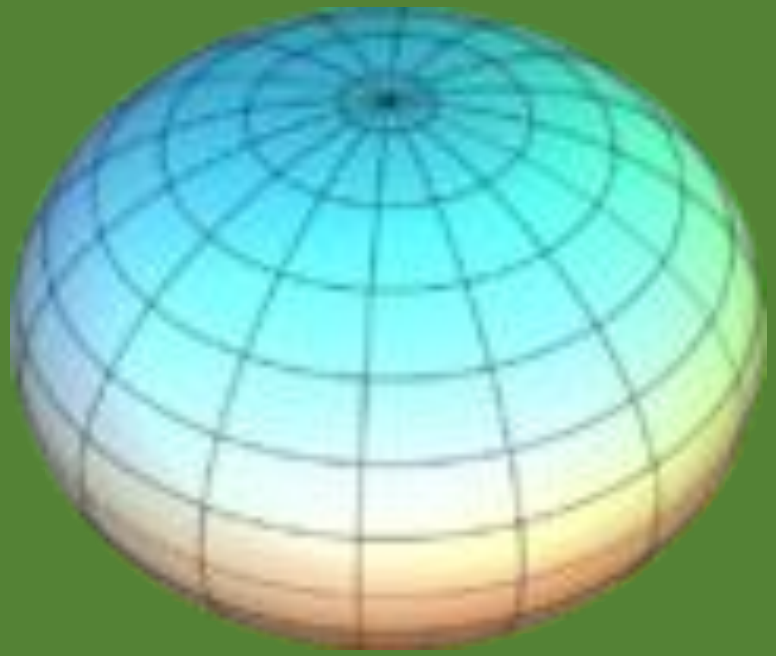
The Shape of the Earth

Derek Jones



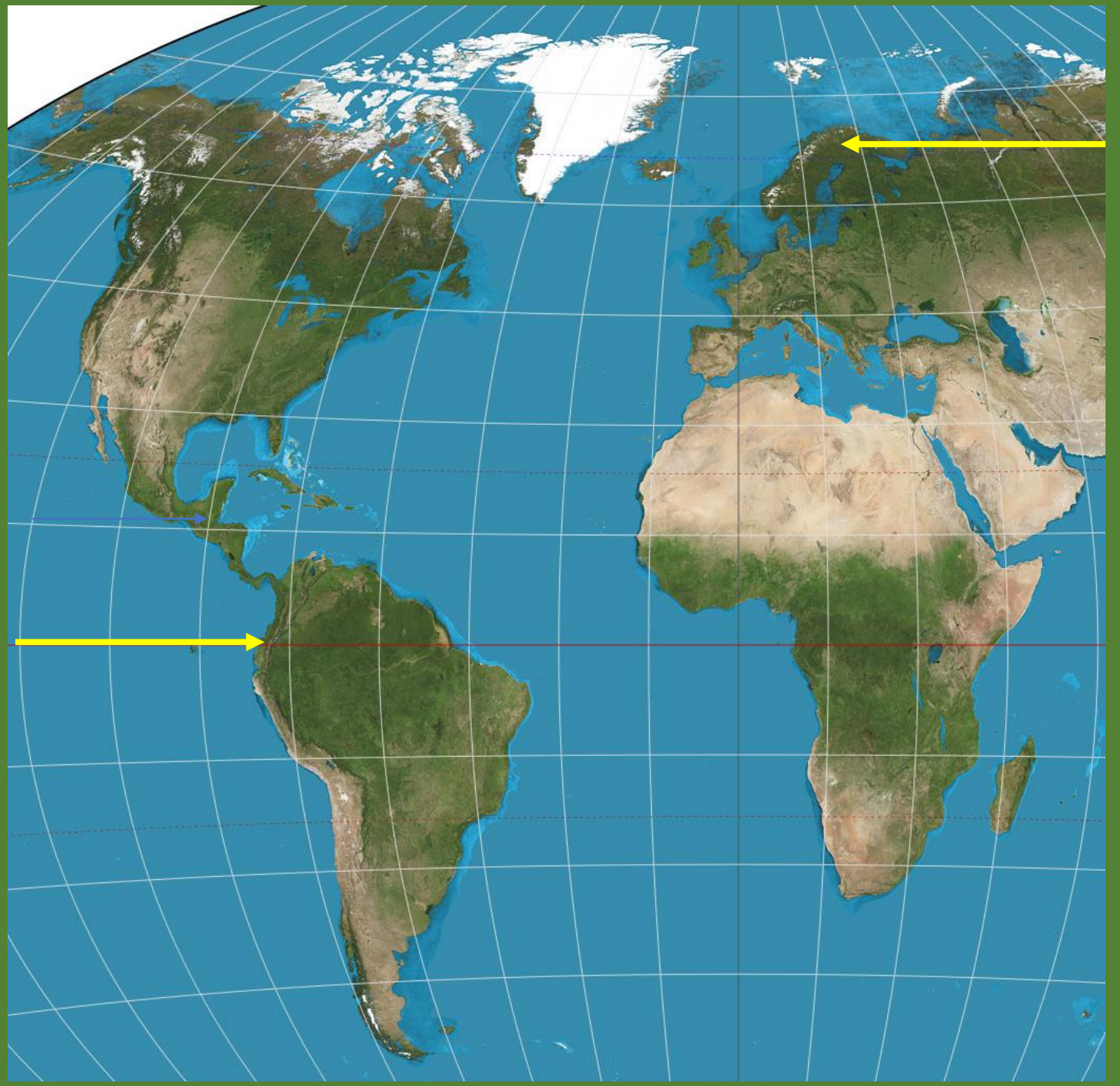
Oblate - Newton

Prolate - Cassini

For an oblate spheroid, the length of one degree, increases from equator to pole

For a prolate spheroid, the length of one degree, decreases from equator to pole

Earth from Space



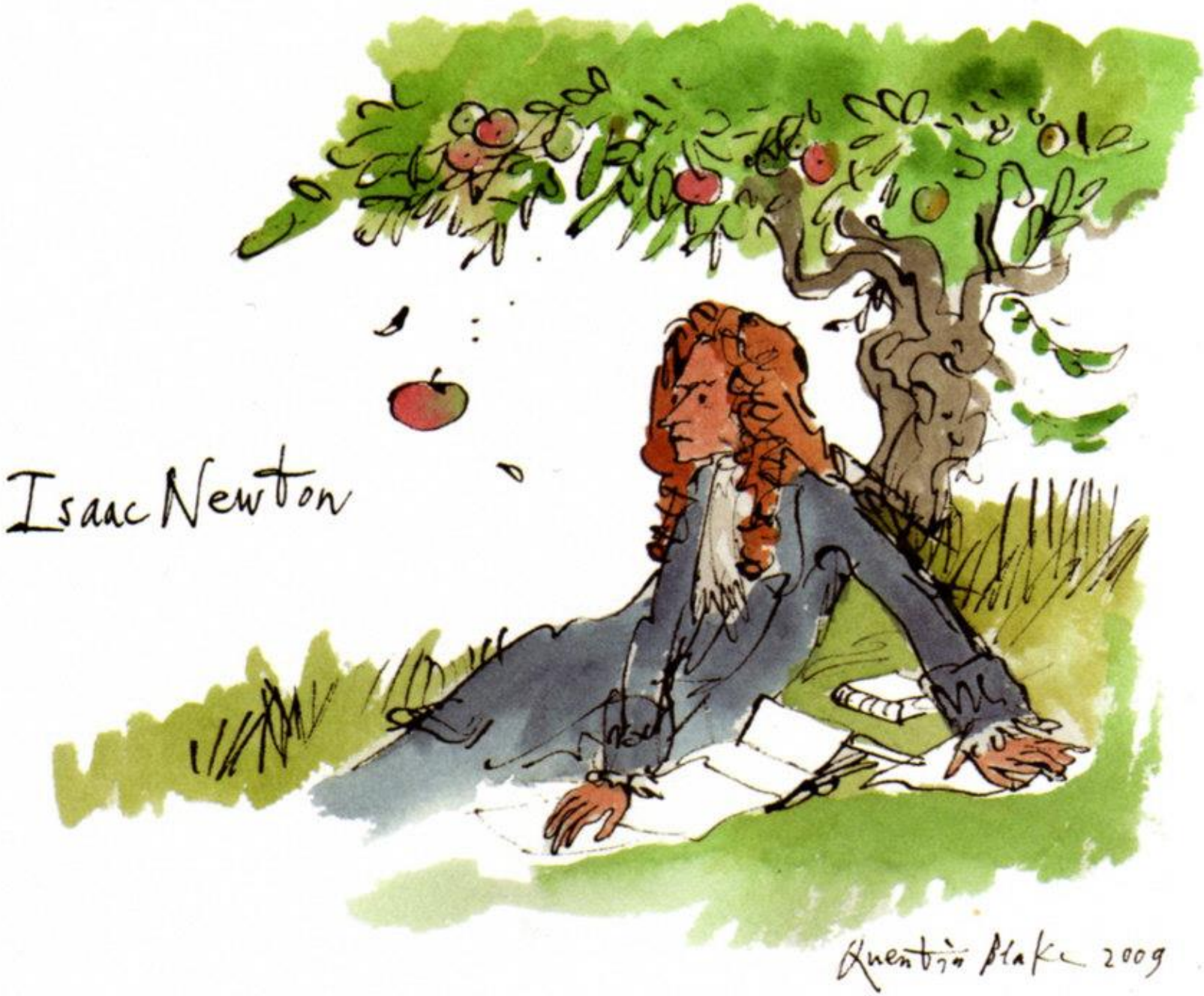
Maupertuis
Lapland
1736 - 1737

La Condamine
Peru
1735 - 1745

Sites chosen for Survey

Newton sees apple fall

1666



Newton's Principia 1687 p422

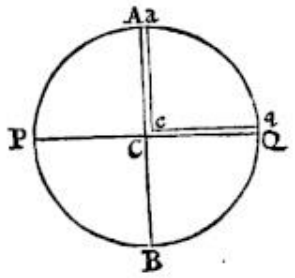
Newton predicts bulge of 1/290; modern value is around 1/300 corresponding to a difference of the major and minor semi-axes of approximately 21 km (13 miles).

paulò altior eſſet ſub æquatore quàm ad polos, Maria ad polos ſubſiderent, & juxta æquatorem aſcendendo, ibi omnia inundarent.

Prop. XIX. Prob. II.

Invenire proportionem axis Planetæ ad diametros eidem perpendiculares.

Ad hujus Problematis ſolutionem requiritur computatio multiplex, quæ facilius exemplis quàm præceptis addiſcitur. Inito igitur calculo invenio, per Prop. IV. Lib. I. quod vis centrifuga partium Terræ ſub æquatore, ex motu diurno oriunda, ſit ad vim gravitatis ut 1 ad $290\frac{4}{5}$. Unde ſi $APBQ$ figuram Terræ deſignet revolutione Ellipſeos circa axem minorem PQ genitam; ſitque $ACQqca$ canalis aquæ plena, à polo Qq ad centrum Cc, & inde ad æquatorem Aa pergens: debebit pondus aquæ in canalis crure $ACca$ eſſe ad pondus aquæ in crure altero $QCcq$ ut 291 ad 290, eò quòd vis centrifuga ex circulari motu orta partem unam è ponderis partibus 291 ſuſtinebit & detrahet, & pondus 290 in altero crure ſuſtinebit partes reliquas. Porrò (ex Propoſitionis XCI. Corollario ſecundo, Lib. I.) computationem ineundo, invenio quod ſi Terra conſtaret ex uniformi materia, motuque omni privaretur, & eſſet ejus axis PQ ad diametrum AB ut 100 ad 101: gravitas in loco Q in Terram, foret ad gravitatem in eodem loco Q in ſphæram centro C radio PC vel QC deſcriptam, ut $126\frac{3}{15}$ ad $125\frac{3}{5}$. Et eodem argumento gravitas in loco A in Sphæroidem, convolutione Ellipſeos $APBQ$ circa axem AB deſcriptam, eſt ad gravitatem in eodem loco A in Sphæram centro C radio AC deſcriptam, ut $125\frac{3}{15}$ ad $126\frac{3}{15}$. Eſt autem gravitas in loco A in Terram, media proportionalis inter gravitates in dictam Sphæroidem & Sphæram, propterea quod Sphæ-



in figuram Terræ; & hæc figura diminuendo in eadem ra
ametrum tertiam, quæ diametris duabus AP, PQ perper
eſt, vertitur in dictam Sphæroidem, & gravitas in A, in c
que, diminuitur in eadem ratione quam proximè. Eſt igi
tas in A in Sphæram centro C radio AC deſcriptam, ad gr
in A in Terram ut 126 ad $125\frac{1}{2}$, & gravitas in loco Q in
centro C radio QC deſcriptam, eſt ad gravitatem in loco A
ram centro C radio AC deſcriptam, in ratione dian
(per Prop. LXXII. Lib. I.) id eſt ut 100 ad 101: Conj
jam hæ tres rationes, $126\frac{3}{15}$ ad $125\frac{3}{15}$, $125\frac{1}{2}$ ad 126 & 10
& fiet gravitas in loco Q in Terram ad gravitatem
A in Terram, ut $126 \times 126 \times 100$ ad $125 \times 125\frac{1}{2} \times 101$, ſ
ad 500.

Jam cum per Corol. 3. Prop. XCI. Lib. I. gravitas
crure utrovis $ACca$ vel $QCcq$ ſit ut diſtantia locorum
Terræ; ſi crura illa ſuperficiebus tranſverſis & æquidiſta
ſtinguantur in partes totis proportionales, erunt ponder
ſingularum in crure $ACca$ ad pondera partium totidem i
tero, ut magnitudines & gravitates acceleratrices conjunct
ut 101 ad 100 & 500 ad 501, hoc eſt ut 505 ad 501.
inde ſi vis centrifuga partis cujuſque in crure $ACca$ ex n
no oriunda, fuiſſet ad pondus partis ejuſdem ut 4 ad 505
pondere partis cujuſque, in partes 505 diviſo, partes quat
heret; manerent pondera in utroque crure æqualia, &
fluidum conſiſteret in æquilibrio. Verum vis centrifuga
juſque eſt ad pondus ejuſdem ut 1 ad 290. Hoc eſt, vis
quæ deberet eſſe ponderis pars $\frac{4}{505}$, eſt tantum pars $\frac{1}{290}$, &
dico, ſecundum Regulam auream, quod ſi vis centrifuga
altitudo aquæ in crure $ACca$ ſuperet altitudinem aqu
$QCcq$ parte centeſima totius altitudinis: vis centrifuga
exceſſus altitudinis in crure $ACca$ ſit altitudinis in crure a
pars tantum $\frac{3}{689}$. Eſt igitur diameter Terræ ſecundum

The French Academy of Sciences

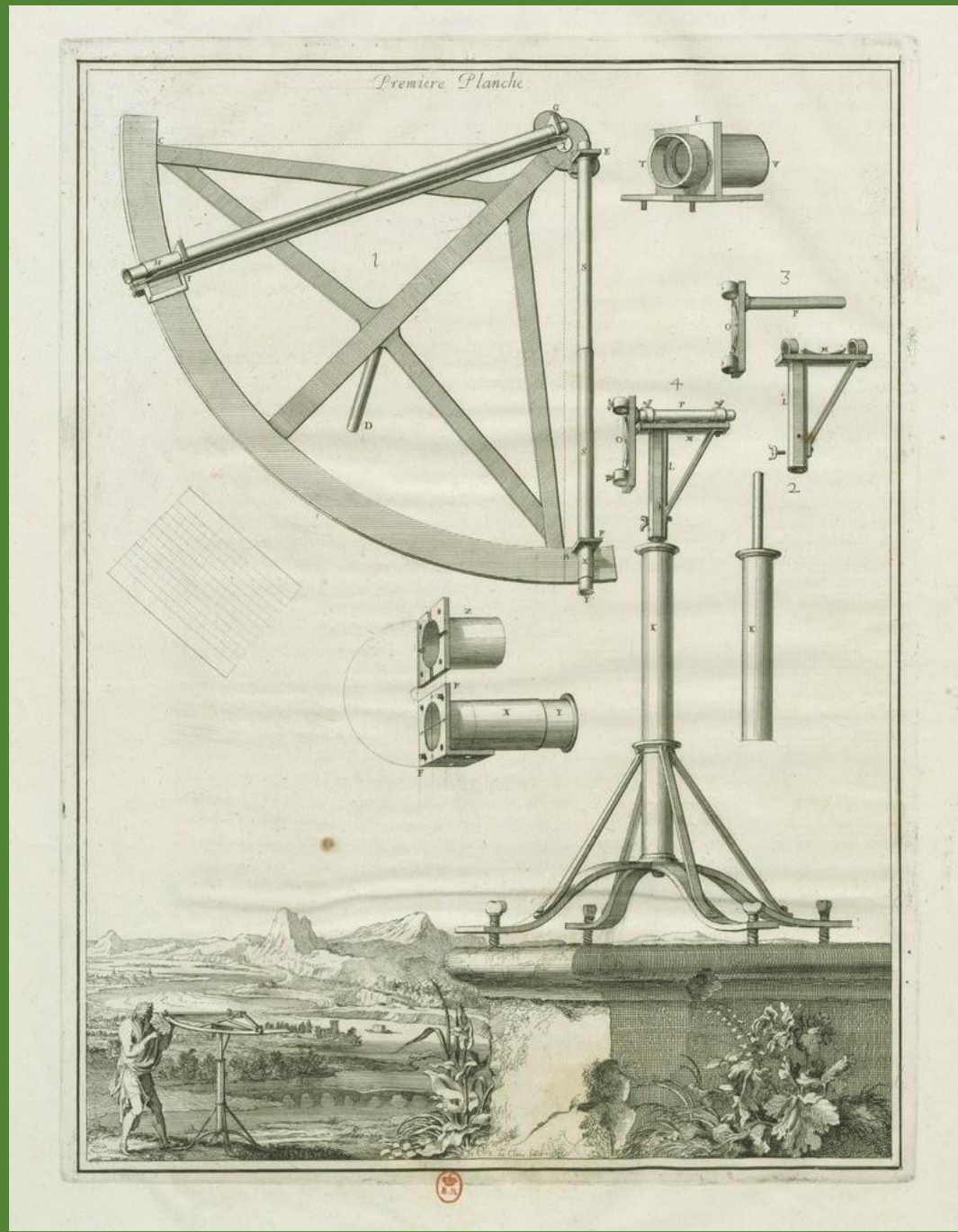
Picard		Jean	1620 - 1682
Cassini	I	Jean Dominique	1625 - 1712
Cassini	II	Jacques	1677 - 1756
Cassini	III	Cesar-Francois	1714 - 1784
Cassini	IV	Jean Dominique	1748 - 1845

Age of Enlightenment

To measure the size of the Earth one compares the difference of latitude between two points lying North-South, with their physical distance.

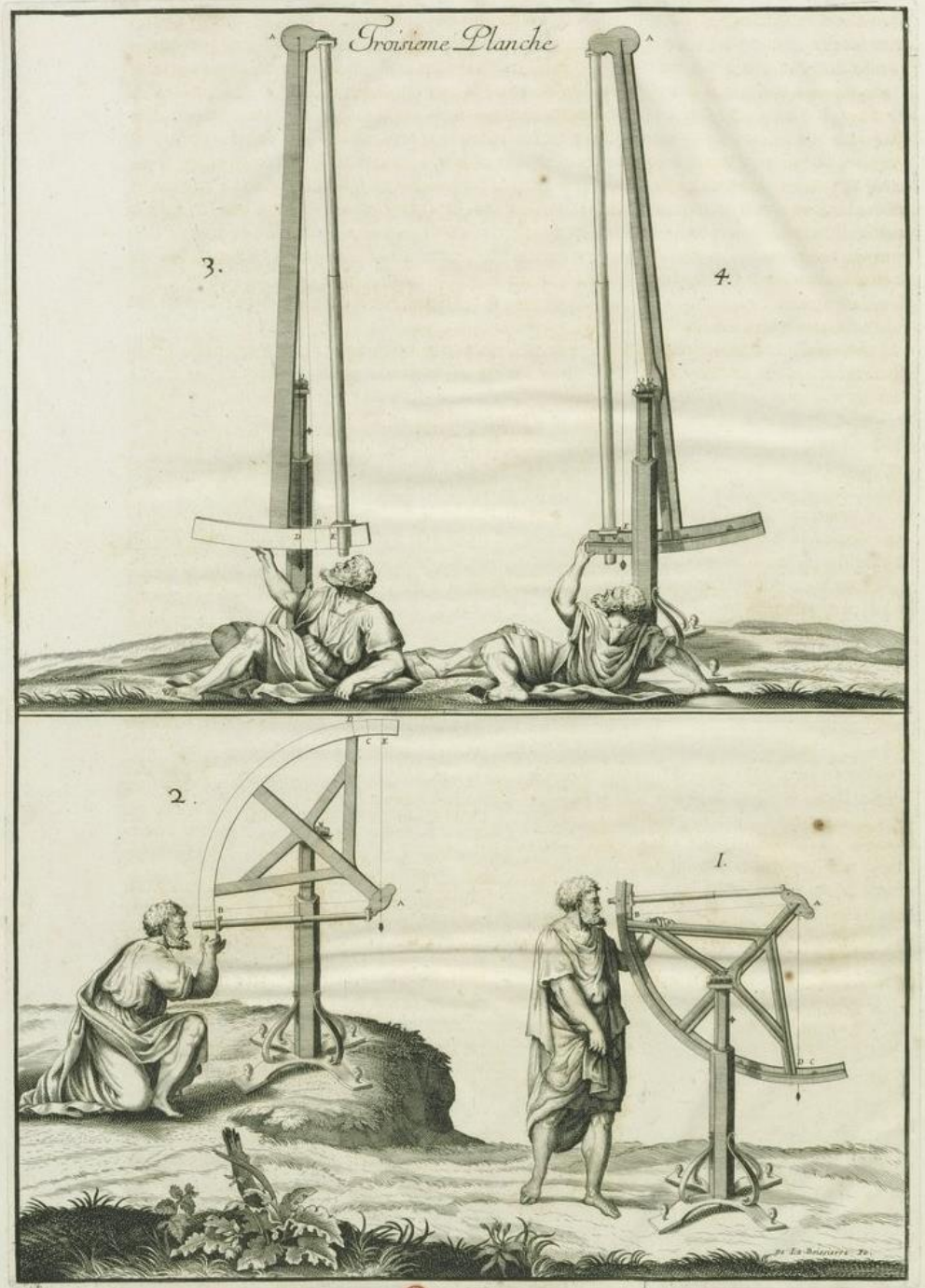
Mesure de la Terre by Jean Picard

Fig. 1



Mesure de la Terre by Jean Picard

Fig.3



Picard's Survey of Paris Meridian

To measure the size of the Earth one compares the difference of latitude between two points lying North-South, with their physical distance.

At this time distances were measured in *toise,* about a fathom or 1.949 metres and surveyors used a one *toise* rod to measure short differences.

For longer distances, surveyors used a method devised by Willebord Snell (1580 -1626) where one carefully measured the distance between two prominent points and measured the bearing of a third point from both. This gave a triangle with all three sides known. Further prominent points could be added without further measures of physical distance.

Picard found that Malvoisin and Amiens differed in latitude by 1 degree, 22 minutes and 55 seconds and were separated by 78,850 *toise*, so 1 degree = 57,060 *toise*

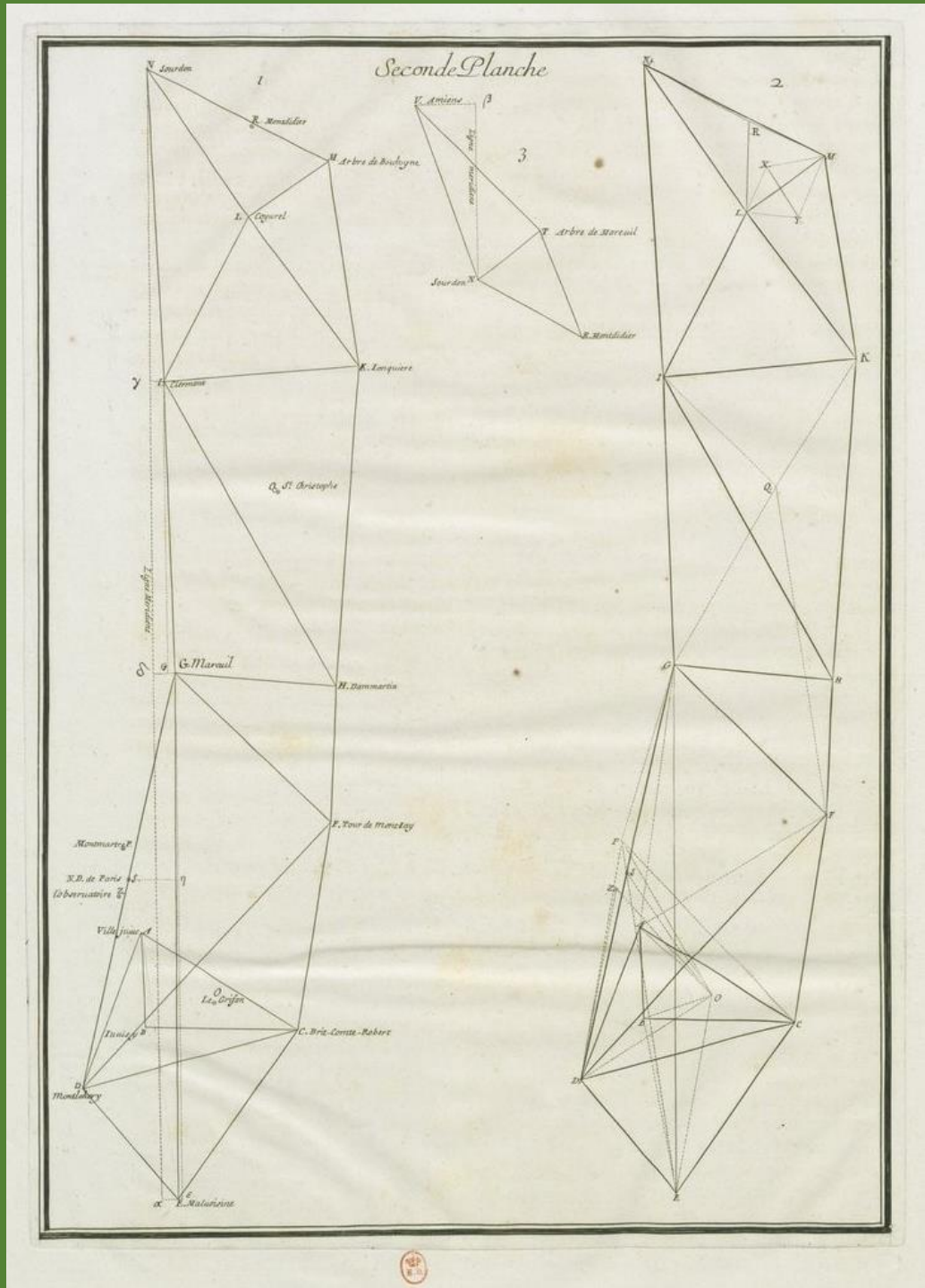
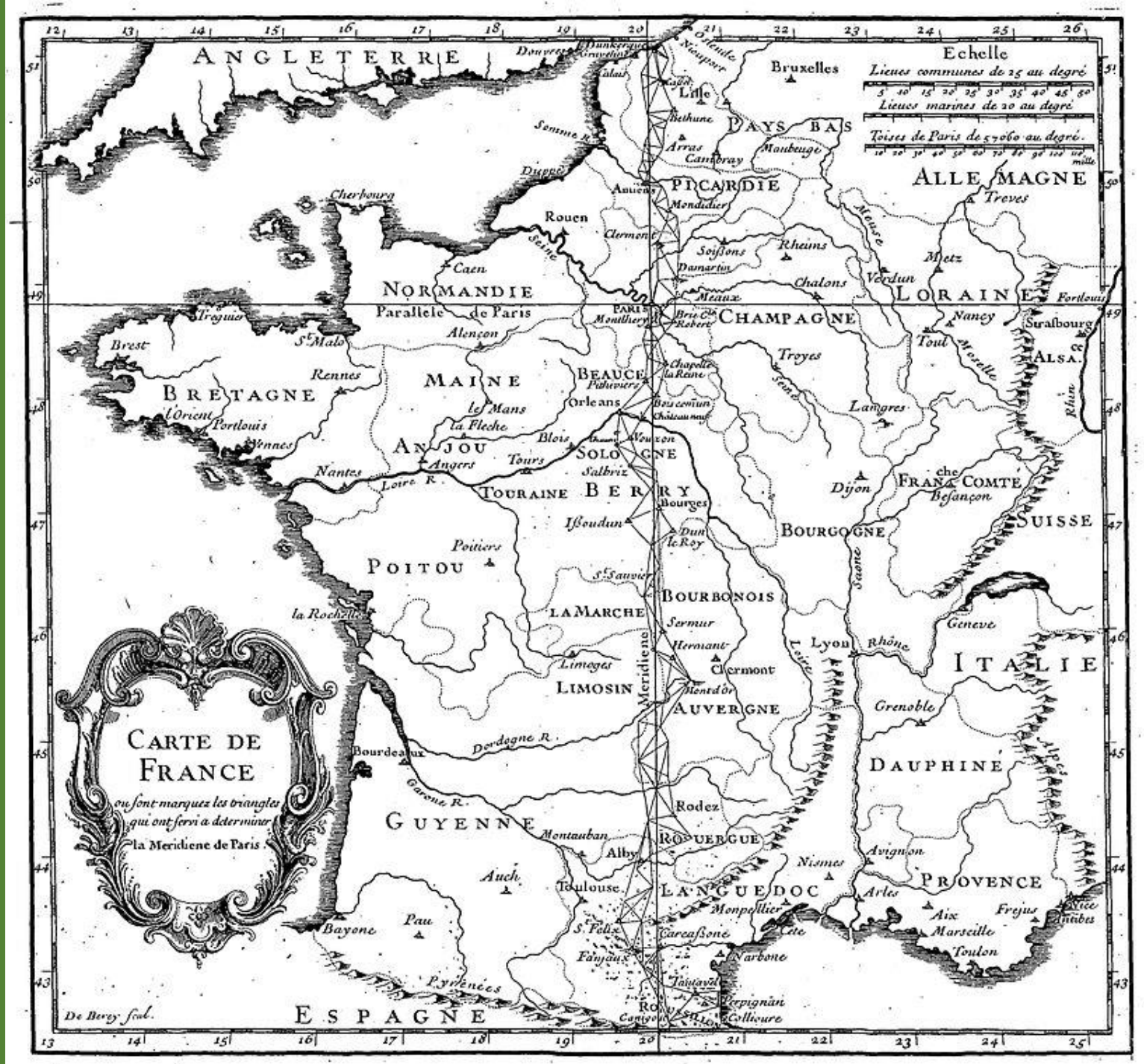


Figure 7. Portrait of Giovanni Domenico Cassini, *ca.* 1690. Artist unknown. Oil on canvas. 81 x 67 cm. (31.8 x 26.4 in.). Courtesy of Civica Biblioteca Aprosiana, Ventimiglia, Italy.

Jean Domenique Cassini (1625 – 1712)

Paris Observatory, Meridian Room

Meridian of Paris



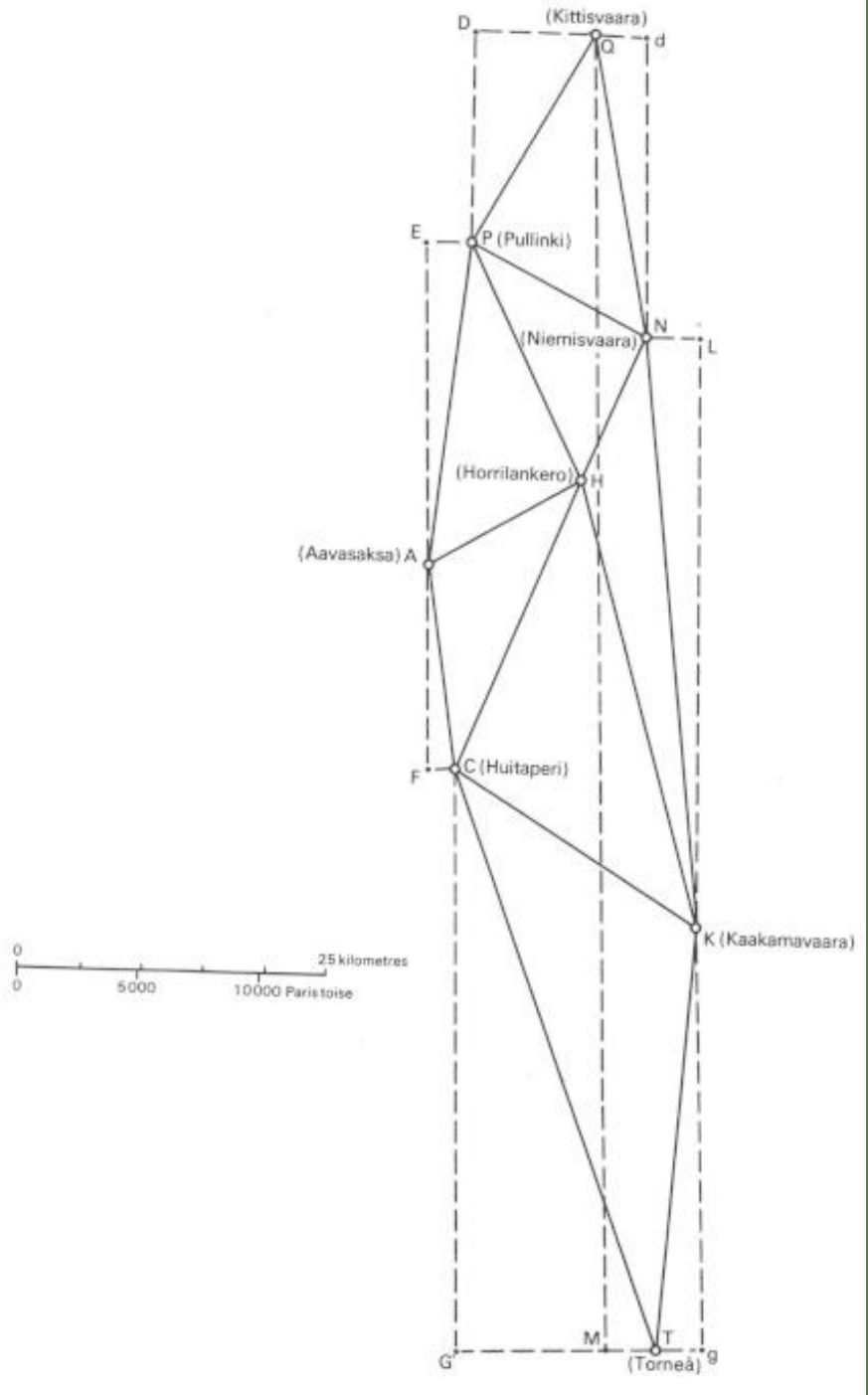
Pierre Louis de Maupertuis (1698 – 1759)

Expedition to Lapland
Maupertius, Celsius, Clauraut, Le Monnier and others

1736 April	Left Paris
1736 June	Sailed from Stockholm
1736 June	Observations Commence
1737 April	Observations complete
1737 June	Shipwreck
1737 July	Arrive Stockholm
1737 August	Arrive Paris

Lapland Survey

1 degree = 55023 toise
So
Earth is flattened at Pole



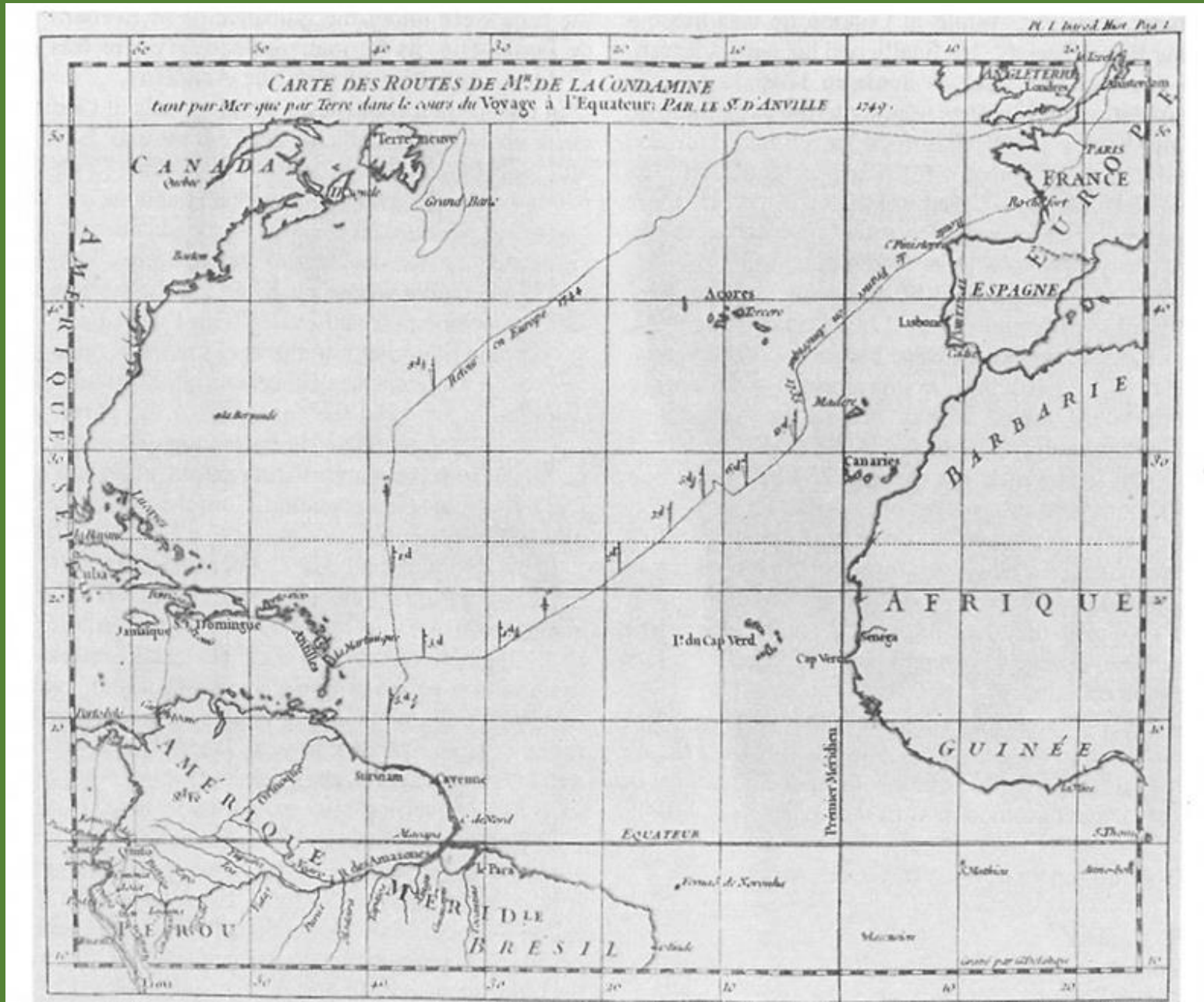
The Peru Expedition 1735 - 1745

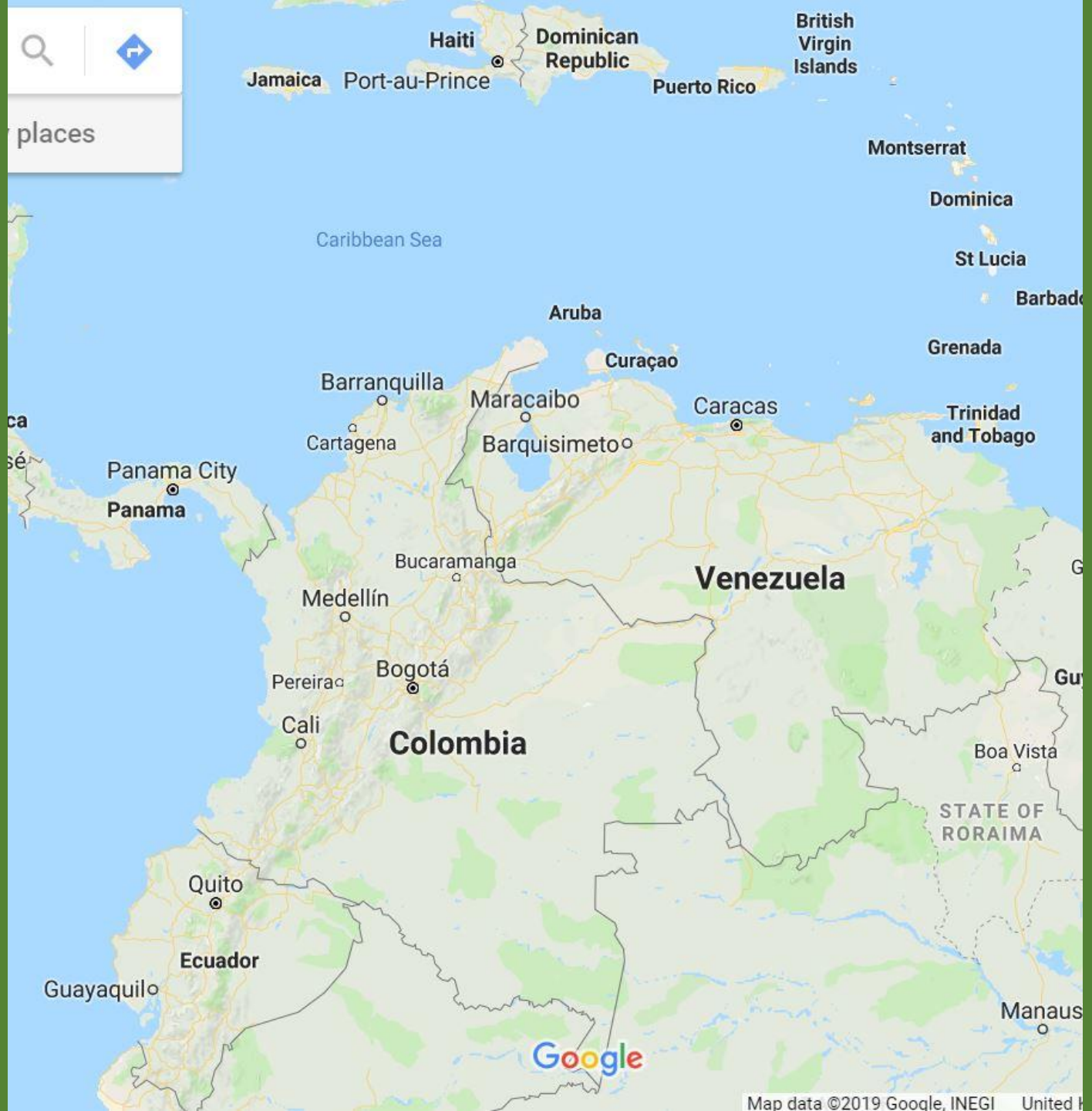
Godin	French Academy of Sciences
Bouguer	Age of Enlightenment
La Condamine	All Polymaths

1735 April	Left Paris
1735 June	Arrive St. Domingo
1735 October	Sail from St. Domingo
1735 November	Arrive Carthagena
1735 December	Arrive Panama
1736 March	Arrive Guayaquil
1736 June	Arrive Quito
1736 October	Survey Starts
1740 August	Survey Complete
1745 February	Arrive Paris

Map of the routes between France & Peru

Indicating the changing values of Magnetic declination.
NB the prime meridian runs through Ferro nowadays *El Hierro*

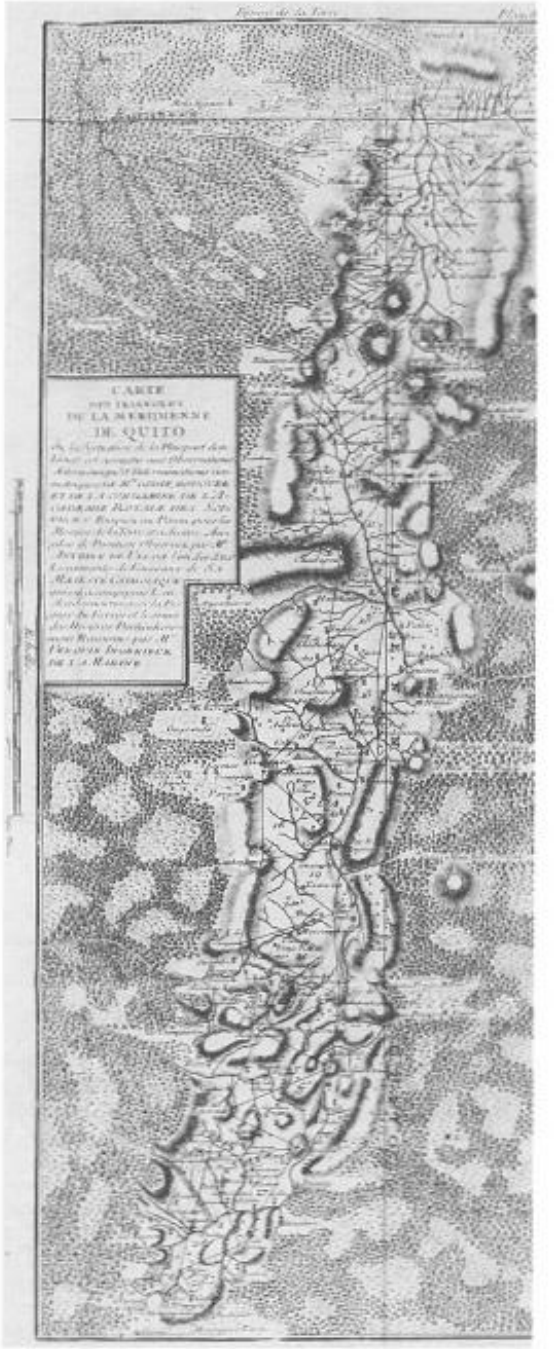



places
Haiti
Dominican Republic
Jamaica
Port-au-Prince
Puerto Rico
British Virgin Islands
Montserrat
Dominica
Caribbean Sea
St Lucia
Aruba
Curaçao
Grenada
Barranquilla
Maracaibo
Caracas
Trinidad and Tobago
Cartagena
Barquisimeto
Panama City
Panama
Bucaramanga
Venezuela
Medellín
Bogotá
Pereira
Cali
Colombia
Boa Vista
STATE OF RORAIMA
Quito
Ecuador
Guayaquil
Manaus
Google
Map data ©2019 Google, INEGI

Modern Ecuador

Quito is at altitude 9350 ft

Map of the area of triangulation scheme in Peru



21. *Map of the area of triangulation scheme in Peru.*

Diagram of the scheme of Bouguer & La Condamine

1 degree = 56760 toise so Earth bulges at equator

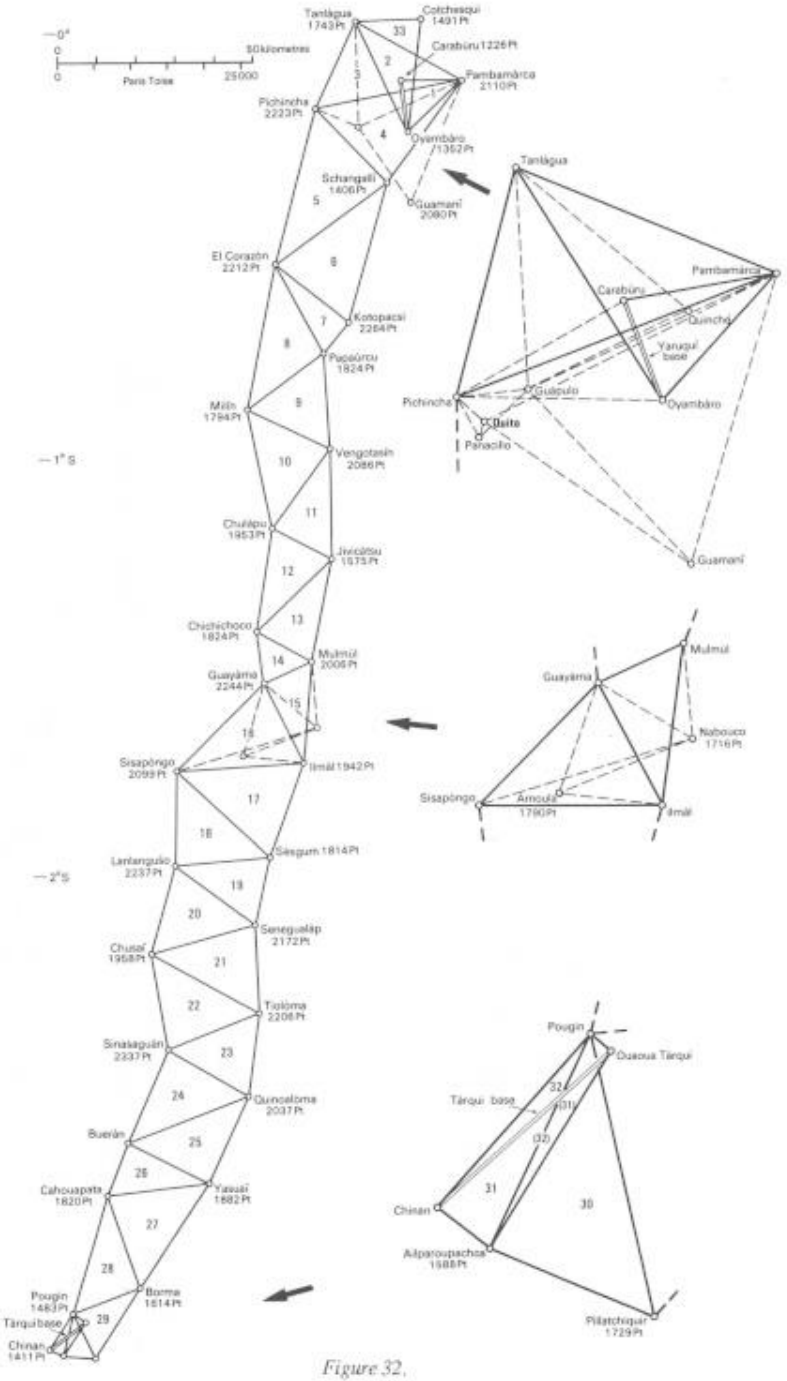
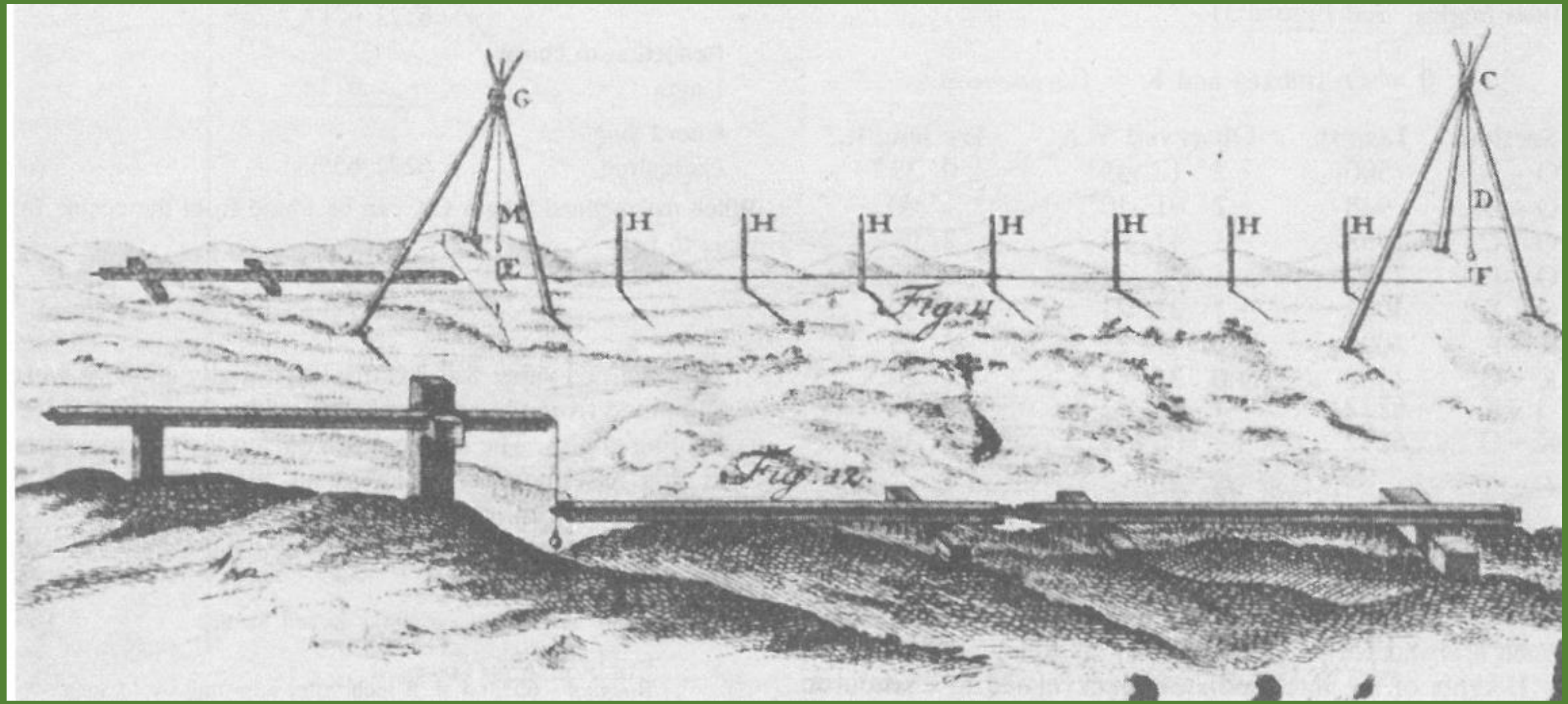
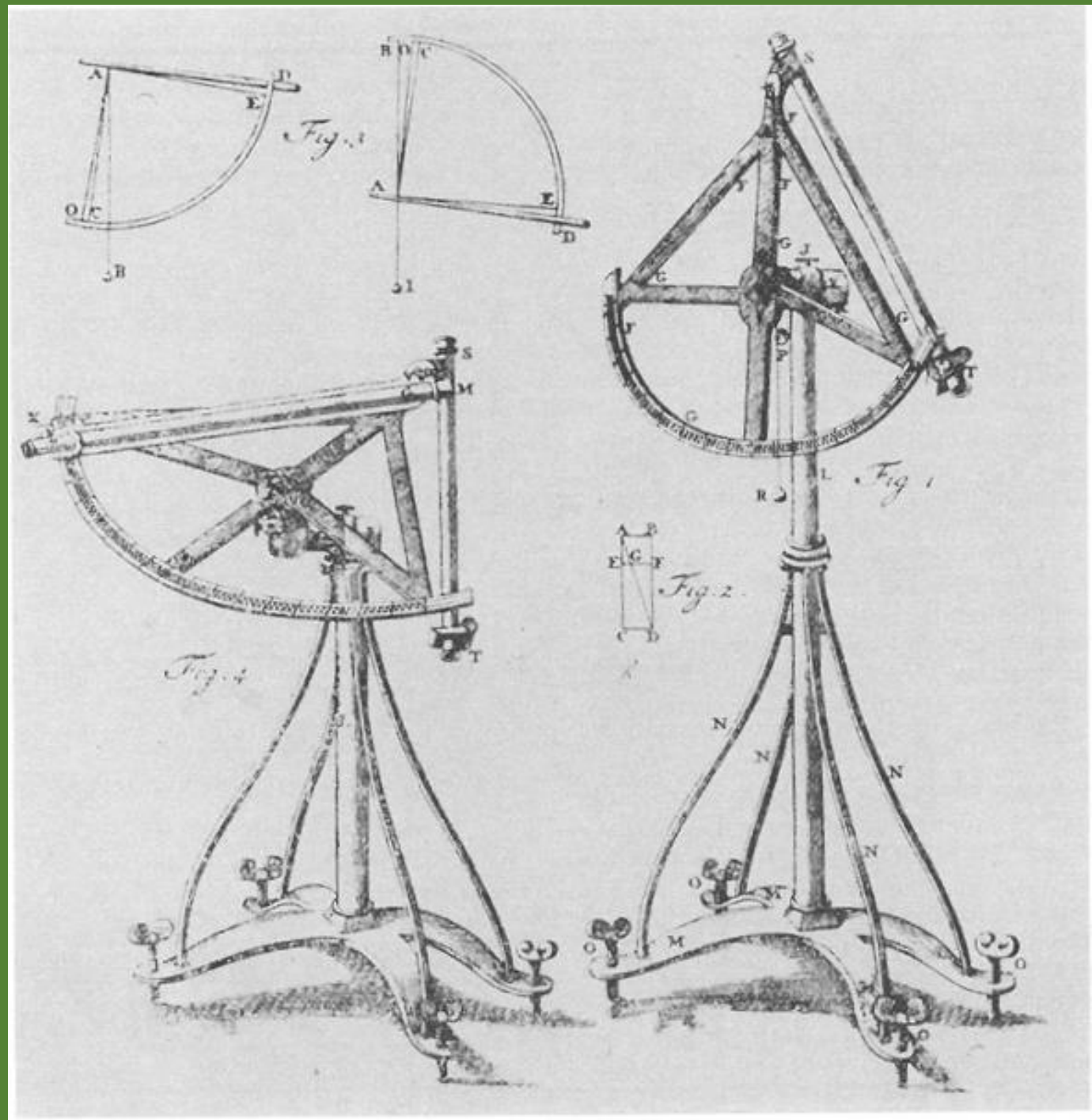


Figure 32.
Diagram of the scheme of Bouguer and La Condamine.

Base line measurement by wooden bars placed end to end



Details of the quadrant illustrating how it can be used in various attitudes



Method of use of the quadrant

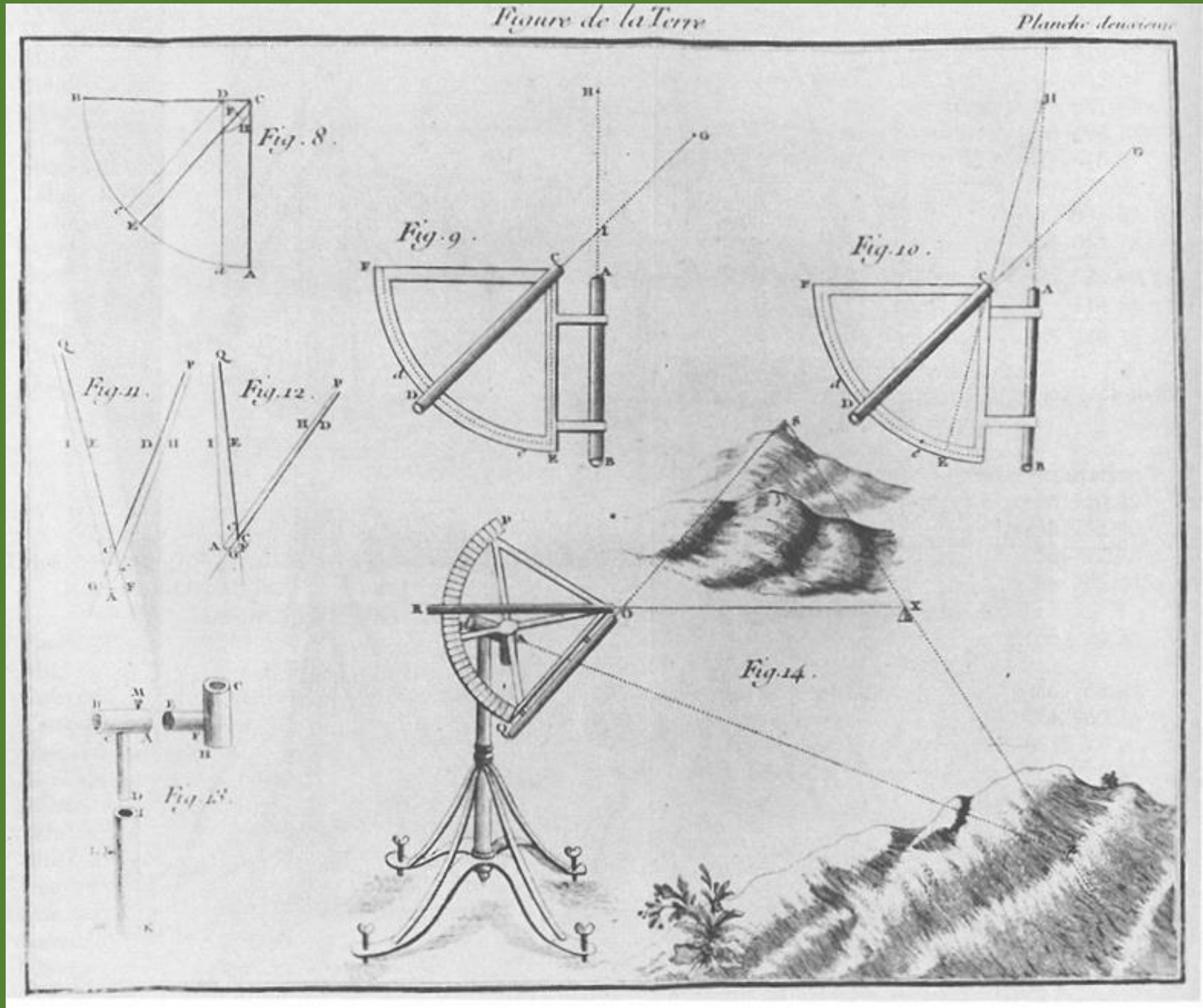
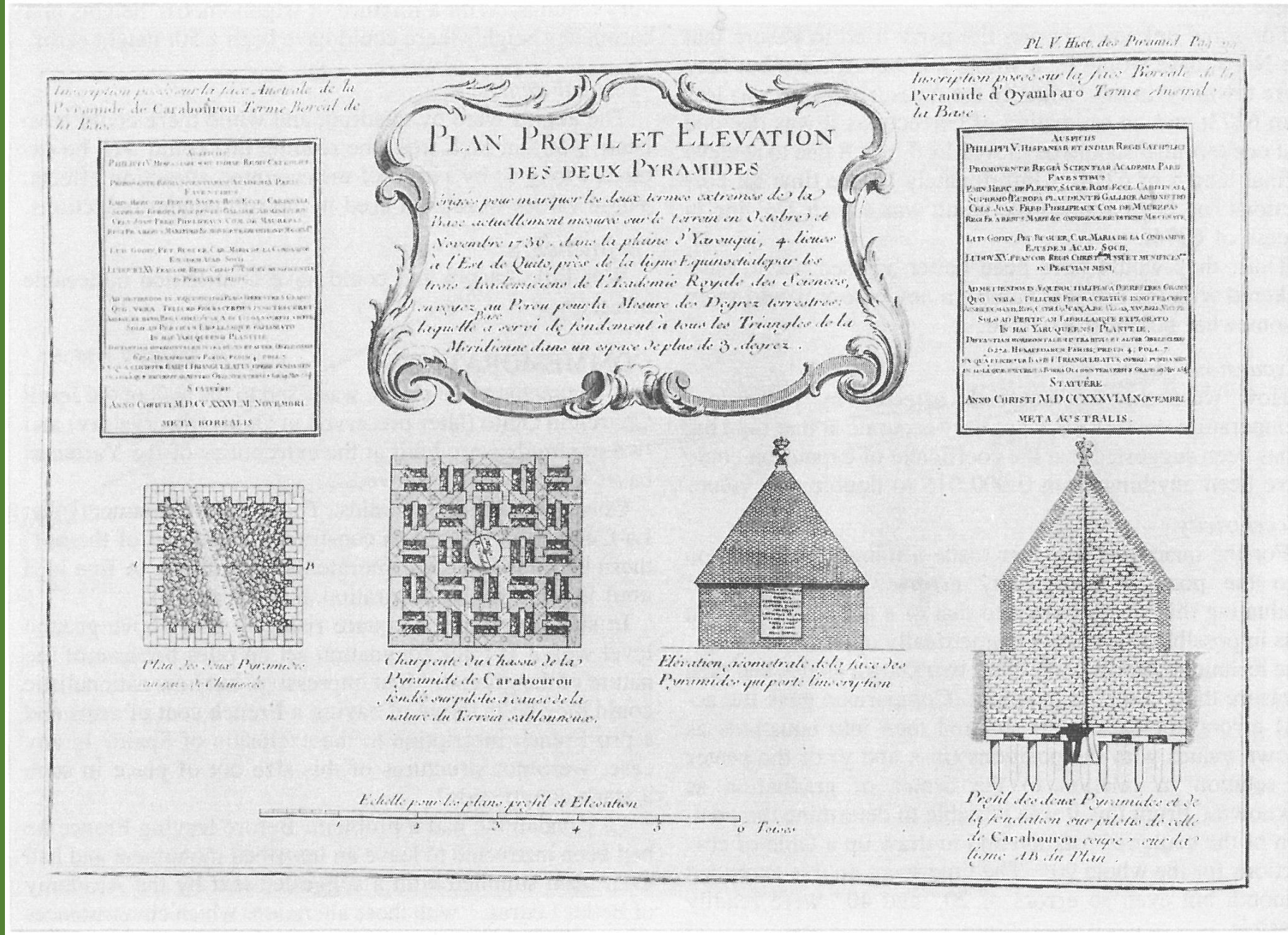


Diagram of the Pyramids

Note the intricate design
And overall size of the monument



27. *Diagram of the pyramids. Note the intricate design and overall size of the monument.*