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Land Converted Wave Seismic Survey Designing-Key Factors to Consider

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Summary

Converted wave (multicomponent) seismic survey has many applications in the field of hydrocarbon exploration and reservoir development. The existing technology makes it more relevant and feasible in routine acquisition, processing & interpretation of multicomponent seismic data. Acquiring converted wave seismic data on land requires 3-component geophone which records shear waves along with primary wave. Due to several reasons the designing of converted wave 3D survey differs from conventional 3D survey and some critical factors need to be considered for optimum designing of converted wave 3D. The present paper discusses the causes which compel us to think different way for the designing of converted wave 3D survey along with possible solutions.

Keywords: *Converted wave, common conversion point (CCP).*

Introduction

P-wave seismic reflection survey has been adopted as a primary exploration tool in the quest of hydrocarbon exploration over many decades. The growing challenges to mitigate the exploration risk necessitate full-wave imaging for characterizing more comprehensive reservoir properties. The recent advancements in seismic data acquisition particularly development of MEMS (Micro Electro Mechanical System) based digital sensors drew significant attention and escalation in Land Multi-component seismic surveys. In most of the land multi-component surveys, mode converted S-wave (PS-wave, down-ward propagating P-wave, converting on reflection to up-ward propagating S-wave) is recorded along with the PP component.

Conventionally, the selection of acquisition geometry is often governed largely by the economical constraints and geographic/topographic logistics. To meet the geo-scientific objectives of the planned seismic surveys, geophysical requirements must play a dominating role particularly in case of converted wave seismic. Converted wave seismic intend to study the spatial distribution of PP and PS waves properties simultaneously and necessitates the optimization of PP & PS subsurface coverage along with spatial distribution of geometrical attributes (fold, offset, and azimuth). Unlike the PP-wave, PS-waves have asymmetric ray-paths and hence results asymmetric illumination of the sub-surface. The asymmetric illumination by PS-wave complicates the designing of land converted wave (3C) seismic surveys and special attention is required during designing.

Converted wave Acquisition Geometry

Subsurface illumination is the most critical factor in determining the acquisition geometry in converted wave seismic surveys. Orthogonal acquisition geometries are most popular for conventional (P-wave) land 3D seismic surveys due to continuous subsurface illumination and spatial continuity of geometrical attributes. In P-wave acquisition the midpoint coverage is fairly representative for illumination fold. In case of converted waves, conversion points are shifted towards the direction of receivers and produces irregular PS illumination. Irregular illumination cannot be avoided by either of the acquisition geometries (parallel, slant or orthogonal). Though, parallel geometry offers relatively regular illumination than orthogonal geometries, azimuth sampling is superior in orthogonal geometries (**Fig.1**). Wide azimuth data with denser azimuth sampling is essentially required for shear wave bi-fringes analysis which in turn provides the fracture density and orientation. Hence, orthogonal geometry may be

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preferred for land 3D-3C seismic surveys particularly with the objective of fracture characterization.

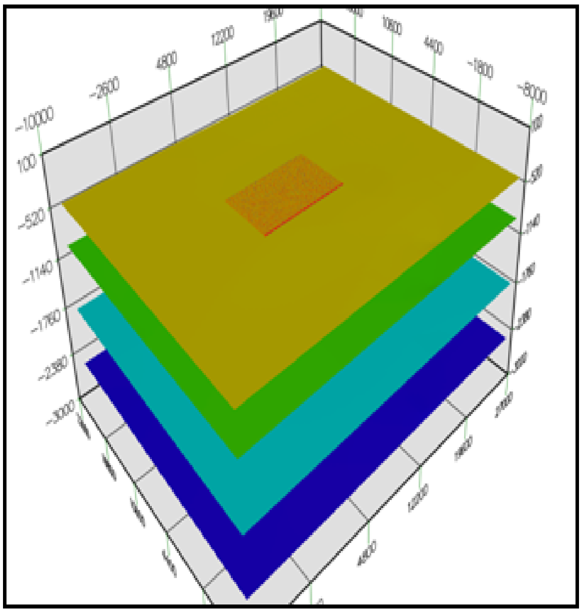

Figure1. Subsurface Illumination by Orthogonal Geometry

Converted Wave Fold

Since the signal strength (amplitude of reflected wave) of the PS wave is always less than that of PP-wave, higher fold is required to eliminate the random noise in PS gathers.

The key challenge in orthogonal PS seismic surveys is the high spatial variability of the PS fold. Since the conversion point is not centered between source and receiver points rather lies at a distance of Xc = r / (1+ Vs / Vp) from the source point (**Fig2**), common conversion point (CCP) is asymptotic and depth dependent. During the initial stages of processing, as Vp/Vs ratio is not available with desired accuracy, asymptotic common conversion point (ACCP) binning using single Vp/Vs ratio is often used. The ACCP binning with CMP spacing as bin size results the spatial discontinuity in the PS fold distribution. The PS fold varies bin to bin and secondly the stripping is seen in cross-line direction at the places of swath overlaps as well. The fold stripping in cross-line direction can be minimized using single receiver line overlap.

Further, careful selection of receiver line spacing (RLI) and source line spacing (SLI) regularize the fold distribution. It has observed that if RLI & SLI selected in such a way that SLI= (integer+0.5) X SI and RLI = (integer+0.25) X RI, the spatial variability of fold can be further reduced. The use of bin size larger than CMP spacing for converted waves i.e. RI / (1+ Vs / Vp) along with proper selection of RLI & SLI not only regularizes the PS fold variability but provide constant PP & PS fold as well .

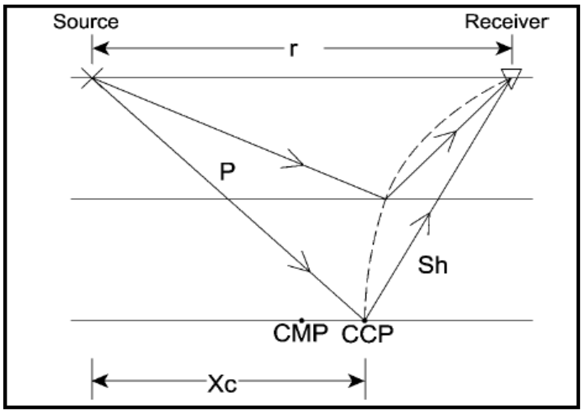

Figure2.CCP generation along the receiver line.

Spatial Sampling

Nyquist anti-aliasing spatial sampling criteria are usually used to optimize the required subsurface sampling interval for properly imaging the subsurface horizons on the basis on smallest apparent velocity, frequency content and signal dip. In case of PS waves the down-going wave P-waves propagates faster than the up-coming wave shear wave, this requires asymmetric sampling. The source sampling does not require any change compare with the P-wave acquisition, where as denser sampling of receivers is required for converted wave acquisition. Practically, during converted seismic acquisition, all the three components of ground motion are recorded simultaneously, so the slower S-wave velocities should generally be used to optimize the spatial sampling. Further, the shear wave propagates disproportionately slower in shallow unconsolidated sediments; this necessitates keeping receiver line spacing relatively small for proper delineation of shallower interests. The other consideration for the optimization of spatial sampling i.e. frequency content is not a dominating factor, as frequency content of the PS gathers is less than PP gathers.

Offset & Azimuth Distribution

The converted waves are generated only at wider incident angles (**Fig3 & Fig 4**), and thus higher offsets are required to record significant amplitude of PS-wave. As a rule of thumb, the acquired long offset should be 1.5 times of the deepest target and most importantly, this long offset must be consistent in all the directions. As the narrow-azimuth design fails to capture long offset data in the cross line direction, converted wave must be acquired with wide-azimuth designs. This allows accurate estimation of complete velocity field and better characterization of AVO (Amplitude verses Offset) response. The higher offsets must be optimized adequately for normal move out (NMO) mute, as magnitude of NMO correction is more in PS waves and faster NMO stretching compared to PP wave is seen at higher offsets.

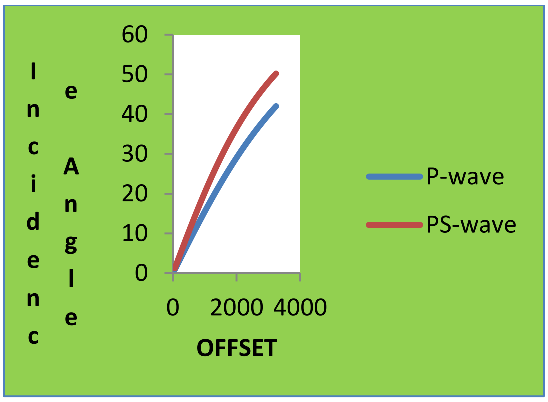

Figure 3.Incident angle variation with offset for P and PS wave.

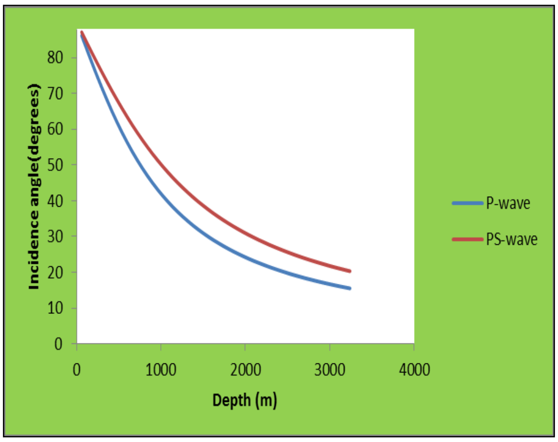

Figure4: Variation of Incident Angle with Depth for P and PS Wave.

Converted wave seismic data often acquired to characterize the fracture density and orientation. The fracture characterization is done by analyzing the converted-wave data in various azimuth sectors. Converted waves must be designed for full azimuth data along with proper azimuth sampling and it is also important that the range of offsets in each azimuth is also well sampled. Such characteristics of offset and azimuth are obtainable keeping comparable source and receiver line spacing, and nearly square source-centered active receiver patches

Point Receiver verses Receiver Array

Quite a few studies has been done to compare effectiveness of the receiver array in converted wave seismic. In most of the cases it is observed that the receiver arrays are useful in suppressing the coherent noises (surface waves etc) at shot gather stage, but not much improvement is seen in the final stacks. In conventional receiver arrays, the intra array statics is usually not taken into account. Since the near surface shear wave velocity is considerable low and very complex in nature, PS statics is not only higher in magnitude but also rapidly varying in space. The deployment of receiver arrays may lead to distortion in the sub-surface image. During converted wave seismic data acquisition, point receiver must be preferred over the receiver array.

Example of converted wave design with optimum parameters

On the basis of above discussion a 3D design for converted wave acquisition can be adopted with following parameters (Fig 5, 6 & 7 represent the desired result with these parameters)

Receiver Interval: 60m
Source Interval : 60m
Receiver Line Interval: 195m
Source Line Interval: 270m
Nominal Fold 36
Patch Size 12 X 54.
Bin size: 30*30(m*m)

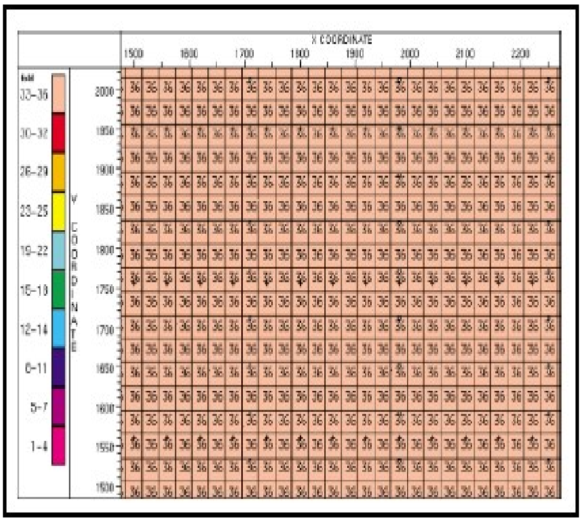

Figure5: Fold Distribution of PS wave.

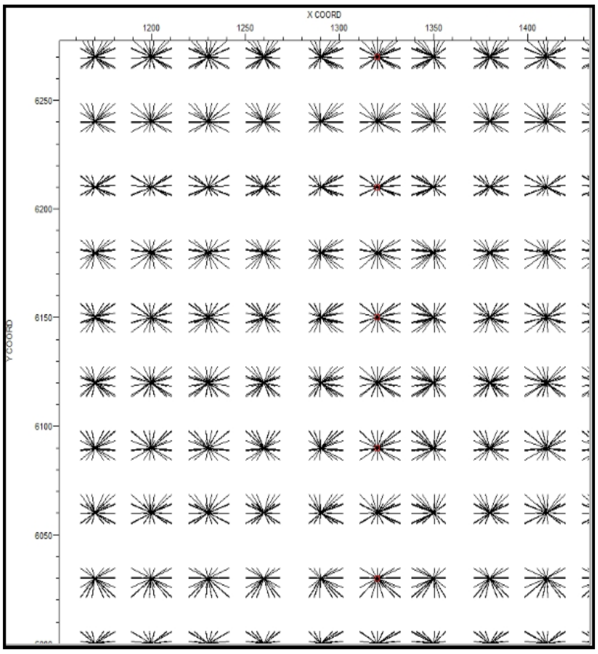

Figure6. Azimuth Distribution For PS wave.

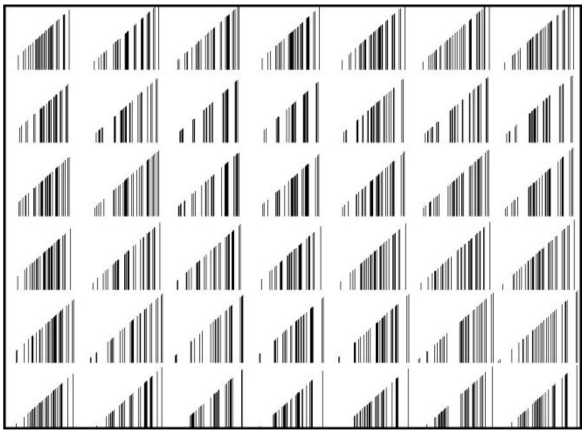

Figure7. Offset Distribution For PS wave.

Conclusion

The asymmetric illumination by PS wave is the major reason that the design of 3D surveys for converted waves is more complicated than conventional 3D. The PS Conversion point dispersal is function of reflector depth and vp/vs ratio in the overlying layer which needs to be considered at the time of survey designing. For large offset to depth ratios, the conversion point moves towards receivers, and large depth to offset ratios, the conversion point approaches to its asymptote. The care must be taken in proper selection of receiver and source line spacing for achieving continuity in fold distribution in the subsurface coverage area. One of the most important utility of multicomponent data is fracture characterization and it needs wide azimuth converted data for proper quantification of fracture density and orientation. Point receiver deployment should be preferred over array receiver deployment in converted wave seismic survey to avoid the error near surface static correction.

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