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Inge Lehmann Discovered the Inner Earth Core in 1936

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Fig. 1: Inge Lehmann. Photograph reproduced from Brush (1980, fig. 9)

In 1936, the Danish seismologist Inge Lehmann (1888–1993), suggested from the analysis of seismic P-wave data that the Earth must have an inner core – an important breakthrough in the understanding of the nature of the Earth's interior.

Inge Lehmann (Fig. 1) was born on May 13th, 1888, near Copenhagen, Denmark, as one of two daughters of Alfred Lehmann, a professor of psychology at the University of Copenhagen. The child was sent to a small private school run by Hannah Adler, an aunt of famous physicist Niels Bohr. This school was co-educational, a feature that was rather unusual and daringly progressive for the time. In 1907, Lehmann entered the University of Copenhagen to study mathematics. She also attended courses in physics, chemistry, and astronomy. In 1910, Lehmann took the first part of the required examinations and then continued her studies at Newnham College, Cambridge (U.K.). Newnham College was one of two women's colleges in Cambridge at that time, but though allowed to attend university lectures and sit the examinations, women were not admitted to university degrees in Cambridge before 1948.

In December, 1911, Lehmann became seriously ill and was forced to return home, where she worked for some years as a 'computer' or calculator in an actuary's office. Computing, i.e. the organization and review of data would always be a part of Lehmann's scientific life. Human 'computers' work much slower than the electronic ones and have difficulties to deal with vast amounts of data, however they have the advantage of being able to reflect on their work – a fact that would prove to be crucial in Lehmann's discovery.

In 1918, Lehmann resumed her university training as mathematician at The University of Copenhagen and graduated in the summer of 1920. From February, 1923 onwards, she worked as assistant to the professor in actuarial sciences. Then, in 1925, she became assistant to Professor N.E. Nörlund, Director of the geodetic institution, Den Danske Gradmaaling.

Nörlund had become interested in establishing seismic stations in Denmark and Greenland, and the best available seismographs were used for the new stations. Lehmann began to do seismic work and studied seismology as an autodidact. In the summer of 1927, Lehmann had the opportunity to visit some notable European seismic stations such as Darmstadt and Hamburg (Germany), Strasbourg (France), De Bilt (The Netherlands) and Uccle (Belgium). In Darmstadt she spent several months under the tutelage of seismologist Beno Gutenberg.

In the summer of 1928, Lehmann obtained a master's degree in geodesy from The University of Copenhagen, submitting a thesis on a seismological topic. The same year, she was appointed chief of the seismological department of the new geodetic institute, a post that she held until her retirement in 1953. However, to call her "chief" is rather stretching the term, since most of the time, she did not have assistants, not even for office work.

Her task was to keep the instruments in Copenhagen well-adjusted and to instruct the staff of the remote Greenland stations. She interpreted the institute's seismograms and published the bulletins of the seismic stations. Original scientific research was not regarded as part of her duties, but she was free to pursue it, if she liked, and she published thirty-five papers during the period of her appointment. Apart from her interest in the travel-time curves of the various types of seismic waves, which in 1936 led her to suggest the existence of an inner core for the Earth, she made determinations on the reliability of seismic stations in Europe and discussed how to obtain meaningful observations. She also worked on small local earthquakes and on microseismic wave motions generated by storms over the Arctic and North Sea.

Like most female scientists of her day, she never married. To have done so would almost certainly have meant the end of her scientific career.

After her retirement in 1953, and when relieved from routine duties, Lehmann entered a second, fruitful research phase, working on the structure of the upper Earth's mantle and its seismic discontinuities. She frequently visited seismic observatories in the USA and Canada. It was in this late phase of her career that she started to receive international recognition in the form of numerous awards for her work and for her exceptional expertise in observing and interpreting seismological raw data. Recognition in Denmark took some time: in 1968, she received an honorary PhD from the University of Copenhagen in her 80th year. She lived another 25 years to enjoy it.

P'

The capital letter P is used to denote longitudinal or 'pressure' seismic waves. Those that travel in the Earth's mantle and crust only are represented by P; P' represents P-waves that pass through the mantle into the core, and then pass through the mantle again. Thus, Inge Lehmann's paper P' is concerned with the travel times of P-waves which after a big earthquake run through the whole globe and thus also penetrate the earth's core.

Such P-waves reach the far side of the globe significantly later than would be expected if the globe were homogeneous. They are retarded by the fluid core, where seismic P waves pass more slowly than through the mantle. Also, the seismic waves are deflected when entering the different medium of the core and become focussed as in a huge, crude lens. Therefore, a shadow zone is created, in which no seismic waves are recorded. However, with the development of better seismic detectors in the 1930s, it became clear that the shadow zone was not completely devoid of seismic activity. But this disturbing news was usually explained away with inhomogeneities within the mantle and with special effects at the core/mantle-boundary. Lehmann, however, noticed, that P-Waves within the shadow zone where weak only if you concentrated on surface parallel movements, which where best measured by contemporary seismometers. The vertical movement however, was quite strong. This is the situation in which Lehmann wrote her paper. As an alternative explanation for seismic activity within the "shadow zone", she postulated the existence of an inner earth's core, with a faster velocity of seismic waves compared to the outer one (Fig. 2).

Two years after Lehmann's paper P', Beno Gutenberg and Charles Richter calculated from available travel-time data an inner core radius of about 1,200 km and a mean inner core P velocity of 11.2 km/sec. In 1939, Harold Jeffreys showed that the older interpretation of P' phases within the shadow zone as diffracted waves was untenable, supporting thus Lehmann's three shells model. The rate of velocity increase at the boundary of the inner core remained controversial for about twenty years, when a true discontinuity was finally accepted. That the inner core was solid, as opposed to the fluid outer core, was proposed independently by Francis Birch in 1940 and by Keith Bullen in 1946.

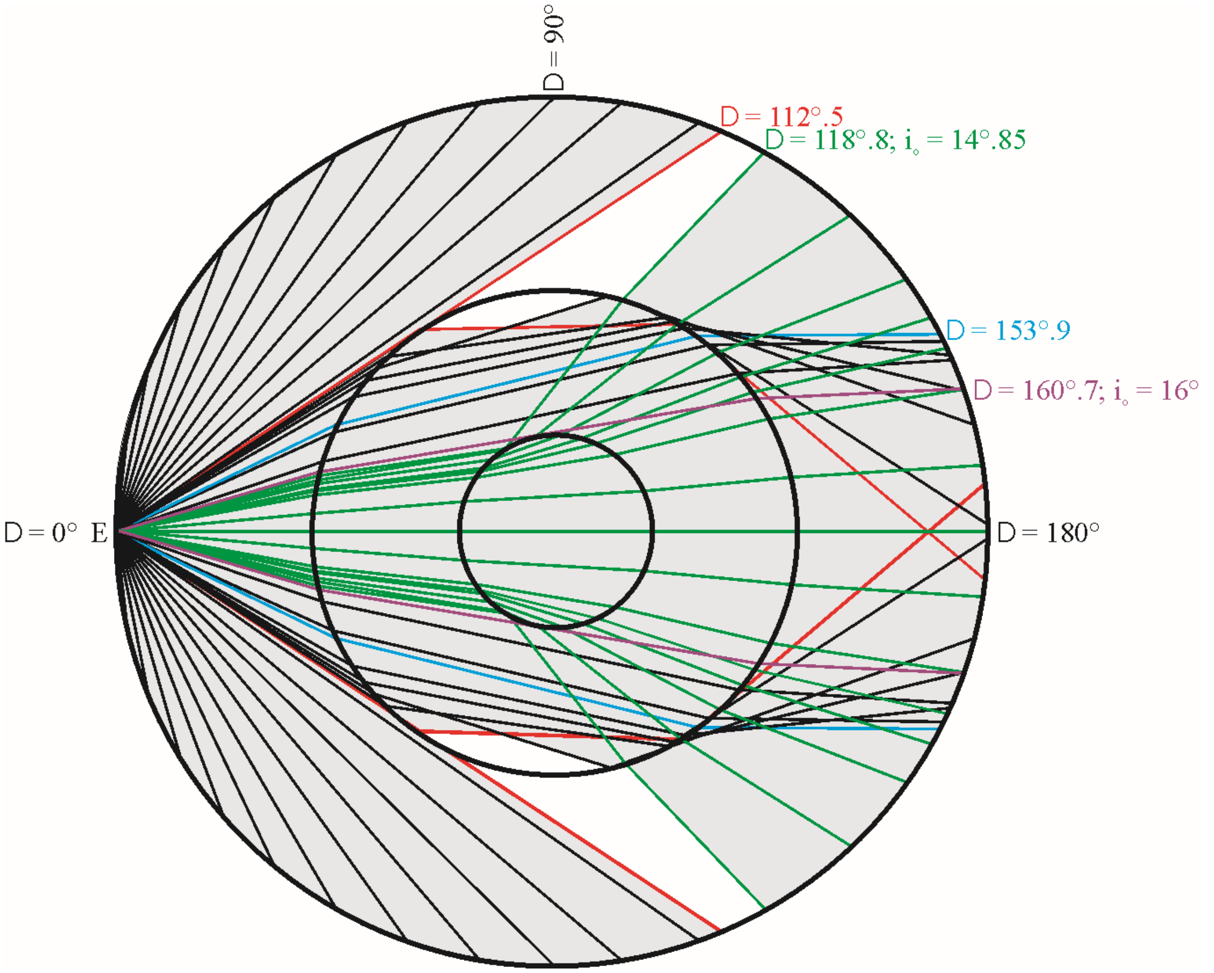

Fig. 2: To show the effect of an Inner Earth Core, Lehmann calculated the effect in using a very much simplified earth model, which made it very clear and easy to understand, and this simplification of the problem, omitting unnecessary detail and complications, was seen as Lehmann's strength and later helped to gain recognition and acceptance of her idea. For the purpose of illustrating the characteristics of the P and P' curves, Lehmann adopted the simple assumption of constant velocity of 10 km/sec in the mantle, 8 km/sec in the outer and 8.6 km/sec in the inner core. This figure is a visualisation of Lehmann's calculations, drawn by the author of this Anniversary using Lehmann's original numbers: The outer Earth's Core with its lower P-wave velocity compared to the mantle acts as a converging lens for seismic waves creating a shadow zone, whereas the inner core with its somewhat higher P-wave velocity acts as a diverging lens, shedding seismic energy into the shadow zone.

Further Reading

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