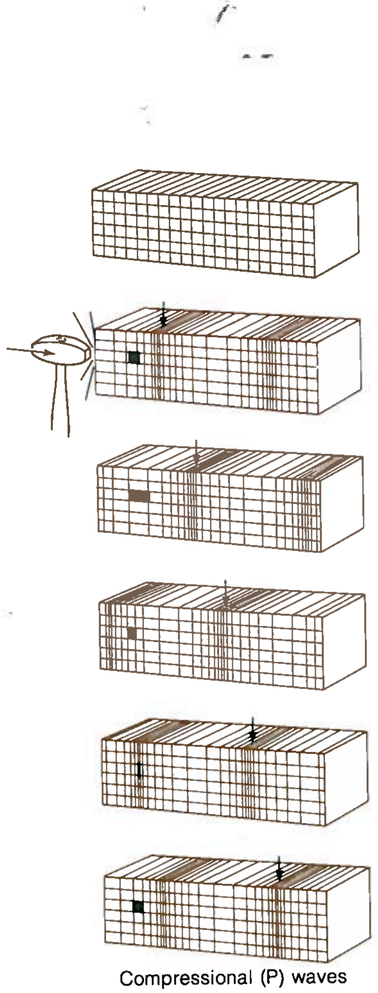

Figure 17-30
Stages in the deformation of a block of material with the passage of compressional, or *P*-waves, through it. The undeformed block is shown at the top. In the sequence from top to the bottom, a crest of compression, marked by an arrow, moves through the block with the *P*-wave velocity. It is followed by an expansion, and any small piece of matter, like the marked square, shakes back and forth in response to alternating compressions and expansions as the wave train moves through. A sudden push (or pull) in the direction of wave propagation, indicated by the hammer blow, would set up *P*-waves. [After O. M. Phillips, *The Heart of the Earth*, Freeman, Cooper & Co.]

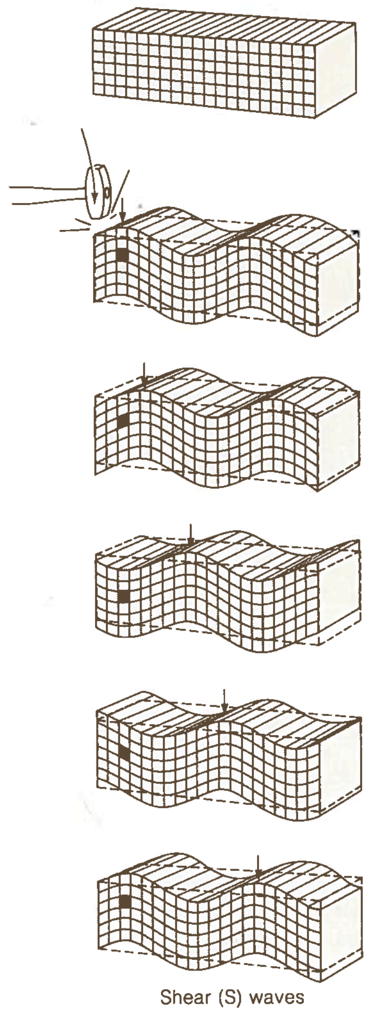

Figure 17-31
Stages in the deformation of a block of material with the passage of shear, or *S*-waves, through it. A wave crest, marked by an arrow, moves through the block with the *S*-wave velocity as vertical planes shake up and down. Any small piece of matter, like the marked one, shakes up and down and experiences a shearing deformation (from a square to a parallelogram in the figure) as the shear wave passes through. A sudden shear displacement, indicated by the hammer blow at right angles to the direction of wave propagation, would set up *S*-waves. [After O. M. Phillips, *The Heart of the Earth*, Freeman, Cooper & Co.]

paper the existence of compressional and shear waves in elastic bodies. Not until the close of the nineteenth century, however, did seismologists devise instruments sensitive enough to detect such waves in the Earth—the *P* waves and *S* waves generated by sudden slip along a fault. Figure 17-30 shows the faster-traveling *P* wave as the propagation of a volume change—a squeezing and unsqueezing of the medium; the individual particles vibrate to and fro in the direction of wave propagation. In Figure 17-31, the *S* wave is shown as a traveling shearing disturbance, the material distorting in shape rather than changing in volume; the particles vibrate back and forth at right angles to the direction of propagation.

Figure 17-32 depicts the trajectory of *P* waves as they travel from the source of an earthquake or explosion into the interior, emerging again at distant points. These wave paths and their travel times have been determined empirically from the seismographic records of earthquakes all over the world. Note particularly the **shadow zone** and its geometrical relationship to the focus and the core. The Earth's core deflects the waves and in effect casts a shadow where very little *P*-wave energy reaches the surface. The existence of shadow zones suggested that the core is molten, because compressional waves decrease sharply in velocity when they pass from a solid into a liquid of the same composition. The suggestion became a firm pronouncement when seismologists found that shear waves could not penetrate this region. Liquids transmit *P* waves but not *S* waves, since the fluids elastically resist and recover from squeezing, but do not resist shearing.

When *P* and *S* waves encounter a boundary such as that between the core and the mantle, they are in general reflected back as well as transmitted across it, just as light may be partly reflected and partly transmitted at a water surface. If in the new medium the wave velocity is different, the waves are bent, or **refracted.** Because of all of these possibilities of reflection, transmission, and refraction, *P* and *S* waves break up into several types as they travel through the Earth, as shown in Figure 17-33. Follow the wave *PcP* in the figure as it bounces in radar-like fashion from the Earth's core and yields its depth from the round-trip time. The wave *PKP*, which penetrates the core, is useful for exploring that region. Many of the *P*-wave trajectories and travel times are sketched in Figure 17-32.

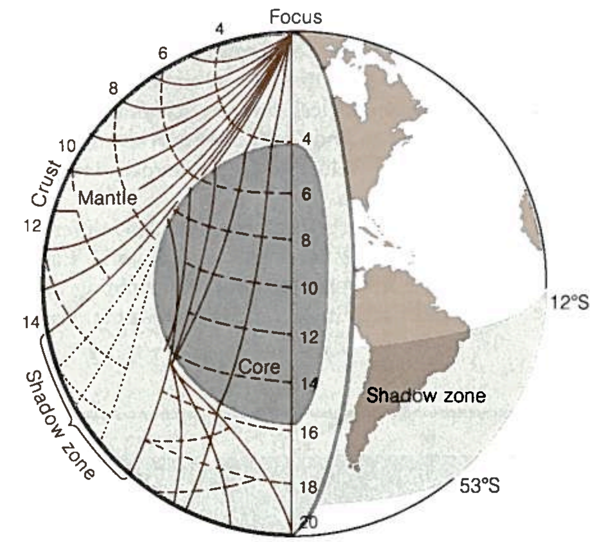

Figure 17-32
Cutout showing the pattern of *P*-wave paths through the Earth's interior. The numbers show the travel time in minutes for the waves to reach the associated broken line. Note the shadow zone, a region not reached by *P*-waves (for this hypothetical earthquake at the north pole) because they are deflected by the Earth's core. [After *Internal Constitution of the Earth* by B. Gutenberg (ed.), Dover Publications, 1951.]

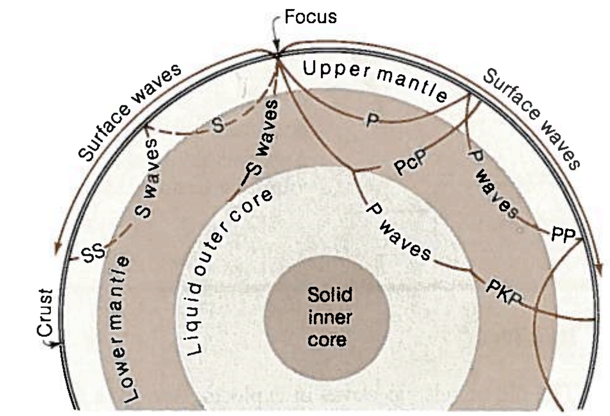

Figure 17-33
P- and *S*-waves radiate from an earthquake focus in many different directions. Waves reflected from the Earth's surface are called *PP* or *SS*. *PcP* is a wave that bounces off the core, and *PKP* is a *P*-wave transmitted through the liquid core. *S*-waves cannot travel in a liquid.

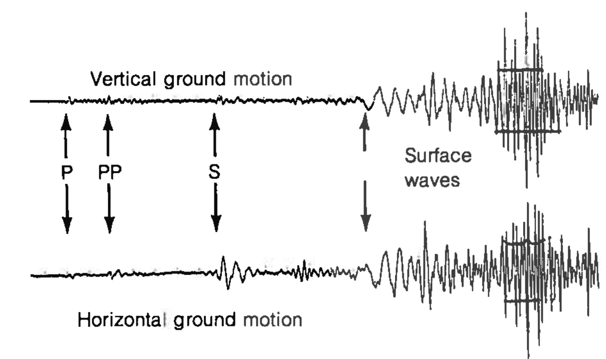

Figure 17-34
Seismograph recording of *P*-, *S*-, and surface waves from a distant earthquake.

In addition to *P* and *S* waves, another category of seismic wave is the surface wave, guided in its propagation by the Earth's surface. These waves travel only through the outer layers of the Earth, just as the motion of ocean waves is mostly surficial. Figure 17-34 shows seismograms in which many of these seismic waves are labeled.

Pluck a violin string and a tone is emitted; strike a bell with a hammer and it rings. The Earth also rings when it is disturbed by a great earthquake that causes the entire globe to vibrate like a bell for as long as several weeks. The tones of Earth's vibrations are pitched too low for the human ear to hear, but modern seismographs are sensitive enough to detect these low-frequency oscillations. The Earth can vibrate in different modes, actually an infinite number of them. Some are shown in Figure 17-35. The mode with the lowest pitch is the "football," or **spheroidal,** mode, which takes 53 minutes to execute one vibration. For our musician-readers, we add that in terms of what one might call music of the spheres, that vibration corresponds to E flat in the twentieth octave below middle C. The "balloon," or **radial,** mode has a frequency of one vibration in 20 mintues; and the twisting, or **torsional,** mode, a frequency of one in 44 minutes.

Finding Earth Models from Travel Times and Vibration Frequencies. The basic experiment with seismic waves is to measure precisely the travel times of *P*, *S*, and surface waves

In the decade of the 1960's, seismologists worked to develop a method to distinguish underground nuclear explosions from earthquakes. They found that explosions excite surface waves with less efficiency than do earthquakes—a discovery that may stimulate statesmen to agree to an underground nuclear test-ban treaty.