Deep earthquakes: observations, experiments and explanations

Specialist discussion meeting of the Royal Astronomical Society

Friday 10 May 2019

Burlington House, London

Schedule

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Time		Speaker	Institution	Title
10:00	10:30			*Arrival and coffee*
10:30				*Meeting starts*
10:30	10:40			Welcome and introduction
10:40	11:20	Hiroo Kanamori (invited)	Caltech	Energy partitioning during deep earthquakes
11:20	11:30			*Discussion*
11:30	12:00	Burak Sakarya	ISC	Enhancement of the ISC-EHB Dataset
12:00	12:30	Marcel Thielman	Bayerisches Geoinstitut	Earthquakes below the brittle–ductile transition: The role of grain size assisted thermal runaway
12:30	13:30			*Lunch and posters*
13:30	14:10	Alex Schubnel (invited)	ENS Paris	Mechanics of intermediate and deep earthquakes: experimental evidences
14:10	14:20			*Discussion*
14:20	15:10	Blandine Gardonio (invited)	ENS Paris	The sensitivity of the deep seismicity to large shallow and deep earthquakes in the Japanese subduction zone
15:10	15:30			*Discussion*
15:30				*Close of meeting*

Oral presentations

Energy partitioning during deep earthquakes

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Seismological Laboratory, California Institute of Technology

Despite their occurrence in presumably ductile environments, deep earthquakes are very similar to shallow earthquakes in many attributes. Rapid ruptures normally occur in brittle environments, but they can also occur in ductile environments. However, the ruptures in ductile environments are highly dissipative. Thus, the ratio of radiated energy to the strain energy release (efficiency) can be a good diagnostic parameter for ruptures in a ductile environment. Although seismological methods cannot determine the efficiency, we can show that modern high-quality seismic data can be used to estimate the upper bound of the efficiency and the lower bound of the dissipated energy in the earthquake source region. We can show that for some very large deep earthquakes the dissipated energy can be extremely large resulting in extensive thermal processes (e.g., melting, weakening, and long-term deformation) near the source region. We will illustrate some examples and discuss future research directions.

Enhancement of the ISC-EHB Dataset

***Burak Sakarya**[1] (burak@isc.ac.uk), Bob Engdahl[2], Charikleia G. Gkarlaouni[1], James Harris[1], Domenico Di Giacomo[1] and Dmitry A. Storchak[1]*
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The EHB dataset, as originally developed with procedures described by Engdahl et al. (1998), has been widely used in various aspects of seismological as well as other geoscience studies. In its original form, the EHB dataset covered the period 1960-2008. Considering the recent increase in the volume of data being reported to the International Seismological Centre and the need to apply more rigorous procedures for event selection, data preparation, processing and relocation, we started to revise the original EHB and produce the ISC-EHB (Weston et al., 2018). Therefore the ISC-EHB is currently available for the period 2000-2015 and it includes well recorded teleseismic events from the ISC Reviewed Bulletin that meet specific selection criteria (Weston et al., 2018; Di Giacomo and Storchak, 2016) in order to minimize the location bias due to the 3D Earth structure. To produce the ISC-EHB we perform the following steps: (1) EHB software relocates all the events using ISC starting depths; (2) Near station and secondary phase arrival residuals are reviewed and a depth is adopted or assigned according to best fit and in some instances depths may be reassigned based on other sources; (3) All events are relocated with their new depths and plotted in subduction zone cross sections, along with events from the ISC-GEM catalogue for comparison; (4) These plots are used to confirm or modify weakly constrained depths. The ISC-EHB is freely available via the ISC website (www.isc.ac.uk/isc-ehb), where maps and cross sections of the seismicity in subduction zones are also included. We intend to reconstruct the original EHB dataset for the period 1964-1999 within 2019 and provide one of the finest seismological datasets for general seismicity studies and high-frequency global tomographic inversions. In this contribution we describe the enhanced procedures to create the ISC-EHB and discuss the results in specific areas.

Earthquakes Below the Brittle-Ductile Transition: The Role of Grain Size Assisted Thermal Runaway

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Intermediate-depth earthquakes are ubiquitous events that occur at depths between 50-300 km. Due to the pressure and temperature conditions at these depths, conventional brittle failure is unlikely and alternative rupture mechanisms have to be invoked. Among others, thermal runaway has been proposed as a potential candidate for intermediate-depth earthquake generation. However, this mechanism requires relatively high stresses that might be difficult to attain in the Earth.

A recently developed model that couples shear heating and grain size evolution has shown that the stresses needed for thermal runaway might be significantly reduced if grain size evolution of a two-phase material is taken into account. The odds of this mechanism being an important mechanism in the nucleation of intermediate-depth earthquakes are thus increased through the feedback between grain size evolution and shear heating.

Here we apply this model to the 2013 Wind River earthquake in the western US. Results indicate that for high background strain rates, grain size assisted thermal runaway is indeed a feasible mechanism that could have generated this earthquake. Furthermore, we speculate on possible settings where such high strain rates occur and present 2D models of grain size assisted thermal runaway.

Mechanics of intermediate and deep earthquakes: experimental evidences

Alexandre Schubnel *(alexandre.schubnel@gmail.com)*
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The sensitivity of the deep seismicity to large shallow and deep earthquakes in the Japanese subduction zone

Blandine Gardonio *(blandine.gardonio@gmail.com)*
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Deep-focus earthquakes located at depth between 300 and 700 km within sinking slabs and under high-pressure conditions are still a seismic conundrum. They present a different behavior compared to the shallow ones (depth less than 100 km). One of the main dissimilarity is that only a few aftershocks are observed after a large deep focus event. Can the absence of such seismic clustering be only attributed to different mechanisms between shallow and deep earthquakes or is it the consequence of undetected events?

To bring new insights to these particular seismic events we analyse one of the largest Japanese deep earthquake, the Ogasawara earthquake that occurred in Izu–Bonin, in 2015 below the 660 km discontinuity. We first analyze the mainshock and aftershock sequence (5 earthquakes in total) and then apply the template matching technique by using the P waves of these 5 events as templates. This area also underwent a decrease of the deep seismic rate after the Tohoku earthquake. The impact of the megathrust event is significant and affect an area that is larger than the Izu–Bonin.

Poster presentation

Source Characteristics of Deep Earthquakes using a Higher-Order Moments Approach

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The mechanism of deep earthquakes remains one of the unsolved problems in Earth Sciences, as the pressure and temperature conditions at which they occur should inhibit brittle failure. From a seismological point of view, key characteristics of rupture such as the area, velocity and stress drop of deep earthquakes have not been studied in a systematic and homogeneous way, limiting our understanding of the physics of rupture. A description beyond the point source is required to determine the spatial and temporal characteristics; however, distributed slip models can be very non-unique. Here, we use a second-order moments approach to estimate spatial dimensions, rupture duration and velocity of deep earthquakes from Monte Carlo inversions of seismic waveforms, which are more robust and stable than typical distributed slip models. Preliminary results show that the duration is reliably determined and comparable to independent estimates obtained in other studies. The spatial extent of rupture is harder to reliably determine, notably the smaller spatial dimension, with two families of solutions found for most inversions. Constraints are placed on the minimum value of spatial extent and on the fault's aspect ratio to ensure realistic lengths. We study the 2015 Mw 7.9 Bonin event, the deepest ever recorded earthquake with a depth of 680km, and find a duration of 16.4 – 16.6 s. We also find that the event exhibits a compact spatial extent (with fault dimensions of 20-40km x 10-20km). Similarly, we study two other earthquakes in the Kuril slab with Mw of 7.3 and 7.7 with depths of 497 km and 598 km respectively. We find rupture durations of these events to be 7 – 10 s and 14 – 16 s and they also seem to favour relatively compact spatial extents.

Acknowledgments

The meeting gratefully acknowledges financial support from:

The Mineral Physics Group of the Mineralogical Society of Great Britain and Ireland (https://www.minersoc.org/mpg.html)

The British Geophysical Association (https://geophysics.org.uk)

The organisers thank the Royal Astronomical Society and its staff for their support, both financial and organisationally.