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Seismic parameter design for reservoir monitoring and improved PS fold distribution; Brooks, Alberta

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ABSTRACT

The main objective of this paper is to design a 3D-3C seismic survey that would enable 4D and reservoir studies to possibly monitor CO_2 injection and to map underground layers and structures. A porous and permeable reservoir formation (the Medicine Hat sandstone) beneath a reliable cap (low permeability Colorado shale) provides a target for CO_2 injection and sequestration, and the reson for this seismic survey design. The project area is a field located southwest of Brooks, Alberta. The first phase of the project is data gathering, and analysis of it, to determine velocity functions and frequency content at shallow and deep targets. The second is parameter estimation to obtain suitable resolution yet avoid spatial aliasing for the reservoir study. Both constant and linear velocity methods were considered for bin size determination and migration aperture estimation. Two options are introduced and their attributes compared on fold maps for PP and PS data, each with different offset, and different distribution of offset and azimuth). Finally, to improve PS fold map quality, we tested randomly spotted receivers.

INTRODUCTION

The project area is located southwest of Brooks, Alberta, west of Newell Lake. This field was selected because of a CO_2 sequestration test, enabling observation of reservoir behaviour and geophysical response during and after the injection process.

Proper design parameters can guarantee success of reservoir studies. For repeated 3D for reservoir monitoring, or 4D seismic, use of the same CMP and CCP having the same offset and azimuth, and the same shots and receiver positions, is required.

BACKGROUND INFORMATION:

Targets

The design area is in the southern Alberta basin. According to well data and existent 2D and 3D seismic data, subsurface layers are flat in the target zones. The shallow target is the Pakowki Formation, about 300m in depth, whereas the main target is the Medicine Hat sandstone, from 450m depth to the top of Second White Specks at 711m.

Frequency content

For a flawless bin size estimation and design, the maximum and dominant frequencies at the target formations should first be analyzed from any existing seismic data.

Fortunately, many old 2D and 3D seismic surveys exist for the area. If row shots are not accessible, the best way is to determine the frequency content of the old data before filtering. According to frequency content analysis, dominant frequencies for the target formations are between 30Hz to 70 Hz and for the max frequency it is 80 Hz.

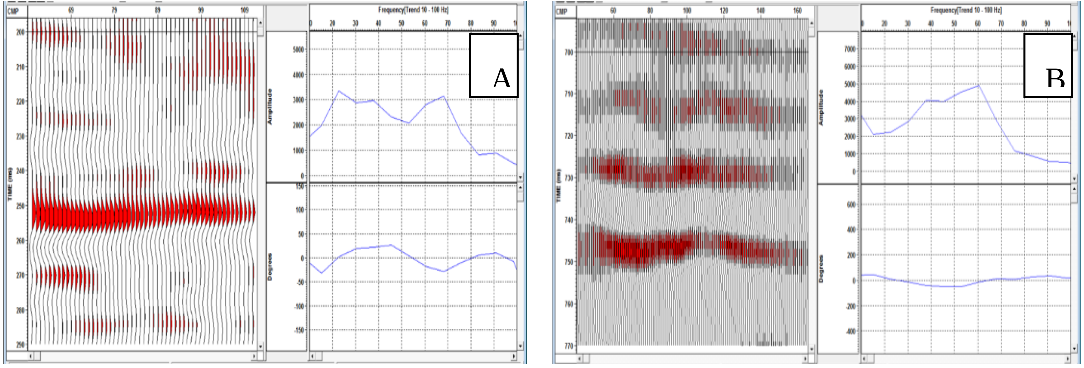

FIG.2. Frequency analysis: for the shallowest target (A), and the deepest target (B).

Velocity-depth Function

Well log data is a reliable source for compressional and shear wave velocity profiles. Because shear wave velocity is not available here, Vs is simply considered to be half of Vp. For bin size and migration aperture estimation, it is possible to use constant and linear velocities. Using linear velocity in the calculations can optimize cost, especially as it decreases both migration aperture and acquisition area (FIG.3 A).

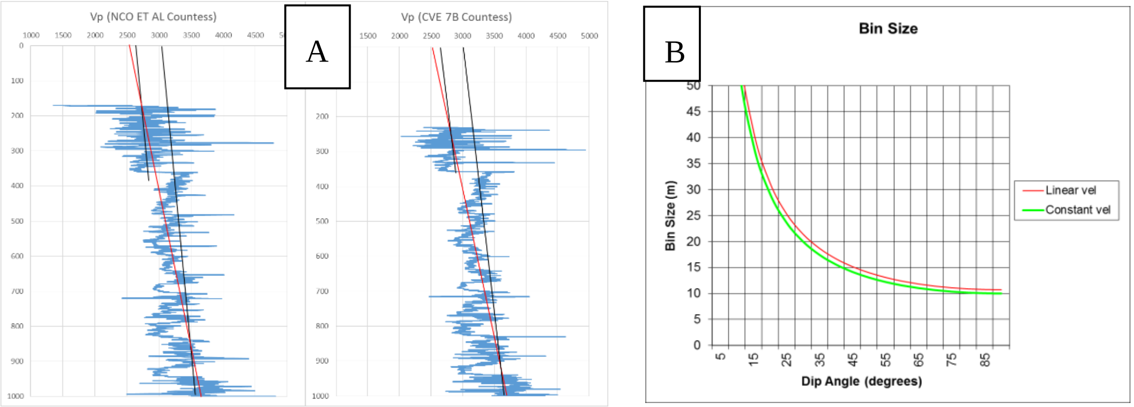

FIG.3. (A): As mentioned, a linear velocity function can be used in both the bin size and migration aperture calculations. The velocity function with regard to well log data for the Brooks project is: V = V0+kz = 2500+1.1z. (B): Bin size for the shallow target with 80Hz max frequency.

BIN SIZE

Appropriate bin size can guarantee a data set without aliasing problems. Small bin size can prevent acquisition of aliased data, but also can decrease S/N ratio (Cordsen et al., 2000). This paper does not consider spatial aliasing concepts and so we use the anti-aliasing bin size formula (Eq.1) directly for the constant (and linear velocity) (FIG.3 B).

The relation between frequency (f), deep angle (θ), interval velocity (V) and bin size (B) for unaliased data is:

$$B = V_{int} / (4 f_{max} Sin\theta) \qquad \text{(Eq.1.)}$$

BOX SIZE AND GEOMETRY

Box size and geometry can bring the LMOS (largest minimum offsets) concept to the design process. As mentioned, the target depth is from 290m to 720m, so for acquiring data with suitable fold at the target depth, LMOS should be equal or smaller than first target depth, because it makes a no data zone equal to LMOS. Another problem that increases fold in the shallow depth is NMO stretch and mute, so they should be considered in the parameter design for the project. The stretch factor (SF) defines the maximum offset; a small SF will decrease fold in the survey and consequently data will be expensive, and a larger one will decrease resolution (Vermeer, 2002).

PATCH SIZE AND MAXIMUM OFFSET

Once XMax or LMOS and bin size are known, another parameter for the template size calculation is the maximum offset (XMax).The deepest layer or final target has the main influence on X_{Max} calculation, source power (charge in explosive and force in vibrator), and record length. There is a rule of thumb for the relation between maximum offset and the deepest target that is X_{Max} > Deepest target.

Stone (1994) considers a maximum offset related to the depth and modified by the velocity field:

$$X_{Max} = \frac{1}{2} Z \left(\frac{V+V_S}{V-V_S}\right)^{\left(\frac{1}{2}\right)} \qquad \text{(Eq.2.)}$$

Where V is rms velocity to the target, and V_s is velocity of the surface layer. Other parameters, such as direct wave interference, refracted wave interference, deep horizon critical reflection offset, and Max NMO stretch are all important for maximum offset calculation and selection. (Cordsen et al., 2000).

MIGRATION APERTURE

For calculating migration aperture in this project, both linear and constant velocities were used. Fig. 5.B. indicates the range of migration apertures for different dip angles. The project area is a flat plain. Subsurface layers have a gentle dip angle, less than 2 degrees. For flat subsurface conditions, the dip angle in the formula is: θ = Max (30, real dip angle) (Vermeer, 2002), making it possible to gather all diffraction events.

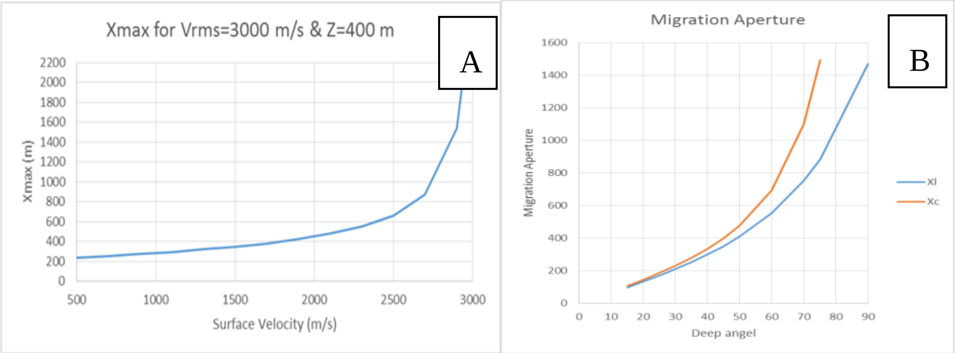

FIG.5. A) Xmax calculation using equation 2. B) Migration aperture calculation by constant and linear velocity.

SUGGESTED OPTIONS

According to the calculated parameters, and the goal of designing an accurate study of the reservoir with high resolution seismic data, two options are recommended:

	Option A		**Option B**
Parameters	**Main**	**Mid core**	
Bin size	5	5	7.5 m
Receiver interval	10	10	15 m
Receiver line interval	100	50	60 m
Shot interval	10	10	15 m
Shot line interval	100	50	75 m
Total Survey area	1000*1000	(500*500)	1020*975 m
Maximum Offset	1407		1407 m
minimum offset	14	7	10.6 m
Largest minimum offset	134	64	85.5 m
Maximum fold	83	185	221
The highest fold (pp)	185		221
Maximum inline offset	1000		1000
Maximum xline offset	1000		1000
Aspect ratio	100%		95.50%
Total shots	1600		952
Total live geophones	1600		1170

IMPROVING PS FOLD COVERAGE

Fold is an important parameter in seismic design. Sufficient fold and constant fold distribution in a survey is the first priority that geophysicists deal with. Prevention of striped fold patterns or fold lack because of acquisition field barriers in PP wave acquisition, or smooth fold change in PS acquisition, are two challenges for designers. For a suitable fold condition and distribution in a 3D seismic survey, mathematically it can be described as the parameter having the lowest possible variance. For a discrete parameter such as fold, the variance (Var) and the expected value or average (μ) in two dimensional matrices, as in a 3D seismic survey with m*n bins are:

$$Var\ (F) = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}(F_{ij} - \mu)^2 \qquad \mu = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}F_{ij} \qquad \text{(Eq. 3.)}$$

Our study shows that a random pattern of receivers can improve PS fold coverage. This is applicable for 4D cases where geophones are fixed and cemented. Variance testing could provide some improvement for the case.

CONCLUSIONS

The project area has a flat surface and subsurface, with no complex geological condition. As mentioned, the project is a limited CO_2 injection test with small plume size, so the acquisition area is 1*1 km. Parameters are selected for a semi-high resolution acquisition. Two sets of parameters, as option A and B, are introduced. Both yield good and flawless coverage for offset and azimuth distribution for the PP acquisition.

The fold map condition for the option A shows a high fold range over the mid core (500m*500m). For the second option, the fold is spread evenly over the acquisition area, and can produce a larger image and data zone if the injection plume grows during injection. When considering shot and receiver points, option B is economically a better choice since shot points are about 40% fewer than those provided by the first option, especially since high fold content is supported more by receiver points rather than by source points. However option A has better resolution because of smaller bin size.

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