SEISMIC IMAGING IN THE OCEANS

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Contents

Summary

Seismic surveys on the sea surface and the sea floor enable us to collect 4D/4C reflected and refracted data for quantitatively understanding the geological oceanography (see Geological Oceanography: Introduction and Historical Perspective) with the highest resolution. Propagation of P waves and S waves introduced in this chapter is the foundation of processing reflected and refracted data and imaging geological structures in the oceans.

The standard technique of processing reflected data consists of CDP gathering, velocity analysis, NMO and migration. In particular, depth migration of 3D reflected signal results in the correct images of the sub-surfaces and the velocity models. On the other hand, refracted and reflected data are simultaneously employed in the travel-time inversion of 3D velocity-depth models. Interpretation and visualization of these 3D geological images and properties can be implemented efficiently in the real time by employing the new technologies of the seismic coherence and the virtual reality.

1. Introduction

Seismic imaging of geological structures in the oceans is rapidly advanced because of the emergence of the understanding of seismic wave propagation, new technologies of seismic acquisition and novel techniques for processing seismic data during the past decades. In this chapter, we will focus on seismic imaging of the oceanic basins and crusts by using the controlled sources only, because they are more predominant than the bore-hole seismology and more precise than earthquake seismology at least in the near future.

Furthermore, seismic imaging of 3D complex geological structures at different time-spans has been a new trend for promotion of mining and oil exploration (see Mining and Oil Exploration in the Oceans and Seas). Therefore, reliable interpretation of 3D complex structures in the real time is required and will be discussed at the end of this chapter.

2. Seismic Wave Propagation

Wave propagation (see Physical Oceanography and Underwater Acoustics) within and beneath the ocean can be exploited for imaging geological structures with the highest resolution in oceans. Ray as the continuous direction of the wave propagation traces the affected region of geological structures under investigation. On the other hand, the wave front characterizes the equal travel-time of the wave propagation that can tell us how far of the geological structures from the source. In general, rays are perpendicular to the wave fronts. For example, a point source (such as an explosive) generates both rays along the radial direction and the wave fronts as the concentric spheres in Figure 1.

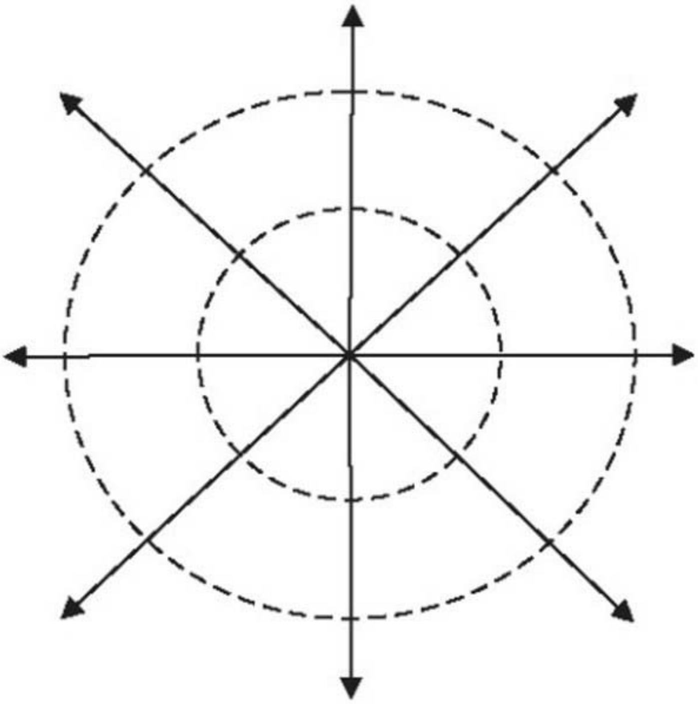

Figure 1: Rays and wave fronts

Recently new technology (described in the next section) promoted P, S and converted waves, rather than only P wave traditionally, for better exploring geological structures in marine environments. The reality of using three wave modes results from the composition of elastic solids (see Continental Margins and Marginal Seas) as the density (ρ) and two elastic constants that can be further reduced to P-wave velocity (V_P) and S-wave velocity (V_S). The physical features of P wave and S wave are quite different. Firstly, P wave is faster than S wave. Secondly, the particle motions (or vibrations) of P wave and S wave are parallel and perpendicular to the direction of the wave propagation, respectively. Thus, P wave and S wave are also known respectively as the longitudinal and transverse waves. The combination of P wave and S wave along a whole ray is the converted wave. The conversion takes place at the interface of two distinct rocks. Figure 2 illustrates that an incident P-wave with an incident angle of θ_{P1} generates a reflected P-wave, a reflected S-wave, a transmitted P-wave and a transmitted S-wave at the interface. Directions of reflected (θ_{S1}) and transmitted (θ_{P2} and θ_{S2}) waves can be determined from the following Snell's law,

$$\frac{\sin\theta_{P1}}{V_{P1}} = \frac{\sin\theta_{S1}}{V_{S1}} = \frac{\sin\theta_{P2}}{V_{P2}} = \frac{\sin\theta_{S2}}{V_{S2}} \qquad (1)$$

Application of Snell's law for imaging geological structures is fundamental because the direction of wave propagation depends mainly on the variation of velocity distribution.

Seismic images are usually quantified by using travel time and amplitude. If the geological structures are assumed known in advance, travel time can be readily calculated from the structural velocities and the ray paths that obey the Snell's law. Furthermore, evaluation of amplitudes needs to consider the attenuation and the velocity discontinuity of the geological structures. For the later one, the ratios of reflected and transmitted amplitudes over the incident amplitude are defined respectively as reflection (R) and transmission (A) coefficients. The coefficients for the acoustical case are

$$R = \frac{1-Z}{1+Z}$$

$$A = \frac{2}{1+Z} \qquad (2)$$

where the impedance coefficient is $Z = \frac{\rho_2 V_{P2}\theta_{P2}}{\rho_1 V_{P1}\theta_{P1}}$ and the geological properties in Z are shown in Figure 2.

Evaluation of travel time and amplitude in advance described above is known as the forward problem. Although the forward problem seems impractical for seismic imaging of geological structures, it can be employed for understanding the nature of seismic wave propagation and for modifying the assumed geological models. The later one is known as the inverse problem and will be introduced later.

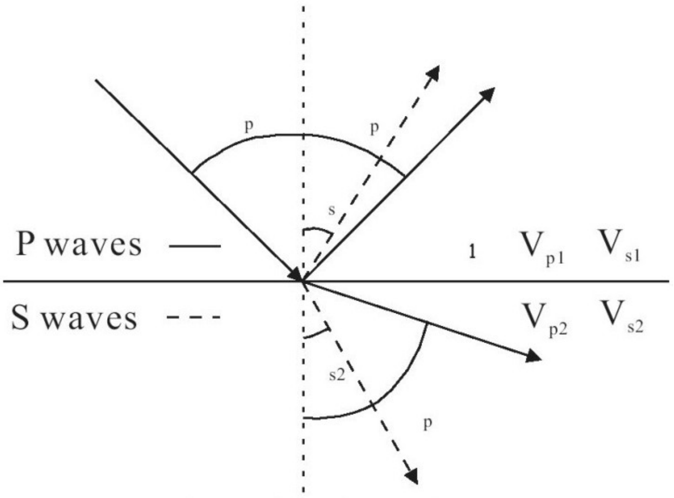

Figure 2: Snell’s law of P waves and S waves

3. Seismic Data Acquisition

The typical controlled sources of the marine seismic acquisition (see Field Measurements) are air-gun shots and solid explosives. In particular, air-gun shots are the main sources because their density, flexibility and safety. Three types of the marine surveys and their states of the art will be introduced according to the collection of reflected or refracted data for imaging the geological structures in oceans.

3.1. Multi-Channel Seismic (MCS) Survey - 4D (*x*, *y*, *z*, *time*) reflected data

Traditional multi-channel seismic (MCS) survey in oceans was designed as a streamer with hydrophones floating on the sea surface and trailed by a shooting ship as illustrated in Figure 3. The marine operation can continuously collect 2D reflected data for exploring the geological layering underneath the seismic line. However, the current trend of the marine survey is advancing rapidly to 4D operation. Widespread of receives by up to 20 streamers from a shooting ship enables us to image the reflecting sub-surfaces in 3D complex structures and for promoting hydrocarbon production. Furthermore, time-lapse operation (acquisition at the same place in various periods) has applied to monitor the petroleum reservoir for evaluation of its content and future production.

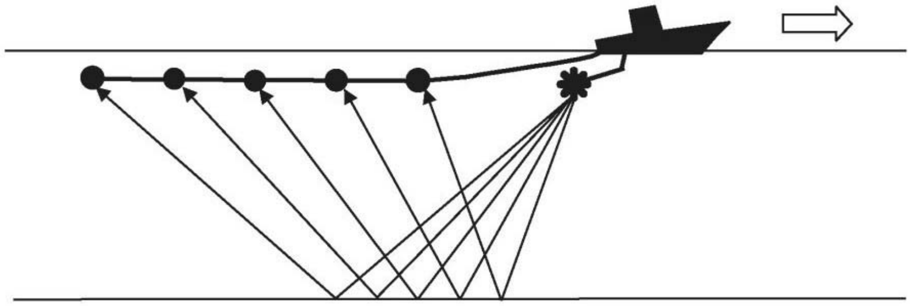

Figure 3: Multi-channel seismic survey

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Biographical Sketch

T. K. Wang is a Professor of Applied Geosciences at the National Taiwan Ocean University. He received a bachelor’s degree in civil engineering from National Chiao Tung University at Taiwan in 1984, completed his master’s degree in applied mechanics from National Taiwan University in 1988, and received his doctorate from University of Illinois at Chicago in 1992. Since his expertise in seismic and non-linear wave propagation, he worked as a research staff at the Fault Dynamic Project (supported by petroleum consortiums) in the Department of Geology, Royal Holloway, University of London during 1992~1994. His research interests include seismic data processing, wave propagation and computer applications on geophysics. He was a member of the standing committee of Chinese Geophysical Society (CGS) during 1996~1997, and has been the active members of SEG, AGU and CGS since 1994.