01249 lignes of the Fortin toise at l3ºR. For the bases at Alten, Over Torneå and Taschbunar the standard was of 1727.99440 lignes. For the Romankautzi base the standard was of 1728.01991 lignes. The value of Tenner’s standard, used for the bases at Ponedeli, Ossownitza and Staro-Konstantinow was of 945.75779 lignes. [**5**]

BASELINES

Sprinkled among the 258 principal triangles were 10 baselines, three of which were measured with Tenner's apparatus and seven with that of Struve. The Struve equipment consisted of four wrought iron bars each of 2 toise in length. One end of each bar had a small cylinder with slightly rounded end; the other end of each had a contact lever which was pivoted to the bar. Two thermometers were set into holes in the bars and the bars were each set in boxes from which their ends protruded. Seven of the baselines were measured using this equipment and Struve estimated the probable errors of each to be around 1 ppm.

The other three baselines were measured by equipment devised by Tenner. Here the bars were of forged iron 2 sajènes long. One end of each bar was fixed and the other free to move. At this latter end was a sliding scale that could be used to determine the distance between consecutive bars.

Struve estimated the probable errors of Tenner's apparatus to be around 3ppm. With a single exception, all the baselines were measured in one direction only, thus control over the lengths of sides connecting successive arc segments was essential.

The last column of Table 3 gives the quoted accuracy when computing from one baseline to the next which is not the same as the accuracies of the individual baselines.

REFERENCE MERIDIAN

Struve was working in Dorpat (now Tartu) Observatory and so it was logical to select the meridian line through that place as a reference line. It was taken as the start (datum) point in both latitude and longitude. Distances were calculated N and S of Dorpat with Dorpat as 0, reaching 710 000 t to the north and 740 000 t to the south. Details are given in [**19**] of the location of the reference point under the centre of the cupola of the observatory. The point was relocated from Struve’s original measurements and is now marked with a 12 mm bronze marker and a commemorative plaque unveiled in 2002.

Table 3. BASELINES (for arc metrology)

Date	Triangle	Country	Latitude	Name	Reduced length Toises / Metres	Reduced to	Accuracy between bases
1850	252	Norway	69° 55'	Alten*	1154.744 2250.67	Arctic Ocean	1/395 991
1851	230	Finland	66 22	Ofver Torneä*	1519.839 2962.27	Gulf of Bothnia	1/29 964
1845	216/7	Finland	65 00	Uleäborg*	1505.317 2933.96	Gulf of Bothnia	1/32 594
1844	162	Finland	60 50	Elima*	1348.746 2628.80	Gulf of Finland	
1827	150	Estonia	59 02	Simonis*	2315.133 4512.35	Gulf of Riga	1/58 502
1820	117	Lithuania	55 58	Ponedeli**	6055.162 11801.92	Gulf of Riga	1/35 130
1827	79	Belarus	52 14	Ossownitza**	5719.643 11147.97	Gulf of Riga	1/26 104
1838	53x	Ukraine	49 42	Staro-Konstantinow**	4563.972 8895.49	Gulf of Riga	1/28 211
1848	42	Ukraine	48 30	Romankautzi*	2910.094 5671.97	Gulf of Riga	1/85 639
1849 1852	6/ 7	Ukraine	45 35	Taschbunar*	2770.317 5399.33 2770.246 5399.40	Gulf of Riga	

Conversion factor 1 toise = 1,949 067 metres * = with Struve apparatus ** = with Tenner apparatus
NB Taschbunar was measured twice

RESULTS

The complete summary and description of all the work and results fill 961 pages in [5] together with maps.

COORDINATES ON THE STRUVE ARC

Due to his incurable illness diagnosed at the beginning of 1858, Struve never managed to publish the 3rd volume of his *Arc du meridien….* A full account of the astronomic operations, final results, a critical evaluation of the world arc measurements and derivation of a series of related earth figure parameters would have been contained there. Perhaps, a full list of geographic coordinates of all the arc stations was also kept in mind for use by the Russian Army General Headquarters that shared the arc field operations from the very beginning in 1816. Such a full list was not computed until 1926.

Before that time some Russian regional nets did include Struve arc stations, with subsequent derivation of their coordinates. For instance, in 1892 the Head of the Russian Survey of Finland Lieut. Gen. Järnefelt published a list of geographic coords of 91 stations of the northern part of the Struve arc from Gogland (Mäkipäällys) to the Norwegian border (Stuoroivi). The values were computed on the 1819 Walbeck ellipsoid with longitudes related to Dorpat meridian. In 1926 a vast list of coordinates of the Russian 1st order triangulation points was published, including Struve arc Russian stations south of Kakamavara (near Tornea) to Izmail, that resulted from computation on the 1841 Bessel ellipsoid, the longitudes being related to Pulkovo. Both the Lists were in the Proceedings of the Russian Military Topographers Corp (in Russian). Since then, due to the collapse of the Russian Empire and subsequent political changes in Eastern Europe, there have been no other computations for the entire arc although there have been separate calculations within national borders (Latvia, Finland, Norway, Poland, Romania). [**17**]

Observations for latitude and azimuth were made at 13 selected stations 3 of these were in Scandinavia and the other 10 in the Russian Empire states. This gave 12 arcs (see Table 5) varying from 1° 22' to 2° 54' in length that could be computed separately. From these the length of 1° (see Table 7) was determined for each of the 12 arcs and these varied from 57 252 t in the far north to 57 068 t in the far south but there were some inconsistencies in between. Using seven different divisions there was a more regular decreasing pattern between similar extreme values. (A decrease as one moves from north to south indicated an oblate rather than a prolate shape for the earth.)

Table 4. AZIMUTHS (for astronomical positioning and orientation)

Date	Station nunber	Country	Astro.Latitude ° ′ ″	From	To	Azimuth ° ′ ″
1850	1N– 4N	Norway	70 40 11.2	Fuglenaes	Jedki	220 30 20.5
1850	16N–18N	Finland	68 40 58.4	Stuor-oivi	Pajtas-vaara	168 22 59.4
1845 1851	2 – 1	Finland	65 49 44.6	Neder-Torneä church	Kaakama-vaara	03 01 30.9
1852	39 – 38	Finland	62 38 05.2	Kilpi-mäki	Silmut-mäki	274 48 04.3
N1843	72 – 70	Russia	60 04 29.2	E on Mäki-pâälys	Ristisaari	342 10 10.9
S1826	72 – 73	Russia	60 04 29.2	E on Mäki-pâälys	Belfry Halljall	209 09 17.3
1826-1828	84 – 82	Estonia	58 22 47.6	Centre Obsery. Tower Dorpat	Kersel	337 36 39.6
1826	104 – 101	Latvia	56 30 05.0	Jacobstadt astro pt.	Dabors-kalns	312 22 02.4
1827, 1855	125 – 121	Lithuania	54 39 04.2	Nemesch	Meschkanzi	359 59 57.1
1827, 1853	154 – 153	Belarus	52 02 42.2	Belin	Leskowitschi	61 44 04.8
1837	172 – 170	Ukraine	50 05 50.0	Kremenetz	Gurniki	18 07 17.4
1838, 1852	187 – 186	Ukraine	48 45 03.0	Ssuprunkowzi	Karatschkowzi	311 35 47.6
1848	208 – 210	Moldova	47 01 25.0	Wodolui	Dschamana	157 41 27.1
1848, 1852	231 – 230	Ukraine	45 20 02.8	Staro-Nekrassowka	Belfry Ismail	270 56 05.5

The results of the 1816-1855 arc measurements were first published by W. Struve in 1857 (unfortunately, without astronomy and the historical preface), then in 1860 (in full) each edition in French. In 1861 an identical Russian edition was issued and some selected chapters of this were re published in 1957. Note that F.G.W. Struve tended to publish under W. Struve.

In these Struve's definitive conclusion was that the overall length of the meridian arc was 1 447 787 toise (= 2 821 833 m) for 25º 20' 08.29". However, Struve became ill and could not complete the compilation of astronomical results and derivation of the definitive values of the earth’s parameters “a” and “f” (Figure 6 and Table 8). He only derived preliminary values of these combining his results with those of Bessel and Everest, resulting in

semi-major axis (a) = 3 272 539 toises and flattening (f) of 1:294.73

He did however make other calculations with varied results.

Others since, including Bessel (from 1834 to 1841) and Clarke (1858 and 1861), and many others afterwards all used Struve's latitudes and arc section lengths to combine with other arcs around the world.

ACCURACY

Among the various figures Struve gave were those for a measure of the accuracy achieved in the various sections were values for the probable error of each of the 12 sections between successive astronomical stations. This gave the following list and indicates the overall high accuracy of around 1/200 000 (i.e. 5 mm per km) achieved [**5**] v.2 p 210:-

Table 5. ACCURACIES

Between stations	Distance (t)	p.e. (t)	Fractional
Fuglenaes - Stuor-oivi	113 753.91	± 1.78	± 1/63 908
Stuor-oivi - Tornea	163 221.90	1.69	1/96 581
Tornea - Kilpi-mäki	182 794.30	1.67	1/108 162
Kilpi-mäki - Hogland (Z)	145 713.57	1.07	1/136 181
Hogland (Z) - Dorpat	97 538.65	0.50	1/195 773
Dorpat - Jacobstadt	107 280.56	0.68	1/157 765
Jacobstadt - Nemesch	105 730.88	0.93	1/113 689
Nemesch - Belin	148 809.52	1.43	1/104 063
Belin - Kremenetz	111 219.01	1.01	1/110 118
Kremenetz - Ssuprunkowzi	76 751.39	0.71	1/108 100
Ssuprunkowzi - Wodolui	98 557.99	1.25	1/78 846
Wodolui - Staro-Nekrassowka	96 415.14	0.66	1/146 083
Overall	**1 447 786.78**	**6.23**	**1/232 390**

SUMMARY

1830 End of phase one. There was a complete meridian arc from Gögland in the Gulf of Finland (latitude 60º 05') to Belin (latitude 52' 02') = 8º 03' extent.
1844 End of phase two. There was a complete arc from Torneå to the Dnestre river (latitude 48º 45')
1851 End of phase three. There was a complete arc from Fuglenaes to Staro Nekrassowka except for the need to add some supplementary data and re-observe various suspect stations- which took place during the last phase.

A summary of the whole arc is given in [**4**] thus:

Northern terminal Hammerfest (Fuglenaes) latitude	70º 40' 11.23" N
Southern terminal Ismail (Staro-Nekrassowka)	45 20 02.94
Difference in geographic latitude	25 20 08.29
Difference in toises	1 447 786.783 ± 6.226
kms	2 821.833 711*
Origin of the meridian arc located in Dorpat latitude	58º 22' 47.56"± 0.05"
Time difference between Greenwich and Dorpat	1h 46m 53.536s ± 0.066s
Then longitude of Dorpat related to Greenwich =	26º 43' 23.04"

* Value in kms. will vary slightly according to conversion factor used.

The Struve chain brought several benefits. The long and accurate chain gave a fine addition to the determination of the spheroid but it also had plenty of indirect influence. The principles of the work were published in all details and this made the arc a good example for others to adopt. Even the personal contacts made over the forty years were important. For instance, Struve had an influence on the measurement of an arc along the line of latitude 52º carried out in the second half of the century. It was Tenner who asked Bessel to derive new dimensions of the earth incorporating use of the Russian arc.

Many chains were measured in different continents in subsequent years. Some results of these activities can be seen in the development of the computed dimensions of the earth.

Table 8 gives just a small sample of generally used values. Very clearly the mutual agreement has become better since the publishing of the Struve arc and succeeding measurements. This has given a good start to uniform mapping, its framework and the map projection systems.

Table 6. MERIDIAN ARC LENGTHS

Stations	**Arc in toises**	**Arc in metres**	**Arc in feet**	**Latitude**
Fuglenaes				70º 40' 11"
	113 754	221 714	727 403	
Stuor-oivi				68 40 58
	163 222	318 130	1 043 728	
Tornea				65 49 45
	182 794	356 278	1 168 884	
Kilpi-Maki				62 38 05
	146 359	285 264	935 900	
Makipallys				60 04 29
	96 893	188 850	619 584	
Dorpat				58 22 48
	107 281	209 097	686 009	
Jacobstadt				56 30 05
	105 731	206 077	676 100	
Nemesch				54 39 04
	148 810	290 040	951 567	
Belin				52 02 42
	111 219	216 773	711 194	
Krementz				50 05 50
	76 751	149 594	490 789	
Ssuprunkowzi				48 45 03
	98 558	192 096	630 232	
Wodolui				47 01 25
	96 415	187 920	616 530	
Staro-Nekrassowka				45 20 03
Totals	**1 447 787**	**2 821 833**	**9 257 921**	**25 20 08**

Toise values from Struve records [**22**]
Metre values by use of conversion factor K = 1.949 067 (from [**17**] cited in [**22**])
Note that Vassiljev in his paper of 1994 appears to have used K = 1.949 and hence all his metre values are less than those above.
In all the toise-metre conversions the last three decimal places make noticeable differences. These digits are found variously as 087, 081, 067 (0668) or 061
Foot values from [**25**] pp 34-35

Indirectly it has also helped the spread of the metric system as it became more generally accepted in principle at the international agreement in the year 1875. It is true, the length of the basic unit no longer depends on the determination of the earth dimensions but in the 19th century it was the chosen way.

Because of the number of countries it passes through the Struve arc has had a remarkable effect on the framework for mapping. Strong chains with permanent marking and good documentation have ever since belonged to the basic work in many countries. New base lines and astronomical stations were distributed along the Struve arc triangulation chain and made it an inseparable part of developing a traditional framework for European geodesy and mapping. These principles have then been followed for nearly 150 years until the Global Positioning System (GPS) has now completely changed the methods.

Table 7. LENGTH OF 1º

Stations	Arc in metres	Amplitude of arc	Length of 1º (km)
Fuglenaes			
	221 714	01º 59' 12.8"	111.589
Stuor-oivi			
	318 130	02 51 13.8	111.475
Tornea			
	356 278	03 11 39.4	111.536
Kilpi-Maki			
	285 264	02 33 36.0	111.431
Makipallys			
	188 850	01 41 41.6	111.423
Dorpat			
	209 097	01 52 42.6	111.311
Jacobstadt			
	206 077	01 51 01.2	111.373
Nemesch			
	290 040	02 36 22.0	111.292
Belin			
	216 773	01 56 52.2	111.289
Krementz			
	149 594	01 20 47.0	111.108
Ssuprunkowzi			
	192 096	01 43 38.0	111.217
Wodolui			
	187 920	01 41 22.1	111.230
Staro-Nekrassowka			

Table 8 EARTH PARAMETERS

Year Name	a (in m)	f	Meridian Quadrant (in m)
1819 Walbeck	6 376 896	1:302.8	10 000 091
1841 Bessel	6 377 397	1:299.15	10 000 966
1853 Struve	6 378 398	1:294.73	10 002 174
1880 Clarke	6 378 249	1:293.5	10 001 869
1924 International	6 378 388	1:297	10 002 288
1935 Krassowsky	6 378 180	1:298.9	10 002 069
1967 International	6 378 160	1:298.2471	10 001 986

Where a = semi-major axis, b = semi-minor axis and f = (a-b)/a, (see fig. 6)

The Struve arc has not only served triangulations as an example. Its points have been the starting points to many new triangulations and traverses in the intervening period. Up to the 1960s the Struve arc was the only connection of coordinates between South and North Finland. An additional advantage has been the careful trigonometric levelling along the points in the chain. [**8**]

Data from this arc was used in 1942 by Izotov and Krassovsky in their ellipsoid calculation and as recently as 1956 in the new determination of the figure of the earth by Chovitz and Fischer. [**6**], [**10**]. Norwegian geodesists repeated the astronomical observations at Fuglenaes in 1928 with Hans Jelstrup and in 1950 with Yngvar Schiott. There was good agreement with a variation in latitude of less than 6m.

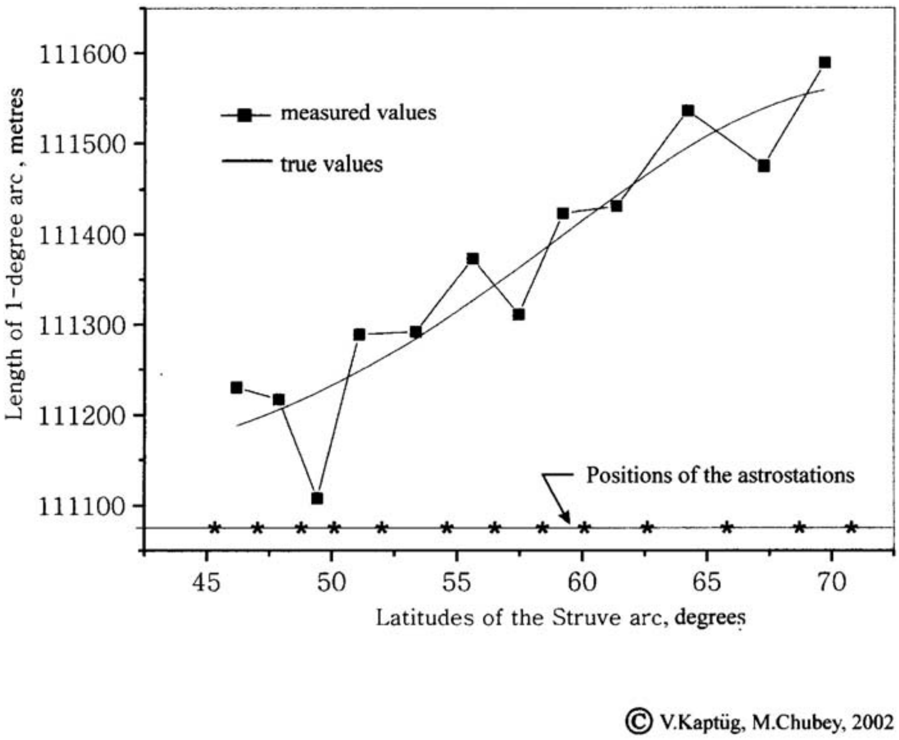

Figure 12. Change of length of 1° with latitude

SUBSEQUENT COMPARISON

The amount of work is not the only merit. Taking the instrument and observation techniques of that time into account the achieved accuracy was amazing. Co-ordinate transformations between some Struve points and coinciding new points measured applying the best methods over one century later, have revealed an unexpected quality. The discrepancies were of the order of some centimetres, maybe one or two decimetres. One lost Struve point was found when measured from a nearby new triangulation point. It was about one decimetre from the computed site. Perhaps the accuracy of the methods of the time deserves admiration.

LATER RESEARCH

In 1861 the Prussian General and geodesist Johann Jacob Baeyer (1794-1885) proposed plans for arc measurements covering Europe. This almost immediately led to the Mitteleuropäische Gradmessung, which soon became renamed as Europäische Gradmessung and which finally became the Association Internationale de Géodésie (IAG) of today.

Dick in his paper [**16**] indicates that much of the inspiration for both the European triangulation and the formation of the IAG can be traced to Wilhelm Struve. Unfortunately severe illness prevented Wilhelm Struve from pursuing this and all was passed on to his son Otto. Baeyer however went further in wishing to investigate regional and local anomalies of the figure of the earth and their physical reasons. All however stemmed from the work of Struve on his celebrated meridian arc.

Alfred Petrelius (later Professor at the Technical University of Helsinki) had checked the stations of the Struve arc in Finland during three expeditions in 1886, 1888 and 1889 and had made a catalogue of his findings. At that time only a few points were missing.

More recently new searches were made in 1968 and 1989 on the initiative of Dr Seppo Härmälä and the task to make an inventory of the points was entrusted to Mr. Aarne Veriö of Finland. He has taken the issue seriously and has collected much information. Doing this he has realized that the preservation of the remaining sites was very important to the honour that the Struve arc deserves. [**8**]; [**11**]

Between 1910 and the 1930s connections were made to the Struve arc in many countries including Norway, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Romania.

Then in 1954 the long awaited connection was made between the arc of the meridian from Scandinavia southward and that from South Africa up the 30º meridian. This divided near Cairo into a western chain along the Egyptian coast, stations of which were used in the Shoran connection from Egypt to Crete, and an eastern chain towards Suez that was linked through the Middle East to the Russian arc of the 32nd meridian. [**9**].

[**6**] p.2 states "Within the past two years, [i.e. 1954-56], two important pieces of geodetic work have been completed. The last un-surveyed section of the long anticipated arc of the 30th meridian extending from Scandinavia to South Africa was finished in 1954 by a field party from the [US] Army Map Service; the Hiran* connection from Crete to Egypt, and an alternative connection through the Middle East joined the African portion of the arc to the European portion."

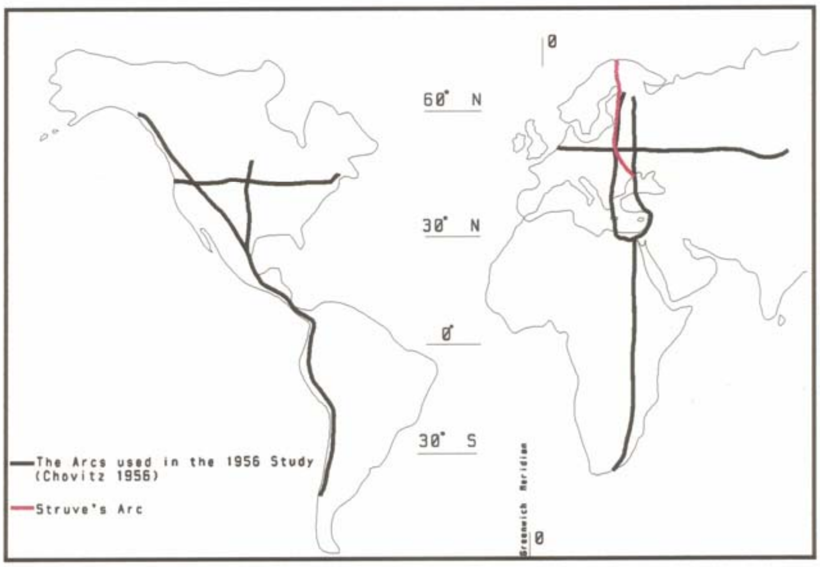

Figure 13 Struve arc superimposed in red on those used by Chovitz and Fischer, 1956, for a new figure of the earth. [**6**], [**10**]

[**6**] p. 3 states "... the African arc is also continued in two different paths. In one, it crosses the Mediterranean by means of the Africa-Crete Hiran* connection, and then roughly follows the 24th meridian up to about 65º N ... The other path forks eastward through the Levant and continues roughly along the 32nd meridian up to 64º N."

*(NB. the quotes above each say Hiran, whereas the actual Report [**15**] says Shoran.

Hiran is simply a high accuracy version of Shoran).

As shown on figure 13 this gave a measure from near Hammerfest in the north to a point at Buffelsfontein near Port Elizabeth. Although the triangulation does continue on from Buffelsfontein to Cape Point this last section diverges by almost 90º from the meridian. [**9**]. As a result Chovitz and Fischer, 1956, (see figure 13) were able to use points on these arcs to determine a new figure of the earth. [**6**]

In 1956 Zhongolovich used the entire Struve arc for a derivation of the earth parameters.

THE FUTURE

There are still other issues to be addressed.

The tome in French by Struve where the Arc was documented [**5**], is valuable and interesting and belongs to the history of surveying. Unfortunately the book is now a rarity, and seldom found in libraries. It is uncertain whether it is even available in all of the ten countries involved. It is true, some chapters from it have been reprinted in Russian in 1957 in Moscow but even that must now be out of print there. [**8**]

It would be a cultural achievement to reprint the tome. In French it could be a facsimile product, but still better if it could be in English to reach more readers. This aspect of the Struve arc will, it is hoped, be part of the project to index the Struve archive that remains mostly in St Petersburg and Moscow.

Now that the initial project has been successful it would not be impossible to extend the idea south into Africa and down the 30th meridian to South Africa. As was indicated by Chovitz & Fischer in 1956 [**6**], for purposes of determining the figure of the earth, the arc of the 30th meridian was linked across the Mediterranean to European arcs. Thus it could be an extension of the Struve meridian arc project to continue through the African arc and so preserve a series of points from the North Cape to Port Elizabeth or even along to Cape Point although this last section is not strictly part of the arc of the 30th meridian.

NOMENCLATURE

In the interval since Struve completed his work many place names have changed. In addition they appear with different spellings in different languages. Some have simply a change of one or two letters, others have completely altered their names. For example:- Dorpat = Tartu; Leningrad = St Petersburg, Gögland is also found as Högland and Hochland.

The regional names also have changed so that, for example, Bessarabia and Livonia have been divided between Ukraine and Moldova, and Estonia and Latvia respectively.

Note also that many of the national boundaries have changed position so that some points originally in one country are now in another.

Place-name orthography

The problems with place names as they change over the years is well illustrated by the following extract from [**21**]

In *Arc du méridien* the spelling of names is with small capitals, e.g. PULLINKI, and the ending VAARA ('mountain') separated e.g PERRA-VAARA. The seven names within Sweden are PERRA-VAARA, PULLINKI, PALJUKKAVAARA, KERROJUPUKKA, LUMI-VAARA, PESSINKI, PAJTAS-VAARA. (In the map section spelling is with small letters, *Pullinki.)*

At the time of the Arc survey there was no modern topographical map. Beginning some 20 years later a survey within Sweden covered the area with a 1:200 000 hachured topographical map. At that operation also a more systematic name collection was carried out. When later on also maps at 1:100 000 and 1:50 000 entered the scene still more names were added. In some cases name placement was changed.

PERRA-VAARA now *Perävaara* (25N NV). More precisely the point is on a part of the mountain called *Alanen Perävaara* (written *Ala Perävaara* in an earlier version of the map).

PULLUNKI unchanged, *Pullinki* (map sheet 27M SO, grid square 27N SV). The name appears as *Pullingi* in the old District Map or *Häradskarta*, 1878.

Also PALJUKKAVAARA is unchanged, *Paljukkavaara* (28M SO).

As for KERROJUPUKKA the former part is probably *Käry-* (thus *Käryjupukka)* as the mountain is close to *Kärykoski* rapids in the Torne river and is surrounded by *Käryjänkkä* and *Käryjänkänlehto* (28M NV). The name Kerrojupukka was not used in later 19th century surveys. It is shortened to *Jupukka.*

LUMI-VAARA, now *Lumivaara* (29M SV). It should be noted that the Struve point is on a southeastern minor summit called *Palolaki* about 950 m from the main Lumivaara top. At Palolaki there is a parish boundary bend between Junosuando and Pajala parishes. The main summit has been entered into some later survey protocols as *Lumivaara (Huornanen)* but Huornanen is the name of another mountain in this area.

PESSINKI, unchanged *Pessinki* (30L SO). The name refers to a vast area and is used also for the Pessinki nature preservation area, covering 972 sq km. There are very few minor names and the Struve place is marked by a spot height only (510.2 m).

PAJTAS-VAARA, now *Paittasvaara* (301, NO). The *Paittasvaara* mountain and the *Paitta järvi* lake with a small settlement (same name) are the "big" names in the area. The Struve point is however not located on Paittasvaara (434 m) west of the lake. Instead it is within an easterly mountain complex called *Pingisvaara* and on its highest and steepest top, *Tynnyrilaki* (445 m). To avoid mistakes the Struve point should be renamed *Tynnyrilaki* or at least this name be added.

The Swedish side of the Torne valley *(Tornedalen)* is a multilingual area, where Swedish, Sami and a variety *(tornedalsfinska)* of Finnish are spoken. During the 1990s the name Meänkieli 'our language' was widely accepted for this last mentioned language variety, and it was given the status of a minority language within this part of Sweden. [**23**]

Table 9. STATISTICS FOR THE ARC

	Struve Geodetic Arc
Northern terminal	Fuglenaes
Latitude	70º 40′ 11″ N
Longitude	23º 38′ 48″ E
Southern terminal	Staro-Nekrassowka
Latitude	45º 20′ 03″ N
Longitude	28º 55′ 40″ N
Overall linear length	2 821.833 km
Overall angular length	25º 20′ 08″
Countries involved (modern-day boundaries)	10 = Norway, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Belarus, Moldova, Ukraine.
Number of main stations	265
Number of baselines	10
Number of astro. stations	13
Started	1816
Completed	1852

EXAMPLES OF STATION POSITIONS

Figure 14. Origin point in Tartu Observatory, Estonia

Figure 15. Tartu (old) Observatory Estonia

Figure 16. SE terminal of Simuna baseline Estonia

Figure 17. Southern terminal of Struve Arc at Staro-Nekrassowka, Ukraine

Figure 18. Plaque at the point on Hogland Russian Federation

Figure 19. N.W. terminal of Simuna Estonia

APPENDIX

Dramatis personae

A few words about the principal individuals involved are appropriate here.

Hansteen

Christopher Hansteen was born 26 September 1784 in Christiana (now Oslo) and died in the same city 15 April 1873. He studied law at Copenhagen and later became Professor at Christiana, Director of the Christiana Observatory and Director of the Royal Norwegian Geographic Department. By 1817 as a President of the Geodetic Institute he played a leading role in the survey of Norway. He was particularly interested in geomagnetism and magnetic charting. For his part he was in charge of 1º 46′ of the arc between Atjik and Fuglenaes on the isle of Kval-oe, in the Arctic Ocean, or from 68º 54′ to 70º 40′ with one baseline and 12 main triangles.

Lindhagen

Daniel Georg Lindhagen was born on 27 July 1819 in Askeby near Linköping, Sweden and died 5 May 1906. He was a Swedish astronomer who worked in Pulkovo before returning to Sweden to work a few years after his marriage. He spent two summers on survey work in Lapland. At that time Struve was over 50 years old and headed the Observatory in Pulkovo so he delegated the astronomical work to Lindhagen whose detailed reports for 1850 and 1851 are presented as appendices in the *Arc du Meridien* [**5**]. Later he became permanent secretary to the Royal Academy of Sciences in Stockholm. He married Wilhelm Struve's daughter Olga. [**12**]

Maupertuis

Pierre-Louis Moreau de Maupertuis was born 28th September 1698 in St Malo and died on 27th July 1759 in Basel. On 8 October 1745 he married Eleonore Catherine von Borck. He was said to have been a spoilt child and this resulted in a certain intransigence and unwillingness to be criticised that later led him into difficulties. His early education was private. His father was ennobled by Louis XIV as Ren, Moreau Sier de Maupertuys. After studying in Paris he was in the French army until 1723 when he became involved in the French Academy of Sciences.

By 1728 he strongly believed in Newton’s idea on the shape of the earth and began to work on his own theories and even published a treatise on the figure of the earth which signalled the beginning of the establishment of the Newtonian hypothesis in France. In 1736 he led an expedition to Lapland to make a measure of a meridian arc and he was later involved in further arc measurements in France. In 1745 he accepted an invitation from Frederick the Great to go to the Academy of Sciences in Berlin where he became its President.

Selander

Nils Haqvin Selander was born on 20 March 1804 in Vibyggerå, Ångermanland, Sweden and died 18 June 1870 in Stockholm. An astronomer and geodesist who became Director of the Royal Swedish Observatory. In 1833 he was elected a member of the Stockholm Academy of Sciences and began assisting at Observatory in Stockholm. From 1850 to 1869 he was Professor of Geodesy at the Topographic Corps which was responsible for topographical mapping of Sweden and of its geodetic systems.

Struve visited Sweden in 1844 and contacted the Swedish Academy of Sciences. The initial idea was to follow the Svanberg Arc and incorporate it. However a Report by Selander and Wrede indicated that the best solution was to complete the Struve arc

over the longest possible distance. They had planned the Arc as a separate Swedish work from Tornea to Kautokeino where there would be a connection to Norway. Although initially intending to do their own computations the work was finally done in Pulkovo in 1855. He was in charge of the 3º 13′ of the arc between Tornea and Bäljatz-vaara in Norwegian Finnmark, or between 65º 50′ to 69º 03′ and with one baseline and 21 main triangles.
He was one of the four persons who signed the report *Arc du Méridien* (“sou la direction de”), de Tenner, Hansteen, Selander and Struve. [**20**]

Struve

Friedrich Georg Wilhelm Struve was born in Altona, Holstein 15 April 1793 and died 23 November 1864 in Pulkovo, Russia. When in Russia he came to be known as Vassily Jakovlevich however he always used his original initials F.G.W. or the name Wilhelm, later with "von” because of his noble status. In the list of his works in his major volume [**5**] he used the initial W rather that F G W. He married twice with a total of 18 children. He graduated in philology from Dorpat and started work at the University observatory. By the age of 20 he became Professor of Mathematics and Astronomy at Dorpat. His involvement in the survey of Livonia was the start of almost 40 years of work on the meridian arc. As a result of which, in 1857 he proposed the measurement of an arc along 45º latitude covering 53º from the west coast of France (Brest) to the mouth of the Volga (Astrakan). He was a founder and Director of the Nicolas of Russia Central Observatory of Poulkowa, then the best in the world, and of the Russian Geographical Society and belonged to some 40 scientific academies, learned societies and the like. He was in charge of 9º 38′ of the arc between the Duna (Dvin) and Kaakama-vaara to the north of Tornea, or from 56º 50′ to 66º 08′ and contained 3 baselines and 100 main triangles.

Svanberg

Jons Svanberg was born 6 July 1771 in Neder-Kalix, Norrbotten, Sweden, and died 15 January 1851 in Uppsala. By 1787 he was studying at Uppsala University where he was to later become Professor of Mathematics.

During the period 1799-1801 he led a team that re-observed the work of Maupertuis 60 years earlier at the north end of the Gulf of Bothnia. In doing so he extended the original scheme. He had a love of decimals (which is evident in the exaggerated accuracy he quoted in his observations) and complicated calculations.

Tenner

Carl F de Tenner, or in the Russian manner, Karl Ivanovitsch de Tenner was born 22 June 1783 near Narva and died 28 December 1859 in Warschau. He spent much of his working life on the arc measurement

He became a professional surveyor by, presumably self-education, as did Struve and Bessel. As a General of Infantry of the Russian Imperial General Staff, he participated in many war campaigns against Napoleon’s troops, where his courage was rewarded with a golden sword and other Orders. In 1816 he was appointed head of the vast Russian triangulation work in western provinces of the Empire where he spent much of his working life. It was he who started measurement of a meridian arc (in 1817 south of Livonia) just on his own initiative, without any funds. He was in charge for a portion of 11º 10′ between the Danube and the Duna (Dvina), or from 45º 20′ and 56º 30′ N, and which contained 5 baselines and 125 main triangles.

He became Struve's friend, and had contact with F Bessel and other prominent scientists. He was an Honorary member of the Russian Academy of Sciences.

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A Project such as that for the Struve arc requires co-operation from many people. A detailed list is appended although it must be appreciated that those responsible in the various countries is continuously changing. Thus apologies are extended to any whose names have been omitted.

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In particular this document has drawn considerably from the papers by Härmälä [**8**], Wennström [**21**] and Härsson et al. [**4**]. and extensive correspondence with Vitali Kaptjug.
Figures 1, 2 6 and 7 are taken from [**7**], figures 8 to 11 are from [**1**], and figure 13 is from [**6**]. Figures 3, 4, 14-16 and 19 are by J Smith, 17 by J Vanvolsem and Figure 12 and 18 by BV Kaptjug. Figure 5 is from the triangulation diagram in [5].

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