What can seismic waves tell us about Earth's history?

Studying the hidden structure of our planet is essential for understanding Earth's geological past and predicting its future. **Dr Fiona Darbyshire,** a seismologist at the **Université du Québec à Montréal** in Canada, is using seismic waves to model Earth's rocky, outer layer and investigate the processes that have shaped our continents over billions of years.

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Using information from seismic waves to model Earth's structure

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PROFILE

Talk like a...

seismologist

Crust — the thin, outermost layer of Earth, made of solid rock and forming the continents and ocean floors

Lithosphere — the rigid outer layer of Earth, made up of the crust and part of the upper mantle

Mantle — the layer beneath the Earth's crust, consisting of hot rock that, although solid, moves slowly over geological time

Seismograph — an instrument used to detect and record seismic waves

Seismometer — the specific part of the seismograph that detects ground movement

Seismic waves — vibrations that travel through Earth's interior, caused by various sources like earthquakes or explosions

Tectonic activity — the movement and interaction of Earth's tectonic plates, which causes earthquakes, volcanic eruptions, and the formation of mountains

Mantle plume — a column of hot, buoyant rock rising from deep within the Earth's mantle that can cause volcanic activity and affect the lithosphere

If we could slice through Earth to see a cross-section, we would reveal distinct layers: a thin crust, a thick mantle, a molten outer core and a solid inner core. However, since we cannot dig thousands of kilometres into the planet, scientists rely on geophysical techniques like seismology – studying seismic waves that travel through Earth's interior – to understand its structure.

Dr Fiona Darbyshire, a seismologist at the Université du Québec à Montréal, is investigating how seismic waves move through ancient rock formations in Canada, Greenland and the northern USA to understand how continents formed, evolved and continue to change over billions of years.

How do scientists study Earth's ancient formations?

Some of the oldest rocks on Earth, which are more than four billion years old, are found in Canada and Greenland. These ancient formations provide a unique window into the history of the planet, preserving evidence of the geological processes that shaped the continents over billions of years.

"We have an ideal 'natural laboratory' to study the history of the Earth and plate-tectonic processes over a long timescale," says Fiona. "Geological maps can show us the distribution of rocks of different ages and types at the surface, but to get the entire picture, we need to understand the structure of the continents below the surface, down to several hundred kilometres in depth." To build a complete picture of


Making the final checks and adjustments on a newly-installed temporary seismograph in central Québec, Canada.

Earth's structure, scientists use seismic waves, which travel at different speeds depending on the type and temperature of the rock. By analysing these wave speeds, seismologists like Fiona can create detailed models of Earth's crust and mantle, much like medical scans reveal hidden structures inside the human body.

What are seismic waves?

"A seismic wave is the transmission of vibrations through the Earth," explains Fiona. "This may be caused by a fault rupturing to produce an earthquake, but could also be caused by other sources, such as explosions, ocean waves crashing on the shores of continents, and even human activities like moving vehicles."

These waves move through rock in different ways. Some compress and expand the material as they pass through, while others create a side-to-side motion. A good way to picture this is by pushing compared to shaking one end of a Slinky and watching the movement travel along its length.

How are seismic waves measured?

When seismic waves reach the Earth's surface, they cause the ground to move slightly in different directions – up and down or side to side. To measure this movement, scientists use a tool called a seismograph. The earliest seismographs used a weight attached to a spring or pendulum that would move with the ground motion, while a pen attached to the weight would record the movement on paper. Today's seismographs still rely on the same basic principle, but modern versions use electronics and sensitive equipment that convert the movement into electrical signals.

"At a typical seismograph station, the seismometer (the instrument that detects the ground motion) is connected to a digitiser (a type of computer), which records the electrical signals and stores the data," explains Fiona. The equipment needs a reliable power source – either a regular power outlet in a building or large batteries charged by solar panels in the field.

What can the 'sound' of a seismic wave reveal?

The speed of seismic waves as they travel through Earth can reveal a lot about the materials they pass through. Different types of seismic waves provide complementary information, helping scientists piece together a clearer picture of Earth's structure. For example, different types of body waves move through Earth's deep interior with different speeds and types of motion, whereas surface waves are trapped in the upper layers of the Earth and travel around, rather than right through, the planet.

Fiona's research aims to answer several key questions, such as how the thickness and composition of the Earth's crust and lithosphere vary across regions, and what the structure of the crust and mantle tell us about tectonic activity and mantle flow. Additionally, her work investigates the evolution of continents: how were they formed, how have they changed over billions of years, and what processes govern their stability?

What have been Fiona's key findings so far?

"One of our main findings is just how complex and variable the structures beneath Earth's surface really are," says Fiona. While scientists have long known that the surface geology varies widely, older studies lacked the resolution to show that the crust and upper mantle are just as diverse. Fiona's research has provided a clearer picture, especially in Canada and Greenland, where deep seismic imaging has revealed structures linked to the early formation of the continents.

For example, seismic models show strong evidence of tectonic activity beneath Hudson Bay (a large body of water in northeastern Canada) dating back at least two billion years. Fiona's findings also highlight significant variations in the thickness of the lithosphere, some of which align with surface geological features, while others do not, suggesting deeper, hidden processes at work. "In addition to thickness variations related to the formation and assembly of the continent, we can also see evidence of later tectonic processes at work. For example, changes in thickness or physical/compositional properties related to mantle plumes have affected the lithosphere at different periods in Earth's history," says Fiona.

What does the future hold?

"I plan to revisit some of my existing seismic models and datasets using different analysis methods (which I am currently learning!) and tease out extra information from them about deformation of the lithosphere and interaction of the lithosphere with the flowing mantle beneath the plate," says Fiona. "With collaborators, I am also hoping to expand the seismograph networks further east in Canada, so we can look in detail at some regions that have not yet been studied in high resolution."

About *seismology*

Seismology is the branch of geophysics that studies earthquakes and seismic waves – vibrations that travel through Earth's interior. These waves provide critical information about the planet's deep structure, helping scientists understand everything from plate tectonics to earthquake hazards. Seismologists also use seismic data to explore natural resources, study volcanic activity, and monitor human-made disturbances like explosions or mining operations.

Seismology offers a mix of theoretical analysis, computer modelling, and hands-on fieldwork. "I spend a lot of time in front of a computer, analysing earthquake signals and running different codes to measure them, but I also get the chance to do fieldwork, installing seismographs in regions of interest," says Fiona. "Many of the seismographs I've installed are in regions with interesting landscapes and wildlife, which is always a treat to see. Then there are the moments of discovery, when the measurements are complete, the codes have run and the models are ready for interpretation – that's always an exciting time, and an interesting challenge to make sense of the new results."

There are several challenges of conducting research in remote locations. "First, there is the issue of getting the scientists and equipment to the location," explains Fiona. "Depending on the region, there may be road access, which requires a lot of driving, or we may try to place the seismographs near existing infrastructure with air transport available, such as remote villages, mining exploration camps, scientific bases, or hunting and fishing lodges. If the research station is in a very remote area, helicopter transport may be needed, which is costly." Once the stations are running, data can either be stored on-site, requiring periodic visits to collect it, or transmitted via satellite, internet, or phone networks, though this can also be expensive.

Seismology is highly collaborative, with scientists working together to analyse data, improve seismic monitoring systems, and develop better hazard assessment tools. "There's the scientific collaboration with colleagues and students, based on the main research questions, data analysis, etc., but also special collaborations related to fieldwork and the seismograph networks," says Fiona. "I work closely with scientific and technical staff responsible for the equipment, and with public and private landowners in the regions where I want to install seismographs."

The future of seismology offers exciting opportunities across various areas. Fundamental research will continue to explore Earth's structure and dynamics at different scales. There is also growing demand for earthquake monitoring, improving seismic hazard assessments, and developing better warning systems. "There is a great deal of interest in prospecting for critical minerals that are essential for 'green' energy, and seismic surveys play a key role in this type of exploration," explains Fiona. "In addition, smaller-scale seismic surveys of the shallow subsurface are important for environmental studies and urban engineering."

Pathway from school to *seismology*

There are multiple pathways into seismology, depending on your interests. "In school, physics and maths are essentials," says Fiona. "Some schools offer geology courses, which would be a good option to take, if available."

At university, you can enter seismology through a variety of degree programmes, including geophysics, geology, physics, engineering, computer science and environmental science. Since seismology involves data analysis and coding, having programming skills is also beneficial.

Explore careers in *seismology*

To learn more about seismology, Fiona recommends resources such as the EarthScope Consortium and its SAGE Facility website (**iris.edu/hq**), Earthquakes Canada (**earthquakescanada.nrcan.gc.ca/index-en.php**) and the US Geological Survey's earthquake programme (**usgs.gov/programs/earthquake-hazards/earthquakes**).

"Societies of interest include the Canadian Geophysical Union (**cgu-ugc.ca**), the American Geophysical Union (**agu.org**), the Seismological Society of America (**seismosoc.org**), the European Geosciences Union (**egu.eu**) and the International Union of Geodesy and Geophysics (**iugg.org**)," says Fiona.


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Q&A

Meet *Fiona*

What inspired you to become a seismologist?

I have been interested in earthquakes, volcanoes, general physical science, and anything related to natural history from a very early age – including repeated demands to my parents for multiple rides on the earthquake simulator during a trip to the Natural History Museum! After watching my first lunar eclipse, I thought about going into astronomy, then considered meteorology, but I got into geoscience properly at university, where my 'natural sciences' degree allowed for a broad range of subjects in the first year. I took geology as part of that degree and was fascinated by plate tectonics, earthquakes and seismological methods.

What experiences have shaped your career?

Quite a bit of serendipity at times! I had not originally considered moving away from the UK (where I did all my studies), but an interesting postdoctoral opportunity came up with the Geological Survey of Canada, and things snowballed from there. I've also had several good experiences at conferences, where chance encounters have led to fruitful new research collaborations with long-term outcomes that have improved my research.

How do you manage the pressures of work?

If I commit to a task, I will do everything I possibly can to make sure that I follow it through and make it work. I ensure I ask colleagues for advice and help if I'm uncertain about something – I'm a great believer in the advantages of teamwork.

As much as I enjoy my work, it's good to do something completely different sometimes. I enjoy spending time in nature (including vacations in geologically exciting places), I sing in two choirs, and I'm a keen ballroom dancer too.

What are your proudest career achievements so far?

I get great satisfaction from mentoring students (both undergraduate and postgraduate) and postdoctoral researchers. The best outcomes are when they continue in research, and we have a chance to continue collaborating.

In 2017, I was asked to be the president of the local organising committee for an international geophysical conference to be held in Montreal in 2019. This involved forming the committee, working closely with the international organisation (the International Union of Geodesy and Geophysics) and its scientific programme committee, hiring and collaborating with a professional conference organiser, and a mad scramble to get everything in place for the event. It was a huge amount of work, but we pulled it off and the conference was very successful.

What are your aims for the future?

To improve understanding of continental evolution using seismological investigations, to mentor new generations of students and postdocs, and, above all, to continue learning more about the Earth.

Fiona's *top tips*

1. Find a subject you can be passionate about and see where it can take you.
2. Persevere! Sometimes studies and work can feel very daunting, but keep at it, and don't be afraid to ask for help and advice.
3. Never lose your sense of curiosity. Remember that learning is a lifelong process.