Chapter 1
Seismic Wave Propagation and Rock-Fluid Properties

Abstract Seismic waves propagating through different rock layers in the earth suffer loss of energy. The different types of energy losses and their mechanisms need to be understood for their geologic significance.

The intrinsic properties of a seismic wave, – amplitude and velocity, are influenced by the properties of rocks through which it travels. The elasticity and density of rocks primarily determine the seismic amplitude and velocity, though other properties such as porosity, texture, fractures, fluid saturation and viscosity, pressure and temperature also affect seismic properties.

Focusing on geologic interpretation of seismic data before introducing fundamentals of seismic principles and rock physics can be something like putting the cart before the horse. Therefore, this chapter is a revisit to the basics of seismic wave propagation and related rock physics. It answers briefly some of the important questions, as given below, which ultimately guide interpretation.

- *How do seismic waves propagate through rocks?*
- *How is seismic energy attenuated?*
- *What are fundamental wave properties?*
- *What are rock-fluid properties and how do they affect seismic response?*

Seismic Wave Propagation

A seismic wave is an elastic wave traveling through a solid rock. When a rock is subjected to a pressure wave, its particles get displaced, transferring energy to the adjacent ones causing a seismic wave to propagate onwards in the rock through particle motions. There are two types of seismic body waves that travel in solid rocks; longitudinal (primary or compressional) waves and transverse (secondary or shear) waves. In fluids, however, only the longitudinal waves can travel.

A seismic wave propagating in the earth encounters several discontinuities (boundaries) between rock types of different physical properties and produces wave phenomena such as reflections, diffractions, absorptions, scatterings and transmissions (refractions). At each boundary or interface between two different rocks, a

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part of the incident energy is reflected back to the surface and the rest of energy is transmitted to the underlying rocks. Seismic methods for exploration of hydrocarbons mostly use the reflected energies of primary or compressional waves returning to the surface. Shear waves reflections are also recorded and are used in specific cases, to provide valuable subsurface information. Chapter 9 (Shear Wave Seismic) provides more detailed discussion on shear seismic.

Also as the wave of energy (seismic pulse) travels downwards in solid media, it undergoes gradual loss of energy (attenuation) depending on the rock-fluid properties. Attenuation, a natural phenomenon, comprises of several types of losses and understanding the process behind each loss can be useful in interpreting the rock type.

Energy Losses

Absorption

The seismic source wave, generated at the surface, as stated earlier, propagates through a rock by transferring energy from one particle to another. In the process, a part of the energy is attenuated due to conversion of mechanical energy to heat energy through frictions at grain contacts, cracks and fractures and fluids present in pores of a rock. The frictional loss primarily due to motion between rock particles at the point of grain contacts is known as *absorption*. Frictional loss is also sensitive, though to a lesser extent, to fluid properties like saturation, permeability and viscosity as the wave travels through the rock. Absorption in rocks is believed to be related to the first power of frequency whereas in liquids it is related to square of the frequency (Anstey 1977).

Absorption is anelastic, frequency selective and cuts out higher frequencies progressively from the source pulse. This results in reduced energy with a wavelet of lower frequency and lower amplitude at deeper depths (Fig. 1.1). Absorption effects are severe within shallow weathering zones and decrease with depth. Magnitude of absorption (friction) loss in a hard rock is liable to be much higher than that in a fluid saturated rock as friction in fluid, considered as a slushy medium, is likely to be small (Gregory 1977). Seismic in offshore deep waters hardly shows low- frequency dominance supporting little energy-loss due to absorption in the water column. However, there can be some absorption loss in partially saturated hydrocarbon reservoirs due to viscous motion between the rock and the fluid.

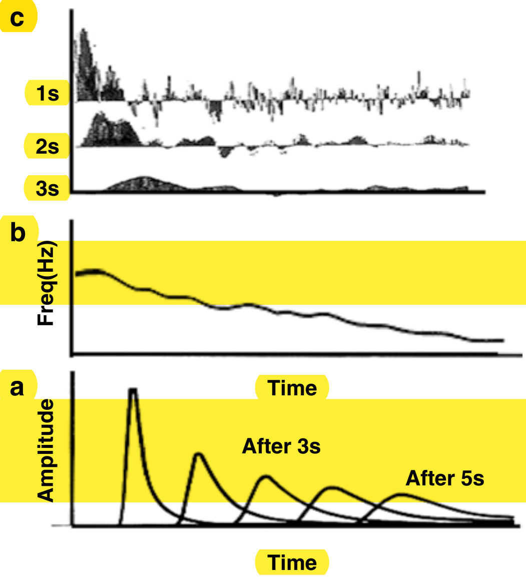


Fig. 1.1 A schematic showing the loss of energy due to absorption during wave propagation. (**a**) Shows a lowering of amplitude with time (**b**) the lowering of frequency with time and (**c**) the overall look of a seismic trace with time (Modified after Anstey 1977)

Scattering

Scattering loss is a frequency dependent *elastic* attenuation linked to dispersion, a phenomenon in which velocities in a rock measure differently with varying frequencies. Scattering losses are irregular dispersions of energy due to heterogeneity in rock sections, usually considered as apparent noise in seismic records. Scattering and absorption losses together are sometimes referred to as attenuation. Geological objects of very small dimensions tend to scatter wave energy and produce diffractions rather than continuous reflections. Highly tectonised shear zones with faults and fractures, very narrow channels, pinnacle mounds etc., are some of the geologic features, most prone to scattering effect.

Transmission

Transmission loss is loss of energy the wave undergoes at every lithologic boundary, as a part of the energy is reflected back to the surface allowing less to go deeper. The loss thus depends on the type and number of reflecting interfaces. It is often believed that a strong reflector like a limestone or an intrusive body reflects most of energy upwards and transmits less in the process, causing poor reflections or shadows below. However, Anstey (1977) has demonstrated that strong reflectors may not be the sole cause for large transmission losses. Instead, such effects may be caused due to large number of thin interfaces, even with small reflectivity, but with alternating signs of contrasts that cause many reflections to account for energy loss.

Transmission losses reduce amplitudes at all frequencies and are not frequency selective as in absorption. One positive spinoff of wave transmission through several thin beds can be the eventual constructive interference of peg-leg multiples from the interfaces of thin beds with reflections at times that aid in recording a reflection amplitude better. But addition of amplitudes tends to lower the frequencies giving an appearance of the pulse similar to the absorption effect. Prima-facie, it may be, hard to distinguish the effects on a seismic pulse due to absorption and transmission losses.

Spherical (Geometrical) Divergence

A seismic wave (usually considered travelling in the form of spherical wave fronts), suffers from reduction of energy as it continually moves away from source and spreads through the subsurface rocks with time (distance). This is also known as geometrical loss as it is linked to the wave-path geometry. The decay is dependent on distance from the source and increases with higher velocities due to greater distance travelled (Fig. 1.2).

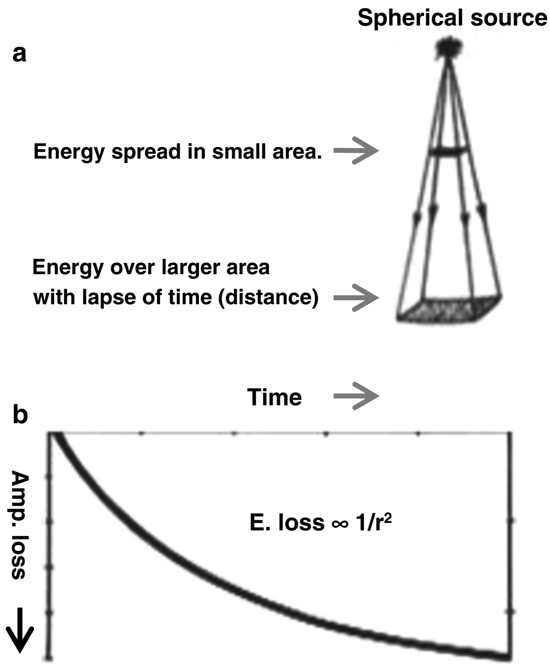


Fig. 1.2 Illustrating loss due to spherical divergence during propagation. (**a**) Spreading of spherical wave causes loss as the energy is distributed over larger area with time and (**b**) is proportional to distance travelled (Modified after Anstey 1977)

Geological Significance of Energy Attenuation

Large attenuation losses in rocks, besides the amplitude, lower the frequencies of seismic wave which lead to lower velocities due to dispersion effect. Measurement of both attenuation and velocity can thus provide complimentary information about the rock and fluid properties. Further, attenuation affecting the frequency and the amplitude content of the wavelet also results in changing the seismic wave shape. Analysis of propagation loss in rocks from the resulting changes in wave shapes can then lead to important geological information about rock and fluid properties. Some significant geological conclusions from analysis of attenuation effect can be as below.

- An indication of high energy loss considered owing to absorption, may give a clue to the type and texture of the reservoir rock. Unconsolidated, fractured, and poorly-sorted rocks having angular grain contacts are likely to have considerable friction (Anstey 1977). A rock, well-sorted and with well-cemented pore spaces, on the other hand, will show negligible loss due to absorption.
- Seismic evidence of high transmission loss can be suggestive of a formation consisting of cyclically alternating impedance contrasts typified by multiple thin sands with intervening shale, the *cyclothems,* in deltaic environment. *Cyclothems* are potentially important geological plays that are commonly sought after by the explorationists.
- Scattering losses due to heterogeneity in strata may provide a clue to the order of irregularities in reservoirs suggesting rapid facies change in a continental depositional environment. Similarly, scattering losses may result in poor to no seismic reflections indicating presence of *mélanges* in highly tectonised zones of subduction which can lead to planning suitable acquisition and processing techniques to achieve better seismic images.

However, energy losses are difficult to identify in real field situations. Can the losses due to absorption be distinguished from those due to transmission, which cause similar effect on a wave pulse? Often the interpreter has little time or access to dig into data processing, which is required to identify and quantify losses. Nevertheless, under certain favorable situations, such as in known geologic areas, relatively shallow targets of exploration, high resolution offshore marine data, it may be possible to detect some of the losses through special processing techniques. This assists in interpreting type and texture of rocks, albeit, qualitatively.

Seismic Properties

The propagating seismic wave has two very important intrinsic elements, which are indispensable to the framework of exploration seismic technology. These are: (1) amplitude of the seismic wave – particle velocity measured by geophones on land or the acoustic pressure measured by hydrophones in marine streamer surveys and (2) velocity of the wave with which it passes through the rocks. Particle velocity conveys the magnitude of the seismic disturbance (micrometers/s) where as wave velocity conveys the speed of the seismic disturbance at which it travels through rocks (km/s). Amplitudes and velocities are the seminal seismic properties and differ over a wide range, depending on rock-fluid properties.

Rock-Fluid Properties (Rock Physics)

Seismic wave propagation with its associated effects brings out vital geological information about different types of subsurface rocks and their fluid contents. The rock-fluid properties, which are many, affect seismic responses and can be intricately complex to decipher. Fortunately, most of the rock-fluid properties affect one way or another the primary properties of a rock, the elasticity and the density, which in turn directly control the seminal properties of a seismic wave, i.e. the velocity and amplitude. Seismic velocity *(V)* is a function of elasticity *(E)* and density *(ρ)*, expressed by the equation

$$V = \sqrt{(E/\rho)},$$

The *amplitude* of a seismic wave, on the other hand is a function of contrasts between two impedances (a product of velocity V and density ρ) of rocks at an interface.

The rock and fluid properties therefore can be determined from seismic properties. Simplistically, a rock is defined in terms of its matrix, pore space and fluid content. All rock-fluid parameters ultimately influence elasticity and density of a rock, and it is expedient to consider the effect of each individual element of the rock and fluid properties separately on elasticity and density separately, to comprehend their seismic responses better. We shall, however, restrict our studies to limited but commonly important rock-fluid properties as below.

Rock Properties

Elasticity

The elasticity of a rock may be defined as the resistance that it offers to stress. The two principal elastic moduli controlling seismic responses are the bulk modulus (k) and the shear modulus (μ). Depending on the type of wave, the elastic moduli play the dominant role in determining the seismic velocity. In the case of compressional waves (P-waves), both bulk modulus and shear modulus control seismic velocity and for shear or transverse waves, the shear modulus plays the dominant role in controlling velocity (S-wave). In an isotropic media, compressional and shear wave velocities are given by the equations

$$Vp = \sqrt{\left[\left(k + 4/3\mu\right)/\rho\right]}, \text{ and}$$
$$Vs = \sqrt{\left[\mu/\rho\right]}.$$

One of the simplest ways to comprehend the elastic moduli of a rock is its incompressibility. A hard rock is difficult to compress because of a high bulk modulus (incompressibility), which ensures high seismic velocity. Likewise, a soft rock with a large compliance has lower elastic modulus and consequently exhibits lower velocity. In a geological sense, elasticity may be likened to a measure of the hardness of a rock, which depends on lithology and commonly increases with depth.

Bulk Density

The bulk density of a sedimentary rock includes the density of the rock matrix and the density of the fluid in the pore spaces. Density of a rock is defined as its mass per unit volume and commonly increases with depth. This is a result of compaction as the rock undergoes burial (Fig. 1.3). Compaction is a diagenesis process that squeezes out water from the pore space of sediments with time (depth) by overburden pressure as they get buried beneath successive layers of sediments. Compact rocks show higher densities whereas under-compacted formations demonstrate lower density values. It may seem paradoxical that compact rocks at depth, though have higher bulk density values, yet show higher velocities. This happens due to relatively increased elasticity of the compacted rock compared to density increase, the elasticity playing the primary role in determining the velocity. It also may be stressed that velocity and bulk density are not directly related, though empirical equations exist which allow an estimation of compressional velocities from bulk densities under certain stipulated conditions as in water-saturated normally pressured sedimentary rocks (Gardener and Greogory 1974). Nonetheless, density determination from seismic remains a difficult task.

Porosity, Pore Size and Shape (Pore Geometry)

Porosity is a measurement of the void space in a given volume of rock. In general, an increase in porosity lowers the density and more so the elasticity of a rock resulting in decreased seismic velocity. Though there is an established relation between porosity and density, no such definitive link exists between porosity and velocity.

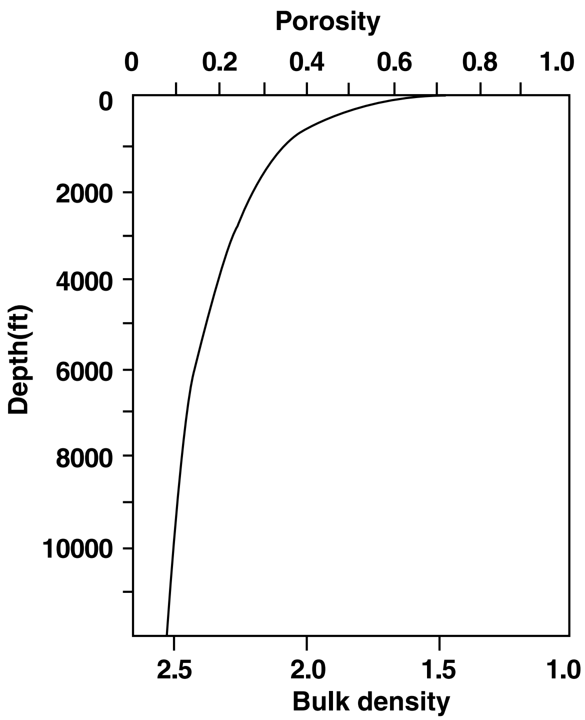


Fig. 1.3 A graph showing an increase in density with depth due to compaction of rock (diagenesis) in normal pressured sections. Compaction leads to the associated reduction in porosity (After Anstey 1977)

Porosity and pore shape varies in different kinds of rock. Unconsolidated sandstones and vuggy carbonates (cavernous porosity) have open, irregular pores whereas partially cemented sedimentary rocks show porosity that occurs between the grains known as intergranular porosity. Cemented sands and tight carbonates, on the other hand, may have dominantly crack-like pore space (fracture porosity). Typically, the seismic velocities depend on both the rock material and the type of porosity controlled by the pore geometry. In general the seismic properties, the velocity and impedance decrease with increasing porosity.

Nevertheless, an empirical time-average equation (Wyllie et al. 1956) provides a basic link between porosity and velocity that is often used by many in interpretation work.

$$1/V_r = 1 - \phi / V_m + \phi / V_f$$

V_r, V_m & V_f are velocities of the whole rock, matrix and liquid in pore space, respectively. φ is porosity. It is known as time-average equation as the total time taken for a wave to travel in the rock is assumed to equal the sum of travel times in each rock component (Fig. 1.4).

The time-average equation has, however, several limitations as it is specific to certain types of rock, degree of porosity, type of fluid and normal pressure etc. It can be used to reasonably predict intergranular porosity of highly porous, water and

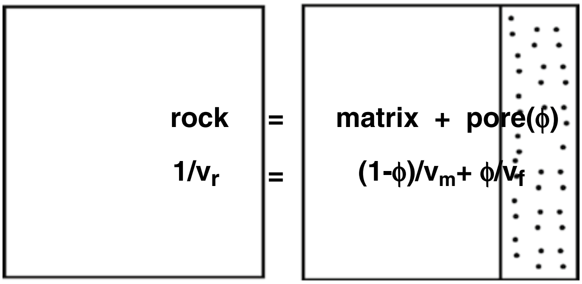


Fig. 1.4 A schematic of 'time average equation' linking velocity and porosity of a rock. The total time taken for a wave to travel in a rock is assumed to be equal to the sum of travel times in the two rock components, i.e. the matrix and the pore space filled with fluid

brine saturated sandstones under normal pressure (Gregory 1977; Anstey 1977) but may not be suitable for highly porous gas saturated unconsolidated sands in over-pressured regimes. The equation has since undergone several modifications and changes (e.g., Raymer et al. 1980; Wang and Nur 1992) for modern day applications.

Behavior of velocity, however, is known to be affected more by the shapes of pores than the porosity per se, as the shape plays a major role in determining the compliance of a rock to stress. For example, flat-pore shapes in a relatively low porosity reservoir may indicate lower seismic velocity (more compliance) than that in a high porosity reservoir with spherical pore shapes.

Texture

Grain sizes, roundness, sorting and cementation describe the texture of a rock. Elasticity and density of a rock depend on contacts of grains, their size and angularity though the latter ceases to play a role after the rock is cemented. Large grain sizes and compact sands have generally higher seismic properties due to larger contact areas causing higher velocity (elasticity) and impedance (density), whereas, unconsolidated sands with angular grains are likely to show lower seismic properties (Wang 2001).

Fractures and Cracks, Geometry

Seismic properties are greatly affected by presence of open fractures in a rock. Fractures and cracks facilitate compressibility (compliance) and significantly lower the velocity and impedance. For example, in a given volume of normally fractured carbonate reservoir with a specific bulk density, similar fracture porosity can be expected either by assuming a large number of microfractures or by fewer numbers of bigger fractures, though the lowering of velocity can be much more in the former case compared to that in the latter (Sayers 2007) This can have a significant implication on reservoir evaluation as the micro fractures linked to lower velocity may not be indicative of better reservoir permeability than that having larger fractures.

In case of cemented fractures, seismic velocity may indicate much higher values compared to what is normally expected at a particular depth. Such anomalous velocities for a rock in a known tectonic area can then be used as a clue to corroborate possible presence of fractures that are highly cemented. Similar to pore shapes, geometry of cracks and fractures with varying *aspect ratio* too affect the seismic properties, intricately and significantly, these being generally lower in cases of flat-shaped fractures. The number and shape of fractures also determine the elasticity (compliance) of a rock which primarily decides the seismic properties.

Fractures also create anisotropy in rock sections. Tectonic stress causing fractures, cracks, and vugs may change the texture of a rock to induce seismic anisotropy which can create technological limitations (refer to Chap. 9 for more information).

Fluid Properties

Pore Fluid and Saturation

Most rocks have fluid in pore space. Fluids typically are known to have negligible shear modulus but affect compressional seismic properties depending on its compressibility and density. In a fully water or brine-saturated reservoir rock, water or brine offers resistance to stress and tends to increase velocity though not to the same extent as in a tight rock having little water. Oil in rock pores lowers velocity marginally compared to that with water, as the smaller bulk modulus of oil is offset to some extent by its lower density and makes one velocity hardly distinguishable from the other. In general, rocks saturated fully with liquids exhibit increased seismic properties (Wang 2001). Gas, on the other hand, has the least bulk modulus (highly compressible) and density, and the velocity and impedance of a rock with gas in the pore space thus tend to show significantly lower values than that of rocks saturated with water and/or oil. The lowering of seismic velocity due to presence of gas, even in small quantity, is conspicuously large, especially at shallow depths. Overall, the effect of fluid-saturation on seismic velocities decreases with increasing depth (Fig. 1.5).

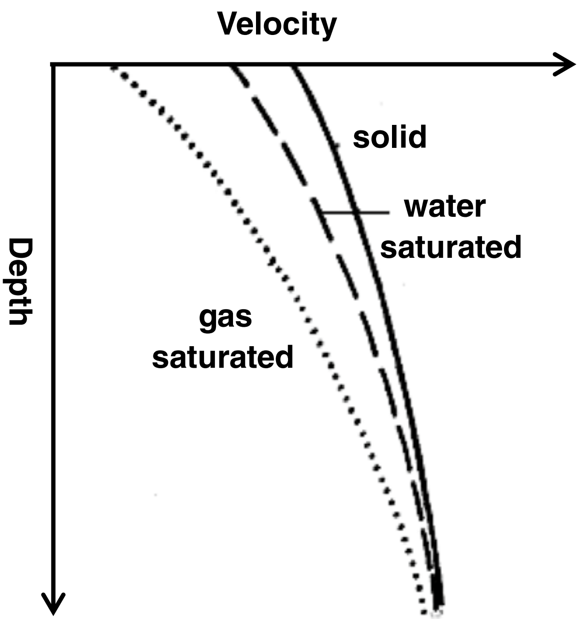


Fig. 1.5 The schematic shows the variation of velocity with depth for solid, water and gas saturated rocks at normal pressure. Velocity variation is significant at shallow depths but tends to be marginal at greater depths (After Anstey 1977)

Viscosity

Rocks tend to exhibit increasing elasticity and density with increase in viscosity of oil. Heavy oil has large bulk modulus and in some cases may tend to act as semisolids in the rock pores (Wang 2001). These rocks obviously exhibit relatively higher seismic properties.

Pressure and Temperature

A rock at depth is primarily under two vertical stresses (ignoring the tectonic stress); the overburden (geostatic or lithostatic) stress and the fluid (formation or pore) pressure. The former is downwards due to gravity and the latter acts upwards due to buoyancy of fluid in the rock pores. The overburden pressure tends to close the pore space, whereas, the fluid pressure tries to retain the voids. The difference between these two pressures, known as the effective pressure or differential pressure (Fig. 1.6) is an important factor in determining seismic properties.

In properly compacted sections where the squeezed water escapes to the surface, the formation shows normal hydrostatic pressure. In normally-pressured sections, effective pressure increases with depth (due to higher overburden pressure) raising elasticity and density of the rock (due to compaction) and resulting in increased seismic properties. The increase in velocity, however, is nonlinear with depth and is

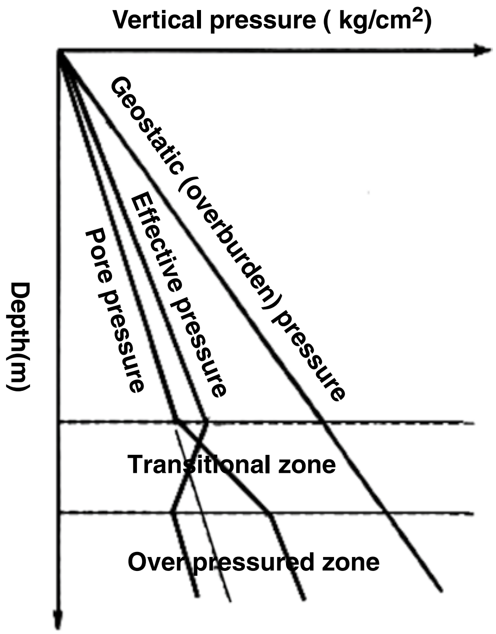


Fig. 1.6 A schematic shows the geostatic, hydrostatic (normal) pore pressure and effective pressure (the difference between the geostatic and pore pressure). Under-compacted rocks withholding water in pores show higher pore pressure than hydrostatic and are known as over-pressured rocks. Over-pressured formations show reduced effective pressure

more pronounced at shallower depths and in lower ranges of effective pressure (Fig. 1.7). The degree of change, however, varies with lithology, depending on hardness; it is maximum in soft unconsolidated sands and minimum in limestone.

In some formations, pore water may be released during compaction but cannot escape due to a non-permeable seal at the top and is thereby forced to stay within the formation with added pore pressure. The formation without undergoing proper compaction remains an under-compacted rock and exhibits higher pressures. The fluid pressure is greater than normal hydrostatic pressure and the formation is termed over-pressured (abnormally pressured). The over-pressured rocks have lower effective pressure, decreased elasticity and density and exhibit lower seismic properties. The decrease in velocity and density, however, typically tends to remain constant with increase in depth of burial of the high-pressured zone (Figs. 1.8 and 1.9). Continued thickening of the overburden does not affect the seismic properties as the high pore-fluid pressure continues to sustain the increasing part of the overburden pressure that occurs with depth.

A rise in temperature leads to changes in pore fluid properties such as viscosity and elasticity. Seismic properties, with increase in temperature, marginally decrease in water and gas saturated rocks but may decrease significantly in oil saturated rocks. Higher temperatures in heavy oil, especially in unconsolidated sands (e.g. tar sands), can result in a remarkable decrease of seismic properties due to more fluid compressibility induced by heat.

Fig. 1.7 A graph showing increase in P-velocity due to increase in effective pressure for different rocks. Velocity variation is more conspicuous at shallow depths and in lower pressure regimes (Modified after Figure 7 of Gregory 1977)

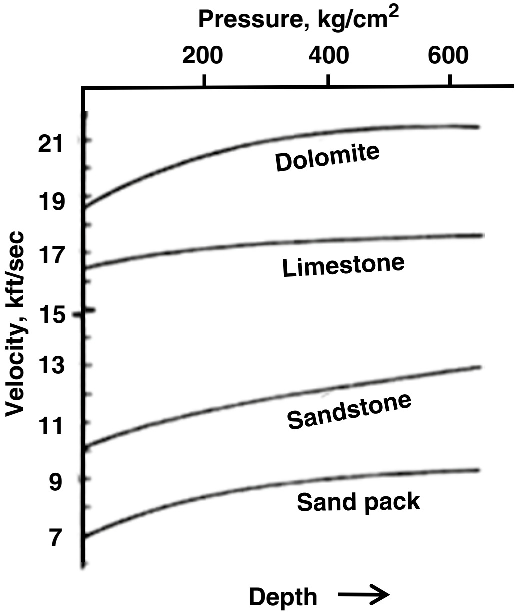
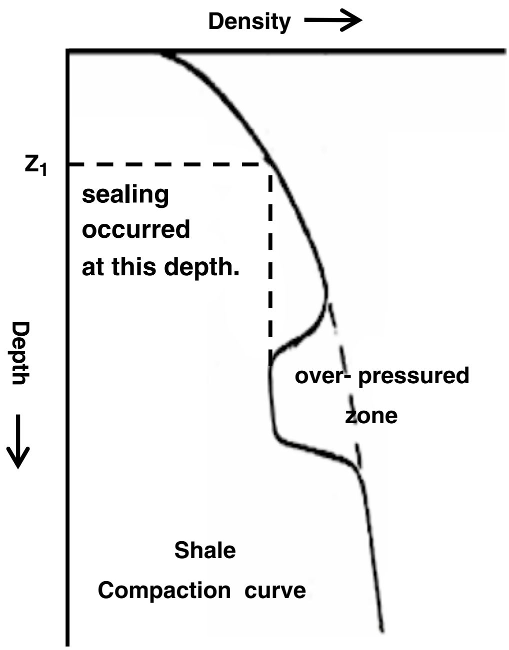


Fig. 1.8 The schematic shows the density variation with depth in normal and over pressured (under-compacted) zones. Note the typical near-vertical curve in the over-pressured zone, showing near constant density without increase with depth. The density shows increase after getting into the normal-pressured zone (After Anstey 1977)



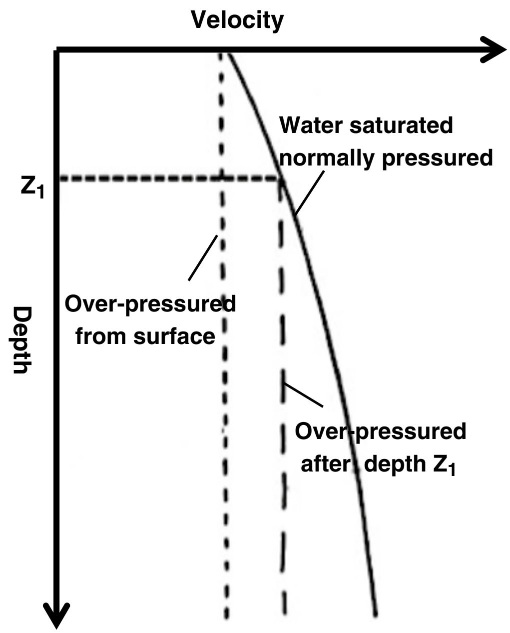


Fig. 1.9 The schematic shows the velocity variation with depth for water saturated formation in normal-pressured and in over-pressured rocks. Over-pressured zones show lower velocity which tends to remain constant with increase in depth. The point where velocity drops (z_1), indicates the depth from where over-pressure started (After Anstey 1977)

Seismic Rock Physics

Seismic rock physics links analysis of rock and seismic properties, the former the causative and the latter the response effect. Properties of rocks and fluids, such as lithology, porosity, fractures, texture, fluid type and saturation, and viscosity etc., and factors like pressure and temperature are all known to affect seismic properties in varying degrees, which can be better understood by realizing their individual roles in influencing the two principal rock properties, the elasticity (incompressibility or compliance) and the density of a rock. The end result depends on the overall effects of each of the individual factors, as many of these interact to reinforce and others to cancel each other.

The most crucial of the rock-fluid properties, permeability, however, remains difficult to be measured or estimated directly from seismic. While estimates of rock properties, such as, lithology and porosity from seismic data has long been a part of routine interpretation; quantitative estimate of the subtler fluid properties like saturation and viscosity remains yet to be fully and effectively realized. This is due to many complicated limitations in seismic manifestation and measurement in routine data, and also perhaps due to lesser understanding in application of rock physics. For example, it is long since reported that some oil/gas saturated reservoirs are associated with low frequency shadow zones below, ostensibly due to much higher absorption in gas as compared to water saturated rocks. However, according to Ebrom (2004) who has extensively researched the phenomena, a convincing good explanation for the observed low-frequency shadow zone below gas reservoir is yet to come up. Ebrom in his paper, on the other hand, has suggested several other possibilities that could be responsible for the phenomena.

Many of the current rock physics studies are, however, theoretical, based on empirical results reported from laboratory tests. Thus, they may need more in-depth investigations for matching the findings with those from real field seismic data. The major limitation, however, remains the critical factor of dimension and scaling, the measured microscopic rock-fluid properties having one-to-one correspondence with properties of macroscopic dimensions imaged by seismic waves. The sensitivity of seismic properties to changes, especially in fluid properties of a rock, seems to be delicate, and its detection and interpretation in a real situation remains a formidable and challenging task for the seismic analyst.

Nevertheless, in some favorable geological and petrophysical setups, such as in highly compliant, shallow unconsolidated gas saturated sands, the effects of individual rock-fluid parameters may be additive so as to result in a seismic response that is discernible in data. 'Bright spot' amplitude anomaly studies may be a case in example which is discussed in Chap. 6. Combined analysis of wave velocity and attenuation losses is another possible approach likely to provide more reliable information about rock and fluid properties.

It may also be noted that the aforesaid discussions are all about compressional seismic properties involving only P waves. Some of the rock-fluid parameters are known to be differently sensitive to compressional and shear waves and a combined analysis of properties of P and S waves is often found to be much more useful. This is dealt in Chap. 9 under the topic of shear seismic.

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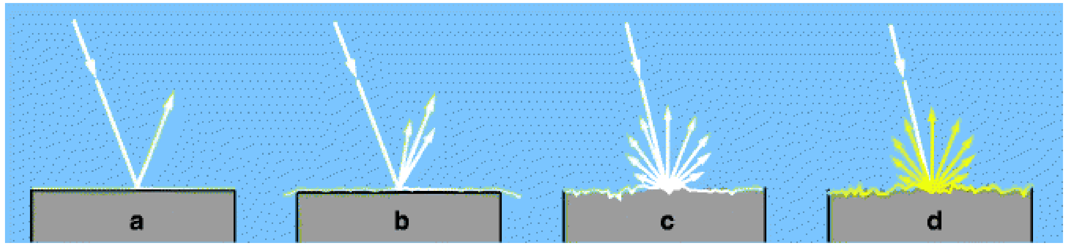
Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.



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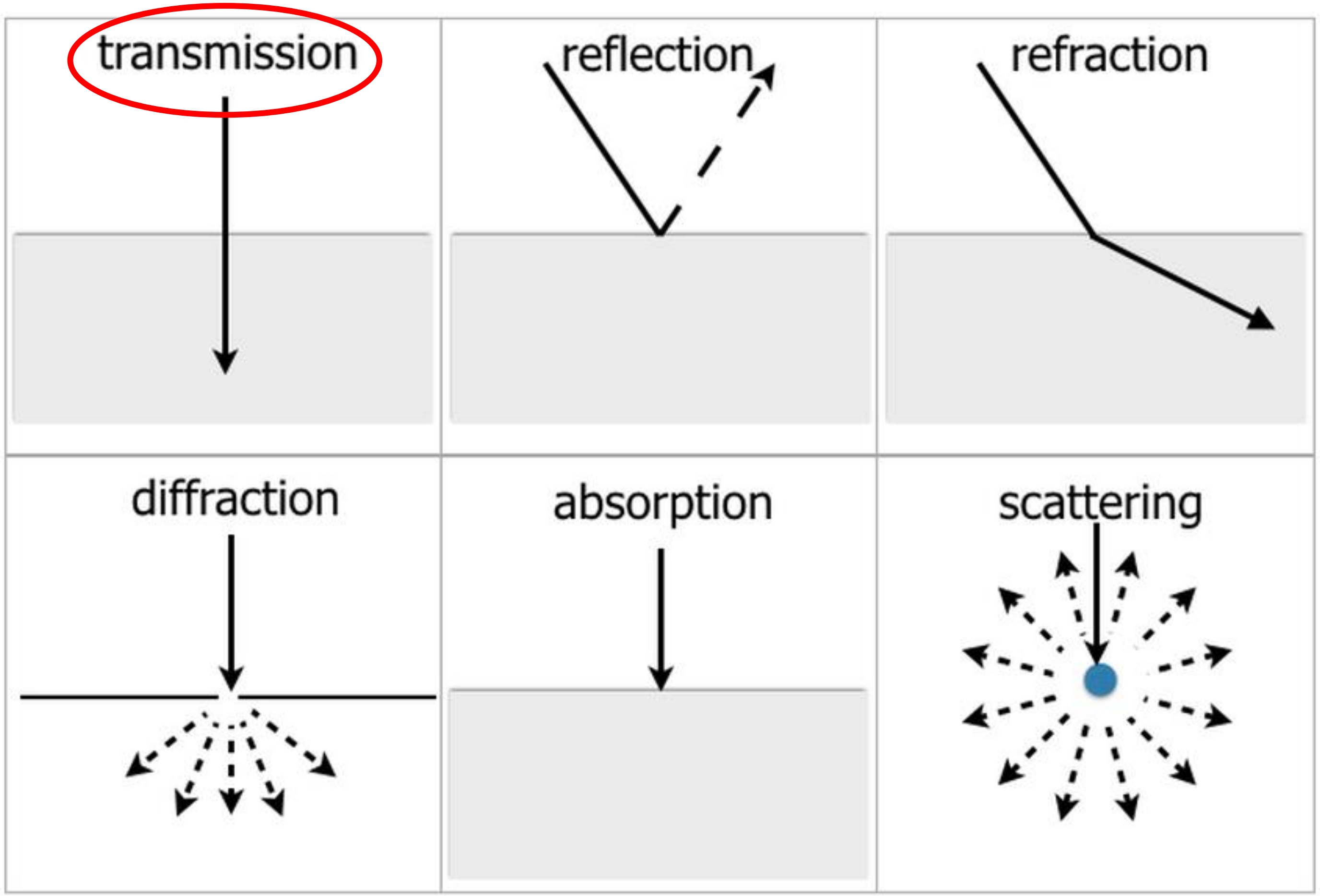
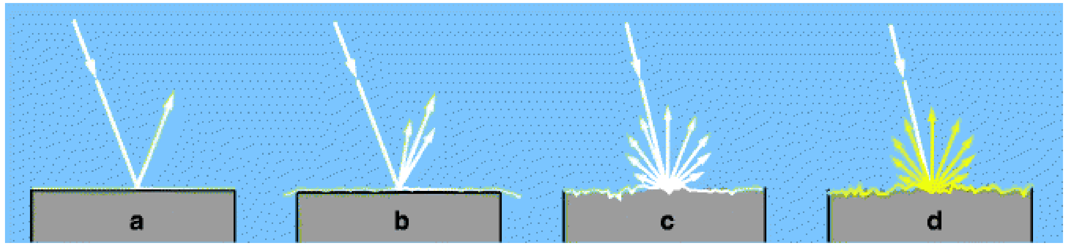
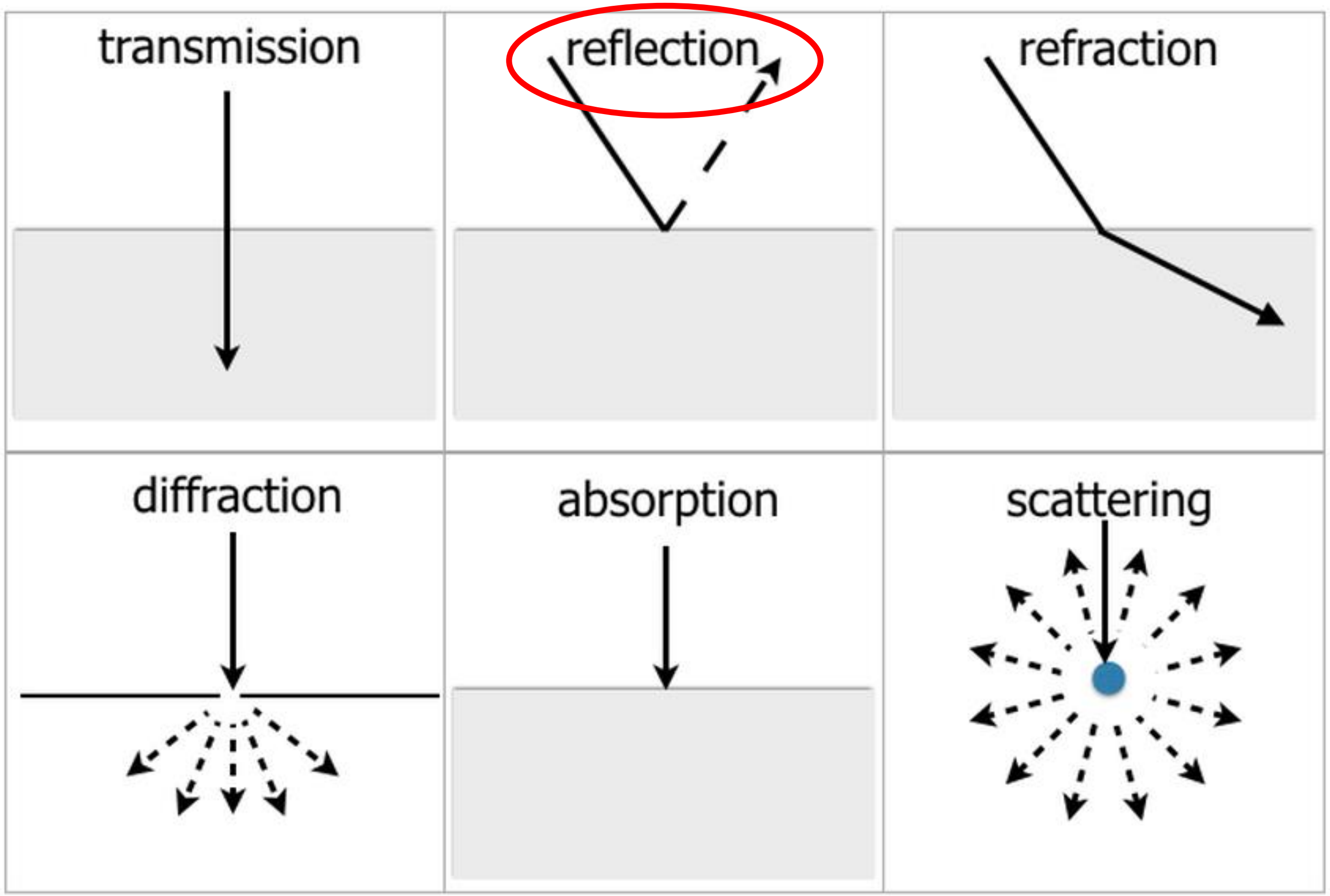


Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.

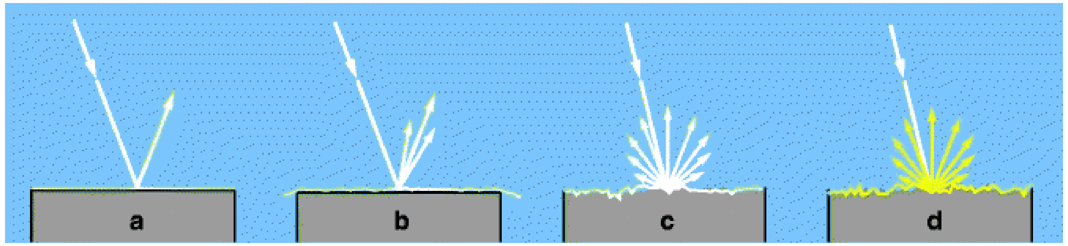


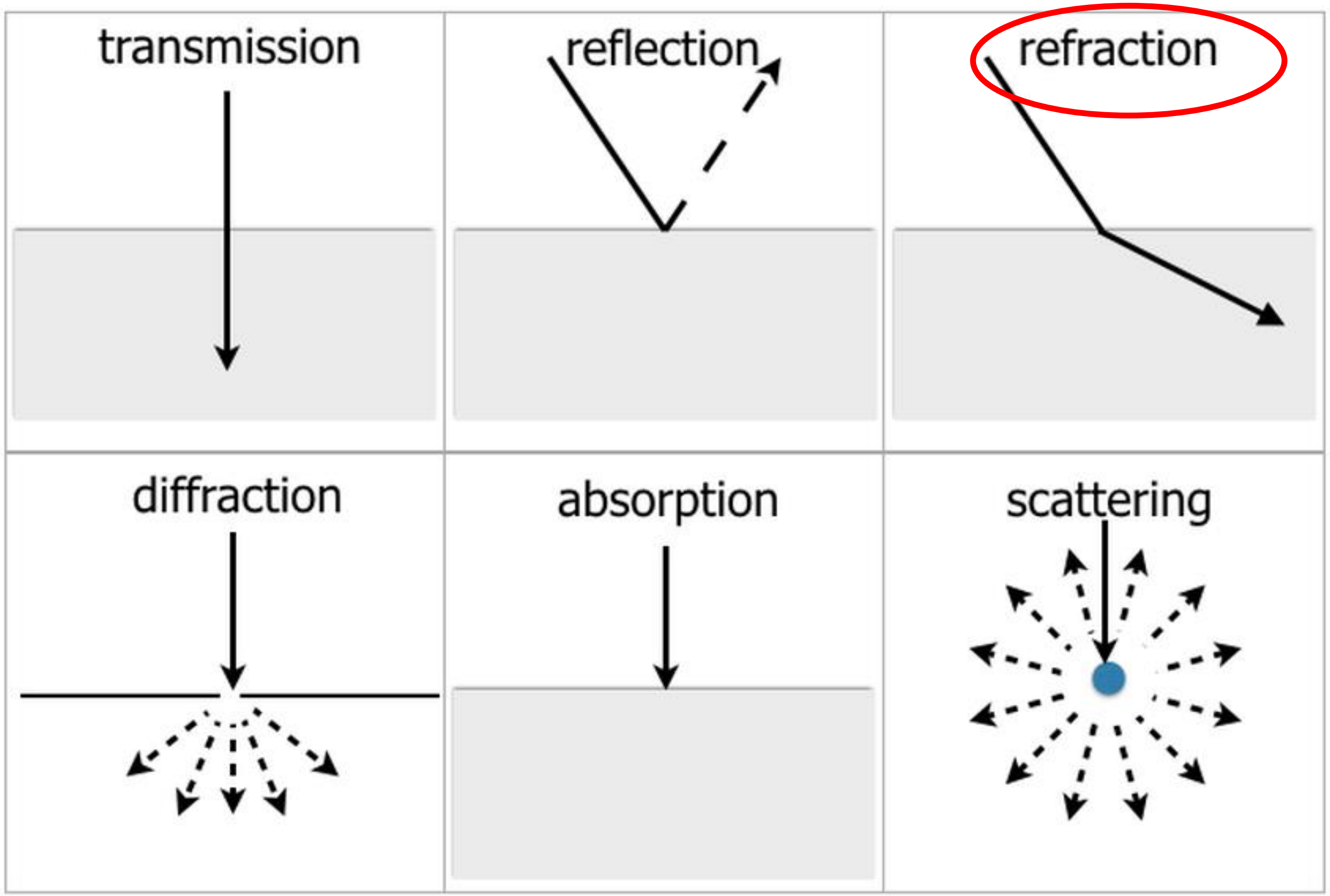
- Seismic reflection is generally applicable to depths greater than 80 to 100 feet, and is widely used on land to map a variety of deep features (e.g., stratigraphy, faults). This technique is also well suited to marine applications (e.g., lakes, rivers, oceans) where the inability of water to transmit shear waves makes collection of high-quality reflection data possible, even at very shallow depths that would be impractical or impossible on land.



Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.



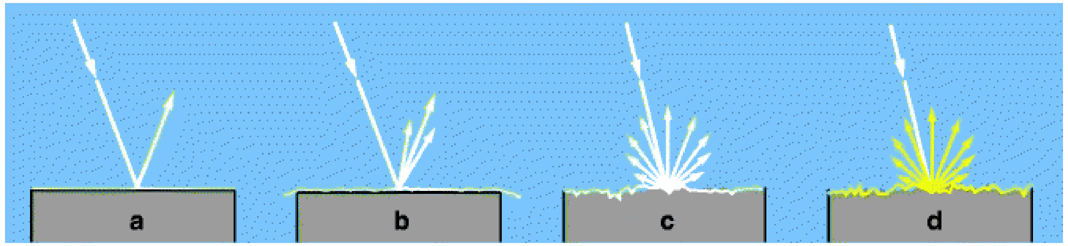


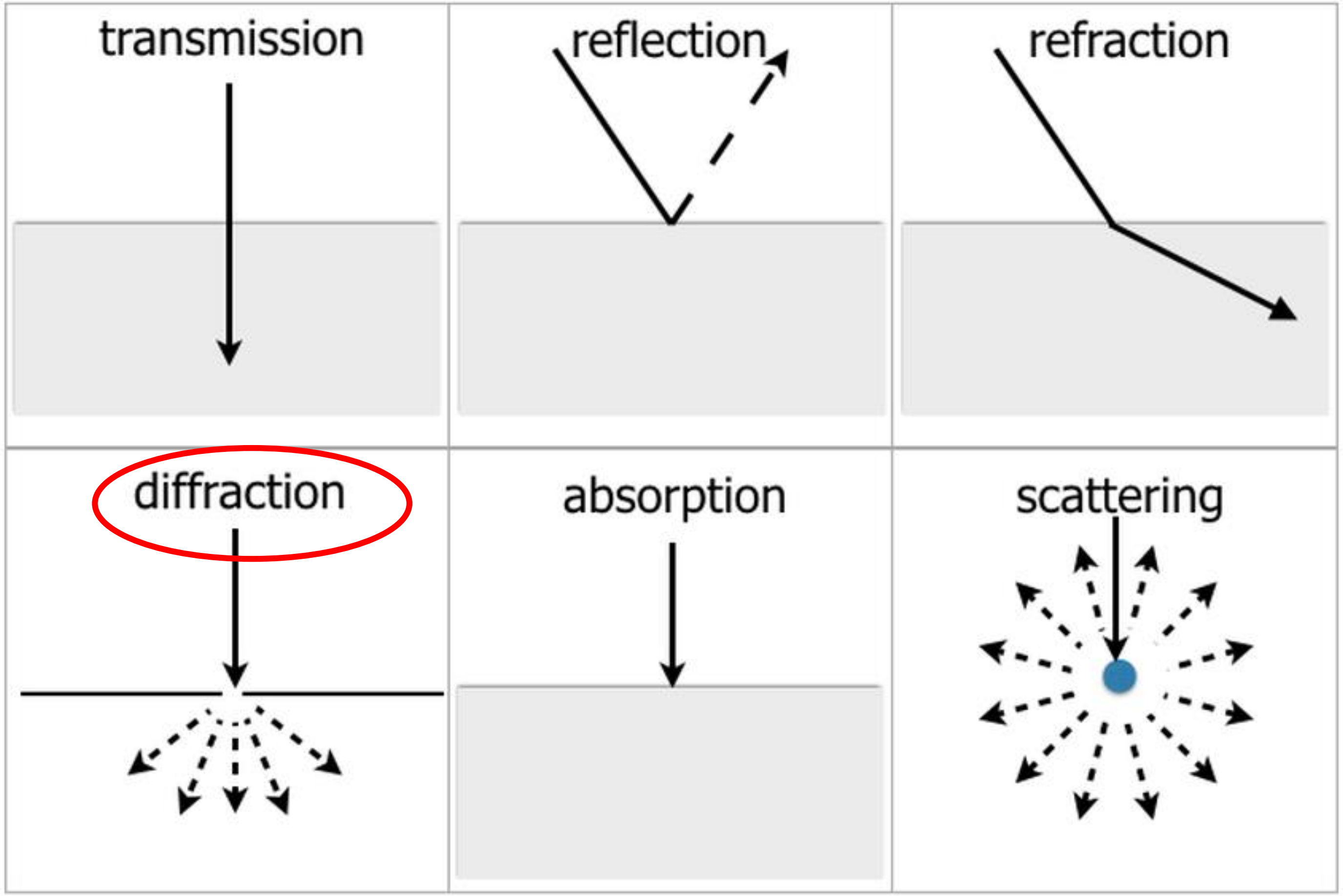
- **Seismic refraction** is commonly limited to mapping bedrock depths and rippabilities at depths less than 100 feet, and is generally applicable only where the seismic velocities of layers increase with depth. Where higher-velocity (e.g., stiff clay) layers may overlie lower-velocity material (e.g., sand or gravel), this technique may not detect those deeper layers.

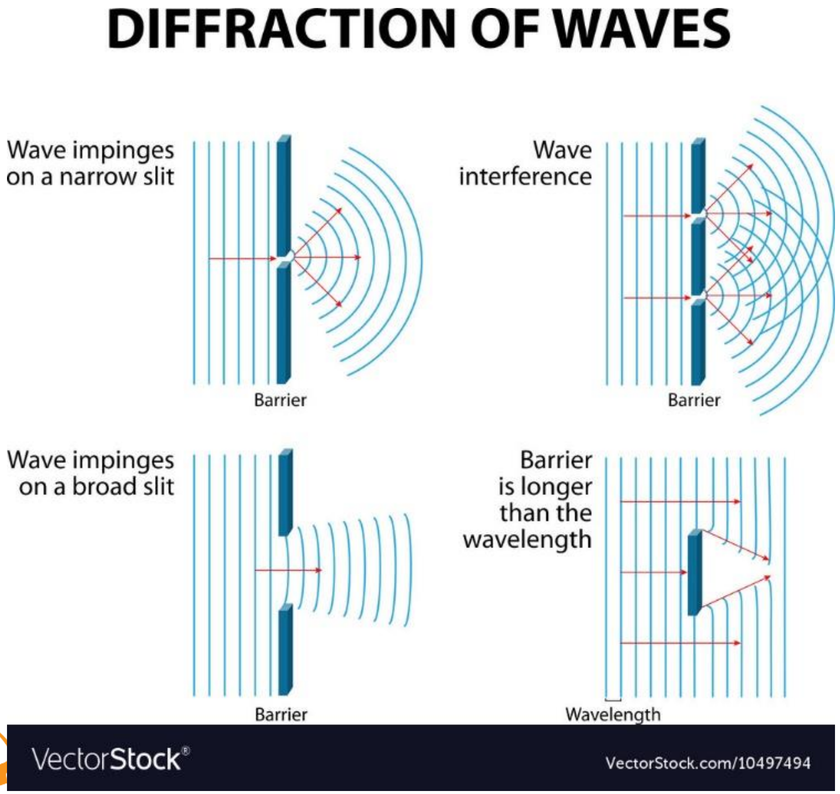
Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.

Faults cause breaks in continuity of seismic horizons and at these discontinuities, **diffraction** patterns in seismic waves are generated. This is a well understood phenomenon but modern seismic acquisition and processing techniques are mainly directed towards providing high resolution images of the reflecting layers in the subsurface. **Diffraction** behavior is largely ignored.

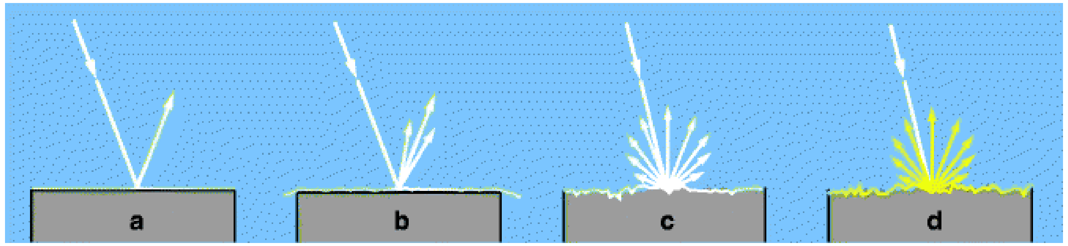




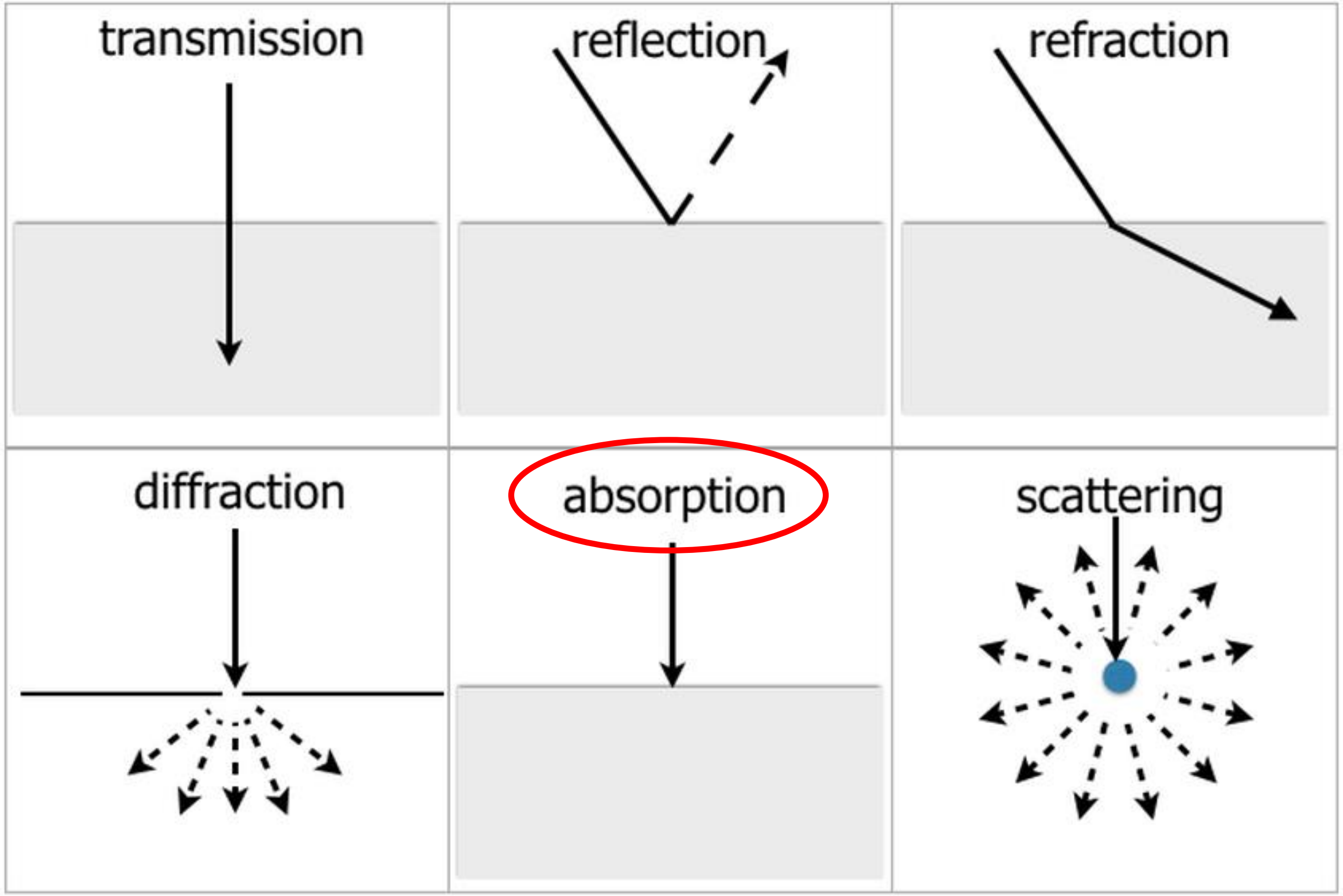


Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.

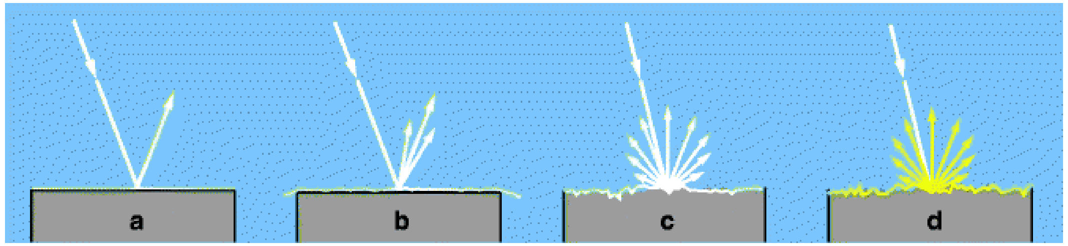


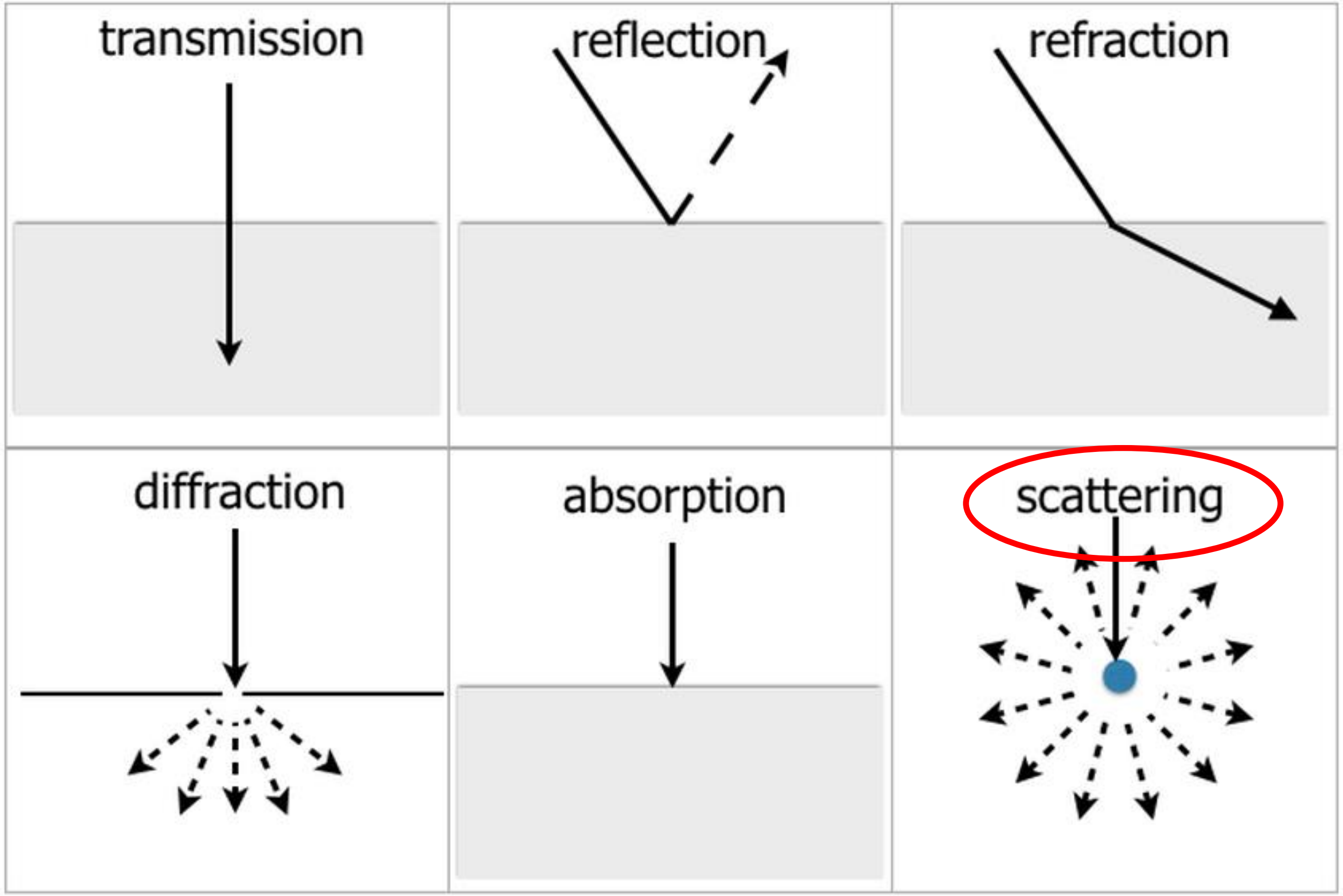
- During propagation of seismic waves, part of the energy is attenuated due to conversion of mechanical energy to heat energy through frictions at grain contacts, cracks and fractures and fluids present in pores of a rock.
- The frictional loss primarily due to motion between rock particles at the point of grain contacts is known as ***absorption*.**



Seismic energy losses

Reflection, refraction, diffraction, transmission and absorption of sound energy.





- **Scattering** losses are irregular dispersions of energy due to heterogeneity in rock sections, usually considered as apparent noise in seismic records.
- Waves being absorbed and then almost immediately released in another direction.