The University of Oxford Department of Earth Sciences

EARTHSCIENCES

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Deep moonquake properties: deciphering stresses and deformation patterns

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Key Words	**Geophysics, Earthquakes, Moon, Seismology, Lunar Structure**

Overview

Deep moonquakes share a number of enigmatic properties with deep terrestrial earthquakes. First, their occurrence is surprising. They occur at depths and temperatures where ductile, not brittle, deformation is expected. They occur in nests. Certain regions or faults host similar moonquakes over and over. But some of the moonquakes and earthquakes in the nests are different. In these moonquakes, the fault seems to slip in the opposite direction. Finally, moonquakes are tidally modulated. Moonquake rates in some nests change strongly in response to Earth-induced stresses.

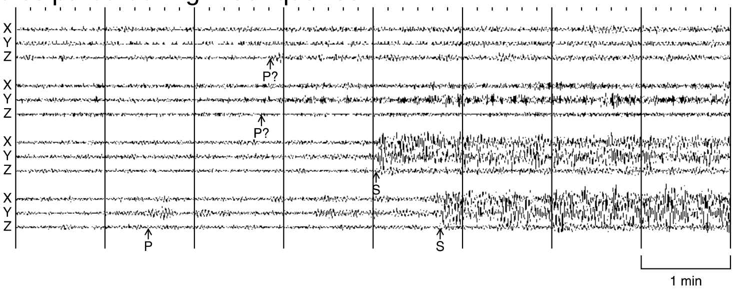
In this project, you will first use seismic data from the Apollo missions to investigate moonquake properties. You will use standard spectral amplitude analysis as well as new coherence-based techniques to estimate the relative locations, rupture extents, durations, stress drops, and radiated energies of a large number of moonquakes.

You will use similar techniques to determine the properties of earthquakes in isolated deep nests on Earth.

You will examine how your estimated properties vary in space and time to answer questions about lunar deformation: (1) how small-scale lunar structure controls moonquake occurrence, (2) whether tidal or tectonic stresses drive moonquake occurrence, and (3) which fault weakening processes are possible.

You may choose to focus on why some earthquakes and moonquakes slip in the opposite direction to the rest of the events in their nests. Some researchers have proposed that a single fault slips in both directions---that the stress on that fault changes sign over the course of the moonquake cycle. In this case, the tectonic stress on the fault is much smaller than the tidal stress (Weber et al, 2010). But other researchers have proposed a plug flow model---that there are two adjacent faults, with a plug of material between them. To assess these models, you will examine the relative locations of moonquakes with various slip directions and consider how earthquake properties vary with earthquake occurrence and with timing in the tidal cycle, on Earth or on the moon. For instance, if all moonquakes rupture the same fault, you may find that stress drops in normal-direction moonquakes are increased when they occur immediately following reverse-direction moonquakes that effectively load the fault.

To better develop specific predictions, you may simulate the evolution of fault slip under tidal stresses with physical models of frictional sliding. And you may further constrain those physical models by using your radiated energy and stress drop estimates to determine how much heat is dissipated during moonquakes.



Seismic signals one moonquake recorded on 4 3-component seismic stations. From Nakamura et al, 2005.

Methodology

To determine moonquake properties, you will use a range of seismological techniques, including corner frequency and coherence analysis. You will have to adjust these techniques to accommodate the lunar seismic data, which was recorded on just a few instruments and which includes long-duration seismic signals produced by large scattering near the lunar surface.

To simulate earthquake ruptures, you will use a suite of existing numerical codes, to be modified as needed.

Timeline

Years 1-2: training, data analysis and technique development, estimation of moonquake and earthquake properties.

Years 2-3: examination of properties as a function of time and tidal cycles, model assessment, fault slip simulations, synthesis.

Training & Skills

You will be trained in a range of seismological techniques to analyse earthquake properties and will develop understanding of deformation on the Earth and moon. You will interact with researchers working models and on geological and geophysical observations and will attend conferences and workshops in the UK, Europe, and the US. You will also receive training in scientific writing and presenting.

References & Further Reading

Frohlich, Cliff, and Yosio Nakamura. “The Physical Mechanisms of Deep Moonquakes and Intermediate-Depth Earthquakes: How Similar and How Different?” *Physics of the Earth and Planetary Interiors* 173 (April 1, 2009): 365–74.

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Further Information

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This project would be suited to a student interested in earthquake mechanics and lunar and terrestrial deformation, with a background in geology, physics, engineering, or computer science.