Long Offset Refraction Surveys for Better Seismic Imaging and Reliable Depth Conversions

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Summary

Over the last decades seismic industry struggles with precise velocity models building. That leads to inaccurate depth imaging problems, especially in complex geological environments such as high velocity and “non-transparent” for reflected waves medias (salt bodies, faults and fractures zones, etc.). To solve these uncertainties seismic companies require to involve wide-azimuth and long-offset datasets on the processing and interpretation stages. Nowadays long offset and wide azimuth surveys can be acquired utilizing OBS, multi vessels, coil and double coil shooting. Unfortunately, these seismic data acquisition techniques are highly time and cost demanding solutions.

Newly developed FloatSeis™ seismic data acquisition and processing technique based on free floating seismic recording modules and joint reflected and refracted waves tomography velocity model building approach was invented to make wide-azimuth and long-offset surveys much more affordable especially in a low oil price environment.

The technology recommended itself as an efficient and cost effective solution and a promising survey tool for making proper staking wells decisions, especially in complex geological environment suited both for 2D and 3D offshore seismic surveys.

Introduction

The key role of any geological and geophysical survey is reducing subsurface exploration and production risks. Proper and reliable velocity model is a key factor to the clear seismic imaging. Clear seismic imaging both in time and depth domain is extremely important on the interpretation and further reservoir delineation stages. Unfortunately, seismic data provide with indirect measurement of velocity. Based on these measurements exploration seismologist derives a large number of different types of velocity – interval, apparent, average, root-mean-square, instantaneous, phase, group, normal moveout, stacking and migration velocities (Yilmaz, 2001). Accuracy of these types of velocities depends on various factors such as: cable length, maximum gained offsets, geological environment complexity, dip angle, velocity itself, etc. Standard towed streamer marine seismic surveys are constrained with the streamer length and recorded shot-receiver offsets. Thus, obtained velocity models can be less accurate than it is required for clear depth imaging, especially in complex geological environments. Wide-azimuth and long-offset seismic surveys can assist geoscientists to solve this problem. The advantages of wide-azimuth and long-offset surveys in comparison to a conventional towed streamer surveys are well described by Regone (2006) and Bouska (2008).

The New Way to Acquire Long-Offset Refraction Seismic Data

Nowadays long offset and wide azimuth surveys can be acquired utilizing OBS, multi vessels, coil and double coil shooting. Unfortunately, these seismic data acquisition techniques are highly time and cost demanding solutions. For example, OBS surveys are typically formed by rolling the entire active patch laterally following the completion of each source patch, what is highly inefficient due to large volume of repeat source points acquired and unproductive vessel utilization e.g. multi-vessel crews where a source vessel is on standby waiting for receivers to be retrieved or deployed (Lewis et al, 2016).

However, there is another different way to build proper velocity model. Refracted wave is an alternative source of information on velocities distribution in the earth strata allowing to supplement the CDP data with true velocities for Pre-Stack Migration processing stage (applicable both in time and depth domains). The only one problem why usage of velocity models derived from refracted wave data is not that common, is because seismic data should contain 5-6 times bigger offsets to record refracted wave in comparison to reflected wave with the same depth of penetration. For example, a CDP reflection survey for depths down to 10 km requires 10 km offsets. To acquire refracted waves from the same depth, 50-60 km offsets are required, what is not being feasible with towed seismic streamer facilities (see Figure 1).

The New Way to Get Long Offset Refraction

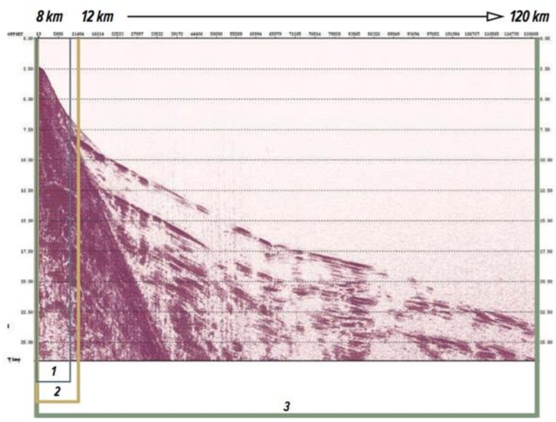

Figure 1: Seismic data offset range recorded by: 1. Standard seismic streamer (8 km); 2. Seismic streamer mainly used for regional studies (12 km); 3. FloatSeis™ seismic surveys (120 km). Offsets 12-120 km are always missing on the towed streamer dataset, but they contain useful seismic information.

To record desired long offset refracted wave data new seismic recording equipment and data acquisition technique were developed. The main idea of the invention was to make long-offset surveys much more affordable especially in a low oil price environment. There are several main factors that allows to considerably reduce the total price of the long-offset refracted wave seismic surveys. 2D long-offset refracted seismic surveys are conducted simultaneously with towed streamer CDP seismic data acquisition. Thus, no additional seismic vessel with a high day rate cost required. Moreover, the deployment process of the recording equipment can be performed from the seismic vessel itself or a chase boat of the seismic vessel making long-offset refracted wave seismic surveys even more affordable. 3D long-offset and wide-azimuth refracted wave seismic surveys are conducted after the towed streamer survey is accomplished. However, they do not require seismic vessel because a chase boat with a portable source installed on deck can be utilized as a source vessel, lowering the price of the data acquisition. Free floating recording units are placed into a special transport container, ensuring quick mobilization/demobilization of the refracted wave seismic party. Possibility to accommodate transport container with the recording equipment on the deck of any non-specialized vessel (support, guard, chase, fishing, etc.) allows quick deployment of a party and also brings down the price of the survey. Diligent survey design including ray coverage and wave field modeling before the start of the survey also plays a great role in cost efficiency of the long-offset refracted seismic surveys. Deblending technique gives an opportunity to record refractions from deep horizons and have a dense ray coverage because of the fine shooting spacing aligned with the CDP streamer survey's shooting spacing. After desired offsets have been already recorded by free floating seismic units, they are recovered by a support vessel. The deployment and recovering process goes continuously till the end of the project, therefore production rate of the long-offset refracted wave seismic surveys approximately equal to the production rate of a towed streamer CDP seismic survey. Figure 2 describes the process of the long-offset refracted wave seismic surveys both for 2D and 3D geometry.

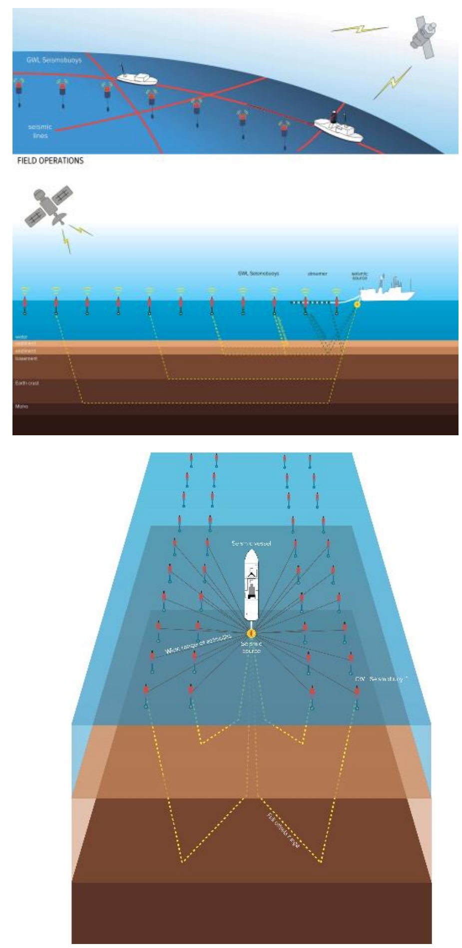

Figure 2: FloatSeis™ Survey in 2D (top) and 3D (bottom) modes.

In the situations when, for example, deep sub-salt reservoirs are not properly imaged with conventional narrow azimuth towed streamer 3D survey or presence of hydrocarbon has been proven by exploration well but better seismic data is needed to de-risk development plans – wide azimuth towed streamer 3D surveys can be applied (Lencrerot et al, 2016). As a cheaper alternative to the wide azimuth towed streamer survey to complement the already recorded narrow azimuth data – FloatSeis™ 3D wide-azimuth seismic surveys can be applied.

Free Floating Recording Unit

GWL Seismobuoy™ is a free floating autonomous recording seismic unit developed by Geology Without Limits as a part of FloatSeis™ marine seismic technology for recording ultra-long offsets refraction data to enhance CDP towed streamer dataset by a supplementary information. Recorded wavefield has the same dynamic and frequency characteristics as a common towed seismic streamer wavefield. This gives us an opportunity to seamlessly merge two datasets and input them into the integrated seismic data processing routine. Ambient noise level of the free floating recording unit for the sea waves 1-3 meters height is approximately the same as for a calm sea state due to special designed damper device. It lets to record data with help of recording unit in weather conditions suitable for towed streamer surveys with the S/N ratio equal to the S/N ratio of the towed seismic streamer data, even though free floating recording unit contains a single hydrophone in comparison to grouped hydrophones mounted into seismic streamers.

The free floating recording unit sensor's frequency range 1-1000 Hz was deliberately expanded toward low frequencies. The result is a significant increase of the research depth due to the ability to record the low frequency signal from extra-deep boundaries of the geological section under study.

The free floating recording unit comprises online tracking system. The tracking system allows online monitoring the position of all recording units at any place of the Earth at any time. In addition, it enables tracking the status of the data recording process, the battery charge level and the readings of internal auxiliary sensors (temperature, humidity and accelerometer). Constant automatic humidity control permits to quickly respond even to a small leakage of the unit and replace it immediately with a leak-tight one. As a result, equipment reliability, survey accuracy and marine operations safety are increased by recording the position and monitoring the status of each device in real time.

Recent Free Floating Recording System's application

Guyana basin free floating recording system regional survey was conducted in 2016. Over 1000 lkm of 2D FloatSeis™ data was obtained during this survey. Free floating recording units deployment spacing was ranged from 6 to 10 km and shot points spacing equaled to 50 m fired by 7060 cu. inch seismic source. The towed seismic streamer length was 12 km. Refracted waves on the offsets up to 100 km were recorded by free floating units. Refracted waves penetrate areas inaccessible for reflected waves due to different principle of distribution. Thus, it helped to recover missing information of velocity structure with help of refracted waves tomography velocity model building approach. This velocity building approach demonstrates distinct results, in comparison to towed streamer seismic data, in deep depth bedding horizons, steep dip angles and high velocity formations areas. Joint processing of refracted and reflected waves data helped to create accurate velocity models free of low-quality definition areas. It eliminated false velocity anomalies and as a final result geologically reliable velocity models were created. This gave us an improvement on clarity of seismic sections and precision of geometry of reflecting boundaries, especially for deep and geologically complex media (Figure 3).

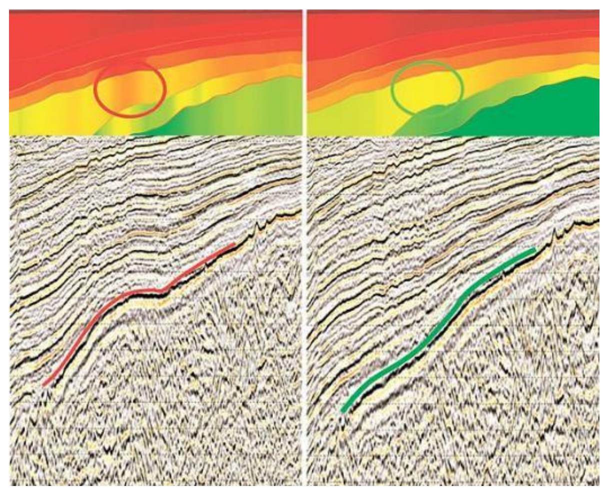

Figure 3: Guyana basin program data sample. PSDM based on CDP velocity model (left) and PSDM based on long offset refracted wave velocity model (right). Regardless of a high-velocity layer in the upper part of the section, utilization of the long offset refracted waves had helped to correctly calculate velocities for the underlying layers that allowed to refine the structural geometry of the layer.

Bjørnøya basin (the Barents Sea, Norwegian sector) free floating recording system survey was conducted in October 2016. Over 100 lkm of 2D long offset data was obtained during this survey. Free floating recording units deployment spacing was equal to 3.5 km due to prospecting job design and shot points spacing equaled to 37.5 m fired by 6100 cu. inch seismic source. The towed seismic streamer length was 12 km. Free floating recording units recorded refracted waves on the offsets up to 30 km, gaining 5.5 km acquisition depth, while initial geological objective investigation depth was 3.5-4.0 km. The seismic line was located in the conjunction zone of different structural elements. The seismic image based on the CDP velocity model is complicated with diffractions from fractured zones and salt bodies also containing 2-6 order multiples. Usage of velocity model build with long offset refracted data, helped to eliminate multiples, achieve better seismic resolution with less random noise and define position of the geological layers in depth domain that corresponds better with wells log data, in comparison to CDP velocities towed streamer data.

Conclusions

Reflected waves structural imaging gives basic geological layers geometry mainly fair only in time domain. Long offset refracted waves tomographic velocity model gives us more realistic velocity distribution over the understudy area. Integration of both data sets on the Pre-Stack Depth Migration stage provides us with true vertical depth of geological structures verified by well data. The final data obtained by long offset refracted data seismic surveys permits to reduce velocity model’s uncertainties, increase level of confidence on the interpretation stage and build detailed geological section of the areas understudy. The described technology is an efficient and cost effective solution and a promising survey tool for making proper staking wells decisions, especially in complex geological environment suited both for 2D and 3D offshore seismic surveys.

Acknowledgments

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