Just over two-thirds (67.1%) of the samples are from males. This means that studies are unevenly statistically powered to detect sex differences. It also means that studies that use the GTEx data as a reference set for comparison with disease state, for example, should take into account the relative proportion of samples from males and females (in both sets) because the relative sex effects on gene expression may not be the same in both.

Also, more than half of the samples come from people 50 years and older. This means that the samples are skewed toward understanding gene expression in tissues that have had many different exposures, potentially contributing to the observed interindividual variation, and does not reflect expression of tissues across the life span. Considering variation across the life span is especially critical for understanding how puberty and menopause, for example, affect gene regulation between the sexes.

Last, representation of global human genetic variation is low, with nearly 85% of samples collected from white people of European descent. There is a dearth of information about genetic variation and gene expression outside of a narrow range of recent genetic ancestries (*14*). This is critical for human health because inferences about genetic risk from one group of people with recent shared ancestry often do not generalize to others (*15*).

Given these limitations of the samples, it is even more surprising—and should be motivating to human geneticists—how much interindividual variation is observed in gene expression among the people included in the GTEx Consortium. This should be a call to projects to expand the representation of human variation in future studies. ■

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SEISMOLOGY

Quiet Anthropocene, quiet Earth

Seismic noise levels that correlate with human activities fell when pandemic lockdown measures were imposed

By **Marine A. Denolle**[1] *and* **Tarje Nissen-Meyer**[2]

Our planet vibrates incessantly, sometimes with notable but more often with imperceptible intensity. Conventional seismology attempts to decipher vibrational sources and path effects by studying seismograms—records of vibrations measured with seismometers. In doing so, scientists seek either to understand the tectonic processes that lead to strong ground motions and earthquake failure (*1*) or to probe otherwise inaccessible planetary interiors (*2*). Progress in these areas of research typically has relied on the rare and geographically irregular occurrence of large earthquakes. However, anthropogenic (human) activities at Earth's surface also generate seismic waves that instruments can detect over great distances. On page 1338 of this issue, Lecocq *et al.* (*3*) report on a quieting of anthropogenic vibrations since the start of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic.

Seismology has benefited from a surge in seismic data volume, computational power, and corresponding methodological development. These advances have enabled seismologists to branch away from traditional source and subsurface characterization of the energy from earthquakes and human-made blasts. The expansion of seismic networks has allowed the observation of previously unseen natural processes as diverse as wildlife activity (*4*), bed load transport in rivers, glacier sliding (*5*), and surface-mass wasting (*6*). In particular, scientists use continuous, ambient seismic vibrations to probe volcanic activities (*7*) and groundwater resources (*8*), to track storms (*9*), and to decipher ice sheet processes (*10*).

Human cultural noise carries seismic signatures mostly at frequencies above 1 Hz, whether the source is transient (entertainment; individual cars, trains, or planes), harmonic (wind turbines, machinery), or diffuse (railroads, highways) (*11*, *12*) (see the figure). Overall, anthropogenic seismic noise levels have increased over the past few decades, and there is a clear positive correlation between this increase and gross domestic product (*13*). But when the SARS-CoV-2 pandemic began to ravage the planet, humans—and Earth—went quiet.

Through a global analysis of seismic noise levels, Lecocq *et al.* found that most sites experienced a drastic reduction in noise levels in the 4- to 14-Hz frequency band. This reduction was much greater than those observed during the annual noise-level cycles of national or religious holidays. Daily CO_2 emissions fell only 11 to 25% (*14*), whereas anthropogenic vibrations dropped by 75% in most countries that imposed lockdown measures. Among countries with the greatest noise reductions were China, Italy, and France—all densely populated places with strong government responses (that is, with high virus-containment indices) (*15*).

Lecocq *et al.* also detected a correlation between seismic data and new types of time series, such as urban audible sound from acoustics data and cell phone mobility data. The authors observed the greatest correlations between seismic noise levels and two common types of pandemic mitigation: surface transportation and nonessential business activities. Lecocq *et al.* did not detect a strong correlation between lockdown and seismic noise reduction at other frequency bands, which might be explained by certain uninterrupted human activities such as power generation (*14*).

For all its hardships, the lockdown has unlocked a door to scientific inquiry into environmental noise and global collaboration. At a fundamental level, low noise benefits traditional seismology, hence the recent noise decrease might open new windows of opportunity; study areas hindered by urban noise might now be targets for detecting microseismicity or for improved subsurface imaging. The crucial next step, as ever in seismology, is to determine the causative nature of these signals beyond their correlation—thus turning anthropogenic noise into informative signals that allow scientists to address new questions. For example: Is there feedback between anthropogenic vibrations and Earth processes? And will seismic monitoring of anthropogenic and environmental activities become complementary, economically valuable alternatives to conventional techniques? To achieve these advances, seismologists must develop new ways of processing data

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and modeling and interpreting results.

Lecocq *et al.* exemplify seismological progress through best practices in scientific research: public data, open-access software and hardware, global cooperation, and crowdsourcing of citizen-science projects. All of the data are publicly available through open-access data centers at the Incorporated Research Institutions for Seismology (IRIS), which hosts and redistributes real-time seismograms from most of the stations participating in the Federation of Digital Seismograph Networks archive. A large proportion of the data used in the Lecocq *et al.* study was measured on seismic instruments that are powered on open-source Raspberry Pi computers hosted by citizen scientists. The Raspberry Shake network counts more than 3500 stations globally, all installed in homes, schools, and research institutions at 2 to 7% of the cost of conventional research or industrial sensors. The authors performed data analyses with open-source Python software Obspy, demonstrating the prevalence and usefulness of open-source community codes in modern science.

Like the pandemic, the seismological community also is shaking up norms. One important example is the reorganization of research activities. Although physical borders are closed, Lecocq *et al.* demonstrate that, much like the global medical research on SARS-CoV-2, seismological research is and ought to be without borders. The new study represents scientists from 25 countries on five continents, and the authors shared the manuscript on public editing platforms (Google Docs, Slack) that allowed for all members of the community to contribute. Indeed, social seismology, which directly relates human activities and seismic waves, has sparked enthusiasm in the scientific community for urban seismology. The fall meeting of the American Geophysical Union (December 2020) will highlight the imminent wave of SARS-CoV-2–related seismological science in a special session called "Social Seismology." ■

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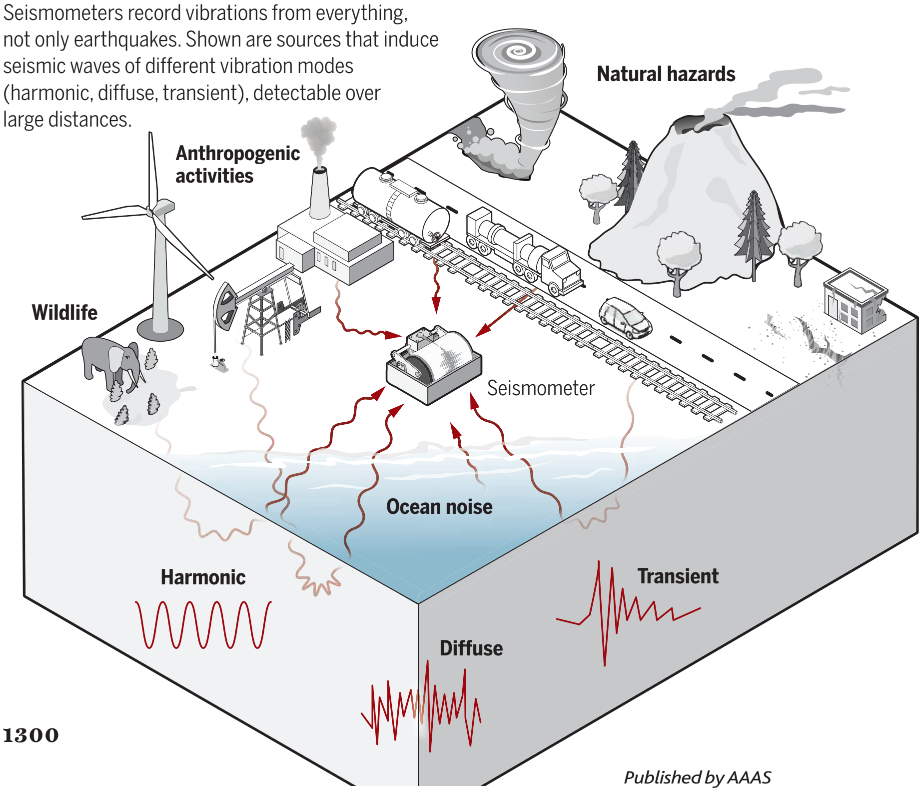
Humans and nature excite seismic waves

Seismometers record vibrations from everything, not only earthquakes. Shown are sources that induce seismic waves of different vibration modes (harmonic, diffuse, transient), detectable over large distances.



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FERROELECTRICS

A key piece of the ferroelectric hafnia puzzle

Dipolar slices explain the origin of ferroelectricity in a material now used for memory devices

By **Beatriz Noheda**[1,2] *and* **Jorge Íñiguez**[3,4]

The ferroelectrics community is witnessing one of those moments in which serendipity changes the course of science. The story of ferroelectric hafnia (HfO_2) resembles that of Cinderella: Not invited to the polar dielectrics ball, nanoscale HfO_2 was dismissed as not being a real ferrolectric, a material that has a switchable spontaneous polarization, despite the experimental evidence for this response. On page 1343 of this issue, Lee *et al.* (*1*) bring us closer to a real-life fairy tale ending with their theoretical calculations, which show that nanoscale HfO_2 becomes a ferroelectric through a different mechanism. Polarization manifests in the form of two-dimensional (2D) slices separated by nonpolar spacers, associated with flat polar phonon bands that allow for homogeneous switching of electric dipoles.

The story starts with research that began in 2006 but was not published until 2011 (*2*). Scientists fabricating silicon transistors with HfO_2-based insulating layers spent several years trying to explain the origin of a strange peak observed in the capacitance-voltage characteristics. The peak looked very much like the ones observed in ferroelectrics when an applied electric field switches the direction of the spontaneous polarization. This feature has made ferroelectrics one of the oldest nonvolatile semiconductor memory types (*3*).

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Science

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