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DEPARTMENT OF GEOLOGY

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SEISMIC METHOD OF EXPLORATION

Amongst all the geophysical exploration methods, seismic surveying is unequivocally the most important because it is capable of detecting large-scale to small-scale subsurface features. Simply stated, seismic methods involve estimation of the shapes and physical properties of Earth's subsurface layers from the return of sound waves that are propagated through the Earth. In general, two types of seismic methods (reflection and refraction) are common.

The basic principle of seismic survey is to initiate a seismic pulse from a ***seismic source*** at or near the Earth's surface and record the amplitudes and travel times of waves returning to the surface after being reflected or refracted from the interface(s) of one or more layers. When a seismic source emits a pulse that propagates through the sedimentary layers, the sound waves travel between the layers with different velocities and will be refracted according to Snell's law:

$$\sin \theta_1 / \sin \theta_2 = V_2/V_1$$

where V_1 and V_2 are the velocities of the first and second media, $\sin\theta_1$ and $\sin\theta_2$ are the sines of the incidence and refracted angles, and θ_3 is the reflected angle.

Snell's law describes the changes in the direction of a wave front as it travels in media of different velocities. If the seismic wave is incident at an angle, both reflected and refracted P- and S-waves will be generated at an interface between two media (Figure-1). However, at a fluid-solid interface like the seafloor, S-waves will not exist in the fluid part.

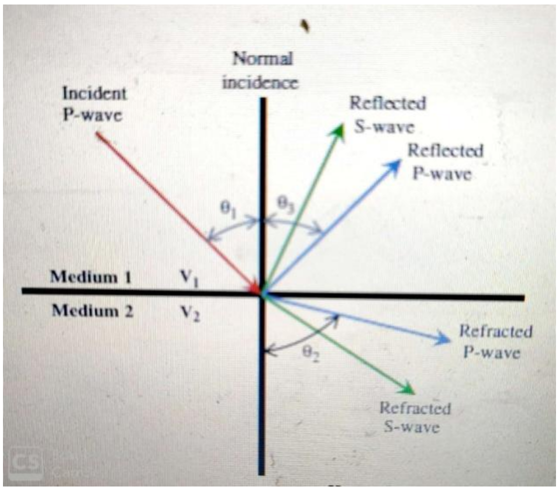

Figure 1 A schematic diagram of reflected and refracted waves generated from an incident P-wave. The angle between the normal to the interface of two media and an incident P-wave is the angle of incidence (θ_1), and is equal to the angle of reflection (θ_3) in isotropic media. The angle of refraction (θ_2) depends on the velocity of the wave in that medium.

Reflections from the layer interfaces in the subsurface are then measured at receivers (time measurements). If the two layers have different velocities, they will as a rule also have different densities, and part of the acoustic energy will not be refracted, but reflected. How much of the energy is reflected depends on the difference in the *impedance* [P-impedance (Zp) or S-impedance (Zs)], which are the product of P-wave (Vp) or S-wave (Vs) velocities and density (ρ). The *reflection coefficient* (R) of a normally incident P-wave on a boundary is given by:

$$\boldsymbol{R} = \frac{(\boldsymbol{\rho 2V2 - \rho 1V1})}{(\boldsymbol{\rho 2V2 + \rho 1V1})}$$

where ρ1 and ρ2 are the densities of the upper and lower layers, V1 and V2 are their respective P-wave velocities, and $\rho 1V$1 and $\rho 2V$2 are the P-impedances of the upper and lower layers respectively. Therefore, anything that causes a large contrast in impedance in the target zone can cause a strong reflection. The possible candidates include changes in *lithology, porosity, pore fluid, degree of saturation* and *diagenesis*.

We see that the greater the difference in density and velocity of two layers, the greater the amount of energy which will be reflected. Sandstone will often have significantly different acoustic impedance from shale, and a considerable amount of sound energy will be reflected from the boundary between a sandstone bed and a shale bed. Limestones will tend to have both high velocities and high densities. The result will be even greater contrast in acoustic impedance between limestones and, for example, shales. However, this contrast will always depend on the porosity of the limestone, though even rather porous limestones have relatively high velocities because they are usually well cemented.

Seismic sources

Different seismic sources are usually used in land and marine acquisitions. In marine environments seismicenergy is normally generated using arrays of air-guns, whereas in land seismic one often uses explosives or vibrators. An *air-gun* is a device that releases highly compressed air (at typically 2,000–5,000 psi) into the water surrounding the gun. A *vibrator* is an adjustable mechanical source that delivers vibratory seismic energy into the ground. A vibrator source sends a controlled-frequency sweep into the ground. The recorded data are then convolved with the original sweep to produce a usable signal. *Dynamite* – a combination of explosive and detonator, is used as a seismic source. The detonator helps to ignite the explosives. When dynamite ignites, a shock wave propagates with a speed of 3,000–10,000 m/s. It provides an impulsive energy that can be converted into ground motion. It is customary to drill a hole to load dynamite and fill it with heavy mud before shooting. Dynamite can generate usable signal strengths and a bandwidth that covers a wide spectrum of seismic energy. It includes a variety of energy sources based on varying explosive output parameters to meet geological and climatic conditions.

Seismic Sensors

The seismic waves are picked up by receivers known as Geophones or hydrophones depending on whether the data collection is on land or sea respectively. The *hydrophone* is a device designed for use in detecting seismic energy in the form of pressure changes in water during marine seismic acquisition. The *geophone* is a device used in surface seismic acquisition, both onshore and on the seabed offshore, that detects ground velocity produced by seismic waves and transforms the motion into electrical impulses. Geophones, unlike hydrophones, detect motion rather than pressure.

Seismic Reflection and Refraction Methods are frequently practiced method for mapping underground structure in sedimentary formation in connection with oil exploration. The principle behind this method follows laws of reflection and refraction of optical waves at the contact of two different media. Similarly, P and S seismic waves move uniformly from the source and reflect and refract on the boundary of a second medium with a different elastic velocity. The energy is partly reflected and partly transmitted in the second medium. Method of reflection profiling can be explained by Fig.2. A wave travels from source "S" and reflects at a point "R" of the interface at a thickness of h1 and arrives at the geophone “G” at time interval of Tx. The velocity V1 of the upper layer and depth h1 to the interface can be obtained mathematically by recording the reflection times at two distances (x, x’). The information obtained by a single reflected pulse at one detector position is not enough to establish the existence of a reflecting horizon. In practice, stepwise shifting of the entire shot-geophone with a series of multi-track geophone placed at short interval is used. A continuous mapping of the reflecting horizon is possible in this way as depicted at Fig. 3. A schematic seismic profile of subsurface geological formation is given at Fig. 4. A schematic illustration of marine and land seismic profiling system is given in Fig. 5 & 6 respectively. Refraction prospecting uses refracted waves from near surface explosions and subsurface layering (Fig. 7). It is detailed on a smaller scale, particularly for unknown geology. It is a powerful tool of petroleum seismology and theoretical seismology for investigating the basement, depth and crustal structure.

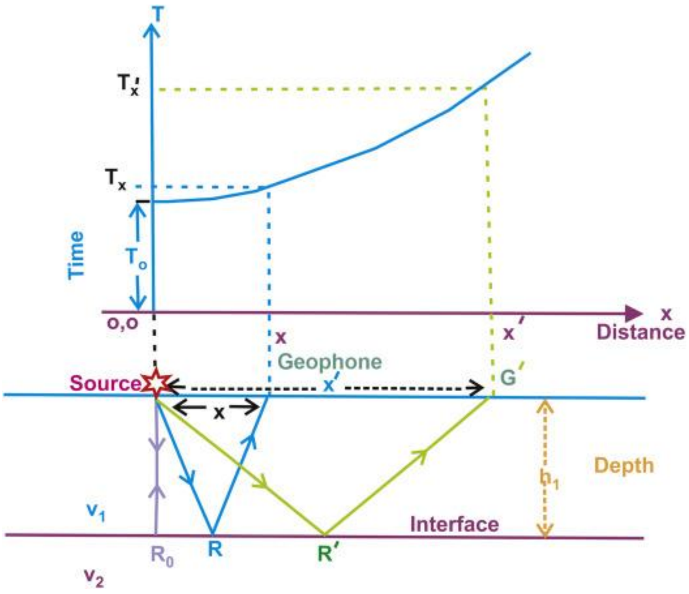

Figure 2- Method of seismic reflection profiling by time versus distance curve at media interface.

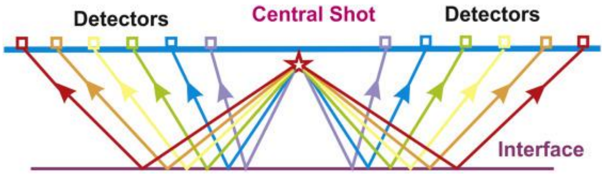

Figure 3 - Multichannel seismic profiling between central shot and multiple detectors on either side (Source: modified after Kearey et al. (2002).

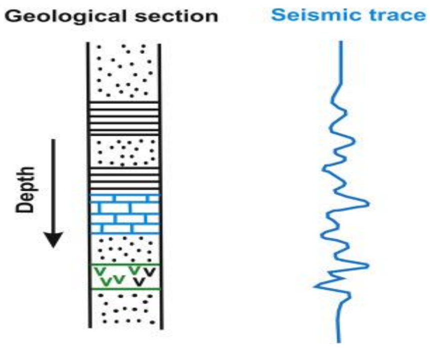

Figure 4 - Seismic reflection profiling of subsurface geological formation (Source: modified after Kearey et al., 2002)

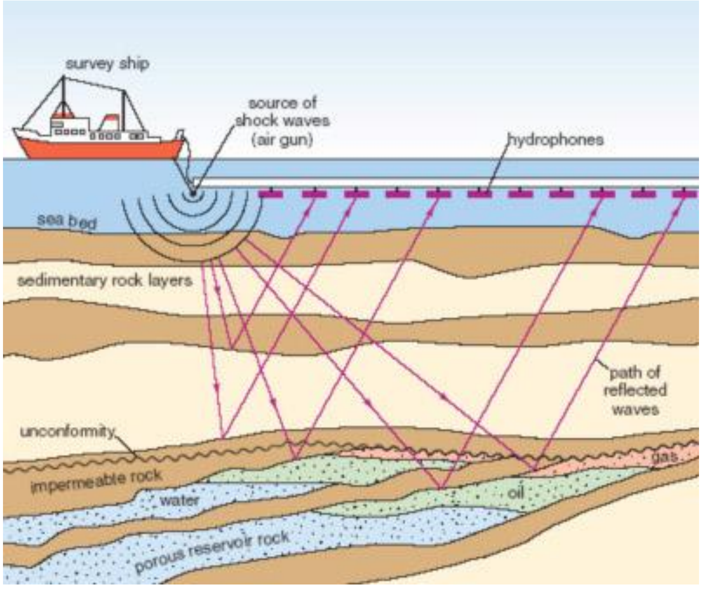

Figure 5- Marine seismic profiling.

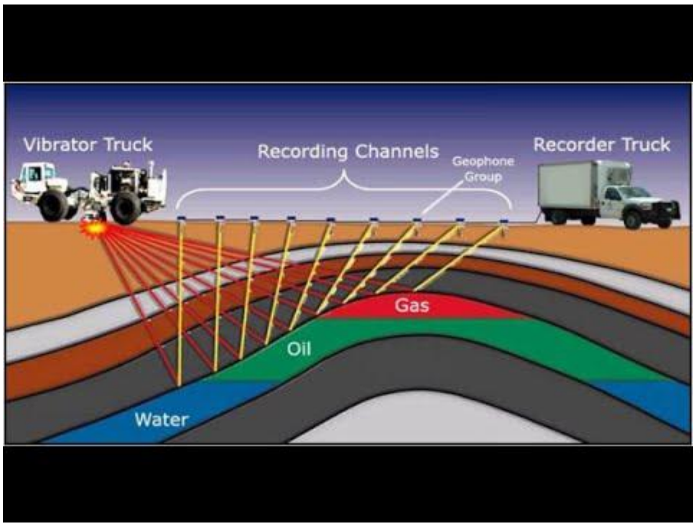

Figure 6- Seismic profiling on land.

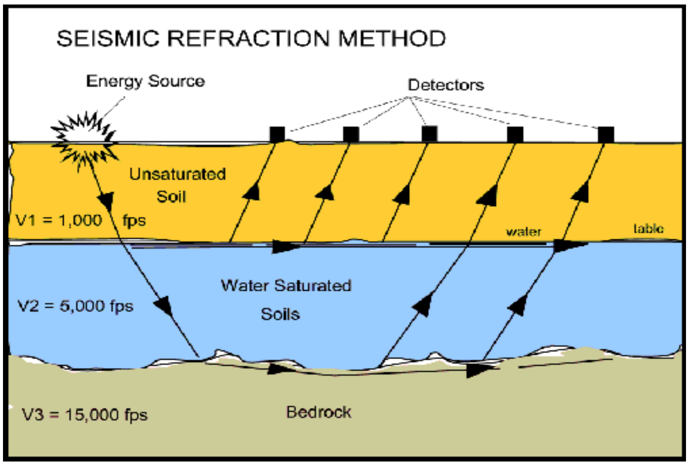

Figure 7- Seismic refraction method illustrating how refracted waves travel through a subsurface consisting of an overburden with a seismic velocity of 1,000 feet per second (305 meters/sec) over water-saturated overburden with a seismic velocity of 5,000 ft/sec (1,500 m/s) over bedrock with a seismic velocity of 15,000 ft/sec (4,600 m/s).