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The French Scientific Surveying Expedition to Peru

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Abstract: The paper describes how the lengths of parts of the meridian arc were measured in Peru (modern-day Ecuador). The field teams encountered great difficulties, due to the climate conditions in which they had to work, and the configuration of the terrain. However, they succeeded in measuring extremely accurately the length of the meridian arc corresponding to the range of latitude 3°07'01'', and were thus able to conclude that the length of one degree of the meridian arc in Peru was equivalent to 56 749 toises (110 604 m). They also established that the shape of the Earth took the approximate form of a rotational ellipsoid, thus confirming the theoretical postulations of Newton and Huygens.

Keywords: trigonometric chain, base length, astronomical measurement, latitudinal difference, sextant, quadrant, length of one degree of the meridian arc, Peru, rotational ellipsoid

1 Introduction

Isaac Newton (1642–1727) and Christiaan Huygens (1629–1695) both concluded theoretically that the Earth is not a sphere, but a rotational ellipsoid, as a result of its rotating about its own axis. When measuring the trigonometric chain along the Paris meridian from Dunkirk to Perpignan, the Cassinis thought they had discovered that the Earth bulged at the poles, but was flattened at the Equator. This directly contradicted Newton and Huygens, who maintained that the Earth was flattened at the poles. A scientific debate ensued. The solution could not be provided by taking measurements along the Paris meridian in France, since at a slight difference in latitude there was a slight difference in the length of one degree of the meridian arc. In fact, there had been many attempts to measure the angles, accompanied by inevitable errors due to the measurement uncertainties of angles and their functional relationships, while measuring different latitudes, which should have been determined with minimal uncertainty, in those days proved extremely difficult. The difference in the length of one degree of the meridian arc is most pronounced at the poles and the Equator, and according to Newton's calculation, may have been as much as 745 toises (1452 m), while the difference between adjacent degrees in France was only 13 toises (25 m). In order to resolve this scientific argument, the French king Louis XV, backed by the *Académie Royale des Sciences*, decided to send one expedition to a location close to the Equator, in what was then Peru (modern-day Ecuador), and another to a location close to the Arctic Circle in Lapland (on the border of modern-day Sweden and Finland).

2 The Scientific Surveying Expedition to Peru

To begin with, here are short biographies of the participants in the scientific surveying expedition to Peru (modern-day Ecuador).

Louis Godin (1704–1760) (Fig. 1) was a French philosopher and astronomer. At the age of 21, he was already a member of the *Académie Royale des Sciences*, and had published his first volume of memoirs. In 1733, he wrote an article discussing the shape of the Earth. He was given a

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Francuska geodetska znanstvena ekspedicija u Peru

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Sažetak: U radu je opisano izvođenje mjerenja duljina dijela meridijanskog luka u Peruu, današnjem Ekvadoru. Ekipe su na terenu imale velike poteškoće s klimatskim uvjetima rada i svladavanjem teških terenskih konfiguracija terena. Međutim, ipak su uspjeli vrlo točno izmjeriti duljinu luka meridijana, koja odgovara rasponu geografskih širina od 3°07'01'', te su zaključili da duljina luka jednog stupnja meridijana u Peruu iznosi 56 749 toisea (110 604 m). Tako je potvrđeno da Zemlja ima približno oblik rotacijskog elipsoida i da su teorijska predviđanja Newtona i Huygensa bila ispravna.

Ključne riječi: trigonometrijski lanac, duljina baze, astronomska mjerenja, razlika geografskih širina, sekstant, kvadrant, duljina jednog stupnja meridijanskog luka, Peru, rotacijski elipsoid

1. Uvod

Isaac Newton (1642–1727) i Christiaan Huygens (1629–1695) teorijski su došli do zaključka da Zemlja nema oblik kugle već da bi trebala imati oblik rotacijskog elipsoida zbog njezine rotacije oko vlastite osi. Cassiniji su mjerenjem u trigonometrijskom lancu uzduž Pariškog meridijana od Dunkerquea do Perpignana mislili da su došli do saznanja da je Zemlja ispupčena na polovima, a spljoštena na ekvatoru. Dakle, suprotno od Newtona i Huygensa, koji su tvrdili da je Zemlja spljoštena na polovima. Tako je nastao znanstveni spor. Mjerenja u Francuskoj na Pariškome meridijanu nisu to mogla riješiti jer je na maloj razlici geografskih širina mala razlika u duljinama jednog stupnja duljine luka meridijana. Naime, u mnogobrojnim mjerenjima kutova pojavljuju se neizbježne pogreške zbog mjernih nesigurnosti kutova i njihovih funkcionalnih povezanosti, a i mjerenje razlike geografskih širina trebalo je odrediti s vrlo malom mjernom nesigurnosti, što je u ono doba bilo vrlo teško. Razlika duljine jednog stupnja luka meridijana je najveća između pola i ekvatora i prema Newtonovu proračunu mogla bi iznositi 745 toisea (1452 m), a razlika između susjednih stupnjeva u Francuskoj je samo 13 toisea (25 m). Da bi se riješio znanstveni spor francuski kralj Luj XV. i Kraljevska akademija znanosti odlučili su poslati jednu ekspediciju blizu ekvatora u tadašnji Peru (današnji Ekvador), a drugu u blizinu polarnoga kruga u Laplad (danas na granici Švedske i Finske).

2. Geodetska znanstvena ekspedicija u Peru

Na početku dat će se kratki biografski podaci sudionika geodetske znanstvene ekspedicije u Peru, u današnjem Ekvadoru.

Louis Godin (1704–1760) (sl. 1) bio je francuski filozof i astronom. Već u 21. godini postao je član *L'Académie Royale des Sciences* (u daljem tekstu *Kraljevska akademija znanosti*) i izdao je početne sveske memoara. Godine 1733. napisao je raspravu o Zemljinu obliku. U ekspediciji u Peruu (Ekvadoru) bio je pretpostavljeni, ali s najmanje znanstvenog iskustva, te se otuđio od Pierrea Bouguera i La Condaminea. Na njegov prijedlog njegov

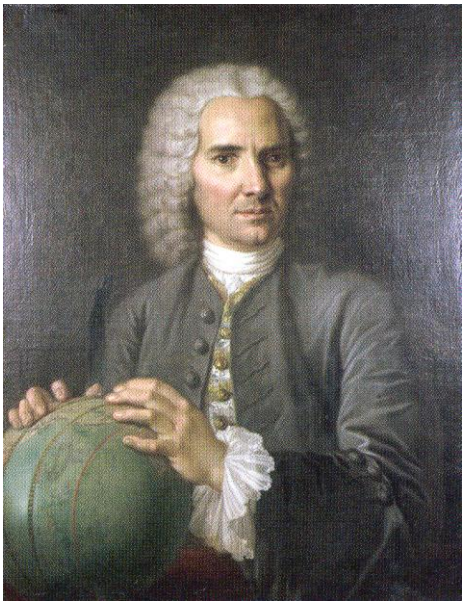

Figure 1 Louis Godin (1704–1760) (URL 1)
Slika 1. Louis Godin (1704–1760) (URL1)

Figure 2 Pierre Bouguer (1698–1758 (URL 4)
Slika 2. Pierre Bouguer (1698–1758) (URL 4)

preferential position in the expedition, although he had the least scientific experience, and so distanced himself from Pierre Bouguer and Charles Marie de La Condamine. At his proposal, his nephew *Jean Godin* was also included as a member of the expedition (URL 1).

Pierre Bouguer (1698–1758) (Fig. 2) was a French mathematician, geophysicist, surveyor and astronomer. In 1727 he received an award from the *Académie Royale des Sciences* for three works which were published in the *Prix de L'Académie Royale des Sciences*. He was also interested in measuring light and constructed a photometer. In 1735 he joined La Condamine on the surveying expedition to Peru to measure the length of one degree of the latitude near the Equator (URL 4 and 5).

Charles Marie de La Condamine (1701–1774) (Fig. 3) originally intended to follow a military career, but realised that he was unsuited to it. He contacted scientists in Paris and became a member of the *Académie Royale des Sciences* in 1730. He did not particularly relish a quiet life in Paris, so sailed to Algiers, Alexandria, Palestine, Cyprus and Constantinople (modern-day Istanbul), where he spent five months. On returning to Paris, he published the mathematical and physical observations from his journey. The members of the Academy were impressed, and sent him on the expedition to Peru, led by Louis Godin. Godin carried out his own work, while La Condamine collaborated with Bouguer (URL 2 and 3).

Jorge Juan y Santacilia (1713–1773) (Fig. 4) was born into an aristocratic Spanish family. He enrolled in the military academy in 1730, where he studied modern technology and scientific subjects such as geometry, trigonometry, astronomy, navigation, hydrography and cartography. His fellow students nicknamed him 'Euclid'. He graduated in 1734 and was assigned command of a corvette. He was selected for the expedition to Peru on the basis of his interest in science (URL 7).

Antonio de Ulloa y de la Torre Giral (1716-1795) (Fig. 5) became a Spanish sailor at the age of 14. Quite separately from his activities on the expedition, he discovered platinum, extracting it from gold and silver, a feat which was also attributed to La Condamine. On their return from Spain, Juan and Ulloa wrote reports on their travels in Peru (URL 8). The ring of light which appears around the Sun and Moon through mist is named after him (Ulloa's halo), though it is called by some Bouguer's halo (Murdin 2010, p. 67).

2.1 Travelling to Peru

The team selected for the scientific surveying expedition to Peru consisted of three Frenchmen, Lous Godin (31), Pierre Bouguer (37) and Charles Marie de La Condamine (34), seven assistants, and two Spaniards, Jorge Juan y Santacilia (23) and Antonio de Ulloa (21) (Vykutil 1972). The leadership of the expedition was entrusted to its youngest member, Godin, as he was the longest-standing member of the *Académie Royale des Sciences*. The French contingent left Paris in April 1735, and in May that year set sail from La Rochelle. They reached Cartagena (Columbia) in November 1735, where they

Figure 3 Charles Marie de La Condamine (1701–1774) (URL 2)
Slika 3. Charles Marie de La Condamine (1701–1774) (URL 2)

Figure 4 Jorge Juan y Santacilia (1713–1773) (URL 7)
Slika 4. Jorge Juan y Santacilia (1713–1773) (URL 7)

Figure 5 Antonio de Ulloa (1716–1795) (URL 8)
Slika 5. Antonio de Ulloa (1716–1795) (URL 8)

nećak *Jean Godin* bio je također primljen za člana ekspedicije (URL 1).

Pierre Bouguer (1698–1758) (sl. 2) bio je francuski matematičar, geofizičar, geodet i astronom. Godine 1727. primio je nagrade od Kraljevske akademije znanosti za tri rada koja su objavljena u *Prix de L'Académie Royale des Sciences*. Osim toga zanimao se za mjerenje svjetlosti te je konstruirao fotometar. Godine 1735. pridružio se La Condamineu u geodetskoj ekspediciji u Peru na mjerenju duljine jednoga stupnja geografske širine u blizini ekvatora (URL 4 i 5).

Charles Marie de La Condamine (1701–1774) (sl. 3) želio se na početku posvetiti vojnom pozivu, ali je uvidio da mu taj poziv ne odgovara. Uspostavio je veze sa znanstvenicima u Parizu i postao je član Kraljevske akademije znanosti 1730. godine. Miran život u Parizu također mu nije odgovarao, te je plovio u Alžir, Aleksandriju, Palestinu, Cipar i Konstantinopol (današnji Carigrad), gdje je proveo pet mjeseci. Po povratku u Pariz objavio je matematička i fizikalna opažanja s putovanja. Članovi Akademije bili su njime impresionirani pa su ga poslali na ekspediciju u tadašnji Peru na mjerenje duljine jednoga stupnja meridijana u blizini ekvatora koju je vodio Louis Godin. Godin je radio posebno, dok je La Condamine radio s Bouguerom (URL 2 i 3).

Jorge Juan y Santacilia (1713–1773) (sl. 4) rođen je u španjolskoj plemićkoj obitelji. U vojnu akademiju ušao je 1730. godine i studirao tada moderne tehnike i znanstvene predmete: geometriju, trigonometriju, astronomiju, navigaciju, hidrografiju i kartografiju. Njegove kolege studenti nazivali su ga Euklid. Studije je završio 1734. godine i dana mu je komanda na brodu – korveti. Za člana ekspedicije u Peru izabran je na osnovi njegova interesa za znanost (URL 7).

Antonio de Ulloa y de la Torre Giral (1716–1795) (sl. 5) postao je španjolski pomorac već u 14. godini. Neovisno o aktivnostima ekspedicije pronašao je plemeniti metal platinu odvajajući ga iz zlata i srebra, što se pripisuje i La Condamineu. Nakon povratka u Španjolsku Juan i Ulloa su pripremili svoja izvješća s putovanja u Peru (URL 8). Po njegovu imenu prsten svjetlosti oko Sunca i Mjeseca koji se pojavi u magli nazvan je Ulloaov halo, no neki ga nazivaju i Bouguerov halo (Murdin 2010, str. 67).

2.1. Putovanje u Peru

U ekipu za geodetsku znanstvenu ekspediciju u Peru bila su izabrana tri Francuza – Louis Godin (31 godina), Pierre Bouguer (37 godina) i Charles Marie de La Condamine (34 godine), sedam pomoćnika te dva Španjolca: Jorge Juan y Santacilia (23 godine) i Antonio de Ulloa (21 godina) (Vykutil 1972). Vođenje ekspedicije bilo je povjereno najmlađem Godinu, jer je bio najdulje član Kraljevske akademije znanosti. Francuski dio ekspedicije krenuo je na put iz Pariza u travnju 1735. godine i u svibnju su otplovili iz La Rochelle. U Carthagenu (Kolumbija) stigli su u studenome 1735., kad su im se pridružili Jorge Juan i Antonio de Ulloa. Naime, tadašnji Peru, u čijem je sastavu bio i današnji Ekvador, bio je pod vladavinom Španjolaca. Tako je na traženje francuskoga kralja Luja XV. španjolski kralj Filip V. dopustio Francuzima da provedu geodetsku ekspediciju u Peruu u blizini ekvatora, ali uz pratnju dvaju španjolskih pomoraca.

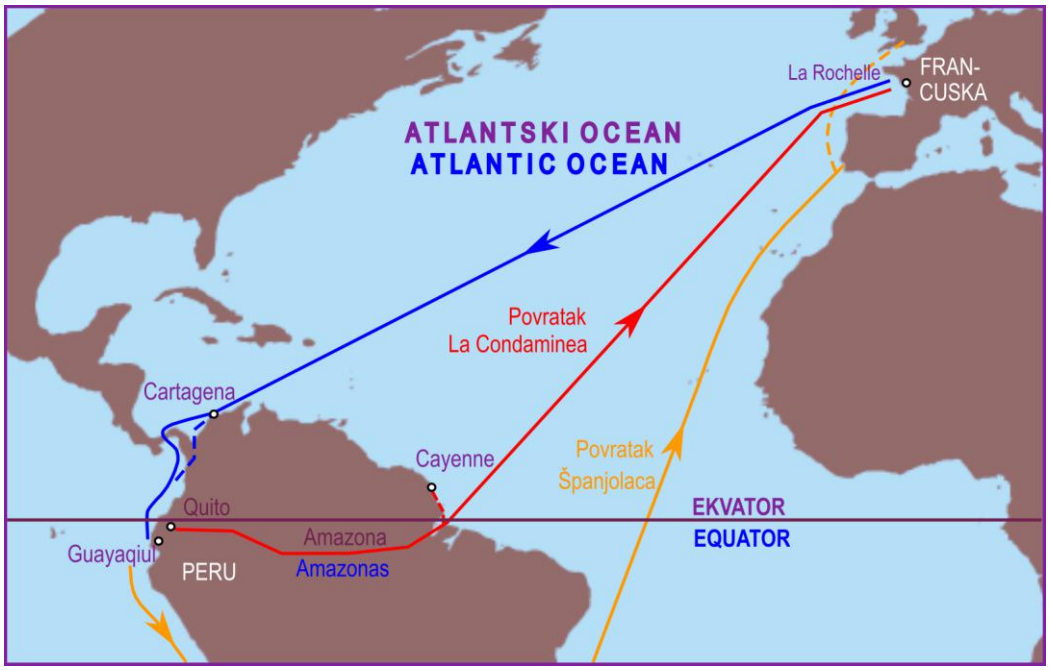

Figure 6 Route of the expedition from La Rochelle to Peru, La Condamine's return journey to France, and the Spaniards' return journey to Spain.

Slika 6. Put ekspedicije iz La Rochelle u Peru i put povratka La Condaminea u Francusku i Španjolaca u Španjolsku.

were joined by Juan and Ulloa. At that time, Peru (including what is Ecuador today) was under Spanish rule. So the Spanish king Philip V, at the request of the French king Louis XV, had granted the French permission to carry out a surveying expedition in Peru, near the Equator, escorted by the two Spanish mariners.

The expedition could have taken one of two routes from Cartagena to Quito. One would have led them up river and over the mountains to the Pacific Ocean, and the other by sea to the Isthmus of Panama and thence to the Pacific. They chose the second route as safer for transporting instruments and other surveying equipment (Fig. 6). The crossing involved travelling by boat and on foot. They then sailed along the coast of South America to Guayaquil Bay, arriving on 25 March 1736 (Fig. 7) (Smith 2002 and Murdin 2009, p. 68). So the journey itself took almost a year. During their travels in Peru, they made many observations on magnetic variations, latitudes and longitudes. These proved extremely important to seafarers using magnetic compasses to navigate at sea.

2.2 The arrival in Peru and division into groups

Even before they left Paris, there had been disagreements, particularly between Bouguer and Godin. It seems Bouguer thought Godin was incompetent and the least qualified scientist on the expedition, though he had been appointed its leader. La Condamine was the youngest member of the *Académie Royale des Sciences*, but he possessed a certain degree of initiative and had actually contributed most to the organisation of the expedition.

When they arrived in Peru, the scientists divided into two groups, the first being Godin and Juan, and the second La Condamine, Bouguer and Ulloa. Bouguer and La Condamine were completely different characters. Bouguer was only interested in the scientific aspects and was quite happy performing mathematical calculations, while La Condamine was a practical person. Godin gradually distanced himself from Bouguer and La Condamine and took up with the Spaniards, so that later, it was the Spaniards who maintained communications between the two groups and ensured the joint work of the expedition continued (Murdin 2009, p. 69). Before they set off into the interior and the Andes, they explored the coast region and mapped it with a topographic table.

From the coast, Bouguer and La Condamine proceeded separately towards Quito, as did Juan and the others. All the routes were extremely risky, with dangerous rapids, terrifying precipices, deep paths through swamps, and almost impassable tropical forests. However, even in these difficult conditions, they did not cease their scientific activities (Smith 2002).

U Carthageni ekspedicija je imala dvije mogućnosti za nastavak putovanja u Quito. Jedna mogućnost bila je putovati rijekom i zatim preko planina do Tihog oceana, a druga mogućnost bila je nastaviti ploviti morem i prijeći Panamskom prevlakom na Tihi ocean. Tu drugu rutu izabrali su zbog sigurnosti prenošenja instrumenata i ostaloga geodetskog pribora (sl. 6). Pritom su se morali koristiti čamcima i pješačiti. Ploveći uz obalu Južne Amerike stigli su do zaljeva Guayaquila 25. ožujka 1736. (sl. 7) (Smith 2002 i Murdin 2009, str. 68). Dakle, samo na putovanje potrošili su gotovo godinu dana. Tijekom putovanja u Peru izveli su mnogobrojna opažanja magnetskih varijacija, geografskih širina i geografskih dužina. Ti podaci bili su vrlo važni pomorcima pri korištenju magnetskih kompasa u navigaciji na moru.

2.2. Dolazak u Peru i podjela u grupe

Već prije polaska iz Pariza dolazilo je do nesporazuma, posebice između Bouguera i Godina. Naime, Bouguer je mislio da Godin nije kompetentna osoba i da je najslabiji znanstvenik u ekspediciji, a postavljen je za vođu ekspedicije. La Condamine je bio najmlađi član Kraljevske akademije znanosti, ali je imao određenu inicijativu te je ipak najviše pridonio organizaciji ekspedicije.

Kad su stigli u Peru znanstvenici su se podijelili u dvije grupe: 1) Godin s Juanom i 2) La Condamine s Bouguerom i Ulloaom. Bouguer i La Condamine bili su potpuno različite osobnosti. Bouguer, zainteresiran samo za znanstveni dio, bio je vrlo sretan pri izvođenju matematičkih proračuna, dok je La Condamine bio praktičan čovjek. Godin se postupno odvajao od Bouguera i La Condaminea i približio Španjolcima, tako da su poslije Španjolci omogućili komunikaciju između grupa i na taj način osigurali zajednički rad ekspedicije (Murdin 2009, str. 69). Prije kretanja u unutrašnjost u Ande istraživali su obalno područje i kartirali ga topografskim stolom.

Od obale Bouguer i La Condamine išli su odvojeno prema Quitu, kao i Juan i drugi. Sve rute bile su ekstremno riskantne s opasnim brzacima, zastrašujućim ponorima, dubokim cestama u močvarama i gotovo neprohodnim tropskim šumama. Međutim, ni u tako teškim uvjetima nije se prestalo sa znanstvenim aktivnostima (Smith 2002).

Tako je La Condamine ponovno otkrio gumu i mogućnost njezine uporabe. Na tom istom putovanju pronašao je plemeniti metal platinu, danas skuplju od zlata, koja se dobiva separacijom iz zlata i srebra. Bouguer je penjući se s morske obale prema Quitu otkrio promjenu tlaka zraka te iz tih mjerenja izveo logaritamsku ovisnost između tlaka i visine.

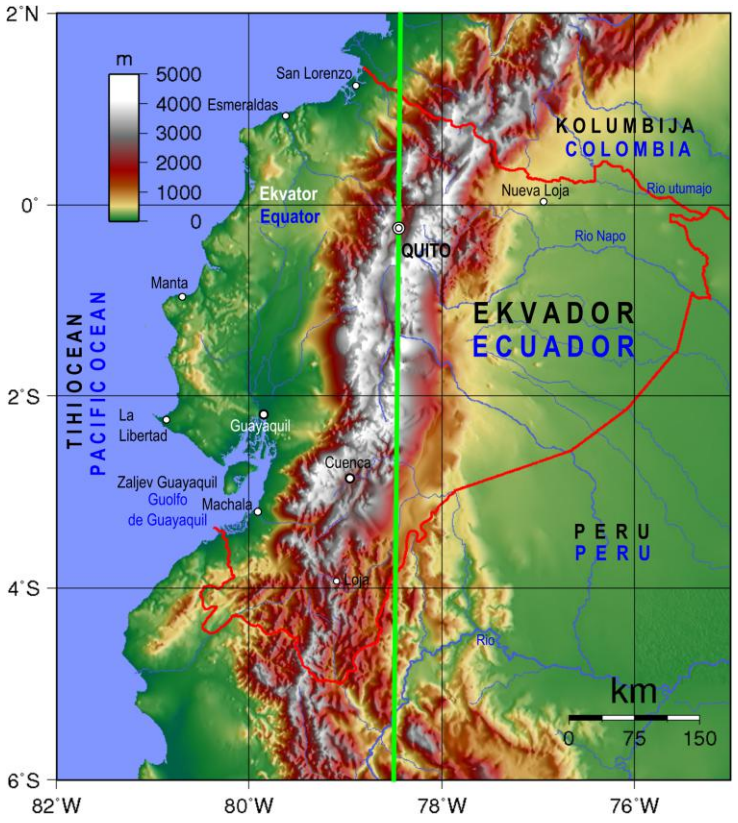

Figure 7 Satellite image of modern-day Ecuador and the Andes, which used to belong to Peru (URL 6).

Slika 7. Satelitska snimka današnjeg Ekvadora i Anda, čiji je teritorij nekada pripadao Peruu (URL 6).

Grupe su se ponovno sastale 10. lipnja 1736. u Quitu.

2.3. Trigonometrijski lanac

Znanstvenici su postavili trigonometrijski lanac od 30 trokuta u visokim Andama (sl. 8), tako da je najniža trigonometrijska točka bila na nadmorskoj visini 2390 m (1226 Peruanskih toisea[1]), a najviša na visini

[1] Toise je stara jedinica za mjerenje duljine. Imala je svoj etalon željeznu motku učvršćenu na zidu palače Châtelet, gdje su trgovci bili dužni usporediti svoje mjere. To je bila udaljenost između dvije igle na motki koja je iznosila 1,949 m 1799. godine. Prema Delambreu, vjerojatno je da je toise bio nešto kraći u razdoblju od 1670. do 1792., jer je zbog stalne usporedbe mjera trgovaca došlo do njegova oštećenja (URL 11). Etalon "toise du Châtelet" uništen je 1802. godine (URL 9). Toise je imao šest francuskih stopa (pieds) (pied = 0,3248 m), jedna stopa imala je 12 palaca (pouces), a jedan palac imao je 12 linija (lignes). Claude Langlois, kraljev inženjer za astronomske instrumente, izradio je 1735. dva standardna toisea na temelju Châtelet toise. Jedan su ponijeli na ekspediciju u Peru, a drugi na ekspediciju u Lapland. Peruanski toise poslije je korišten i u mjerenju duljina baza trigonometrijskog lanca Pariškog meridijana kad su izmjeru izvodili Delambre i Méchain (URL 10). Poslije je toise du Pérou nazvan *toise de l'Académie*.

La Condamine, for example, rediscovered rubber again its potential uses. On the same journey, he discovered platinum, today more valuable than gold, by extracting it from gold and silver. Bouguer climbed up from the shore towards Quito, discovering the change in air pressure, and from his measurements was able to formulate the logarithmic dependence of pressure and height.

The two groups were reunited on 10 June 1736 in Quito.

2.3 Trigonometric chain

The scientists set up a trigonometric chain consisting of 30 triangles in the upper Andes (Fig. 8), of which the lowest trigonometric point was 2390 m above sea level (1226 Peruvian toises[1]) and the highest 4555 m (2337 toises). (For the sake of comparison, the highest peak in Europe, Mont Blanc, is 4810 m, and Sljeme, the peak of Mt. Medvenica in Croatia is half that – to be exact, 1350 m lower than the expedition's lowest trigonometric point). Even in the equatorial, tropical region, some peaks had snow cover, and there were also volcanoes. The Chimborazo volcano (6272 m – Fig. 11) is found in this part of Ecuador. The weather conditions in the mountains were particularly difficult. The peaks were often shrouded in mist (cloud), so it was impossible to look from one trigonometric point to another. The scientists often spent the night in freezing huts and their local assistants had to free them from the outside in the morning. There were extremely strong, cold winds and the locals who were helping the scientists begged them to return to lower areas. The paths wound between steep mountain precipices, which the pack mules carrying the heavy instruments found it hard to pass. In some circumstances, it took a month to get an hour's worth of observations. Some trigonometric points were on peaks higher than any surveyor had ever measured before. On the peak of Rucu Pichincha (4.7 km), they were amazed to see the barometer showing lower than normal air pressure (300 mm of mercury instead of 760 mm). Of course, in these conditions they began to suffer from altitude sickness. Food was scarce, and the local Indian helpers proved unreliable (Murdin 2009, p. 69 and Smith 2002). It rained heavily, there were innumerable dangerous insects, snakes and scorpions, and some of the porters died.

In 1738, the members of the expedition in Peru received a letter telling them that the expedition led by Maupertuis to Lapland had measured the length of one degree of the meridian arc. This meant that Newton and Huygens' theory about the Earth's shape had been verified. So they began to wonder about the further purpose of their expedition in Peru. This had a demoralising effect, and the expedition members became disillusioned, particularly when they received another letter from Alexis Clairaut (another member of the Lapland expedition), who explained that their measurements in Peru "were of vital importance in conforming Maupertuis's theory". So La Condamine wanted to extend the aim of the expedition to Peru to research into other natural phenomena in that hitherto unexplored part of the world (Murdin 2009, p.72).

The expedition had difficulties overcoming the mountainous configuration of the terrain, in communications with far-off France, and also diplomatic problems due to poor financial support. However, as they travelled, the scientists collected and made notes on natural phenomena. They observed the optical phenomenon of light acting on fog and mist to produce a ring of light around the Sun or Moon, known as Ulloa's halo or Bouguer's halo. Bouguer observed the periods of the pendulum in the mountains and confirmed for the first time the influence of the density of local rock on gravity, thus introducing Bouger's anomaly into the disciple of gravimetry.

Life during the expedition was not always uncomfortable. In their free time, they taught Peruvian girls the latest dances from Europe. La Condamine received instructions from the *Académie Royale des Sciences* to erect a monument in honour of the expedition's work, and built two pyramids near Quito, at the beginning and end of the Yaruqui base, as a lasting memorial. The monuments had a ground-plan measuring 4 m² and were 5 m tall, inscribed with a text brought by La Condamine from France. This caused problems with the Spaniards, who felt their role and contribution had been overlooked. It was not long before the Spanish authorities ordered the pyramids to be removed. They were erected again in 1835, in another location (Smith 2002).

[1] A toise is an old unit for measuring length. The standard toise was an iron bar on the wall of the Grand Châtelet in Paris, where merchants were obliged to compare their own measurements. It was defined as the distance between two needles on the bar, and measured 1.949 m in 1799. According to Delambre, the toise was probably a little shorter between 1670 and 1792, because the standard on the wall was damaged through constant use (URL 11). The 'toise du Châtelet' standard was abolished in 1802 (URL 9). The toise consisted of six French feet (*pied* – 0.3248 m), and one foot consisted of 12 inches (*pouce*), while each inch had 12 lines (*lignes*). Claude Langlois, the Royal Engineer for astronomic instruments, produced two standard toises in 1735 based on the *toise du Châtelet*. One was taken on the expedition to Peru and the other on the expedition to Lapland. The Peruvian toise was later used to measure the length of the bases of the trigonometric chain of the Paris meridian, measured by Delambre and Méchain (URL 10). Later, this toise was named the *toise de l'Académie*.

4555 m (2337 toisea). (Za usporedbu, najviši vrh u Europi Mt. Blanc visok je 4810 m, a vrh Medvednice Sljeme je dvostruko niži, točnije niži čak 1350 m od njihove najniže trigonometrijske točke.) Neki vrhovi, iako u području ekvatora, tropskog pojasa, bili su pokriveni snijegom, a bilo je i vulkana. U tom području Ekvadora nalazi se i vulkan Chimborazo, visok 6272 m (sl. 11). Vremenske prilike u planinama bile su posebno teške. Vrhovi su bili često zavijeni u magli (oblaku), tako da s jedne trigonometrijske točke nije bilo moguće vidjeti druge. Znanstvenici su često bili preko noći u zamrznutim kolibama te su ih pomoćni radnici morali izvana oslobađati. Puhali su snažni i ekstremno hladni vjetrovi pa su ih domaći pomoćni radnici molili da se vrate u niže predjele. Staze su prolazile između strmih planinskih padina, gdje je i mulama, koje su prenosile teške instrumente, bilo teško naći prolaz. U nekim prigodama moralo se potrošiti mjesec dana za samo sat opažanja. Neke trigonometrijske točke bile su na vrhovima na visini gdje do tada još ni jedan geodet nije mjerio. Na vrhu Rucu Pichincha, visokom 4,7 km, začudili su se kad su vidjeli da je barometar pokazivao tlak zraka niži od normalnog tlaka 760 mm za čak 300 mm stupca žive. U tim vremenskim uvjetima pobolijevali su i od visinske bolesti. Hrana je bila oskudna, a lokalni indijanski pomoćni radnici nepouzdani (Murdin 2009, str. 69 i Smith 2002). Bilo je jakih kiša, mnogobrojnih opasnih insekata, zmija, škorpiona, a neki su radnici i poginuli.

Članovi ekspedicije u Peruu primili su 1738. godine pismo iz kojega su saznali da je ekspedicija na čelu s Maupertuisom izmjerila duljinu jednog stupnja meridijanskog luka u Laplandu te da je potvrđena Newtonova i Huygensova teorija o Zemljinu obliku. Zato su se pitali što je sada cilj njihove ekspedicije u Peruu. To je na njih djelovalo obeshrabljujuće, te su bili razočarani i sadržajem sljedećeg pisma primljenog od Alexisa Clairauta (člana ekspedicije u Lapland), u kojem ih je ohrabrivao i tvrdio "da njihova mjerenja u Peruu imaju vitalan značaj da potvrde Maupertuisovo mjerenje". Zato je La Condamine želio proširiti cilj ekspedicije u Peruu na istraživanje drugih prirodnih fenomena u tom, do tada, neistraženom dijelu Zemlje (Murdin 2009, str. 72).

Ekspedicija nije imala samo poteškoće u svladavanju planinske konfiguracije terena već i u komunikaciji s udaljenom Francuskom, ali i diplomatske poteškoće te slabiju financijsku potporu. Znanstvenici su usput skupljali i bilježili podatke o prirodnim fenomenima. Tako su zabilježili optički fenomen u magli i sumaglici kao prsten svjetla oko Sunca i Mjeseca koji je nazvan Ulloa halo ili Bouguerov halo. Bouguer je opažao periode njihala u planinama i prvi puta utvrdio utjecaj gustoće lokalnog stijenja na gravitaciju. Tako je u gravimetriji uveden pojam *Bouguerova anomalija*.

Život članova ekspedicije nije bio samo neugodan. U slobodno vrijeme podučavali su peruanske djevojke novim plesovima iz Europe. La Condamine je primio upute od Kraljevske akademije znanosti da se podigne spomenik u čast rada ekspedicije, te je u blizini Quita izgradio dvije piramide na početku i kraju baze Yarouqui, kao trajne spomenike. Ti su spomenici imali tlocrte u površini od 4 m2 i bili su visoki 5 m, a na njima je bio zapisan tekst koji je La Condamine donio iz Francuske. To je izazvalo probleme jer se zanemarivala uloga i doprinos Španjolaca. Stoga su piramide uskoro po nalogu španjolskih vlasti srušene. Ponovno su podignute 1836. godine, ali na drugim mjestima (Smith 2002).

2.4. Instrumenti za mjerenje kutova u trigonometrijskom lancu

Kutove u trigonometrijskom lancu mjerili su s pomoću kvadranata dimenzija radijusa od 0,53 m do 0,91 m smještenih na teškim željeznim stalcima. Podjela

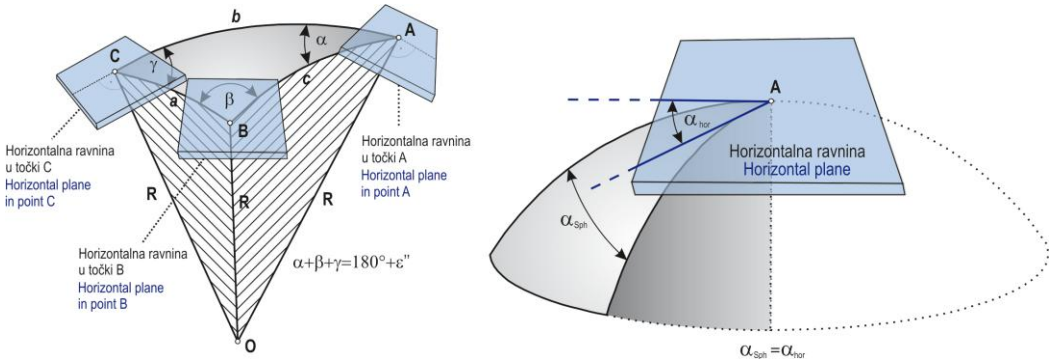

Figure 9 The sum of angles in a triangle on a sphere is greater than 180°, giving the spherical excess ε''.
Slika 9. Zbroj kutova u trokutu na sferi veći je od 180° za sferni eksces ε''.

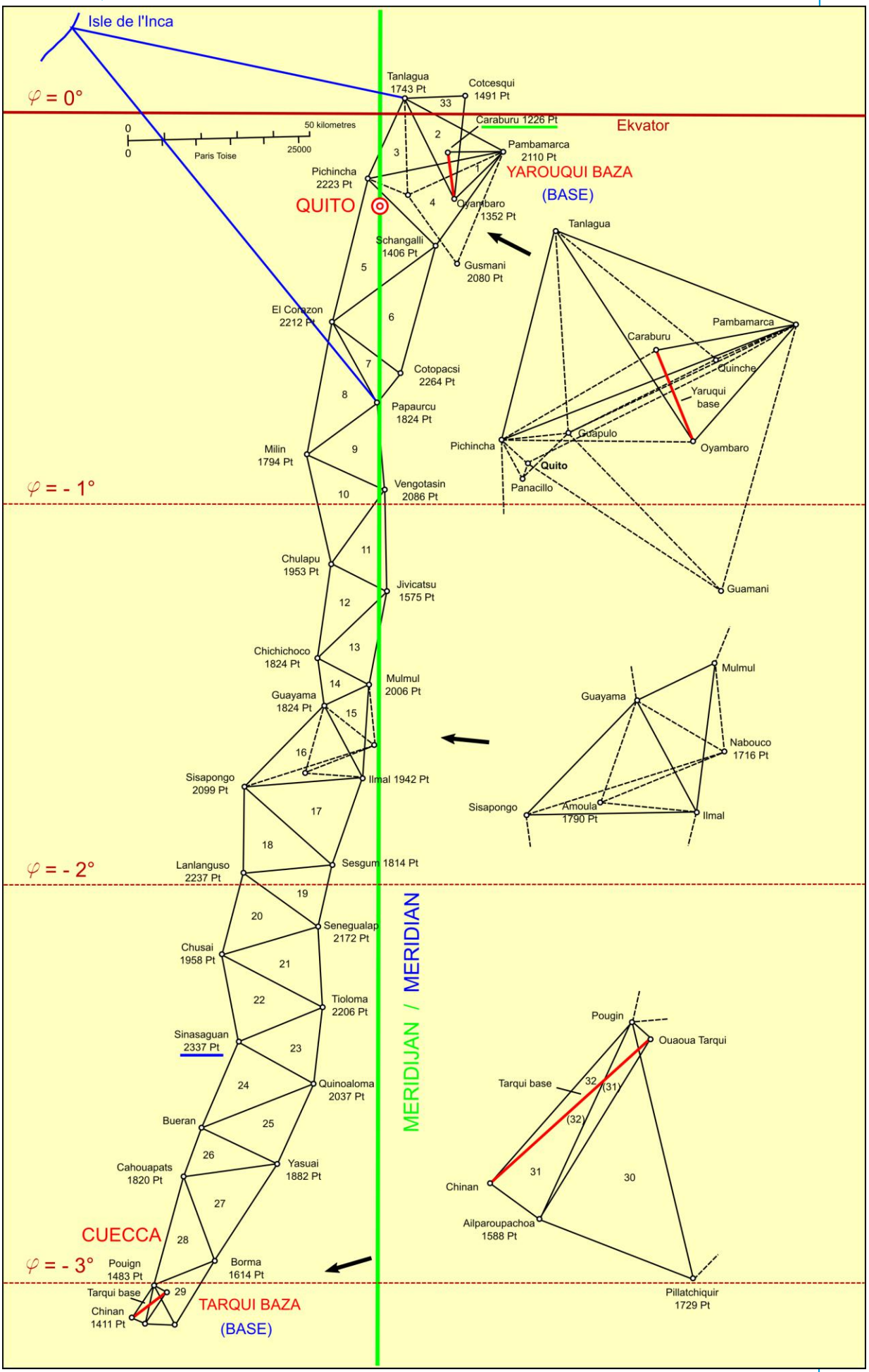

Figure 8 The trigonometric network for measuring the length of the meridian arc in Peru, 1735–1745, according to Bouguer and La Condamine (Smith 2002) (Pt – Peruvian toise). Two blue lines show the connection of heights to the level of the ocean.

Slika 8. Grafički prikaz trigonometrijske mreže na mjerenju duljine luka meridijana u Peruu od 1735. do 1745. prema Bougueru i La Condamineu (Smith 2002) (Pt – Peruanski toise). Dvije plave linije pokazuju povezivanje visina s razinom oceana.

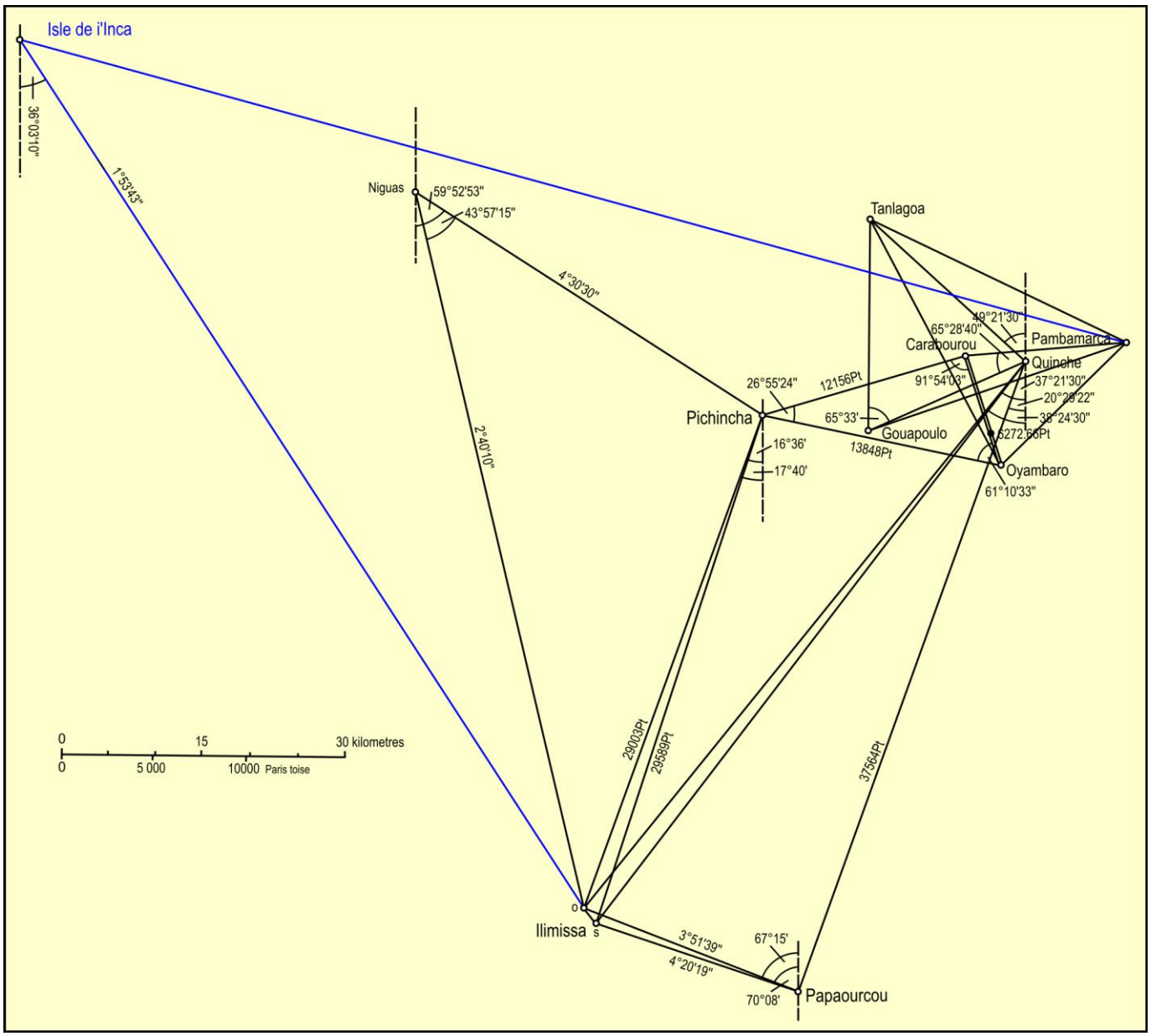

Figure 10 Relating the altitudes of trigonometric points to ocean level (Smith 2002).
Slika10. Povezivanje visina trigonometrijskih točaka na razinu oceana (Smith 2002).

na luku kvadranta bila je pažljivo nanesena, a La Condamine je izmislio interesantnu metodu za njezinu provjeru s točnošću od nekoliko kutnih sekundi.

Kvadrantom su bili izmjereni kutovi u nagnutoj ravnini, pa su ih morali zatim računskim putem reducirati na horizont. Za veće trokute oni su *prvi put u povijesti geodezije računali sferni eksces ε''*, tj. odstupanje zbroja kutova u sfernom trokutu od 180°. Naime, u sfernom trokutu uvijek je zbroj kutova veći od zbroja kutova u ravnini (sl. 9).

U trigonometrijskoj mreži u Peruu sferni eksces iznosio je samo nekoliko kutnih sekundi. Kutove u lancu trokuta mjerile su tri različite neovisne grupe u tri serije i pritom opažali sve kutove u trokutima (Bialas 2002, str. 135).

2.5. Astronomska mjerenja

Za astronomska opažanja koristili su se zenitnim sektorima radijusa 3,7 m. Njihovi limbovi bili su ograničeni svojom podjelom samo na nekoliko stupnjeva. Na sektorima su se nalazili mikrometri gdje su tri podjele iznosile oko 1'' (kutne sekunde). Za verifikaciju podjele sektora i mikrometra bio je sličan postupak kao za kvadrant (Smith 2002). Međutim, imali su poteškoće s tim instrumentom velikih dimenzija već u

2.4 Instruments for measuring angles in the trigonometric chain

The angles in the trigonometric chain were measured using a quadrant with a radius of 0.53 – 0.91 m, set on heavy iron stands. The division into the arcs of the quadrant was carefully marked, then La Condamine invented an interesting method for testing its accuracy to within a few seconds.

The quadrant was used to measure angles on a sloping plane, which then had to be reduced to the horizon through calculation. *For the first time in surveying history, the spherical excess ε" was calculated*, i.e. the difference of the sum of angles in a spherical triangle from 180°. In a spherical triangle, the sum of angles is always greater than the sum of angles in a plane triangle (Fig. 9).

In the trigonometric network in Peru, the spherical excess amounted to only a few seconds. The angles in the chain of triangles were measured by three different, independent groups in three series, according to which all the angles in the triangles were observed (Bialas 2002, p. 135).

2.5 Astronomical measurements

For the astronomical observations, zenith sectors with a radius of 3.7 m were used. Their limbs were restricted by division into a small number of degrees. On the sectors there were micrometers where the three divisions amounted to about 1". The procedure for verifying the sector division and micrometers was similar to that used for the quadrant (Smith 2002). However, there had already been problems using instruments of such enormous dimensions in Cocha-squi (near Quito), while in Cuenca Godin and Juan had to construct their own instruments from parts to hand. It would have taken more than six months to send the instruments back to Europe for repairs, so they decided to do what they could with the materials they had at their disposal (Murdin 2009, p. 72). In order to determine the difference in latitude between the first and last trigonometric points, they measured the elevation angles for the star ε from the Orion constellation (Bialas 2002, p. 135).

In addition, they determined the position of the meridian which passed through Quito using the astronomical method (Bialas 1982, p. 134).

2.6 Relating altitudes to ocean level

In order to relate lengths to ocean level, Bouguer had to measure the difference in altitude from ocean level, i.e. from Isla de l'Inca on the Pacific coast to the peak of Taniàgos (1743 toises, 3399 m), and then apply it to the other points using trigonometric levelling (Fig. 10). In fact, by measuring the vertical angles from observation points at neighbouring trigonometric points, and determining the distance between those two points from the trigonometric network, it was possible to determine the altitude of all points in the entire trigonometric chain along this section of the meridian. However, it was particularly difficult to determine the altitude difference between the ocean and the mountains, since the peaks were almost constantly shrouded in mist (Smith 2002). This is obvious even today from Google satellite images (Fig. 11).

2.7 Measuring the length of the base of the trigonometric chain

The expedition set the base for the trigonometric chain in Yaruqui, near Quito, 6274 toises long (12 228 m), between two marked points. The measurement of the base length was performed using three wooden rods sheathed in copper, each 3 toises long (5.847 m), so that the ends touched. The group which included Bouguer, La Condamine and Ulloa measured the base in one direction, while the group which included Godin and Juan measured it in the opposite direction. The difference amounted to only 8 cm (Murdin 2009, p. 69). The lengths of the wooden rods were constantly compared with the "Peruvian Toise", made in iron by Claude Langlois in Paris (Bialas 2002, p. 135).

Having established the trigonometric points and measured the angles in the triangles of trigonometric chain which extended 345 km southwards, a control base length was set up in Tarqui (5259 toises, 10 250 m). Bouguer and Ulloa measured in one direction, while La Condamine and Verguin, the expedition's draughtsman, measured in the opposite direction. At the same time, Godin and Juan measured a control base length nearby (Bialas 2002, p. 135). The Tarqui base length passed through a shallow marsh, so the length was measured using measuring rods at the surface level of the water. The scientists were extremely satisfied when they discovered that the difference in their calculations between the direct measurements taken at the Tarqui base, the distances along the entire trigonometric chain, and the lengths of the Yaruqui base, amounted to only 0.2 toise (39 cm) and 1.1 toise (214 cm).

2.8 Results of the survey

The interval between the first and last points in the trigonometric chain where astronomical measurements

Conchesqui (blizu Quita), a u Cuencai su si Godin i Juan morali sami izraditi instrument od priručnih dijelova. Naime, za popravak instrumenta već bi na samo putovanje iz Južne Amerike u Europu potrošili pola godine i više, pa su se odlučili na priručne mogućnosti (Murdin 2009, str. 72). Kako bi odredili razliku geografskih širina između početne i krajnje trigonometrijske točke mjerili su elevacijske kutove na zvijezdu ε iz zviježđa Orion (Bialas 2002, str. 135).

Osim toga su astronomskim načinom odredili položaj meridijana koji je prolazio kroz Quito (Bialas 1982, str. 134).

2.6. Povezivanje visina s razinom oceana

Kako bi dužine bile svedene na razinu oceana, Bouguer je izmjerio visinsku razliku od razine oceana, tj. od Isle de l'Inca na obali Tihog oceana do vrha Taniàgos visokog 1743 toisea (3399 m) i zatim do ostalih točaka s pomoću trigonometrijskog nivelmana (sl. 10). Naime, mjerenjem vertikalnih kutova iz opažačke točke na susjedne trigonometrijske točke i određivanjem udaljenosti između tih dviju točaka iz trigonometrijske mreže mogle su se odrediti visine svih točaka u čitavom trigonometrijskom lancu na tom dijelu meridijana. Pritom je bilo posebno teško odrediti visinsku razliku između oceana i planina, jer su vrhovi bili praktično stalno u magli (Smith 2002). To se vidi i danas na Googleovoj satelitskoj snimci (sl. 11).

2.7. Izmjera duljina baza trigonometrijskog lanca

Ekspedicija je u Yarouqui, u blizini Quita, postavila bazu za trigonometrijski lanac dugu 6274 toisea (12 228 m) između dviju označenih točaka. Mjerena je duljina baze s tri drvena štapa izrađena od drveta okovana bakrom, duga 3 toisea (5,847 m), tako da su se krajevi mogli točno dodirivati. Grupa u kojoj su bili Bouguer, La Condamine i Ulloa mjerila je bazu u jednom smjeru, a grupa u kojoj su bili Godin i Juan mjerila je u suprotnom smjeru. Razlika je bila samo 8 cm (Murdin 2009, str. 69). Prema (Bialas 2002, str. 135) duljine drvenih letvi bile su stalno uspoređivane s duljinom "Toise du Pérou", što ga je u Parizu izradio Claude Langlois od željeza.

Nakon postavljanja trigonometrijskih točaka i izmjere kutova u trokutima trigonometrijskog lanca dugog oko 345 km na jugu su postavili kontrolnu bazu Tarqui dugu 5259 toisea (10 250 m). U jednom smjeru mjerili su Bouguer i Ulloa, a u drugome La Condamine i crtač ekspedicije Verguin, dok su Godin i Juan u blizini mjerili neku kontrolnu bazu (Bialas 2002, str. 135). Baza Tarqui prolazila je kroz plitku močvaru, te su mjerili duljinu baze postavljajući mjerne štapove na površinu vode. Bili su vrlo zadovoljni kad su izračunali da je razlika između izravno izmjerene duljine baze Tarqui i izračunane duljine iz čitavog trigonometrijskog lanca i duljine baze u Yarouquiu samo 0,2 toisea (39 cm).

2.8. Rezultati izmjere

Razmak između prve i posljednje točke u trigonometrijskom lancu gdje su izvođena astronomska mjerenja iznosio je 3°07'01". Iz trigonometrijskog lanca La Condamine i Bouguer izračunali su duljinu dijela luka od prve do posljednje točke trigonometrijskog lanca svedenu na razinu mora. Ta dva njihova rezultata malo su se razlikovala, a zatim su izračunali duljinu luka jednog stupnja luka meridijana u Peruu i dobili sljedeće rezultate:

56 746 toisea (110 598 m) (Bouguer)
56 749 toisea (110 604 m) (La Condamine)

Figure 11 Cloudy mist can be seen in front of the Andes in Ecuador on the Google's snapshot (Google Earth)

Slika 11. Oblak magle ispred Anda u Ekvadoru na Googleovoj snimci (Google Earth)

were taken amounted to 3°07'01". Using the trigonometric chain, La Condamine and Bouguer calculated the length of the section of the arc from the first to the last point of the trigonometric chain, reduced to sea level. The two results they achieved differed slightly, nevertheless their calculations of the length of the arc of one degree of the meridian in Peru and produced the following results:
56 746 toises (110 598 m) (Bouguer)
56 749 toises (110 604 m) (La Condamine).

2.9 Returning to Europe

All the members of the expedition fell out with each other at one time or another, as their work lasted almost a decade and was rife with friction. When it was over, they split up and each made his own way back to Europe.

La Condamine: in 1743, he began his return journey by rafting down the Amazon for four months, eventually reaching Cayenne (French Guyana), where he stayed for five months. During that time, he repeated more experiments by using Jean Richer's pendulum from 1673 to investigate changes in the force of gravity at different geographical latitudes. He returned to Paris on 23 February 1745, almost ten years after setting out for Peru. He brought with him countless notes and results of measurements, and about 200 natural history specimens (URL 3). In Paris, he produced the first scientific report on the Amazon, based on his incredible journey, and a map of the Amazon, which was published in the *Journal du voyage fait par ordre du roi à l'équateur* (1751).

In it, he described:

- The appropriate use of quinine to combat malaria
- The use of poison darts containing curare by the Indians
- His rediscovery of rubber and its uses
- His discovery of platinum, extracted from gold and silver.

In Paris, he published many works, including *Mesure des trois premiers degrés du méridien dans l'hémisphère australe* (1751). La Condamine's result for the measurement of the length of one degree of the arc of the meridian in Peru was 56 749 toises (110 604 m). La Condamine was a close friend of Pierre-Louis Moreau de Maupertuis (1698–1759), who led the surveying expedition to Lapland.

Bouguer reached Paris in June 1744 (Murdin 2002, p. 73). In the meantime, the disagreements between the members of the expedition had become a matter of public interest. While they were still in Peru, La Condamine had wanted to measure the length of the arc along the latitude, rather than along the meridian, even though the task set was to measure the length of the meridian arc. Accordingly, Bouguer had accused La Condamine of failing to understand the entire purpose of the expedition (Murdin 2009, p. 73). In 1741 in Peru, Bouguer discovered slight errors in the concluding measurements he had conducted with La Condamine for determining the length of one degree of the meridian arc. However, they then fell out, because Bouguer refused to let Condamine make new measurements. So they returned to Paris via different routes.

After a decade spent on the expedition, Bouguer published his results in 1749, in *La figure de la terre*. His result for the length of one degree of the meridian arc was:
56 746 toises (110 598 m).

Jean Godin was declared bankrupt in 1744, married Isabel Grameson, a girl from Peru, and was appointed a professor at the University of Lima. On his return to Europe, he became Director of the Maritime Academy in Cadiz (URL 1).

The Spanish officers returned on separate vessels, sailing along the coast of South America and then around Cape Horn, on a slow journey back to Europe. However, Ulloa's ship was involved in an incident and captured by the English, who took him to England. He only returned to Madrid on 25 July 1746 (Smith 2002). Shortly after his return to Spain, he was reunited with Jorge Juan. Together, they wrote a report on their journey. Jorge Juan was responsible for the astronomical and physical observations, while Ulloa described their historical expedition to South America (URL 8). In his subsequent surveying tasks, Juan successfully measured the altitude of the peaks of the Andes using a barometer.

3 Conclusion

The scientific surveying expedition to Peru, in spite of the great difficulties encountered, and the fact that it lasted almost a decade, succeeded in measuring a trigonometric chain about 345 km long, and establishing the length of one degree of the meridian arc close to the Equator as 56 749 toises (110 604 m). In addition, La Condamine repeated Jean Richer's 1673 measurements using a seconds pendulum in Cayenne, which were in fact the first indications that there were graduations in the force of gravity on Earth, showing that it was less at the Equator in comparison with Paris or Lapland. The surveying expedition to Peru also confirmed in principle the results of Maupertuis' expedition to Lapland, and definitely confirmed that the Earth was not a sphere, but a rotational ellipsoid. Later surveying research showed that the shape of the Earth was even more irregular, so that it could only be said to approximate a rotational ellipsoid.

Table 1. Length of one degree of the meridian arc, expressed in toises, according to Newton's calculations and those of the surveying expeditions to Peru, Lapland and France (Murdin 2009, p. 75)

Tablica 1. Duljina jednog stupnja luka meridijana izražena u toiseima prema proračunu Newtona i geodetskih ekspedicija u Peru, Lapland i iz Francuske (Murdin 2009, str. 75)

Place Mjesto	Newton's calculation Newtonov proračun	Average lat. Srednja geo. širina	Dist. in toises Duljina u toiseima	Authors Autori
Peru (Ecuador) /	56 637 t	-1° 33'	56 746 t	Bouguer
Peru (Ekvador)			56 749 t	La Condamine
France /	57 048 t	49° 23'	57 060 t	Picard
Francuska		46° 3'	57 097 t	Cassini
Lapland /	57 322 t	66° 20'	57 438 t	Maupertuis
Lapland			57 196 t	Svanberg

2.9. Povratak u Europu

Članovi ekspedicije međusobno su se posvađali jer im je rad tijekom gotovo deset godina bio naporan i nervno napet. Zato su se na završetku posla razdvojili i različitim putovima vraćali u Europu.

La Condamine je 1743. godine započeo svoj povratak četveromjesečnim splavarenjem po rijeci Amazoni te je naposljetku stigao i u Cayenne (Francusku Gvajanu), gdje se zadržao pet mjeseci. Za to vrijeme ponovio je pokuse sa sekundnim njihalom Jeana Richera iz 1673. godine o promjeni ubrzanja sile težine na različitim geografskim širinama. U Pariz se vratio 23. veljače 1745., tj. deset godina nakon polaska u Peru. Sa sobom je donio mnogo bilježaka, rezultata mjerenja i oko 200 prirodoslovnih primjeraka (URL 3). U Parizu je s tog zanimljivog putovanja izradio prvo znanstveno izvješće o Amazoni kao i kartu Amazone, što je objavio u *Journal du voyage fait par ordre du roi à l'équateur* (1751).

Opisao je:

- pravilnu uporabu *kinina* u borbi s malarijom
- uporabu otrova *kurare* za strelice koji pripremaju Indijanci
- ponovno je pronašao gumu i njezinu korisnu uporabu
- otkrio je plemeniti metal platinu odvajanjem iz zlata i srebra.

U Parizu je objavio više radova: *Mesure des trois premiers degrés du méridien dans l'hémisphère australe* (1751) i druge. Njegov rezuotkrio je plemeniti metal platinu odvajanjem iz zlata i srebra. iznosi:
56 749 toisea (110 604 m).

La Condamine je bio blizak prijatelj s Pierre-Louisom Moreauom de Maupertuisom (1698–1759), koji je vodio geodetsku ekspediciju u Lapland.

Bouguer je stigao u Pariz u lipnju 1744. (Murdin 2002, str. 73). U međuvremenu u Parizu su se nastavili nesporazumi između članova ekspedicije koji su se pojavili još za vrijeme ekspedicije. Naime, u Peruu je već na početku La Condamine želio mjeriti duljinu luka po geografskoj dužini, a ne po meridijanu, unatoč tome što su primili zadatak da mjere duljinu luka po meridijanu. Pritom je Bouguer predbacivao La Condamineu da nije razumio svrhu ekspedicije u cijelosti (Murdin 2009, str.73). Još u Peruu Bouguer je 1741. godine otkrio male pogreške u priključnim mjerenjima koje je učinio zajedno s La Condamineom za određivanje duljine luka jednog stupnja meridijana. Međutim, tada je došlo do nesporazuma jer je Bouguer odbio dopustiti Condamineu da ponovno provjeri ta mjerenja. Tako su se i u Pariz vraćali raznim putovima.

Nakon 10 godina provedenih u toj ekspediciji Bouguer je objavio svoj rezultat mjerenja u *La figure de la terre* 1749. godine. Njegov rezultat za duljinu jednog stupnja luka meridijana iznosio je:
56 746 toisea (110 598 m).

Jean Godin doživio je bankrot 1744. godine, oženio se Isabelom Grameson, djevojkom iz Perua, i postao profesor na sveučilištu u Limi. Nakon povratka u Europu postao je ravnatelj Pomorske akademije kod Cadiza (URL 1).

Španjolski časnici vratili su se odvojenim brodovima oplovivši Južnu Ameriku nakon jedrenja oko Cape Horna uz sporo napredovanje prema Europi. Na

The results of the Peru expedition were used together with the French resuls in definition of the metre, as the basic measurement of length in the international system of units. The following table is given in order to provide an insight into just how significant the results of the geodetic survey were, since they contributed to the definitive conclusion that the Earth's shape was that of an approximate rotational ellipsoid, flattened at the poles.

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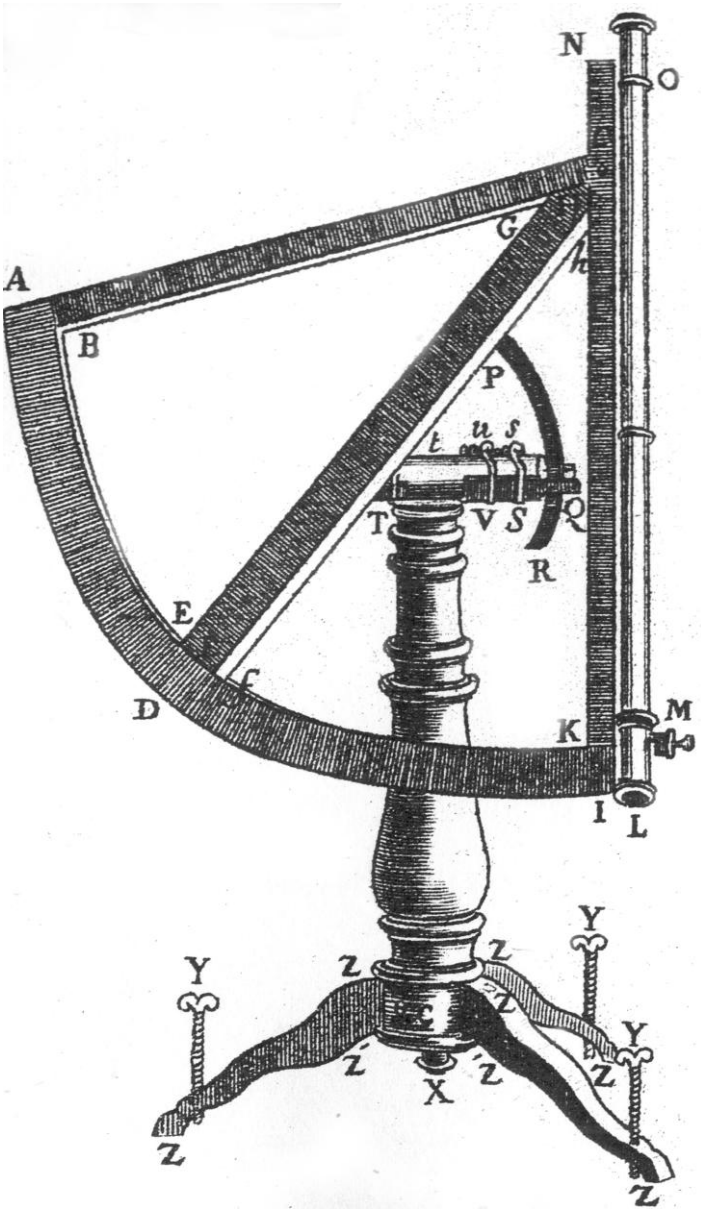

Quadrant from 18th Century

Kvadrant iz 18. st.

nesreću, brod s Ulloom zarobili su Englezi i odveli u Englesku, a u Madrid se vratio 25. srpnja 1746. (Smith 2002). Nedugo nakon povratka u Španjolsku Ulloa se sastao s Jorgeom Juanom. Zajedno su pripremili objavljivanje izvješća s putovanja. Jorge Juan je pripremio opise astronomskih i fizikalnih opažanja, a Ulloa opise toga povijesnog putovanja u Južnu Ameriku (URL 8). Uz ostala mjerenja Juan je vrlo uspješno mjerio visine vrhova Anda upotrebom barometara.

3. Zaključak

Geodetska znanstvena ekspedicija u Peru, unatoč velikim poteškoćama i gotovo desetogodišnjem trajanju ekspedicije, izmjerila je trigonometrijski lanac dug oko 345 km i utvrdila da je duljina jednog stupnja meridijanskog luka u blizini ekvatora jednaka 56 749 toisea (110 604 m). Osim toga La Condamine je ponovio mjerenja Jeana Richera sa sekundnim njihalom iz 1673. godine u Cayenneu koja su prva pokazala da postoji promjena ubrzanja sile teže na Zemlji i da je ono manje u blizini ekvatora nego u Parizu i u Laplandu. Tako je geodetska ekspedicija u Peru u principu potvrdila rezultate Maupertuisove ekspedicije u Lapland i definitivno utvrdila da Zemlja nema oblik kugle već da se može kazati da ima oblik rotacijskog elipsoida. Poslije su geodeti istražujući oblik Zemlje išli dalje i utvrdili da je oblik Zemlje još nepravilniji i da se može reći da Zemlja ima samo približno oblik rotacijskog elipsoida.

Rezultati izmjere peruanske ekspedicije korišteni su i za određivanje ukupne duljine Pariškog meridijana od pola do ekvatora pri računanju duljine Pariškog meridijana za potrebe definiranja duljine metra kao osnovne duljine u međunarodnom sustavu jedinica. Kako bi se dobio uvid u te značajne rezultate geodetskih mjerenja koja su pridonijela konačnom saznanju da Zemlja ima približno oblik rotacijskog elipsoida spljoštenog na polovima, prilaže se tablica 1.

Zahvala

Najljepše zahvaljujemo recenzentima na korisnim primjedbama, kojima su pridonijeli boljoj kvaliteti ovog istraživanja geodetske prošlosti. Izmjere duljina dijelova meridijana u blizini ekvatora i u blizini polarnoga kruga pomogle su da se definitivno može zaključiti da Zemlja ima približno oblik rotacijskog elipsoida. Zahvaljujemo također Ministarstvu znanosti, obrazovanja i športa RH, što je djelomično financiralo ovaj rad, koji je izrađen u okviru projekta "*Razvoj znanstvenog mjeriteljskog laboratorija za geodetske instrumente*" br. 007-1201785-3539.

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