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ENERGY IS CARRIED BY THE EARTH THROUGH SEISMIC WAVES AND SOUND WAVES: FROM EARTHQUAKES

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Abstract
“Seismic Waves and Sound Waves: From Earthquakes to Music” we use to present seismology in an approachable way. It is intended to give the audience an in-depth explanation about earthquake physics and how energy is carried through the Earth by seismic waves. This paper was inspired by three considerations. First, an interactive session requires and enables the participants to be involved more deeply than they would be if they were simply listening. Second, seismic P waves and sound waves share the same nature, both being mechanical and longitudinal waves. Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs. Sound is a mechanical wave. The physics of waves helps to explain the process by which sound is produced, travels, and is received. Sound is a wave that is produced by objects that are vibrating. It travels through a medium from one point, to another point; the third consideration is the power of music to communicate in deep, non-verbal ways.

Key word: “Seismic Waves and Sound Waves, P wave and S wave.

Introduction

Seismology is the study of earthquakes and seismic waves that move through and around the earth. A seismologist is a scientist who studies earthquakes and seismic waves. Art is one of the main tools through which humans have, since their origins, chosen to interpret reality and to communicate. However, the intellectual spheres of arts and science remain as far apart. 50 years of deprecation, is particularly dangerous in the field of seismology, because the subject of earthquakes strongly links a scientific topic to the life, history, and culture of millions of people living in seismically active regions. The lack of seismological education at all levels, in any region, translates into an insufficient awareness of seismic hazard. With the aim of crossing this cultural divide, we have built and tested a format for conveying scientific information about earthquakes through the medium of music. Clearly, it is essential for any country that includes a seismically active region to educate the greatest possible number of people about where, how, and why earthquakes occur. Our goal is to increase resilience to earthquakes and their related hazards by educating people who are, perhaps, impervious to conventional scientific exegesis but respond readily to explanations grounded in the humanities. “Seismic Waves and Sound Waves: From Earthquakes to Music” that we use to present seismology in an approachable way. It is intended to give the audience an in-depth explanation about earthquake physics and how energy is carried through the Earth by seismic waves.

This paper was inspired by three considerations. First, an interactive session requires and enables the participants to be involved more deeply than they would be if they were simply listening to a lesson. Second, seismic pwavs and sound waves share the same nature, both being mechanical longitudinal waves. The third consideration is the power of music to com- municate in deep, non-verbal ways. The congruence between P waves and sound waves allows us to draw parallels between an apparently esoteric science and the audience’s everyday experience. We explain the physical Properties of seismic waves through enjoyable experiments that draw upon concepts that both are familiar to the audience and are fundamentally linked to music, something to which most people respond.

Seismic Waves

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs.

Types of Seismic Waves

There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves.

Body waves

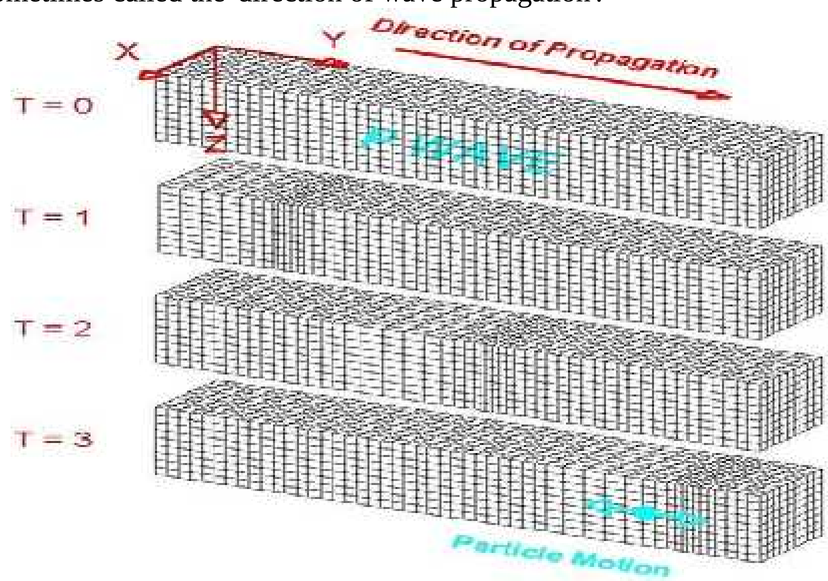
Traveling through the interior of the earth, body waves arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves.

Surface Waves

Surface Waves are also called long period waves because of their long wavelength. They are low–frequency transverse waves (shear waves). They develop in the immediate neighborhood of the epicenter and affect only the surface of the earth and die out at smaller depth. They lose energy more slowly with distance than the body waves because they travel only across the surface unlike the body waves which travel in all directions. Particle motion of surface waves (amplitude) is larger than that of body waves, so surface waves are the most destructive among the earthquake waves. They are slowest among the earthquake waves and are recorded last on the seismograph

P waves

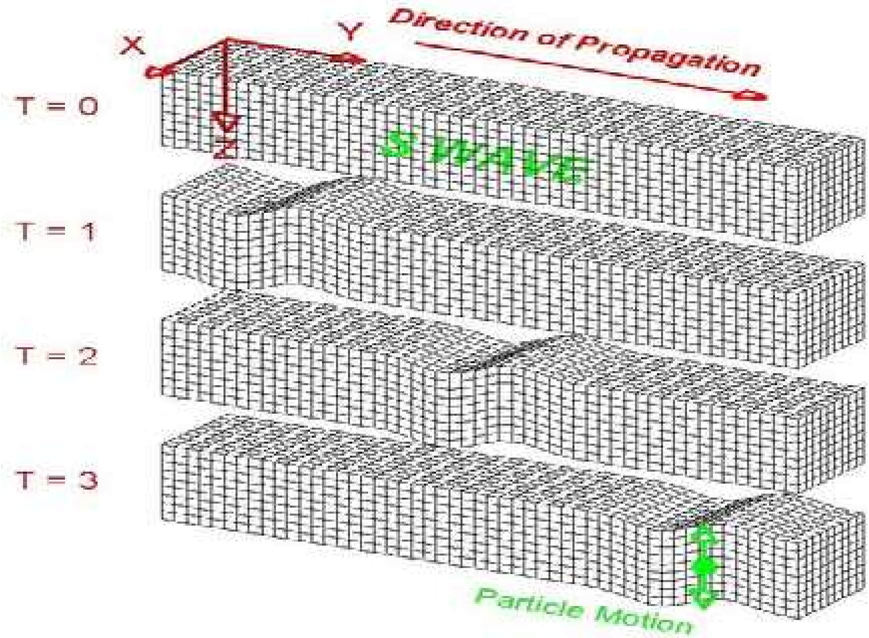
The first kind of body wave is the P wave or primary wave. This is the fastest kind of seismic wave, and, consequently, the first to 'arrive' at a seismic station. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air. Have you ever heard a big clap of thunder and heard the windows rattle at the same time. The windows rattle because the sound waves were pushing and pulling on the window glass much like P waves push and pull on rock. Sometimes animals can hear the P waves of an earthquake. Dogs, for instance, commonly begin barking hysterically just before an earthquake 'hits' (or more specifically, before the surface waves arrive). P waves are also known as compressional waves, because of the pushing and pulling they do. Subjected to a P wave, particles move in the same direction that the wave is moving in, which is the direction that the energy is traveling in, and is sometimes called the 'direction of wave propagation'.



P WAVE TRAVELS THROUGH A MEDIUM BY MEANS OF COMPRESSION AND DILATION.

S waves

The second type of body wave is the S wave or secondary wave, which is the second wave you feel in an earthquake. An S wave is slower than a P wave and can only move through solid rock, not through any liquid medium. It is this property of S waves that led seismologists to conclude that the Earth's outer core is a liquid. S waves move rock particles up and down, or side-to-side--perpendicular to the direction that the wave is traveling in (the direction of wave propagation



S Wave Travels through a medium. Particles are represented by cubes in this model.

Sound Waves

Sound is a mechanical wave. The physics of waves helps to explain the process by which sound is produced, travels, and is received. Sound is a wave that is produced by objects that are vibrating. It travels through a medium from one point, to another point. As is true of all types of waves, specific behaviors, properties, and characteristics apply to sound waves. Similar to the slinky wave, a sound wave carries a disturbance (vibration) from one location (point) to another. For the most part the medium through which it travels is air, although sound waves can just as readily travel though water or metal materials. There must be a source of the wave, some type of vibrating object that is capable of setting into motion the entire chain of events for the disturbance. For sound waves to sound waves, an originating source might be a pair of vocal chords, a stereo speaker, or a tree falling in the forest.

A long-held philosophical discussion has surrounded the question, "If a tree falls in the forest and no one is around to hear it, does it really make a sound?" The point of this debate is that although a sound wave is produced, if there is no receiver is the wave really considered to be a complete sound. Certainly the sound could travel because what is known as "particle interaction" allows the vibrating wave to be transported from one location to another. However, ultimately, the mechanical sound waves need a receiver in order to complete their journey. And although there may be a body present to receive the transmitted waves, because they are vibrating at such a high frequency they are virtually undetectable to the unaided ear.

Sound Waves. Measurement Methods

Waves can be measured in a range of different ways: by their amplitude, wavelength, frequency, speed, and, at times, their phase. Amplitude is a metric method associated with hearing. It is commonly grouped with intensity, loudness, and (or) volume. The wavelength is easy enough to detect, you simply note, during one complete wave cycle, the distance a disturbance travels through the medium in one complete wave cycle .Once every wave cycle, a wave will repeat its pattern. For this reason, the wavelength is sometimes referred to as the length of the repeating pattern or the length of one complete cycle. The speed of sound depends upon the type of medium and its state. It is generally affected by two things: elasticity (ease with which molecules move or degree to which molecules move away from their neutral position when disturbed) and inertia (the denser the air or medium, the more inertia the sound wave has).

Sound Waves. Summary

A sound wave is not a transverse wave with crests and troughs, but rather a longitudinal wave with compressions and rarefactions. These regions of high pressure and low pressure, known respectively as *compressions* and *rarefactions,* are established as the result of the vibrations of the sound source. Sound waves can be measured according to several different paradigms, amplitude, wavelength, frequency, speed, and, at times, phase. Each of these is associated with certain characteristics, such as loudness and pitch with amplitude; rarefactions and compressions with frequency; distance with wavelength; and elasticity and inertia with speed.

An earthquake

An earthquake (also known as a quake, tremor or temblor) is the shaking of the surface of the Earth resulting from a sudden release of energy in the Earth's lithosphere that creates seismic waves. Earthquakes can range in size from those that are so weak that they cannot be felt to those violent enough to propel objects and people into the air, and wreak destruction across entire cities. The seismicity, or seismic activity, of an area is the frequency, type, and size of earthquakes experienced over a period of time. The word *tremor* is also used for non-earthquake seismic rumbling. At the Earth's surface, earthquakes manifest themselves by shaking and displacing or disrupting the ground. When the epicenter of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami. Earthquakes can also trigger landslides and occasionally, volcanic activity. In its most general sense, the word *earthquake* is used to describe any seismic event whether natural or caused by humans that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. An earthquake's point of initial rupture is called its hypocenter or focus. The epicenter is the point at ground level directly above the hypocenter.

Talking About Waves.

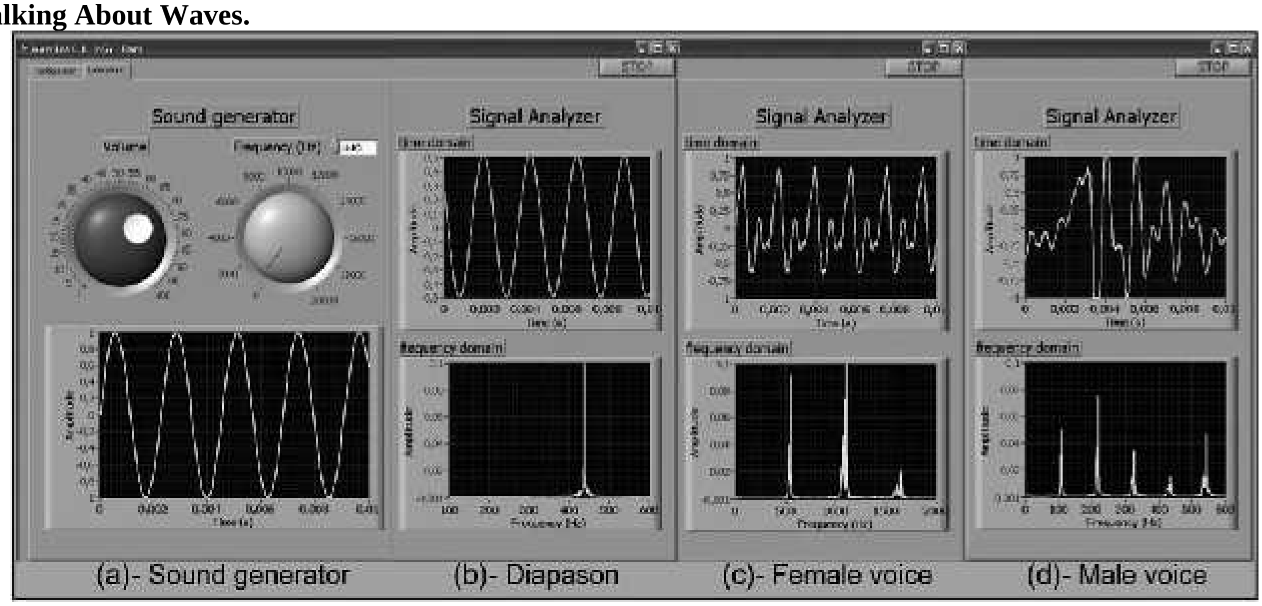
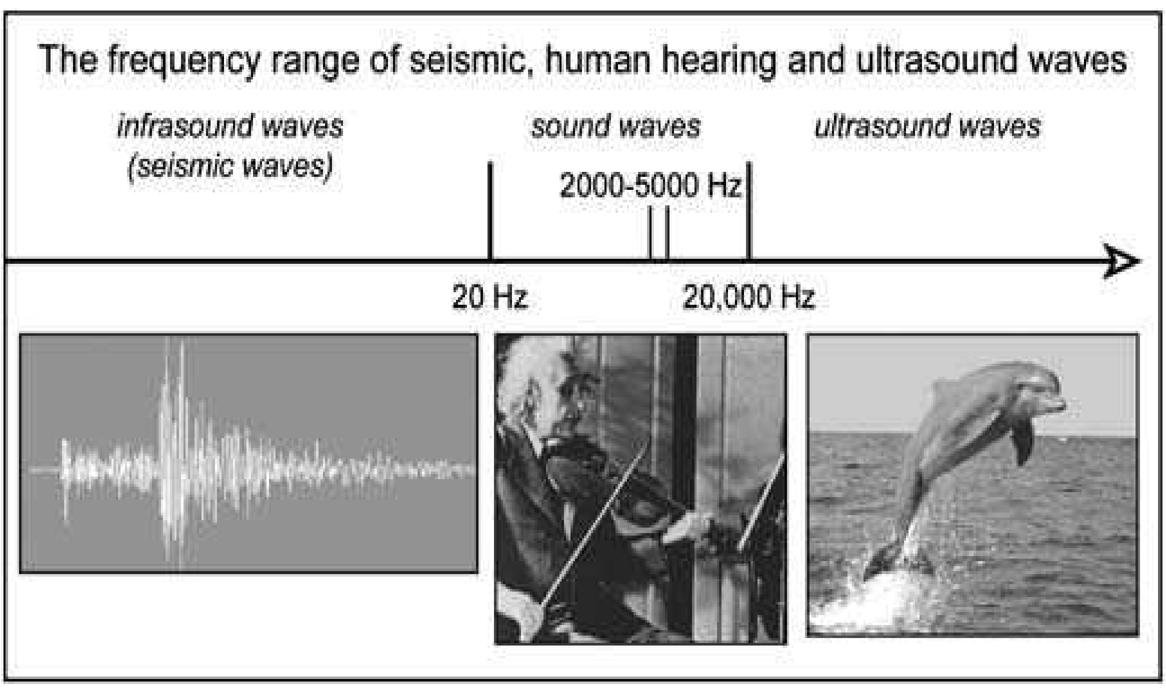


Figure 1. The Wave Lab, a tone generator and signal-analysis software. (a) A synthetic 440-Hz sound; (b) the signal analysis of the sound produced by a diapason in both time and frequency domains; (c) female voice shown in time and frequency domains; (d) male voice shown in time and frequency domains.

"Talking about Waves" is split into three phases: (1) Earthquakes: why and how they happen; (2) from seismic waves to sound waves; (3) the chorus of the Earth. During "Earthquakes: why and how they happen," we explain the origins of plate motion. We show how the associated forces lead to deformation in narrow zones at plate boundaries and in diffuse networks of faults in plate interiors. Once the cause of the earthquakes is explained, we are in a position to show how the energy released by an earthquake is carried through the Earth by seismic waves. We then describe P, S, and surface waves, showing how they appear on a seismogram and how humans perceive each type of wave, particularly in the near-field. A teaching animation shows how the waves travel through the Earth. During the second phase, "From seismic waves to sound waves," researchers guide the audience through the introduction of essential knowledge about waves. Again we use teaching animations to explain that a wave represents transport of energy, and that P waves carry energy in the same way that sound does, even though in the former case the source of energy is the earthquake, whereas in the latter the source may be our voice or an instrument. This phase requires the public to interact with the Wave Lab, a tone generator and signal analysis (Fig. 1). The Wave Lab first generates monochromatic sound waves at different frequencies from the center to the limit of human hearing, and we ask the audience to recognize them. This experiment proves that human listening capability is in theory as wide as 20 Hz to 20 kHz, but it can slightly change with individual sensibility (Fig. 2). In general, young people can hear the whole frequency range whereas old people usually do not. Some people with a different tone of voice (for example, adult males, adult females, and children) are asked to sing a note into the Wave Lab microphone, showing the time and frequency diagrams in real time (signal analysis). The same experiment is repeated with a xylophone, a diapason, or other available instruments, to show some basic acoustic principles. This phase helps the audience to become familiar with scientific terms such as frequency, period, amplitude, and resonance, which are all important quantities in understanding waves and how they relate to seismic hazard. The last phase of the section "Talking about Waves" is "The chorus of the Earth." In addition to earthquakes, the Earth emits waves in different frequency ranges as a consequence of other natural phenomena. Figure 2. An example of slide used during the workshop. It shows that the only difference between longitudinal sound waves and seismic *P* waves is the frequency, and that the voice of some animals, such as dolphins, is an ultrasound wave Waves in the range 10^{-7}–50 Hz, are mostly out of the hearing range of humans (Fig. 2), but are recorded by seismometers.



We compare the Earth's natural vibrations with the singing of a polyphonic chorus by dividing these waves into five groups: soprano, contralto, tenor, baritone, and bass (Table 1). This analogy places the waves into a common life experience, allowing the audience to understand that the Earth can vibrate like a giant bell (baritone in Table 1), that the moon's tide (bass in Table 1) produces waves (Wahr, 1995), that atmospheric pressure changes transmit waves to the solid earth (tenor in Table 1), and that the vibration produced by the sea waves can be seen on the seismograms (contralto in Table 1). The participants come to realize that the seismometer is our artificial ear, which hears, so to speak, the very low frequency waves outside human-hearing range. These examples emphasize that waves generated by natural physical phenomena in the bass to contralto ranges are, in principle, very similar to our daily experience and perception of waves, but just occur at lower frequencies

Listening to waves

"Listening to Waves we tailored the music of each workshop to the type of audience, which ranged from young students to adults; the genres included music for strings played by youngsters, a young polyphonic choir, and jazz and blues groups. We found that music is important not only in raising the sensitivity of the audience to the scientific message; the promise of a musical component to the workshop can itself induce people to participate who would otherwise have regarded the scientific subject as inaccessible. Because the music in our process taps into the emotions of our audiences, they leave the workshops with deeper engagement with the scientific message than, perhaps, would have resulted from a purely rational exposition (Hein, 1998). Surprisingly, we found that this engagement could also modulate our audience's emotional responses to earthquakes. Leaving the workshops, members of our audiences expressed a realization that earthquakes not only are events that have tragic consequences when they interact with society (and the built environment), but they also are manifestations of the workings of the planet on which we live that have a beauty of their own, and we must therefore learn to live with them.

Cooperation with youth orchestras and choirs

It's widely recognized that education is central to raising awareness of, and favoring actions to mitigate, seismic hazard. But the same could be said of any society's response to many of its ills. The uniqueness of our program is that we are able to direct a powerful general educational tool, music, towards a specific goal, seismic hazard, because the physics of the two phenomena is the same. Maestro Abreu, founder of the National System of Youth and Children's Orchestras of Venezuela (commonly known as El Sistema), reminds us that "education is the synthesis of wisdom and knowledge; it's the means to strive for a more perfect, more aware, nobler and more just society" (Borzacchini, 2010). El Sistema has shown that a music program can both create great musicians and dramatically change the table. l

Table 1, The Chorus of the Earth

Frequency Range (Hz)	Period Range (time)	Phenomena	Voice in the Choir of the Earth
10^{-7} – 10^{-4}	3 months 3hours	Solid tide (caused by gravitational forces among the Earth, the moon and the sun	Bass
3×10^{-4} – 3×10^{-3}	1 hour –5 min	Normal mode of the Earth (free oscillations of the Earth excited by very strong earthquakes)	Baritone
10^{-3} – 10^{-1}	15 min –10 s	Atmospheric pressure changes Most energetic waves of strong earthquakes	Tenor
0.03 –1	30 s –1 s	Sea waves Most energetic waves of Intermediate earthquakes	Contralto
1 – 50	1 s –0.02 s	Human activity Rain, Wind and Weak earthquakes	Soprano

Phenomena at various frequencies cause mechanical waves to travel through the Earth, waves which can be registered by seismometers exactly like seismic waves. In the last column is indicated the parallel with the choristers in terms of voices in the Chorus of the Earth. Trajectory of hundreds of thousands of a nation's neediest children. The value of El Sistema is now widely understood, particularly in countries that seek to increase the levels of literacy among their young populations. Among the twenty-six countries that have joined El Sistema many, such as Chile, Colombia, India, Mexico, Nicaragua, Peru, Italy, and the United States, are seismically active. We believe that science must serve society, its children, and its weakest members, in the same way that Maestro Abreu envisages for music. By aligning our seismic-hazard educational experience to the philosophy of El Sistema we can give rising generations the skills to improve resilience to earthquakes in their own countries.

The experimental phase of our format were attended by about 500 people. Our next target is to reach out to the roughly 6,500 children of the Youth Orchestras and Choirs within Italy and educate through our program not only the children themselves, but their families and friends. The young musicians will be the protagonists of the phase "Listening to Waves". We believe that with the same spontaneity that they bring to the playing of music, the children will absorb understanding and awareness of seismic hazard, and that this understanding will be an effective resource to their society. Furthermore, this cohort will grow every year as new children join the system, and the older children graduate to become mature and effective advocates for all that they have learned from their experience. Our hope is that in the future, through Youth Orchestras and Choirs in seismically active countries, our workshop will be able to reach many thousands of children, helping them to foster their appreciation of the natural world, and to develop their critical thinking skills so that they can help their societies to respond effectively to the hazards, and opportunities, that nature presents to them.

Conclusion

"Seismic Waves and Sound Waves: From Earthquakes to Music that we use to present seismology in an approachable way. It is intended to give the audience an in-depth explanation about earthquake physics and how energy is carried through the Earth by seismic waves to sound waves. Seismic: relating to earthquakes or other vibrations of the earth and its crust. Seismic waves are waves of energy that travel through the Earth's layers and are a result of earthquakes, volcanic eruptions, magma movement, large landslides and large human-made explosions. The refraction or reflection of seismic waves is used for research into the structure of the Earth's interior. The terms seismic waves and earthquake waves are often used interchangeably

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