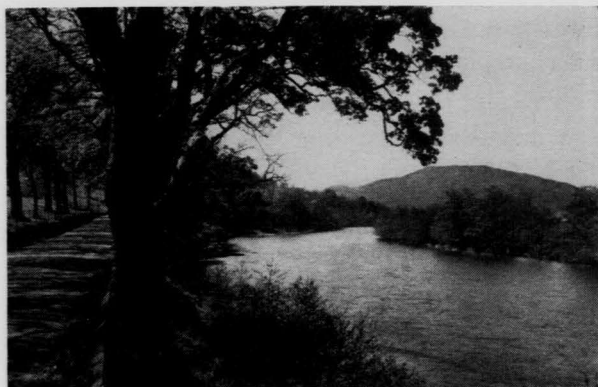


## A MOUNTAIN IN PERTHSHIRE

BY THOMAS D. COPE\*

**S**CHEHALLIEN, the Hill of the Caledonians, was introduced into Pennsylvania history by an experiment performed on the mountain during the 1770's. Benjamin Franklin had a hand in it, and other men associated with our Commonwealth were major participants. The experiment had a positive outcome and the results play an ever increasing role in our lives.



RIVER TAY AND SCHEHALLIEN

*From near Aberfeldy, showing southeastern foothills.*

*Photo by Valentine, Dundee*

The principle of Universal Gravitation announced by Isaac Newton in 1687 asserts that every particle of matter in the Universe attracts every other particle. That is to say, my hand and the pen for which it reaches attract each other. Isaac Newton dealt convincingly with the sun and the planets and comets that circulate around it. He transferred the mutual attractions of the earth and the apple to the earth and the moon and proved his case. And

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finally late in life, in his *System of the World*, Sir Isaac considered the lesser bodies. He said:

The forces due to relatively very small bodies are inappreciable. Whole mountains will not be sufficient to produce any sensible effect. A mountain of an hemispherical figure, three miles high, and six broad, will not by its attraction draw the plumb-line two minutes out of the true perpendicular.

This assertion, first published in 1727, was a challenge to men of science. It had to be put to the test. Today an undergraduate, apt in physical science, can confirm it by a simple calculation, such as Sir Isaac made.

During the 1730's French scientists, members of the Royal Academy of Sciences, were sent to the Andes by order of the King of France to measure an arc of meridian under the Equator. Messieurs Bouguer and de la Condamine of this expedition decided to test Sir Isaac's prediction about the deflection of the plumb-line on the flanks of Chimborazo. The outcomes were disappointing. Their instruments lacked the sensitivity necessary. And at their stations high on the mountain, low temperature, high winds, snow, and flying dust blinded and benumbed the observers. Bouguer proposed that the trial be repeated on smaller and denser mountains. "It is very probable," said he, "that we shall find in France or England some hill of sufficient size. . . ."

In 1772 Rev. Nevil Maskelyne, His Majesty's Astronomer at the Royal Observatory Greenwich, read a proposal to the Royal Society that a suitable hill be found in the British Isles and that the experiment be performed. He suggested hills in Yorkshire, Lancashire, and in Cumberland for consideration. And he reminded the Society that it owned a superior instrument which combined a plumb-line, a telescope, and a graduated arc for measuring the angle between the axis of the telescope and the plumb-line. With a simple change in the suspension of the plumb-line, this instrument would be adequate.

The suggestion was accepted by the Society, and at its meeting held on July 23, 1772, the Council of the Society named the Hon.

Mr. Cavendish, Rev. Mr. Horsley, the Astronomer Royal, Dr. Franklin, and the Hon. Mr. Barrington a committee

for considering some experiments which are proposed to be made for measuring the Attraction of Hills and Mountains; and that they have power to draw upon the Treasury for what money they think expedient and necessary.

Of this committee of five Dr. Franklin was the agent for Pennsylvania in London, looking after the interests of the Province, and agent for Georgia, New Jersey, and Massachusetts as well. And while the Astronomer Royal, Rev. Nevil Maskelyne, never set foot on Pennsylvania soil, he was no stranger in the Province. For while Mason and Dixon were in America, from 1763 to 1768, surveying the boundaries between Maryland and Pennsylvania and the Three Lower Counties, and doing scientific work for the Royal Society, Nevil Maskelyne was by appointment of the Royal Society their counselor in all of their work for the Society.

On June 3, 1769, the American Philosophical Society had done notable work in observing the transit of Venus. The planning for this achievement was done not in Philadelphia alone but also in London where, beginning in 1765, Franklin and Maskelyne as Fellows of the Royal Society, and during much of the time members of its Council, worked together in aiding the Philadelphia astronomers to prepare and equip themselves for the undertaking. On the day of the transit Maskelyne observed from Greenwich while the Philadelphians were observing from Norriton, from State House Yard, and from Lewes on Delaware Bay. For his great services to science Rev. Nevil Maskelyne had been elected a member of the American Philosophical Society on January 18, 1771.

The committee for the Attraction of Mountains was an active one. At a meeting held on June 24, 1773, Council ordered:

that Mr. Charles Mason be employed in the Observation respecting the Attraction of Mountains in Scotland, (provided Glendilt appears proper for the purpose) at the rate of £50 for his expenses for three months, if a longer time, more in proportion.

And it was further ordered:

that the Committee for the Attraction of Mountains be empowered to take and employ such of the Society's Instruments as they think proper; taking due order for the safe return.

On the following July 29, upon recommendation of the Committee on Attraction, Council decided:

to engage and employ Mr. Charles Mason immediately to survey the Mountains Ben Nevis, Glen Coe and Cruachen-Ben and such others in the highlands of Scotland as he may think proper for the experiment of Attraction: and also the Mountains Pennygant, Ingleborough & Wernside on the borders of Yorkshire & Lancashire on his return if he can do it conveniently; and that he be paid at the rate of half a guinea a day by way of gratuity for his trouble over & above his expenses.

In 1773 Charles Mason, of "our Mason and Dixon," was living in his native Gloucestershire, was preparing material for the *Nautical Almanac*, and was revising Mayer's "Lunar Tables" under the supervision of the Astronomer Royal. His expeditions were mostly behind him. They had taken him to South Africa, to St. Helena, to America, and to Northern Ireland, all in the service of the Royal Society.

The American Philosophical Society held at Philadelphia for Promoting Useful Knowledge had made Mason a member while he was still in America, on March 27, 1767. And Charles Mason sleeps in Pennsylvania soil. He was laid to rest on October 26, 1786, in Christ Church Burying Ground at Fifth and Arch Streets, Philadelphia. The grave is not marked and its exact location is unknown. Benjamin Franklin and his wife Deborah rest nearby.

Charles Mason rode north during the summer of 1773, in the service of the Committee on Attraction, seeking a hill "of sufficient height, tolerably detached from other hills, and considerably larger from East to West than from North to South." He selected Schehallien, and the Committee approved the selection.

King George III is remembered by most Americans for his political views. Many Britons recall his generous benefactions to

science and to scientists. He had financed generously the expeditions sent by the Royal Society to observe the transits of Venus of 1761 and of 1769, and after all expenses had been paid a substantial balance remained. Inquiry was made as to how His Majesty would have it disposed of. His reply was that the Society should "lay it out in such manner as they thought proper, and was most agreeable to the end of their 'institution.'" It was decided to use the balance in meeting the expenses of the experiment about to be performed on Schehallien.



SCHEHALLIEN FROM KINLOCH RANNOCH

*Showing the northern face.*

*Photo by Valentine, Dundee*

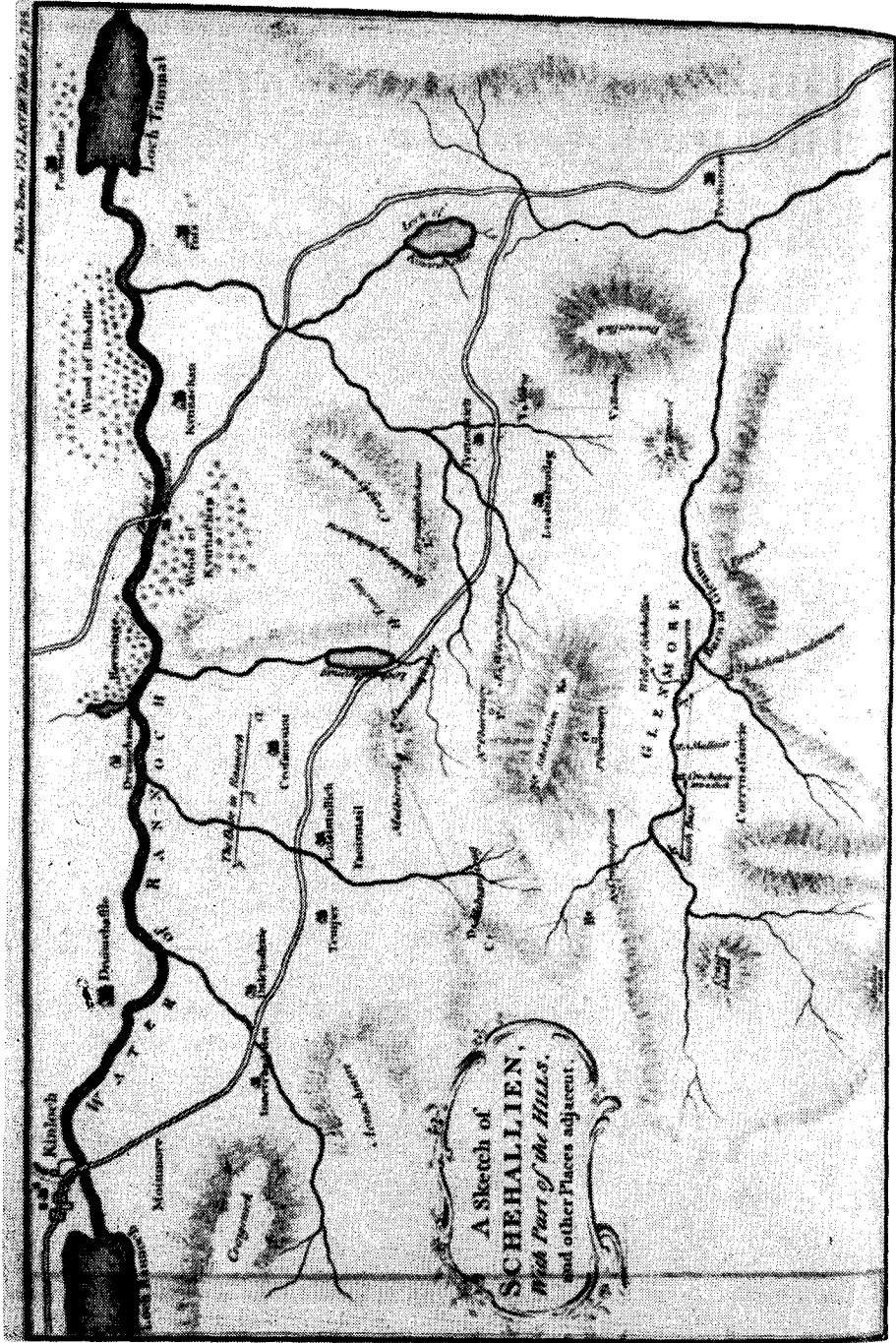
Charles Mason was offered the work of making observations on the mountain, but he found the terms unsatisfactory and declined. Reuben Burrow, who had been Maskelyne's assistant observer at Greenwich, agreed to undertake the work. But finally the Committee appealed to Maskelyne to do the work in person. Maskelyne sought permission from King George III to absent himself from his duties at Greenwich. His request was granted at once with the directive that he remain on the mountain as long as should be necessary to complete the observations. The observing was done during the late summer and the autumn of 1774.

A study of the map here reproduced may make clear what was done on the mountain and around it. The original map (from Charles Hutton's report) was published in *Philosophical Transactions*\* for 1778. At the point marked S° Observatory, located half-way up the hill, living quarters and a field observatory were erected. The plumb-line was hung and the telescope linked with it was trained sharply upon prominent stars as they crossed the meridian. Only stars that crossed near the zenith were observed. The angular distance of each star from the "zenith" (as indicated by the plumb-line) was noted with great care. Thirty-nine stars were observed and 169 observations were made, the first being made on July 20. They were continued on the south side until August 15. During this period a meridian line was established and marked through the observatory on the south side of the hill. Two cairns were erected on the ridge of the mountain and sharply marked, and a survey of the mountain was put in progress from an array of stations that completely surround it, each at a considerable distance from it. These stations and the courses joining them are shown on the map. And two base lines are shown, one just west of south of Schehallien, the other at a greater distance and somewhat west of north.

In late August all equipment was transported over the ridge of the mountain and the observatory and living quarters were re-established at the post marked N° Observatory on the map. From this station 168 observations were made on 37 stars, nearly all of which had been observed from the S° Observatory. From both sides of the hill 337 observations had been made on 43 different stars. A meridian line was established and marked through the N° Observatory. All observations of the stars were corrected for the effects of refraction and for precession, aberration, deviation, and nutation, as is usual.

Had all of these observations been made on level land far from any attracting body, a very precise determination of the difference of latitude of the N° Observatory and the S° Observatory would have been made. As the observations stood, a shift of the zenith to the northward among the stars was indicated of 54.6 seconds. But the survey made around the mountain showed that the N° Observatory stood 42.94 seconds north of S° Observatory. The difference,

\*Vol. 65, Part 2, p. 788.



From Philosophical Transactions, 68, 268 (1778)

11.7 seconds, was accounted for by assuming that at S° Observatory the zenith had appeared to shift southward among the stars because the bob of the plumb-line had been drawn by gravitational attraction northwards towards the mountain. At N° Observatory the apparent shift had been northward because the bob had been pulled southward.

This was the first decisive evidence in all human history that a mountain attracts the bob of a plumb-line. And the Royal Society proceeded to follow up the achievement. Charles Hutton, one of its distinguished fellows, professor of mathematics at the Royal Academy, Woolwich, analyzed all the data that had been accumulated at Schehallien, the astronomical observations and the results of the surveys made by Maskelyne's coworkers. The surveys had continued during 1775 and 1776. Hutton concluded that the average density of the material in the whole Earth is nine-fifths of the average density of the material in Schehallien. Various estimates of the average specific gravity of the material in the mountain gave values for the average specific gravity of the material in the Earth ranging from 4.5 to 5.5. Isaac Newton at one time had suggested that the value might be 5 or 6.

For his "Curious and Laborious Observations on the Attraction of Mountains" the Royal Society awarded Nevil Maskelyne its Copley Medal for 1775. To Charles Hutton went the Copley Medal for 1778 for "The Force of Fine Gunpowder, and the Initial Velocity of Cannon Balls." The award for 1773 had been to Joseph Priestley (later of Northumberland, Pa.) for "Many Curious and Useful Experiments on Different Kinds of Air." At each of these presentations Sir John Pringle, President of the Society from 1772 to 1778, delivered one of his famous Copley Addresses.

The Copley Medal for 1753 had been awarded to Benjamin Franklin for "Curious Experiments and Observations on Electricity." This "ancient olive-crown of the Society" has been awarded annually since 1731, except for a few omissions, "to the author of the most important scientific discovery, or contribution to science, by experiment or otherwise."

The Honorable Henry Cavendish was mentioned as a member of the Committee on Attraction. He was the son of Lord Charles Cavendish, a nephew of the third Duke of Devonshire, a man of great fortune, and a scientist of the highest rank. He took the

problems of the mutual attractions of small bodies and of the mean specific gravity of the Earth away from the mountains and into the laboratory. Here he constructed a sensitive torsion balance, an improvement of a balance of similar design contrived by the Rev. John Michell years before but never used. With his balance Cavendish measured the attractions between metal spheres a few inches in diameter with meticulous care. Possible effects of currents of air, electric charges and magnetic materials were eliminated. The attractions of other parts than the spheres were allowed for. The report, a classic of physical science, was read to the Royal Society on June 21, 1798. It was published in *Philosophical Transactions* for that year. It announced 5.48 as the mean specific gravity of the Earth. Corrections of numerical errors made no substantial change in the outcome. Successive repetitions of the Cavendish Experiment with modifications and improvements through the nineteenth century brought results close to Cavendish's 5.48.

Pennsylvanians have not neglected the gravitational attractions of small bodies and the mean specific gravity of the Earth. In 1899 A. Stanley Mackenzie, who was then professor of physics at Bryn Mawr College, published a volume in a series of "Scientific Memoirs," this one entitled, "The Laws of Gravitation." It reviews all fundamental work in the field from 1600 to 1900. It lists 200 major contributions that were published during the three centuries. And it exhibits in tabular form 54 major determinations of the mean specific gravity of the Earth reported from Bouguer's result in 1737 to Berget's result in 1893. All were derived from experiments on small bodies, including mountains and other small portions of the Earth, and all confirm Isaac Newton's inspired estimate that "the quantity of the whole matter of the earth may be five or six times greater than if it consisted all of water."

Pennsylvanians continue to study Gravitation, the mutual attractions of small bodies, and the mean specific gravity of the Earth. In the *Scientific Monthly* for May, 1954, Paul R. Heyl of Washington, D. C., writes on "Gravitation—Still a Mystery." Dr. Heyl was born in Philadelphia, was educated there, and for a decade taught physical science in high schools of Philadelphia. From 1920 to 1942 he was a physicist in the National Bureau of Standards, and during that period he did notable work in Gravitation. In the constant temperature vault at the Bureau, 40 feet under ground,

he set up a torsion balance in vacuo and on it measured the attraction between accurately-made 150 pound steel cylinders and small spheres of gold, platinum, and optical glass. All of the experience of past centuries was heeded. From his observations Dr. Heyl calculated the constant of gravitation which is the attraction of a small gram sphere for its duplicate when their centers are a centimeter apart. His value is accepted round the scientific world as the best yet obtained. And the value of the mean specific gravity of the Earth deduced from it is held in like esteem. It is 5.517.

In his article, Dr. Heyl points out some uses to which gravitational studies are put. They have been used for centuries in figuring the shape of the Earth's surface, something that must be done before large areas can be mapped. And of recent years they have aided prospectors in locating deposits of oil. Many geological structures that contain oil reveal themselves when the gravitational attraction on the surface above them is surveyed. They are different from surrounding territory. Some Pennsylvanians are experts in geophysical prospecting and their services are in great demand.

And to these uses may be added the comment that gravitational studies strive to answer questions that alert people ask. Prospects are bright that Pennsylvanians will continue to study Gravitation in all its aspects.

#### ACKNOWLEDGEMENTS

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Photographs of Schehallien were secured from Scotland with the advice and aid of Mr. and Mrs. William Robertson of Wayne, Pennsylvania. Both were born in Scotland and spent their early years there, Mr. Robertson in Perthshire.

Schehallien is the spelling used by Maskelyne and Hutton. Current maps of the Ordnance Survey use Schichallion.

Information about decisions of Council of the Royal Society of London has been taken from film copies of Minutes of Council (from the mid-eighteenth to early nineteenth century). These copies are deposited in the Library of the American Philosophical Society, by permission of President and Council.

Mr. William W. Montgomery and Dr. Joseph S. Hepburn furnished information about the place of burial of Charles Mason.

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