Gulf of Suez Acquisition Design Using 2D and 3D Full Wave Equation Simulation

Dana Jurick, Ocean International Ltd.
Jeff Codd, Fatmir Hoxha, Julia Naumenko, David Kessler, SeismicCity, Inc.

Summary

A 3D seismic acquisition program took place in the northern Gulf of Suez, Egypt during early 2003 (figure 1). The marine towed streamer survey was preceded by an acquisition feasibility, design and modeling study that used a variety of techniques. The primary goal of the 3D survey design work was to specify and assess a set of key acquisition parameters that could be implemented in the field which, critically, had to support the successful implementation of modern demultiple, noise attenuation and 3D image processing techniques and technology.
It was important to look for a solution that integrated operational realities and specific processing requirements.

As a primary design tool on this project, we used 2D and 3D wave equation simulation. The aim of the wave equation simulation was to generate realistic synthetic seismograms that could be used to assess the effect of different field design parameters on exploration objectives. The goal was to design an economic and operationally feasible 3D survey that met the exploration objectives of our staff. This presentation will demonstrate how the wavefield simulation work was utilized and found to be useful for 3D seismic survey planning.

Introduction

The exploration objective of this survey is to provide a clear and accurate image of the 3D subsurface structure across a 500 square kilometer area at target depths ranging from 1,500 to 4,500 meters. The target is characterized by a series of NW-SE trending tilted fault blocks, half grabens and bounding faults, overlain by a basin thickening wedge of inter-bedded clastics, evaporites and carbonates. Tilted fault blocks have dips that range between 15 and 25 degrees; the blocks are intersected by a normal fault framework, characterized by a series of dominant NW-SE trending faults intersected by a secondary set of NE-SW trending faults. The primary pre-Miocene exploration objective is buried beneath a gently dipping basin, thickening wedge of interbedded clastics, evaporites and carbonates that generate significant levels of multiple energy of various origins. This is also an area with a relatively shallow and hard water bottom (12 to 55 meters) that produces significant levels of free surface multiple energy. The current day water bottom is relatively flat with no obvious or significant evidence of erosional channeling or structure. Minor faults do intersect the sea floor, which are seen to produce minor structural dislocation and consequent energy scattering.

The operational condition that dominates the survey planning and implementation is the presence of major shipping transit fairway to and from the Suez Canal. This shipping thoroughfare covers about 70% of the survey area. Operational considerations necessitate a shooting orientation that closely parallels the shipping lanes, which approximates the strike direction of the subsurface target. Shooting in the dip direction, across the shipping lanes, was not considered to be operationally feasible for a 3D spread or operation.

Previous 2D seismic acquisition programs in the area have utilized a limited offset streamer, presumably to accommodate dip and strike shooting through the shipping lanes. The 2D results typically suffer from marginal to very poor demultiple results and very poor imaging of the target structures. It was estimated that poor results were probably due to a combination of high residual noise levels related to limited demultiple technology and 2D imaging limitations. Exploration drilling results, based at least partially on the 2D datasets, have been disappointing to date.

Wave equation simulation was used in preparation of the acquisition program specifications. The technique was utilized to produce synthetic seismogram shot records that were in turn examined, interpreted and processed to assess the impact of various parameter combinations on meeting technical, operational and economic requirements set by the exploration staff.

Figure 1: New 3D acquisition in the Gulf of Suez.

Gulf of Suez Acquisition Design Using 2D and 3D Full Wave Equation Simulation

Operational Limitations and Acquisition Parameters Examined

A key parameter to assess and define in most marine towed streamer acquisition designs is the direction of shooting (sail line bearing). This parameter usually has operational, geophysical and economic significance. This parameter is especially pertinent in the pre-Miocene Gulf of Suez play because accurate imaging of the 3D structural configuration is imperative for prospect definition and exploration risk assessment. In this portion of the Gulf of Suez, the dip orientation of the structure runs approximately orthogonal to the long axis of the Gulf. The Gulf here is about 15 nautical miles wide, crossed by shipping lanes and with the presence of active marine port on the west side of the area. This combination of factors effectively precludes 3D acquisition in the dip orientation. Therefore, it becomes important to understand whether strike oriented shooting will support 3D exploration requirements.
In addition, there was a need to determine the requirements and impact of streamer length, streamer separation, migration aperture, source interval, group interval and recording length.

Geological Models

A dip oriented depth-velocity model was derived from geologic structural models and well based velocity control. The 2D model was 65 Km long, with spatial sampling of 12.5 m and depth sampling of 12.2 m. The “first” model was simpler and based on constant average velocity per layer (figure 2). This model served as the reference model. A “second” more complex model was constructed using check shot corrected sonic log data (figure 4). Simulation using this model produced seismic data having similar characteristics of the field data. The “3-dimensional” model is a north-south extension of the model shown in figure 2, and therefore, in essence, can be referred to as a 2.5D reference model.

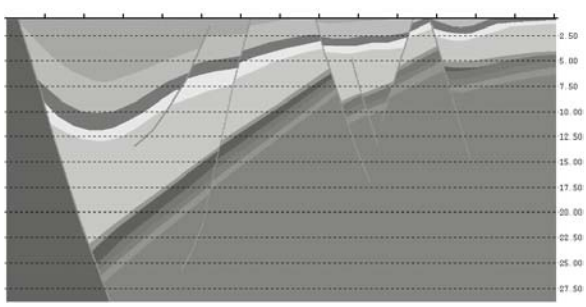

Figure 2: Average velocity dip direction geological model. Vertical scale is depth in ft.

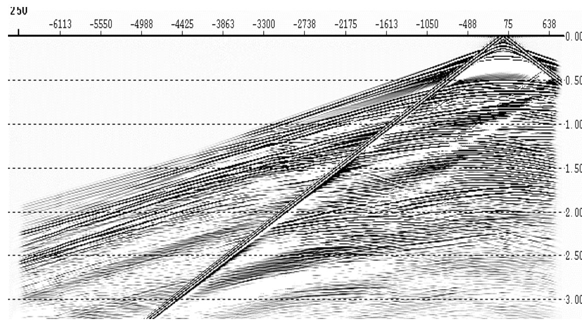

Figure 3: Test shot gather generated with the “reference” model shown in figure 2. Vertical scale is time in seconds. Horizontal scale is offset in meters.

The numerical simulation was based on a high order finite-differences solution of the acoustic wave equation. The numerical grid size was 12.5 m and the cable length was 7 Km. Simulation using the simpler “reference” dip model (shown in figure 2) produced a fairly “clean” shot gather (figure 3). A shot gather that more closely matched vintage 2D shot gathers was produced using the well velocity derived model (shown in figure 4). The shot gathers produced from the more complex depth–velocity model were contaminated with multiple energy emanating from many layers with high acoustic impedance contrast, especially present in the overburden section (figure 5).

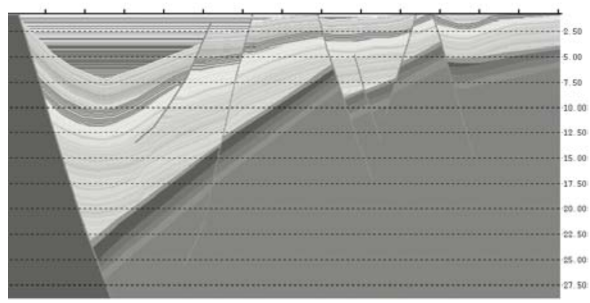

Figure 4: Well derived dip direction geological model. Vertical scale is depth in ft. The layers interval velocity are taken from a well and extrapolated within the structure segments.

Gulf of Suez Acquisition Design Using 2D and 3D Full Wave Equation Simulation

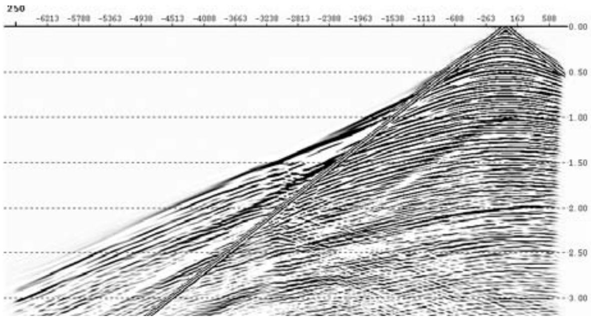

Figure 5: Test shot gather generated with the well velocity derived model shown in figure 4. Strong multiple energy interferes with primary reflections, which is very typical of data acquired in this area of the Gulf of Suez. Vertical scale is time in seconds. Horizontal scale is offset in meters.

Dip Direction Acquisition

Since the tilted fault block structure is oriented in the dip direction, two-dimensional dip direction simulation, following by processing, imaging and analysis was performed first. The simulation was performed twice, using the two input models (shown in figures 2 and 4). 560 shot gathers were produced for each model, using a single towed streamer configuration, with a shot interval of 75 m and a group interval of 12.5 m. Conventional time based processing steps were applied to the data to generate NMO stacks (figures 6 and 7).

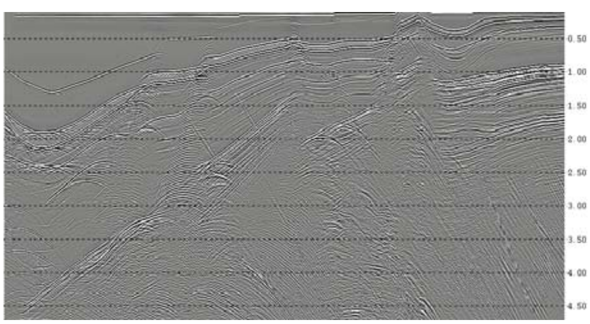

Figure 6: "Simple Dip Model" data NMO stacked section using conventional time based processing methods. Vertical scale is time in seconds.

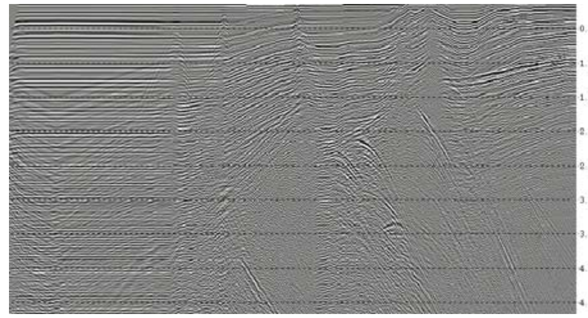

Figure 7: "Complex Dip Model" data NMO stacked using conventional time based processing methods. Vertical scale is time in seconds. This section is dominated by multiples, which obscure the target, and is typical of 2D stack data produced from this area of the Gulf of Suez.

Due to the dipping "velocity wedge" overlying the target structure combined with the structural configuration of the target interval, prestack depth migration was applied to the two data sets using the known depth-velocity model (figures 8 and 9). Analysis of these results revealed an important observation. Although most of the structure was correctly imaged, there appeared to be a "no illumination zone" at the high corners of the tilted fault blocks, close to the intersection points between the fault planes and the target layers (figures 8, 9). These areas represent key exploration zones of interest and the data from these areas were critically examined and model parameters assessed. It was our interpretation that these zones were very poorly illuminated by the dip oriented shooting direction, and that the poor image was not related to the model or the imaging algorithm employed.

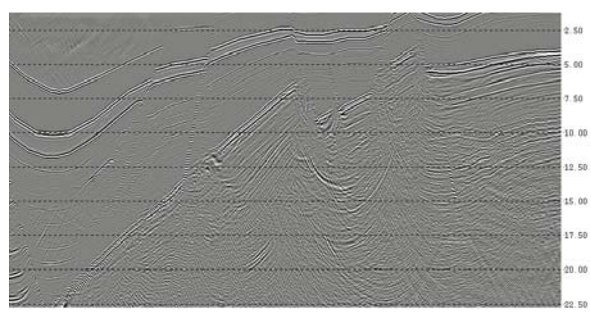

Figure 8: "Simple Dip Model" data prestack depth migrated section using the layer average velocity model. Vertical scale is depth in ft. Depth migration is a shot domain downward continuation using a localized phase screen algorithm.

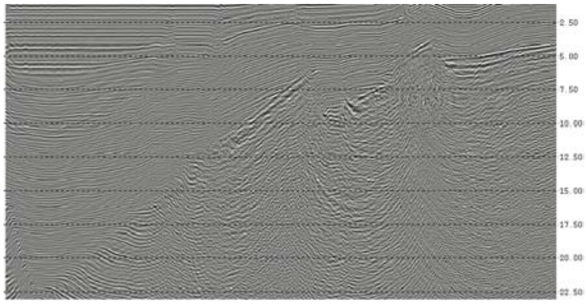

Figure 9: "Complex Dip Model" data prestack depth migrated using the well-derived velocity model. Vertical scale is depth in ft. Depth migration is a shot domain downward continuation using a localized phase screen algorithm.

Strike Direction Acquisition

Since these "high corner" areas are critical to the exploration requirements, we next investigated if strike oriented acquisition simulation results suffered from the same illumination and imaging problems as the dip oriented acquisition simulation results. It was important for us to understand whether the strike oriented acquisition could provide the required imaging results.
We expanded the dip oriented "layer average velocity" model shown in figure 2 along the strike direction creating a 3-dimensional model based upon a 2.5D structural assumption. A 3D full wave equation simulation was executed using a grid of 25m X 25m X 25m, creating 400 shot gathers using a three-streamer marine tow configuration (figure 10). Group interval was 25 m and streamer spacing was 75 m. Since the strike direction of the model is 'simpler' compared to the dip direction, the simulated shot gathers are more hyperbolic in nature and therefore are easier to process. Pre-processing of the 3D shots used conventional time based methods through NMO stack (shown in figure 11). The "strike acquired" dip oriented "cross line" stack was next post-stack depth migrated resulting in a depth section shown in figure 12.

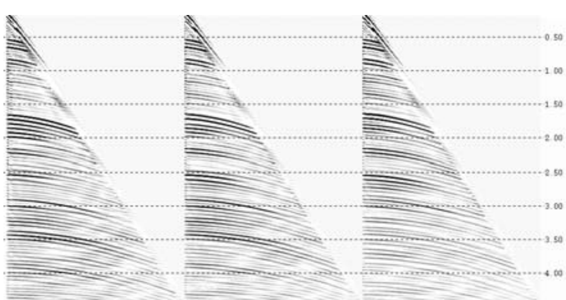

Figure 10: A single three-streamer shot gather acquired in the strike direction. Vertical scale is time in seconds. Each streamer has 240 channels with maximum offset of 6 Km.

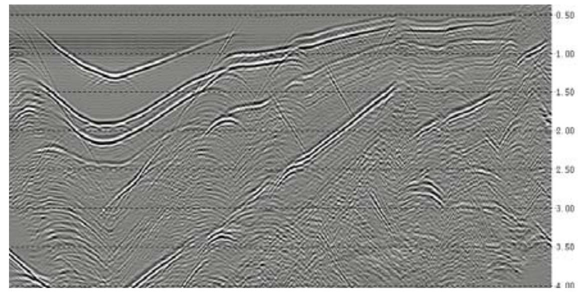

Figure 11: Dip direction stack resulting from strike direction acquisition. Vertical scale is time in seconds.

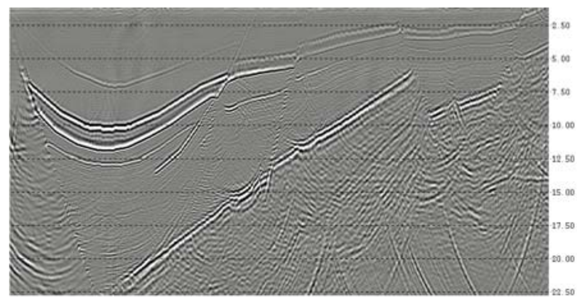

Figure 12: Dip direction depth migrated section of the data acquired in the strike direction. Vertical scale is depth in ft.

Comparison of the depth migrated "cross line" section with the dip acquired depth section reveals that using the strike oriented acquisition produces a clearer and more accurate image of the exploration objective. This interpretation, founded on the assumption that the subsurface is approximately 2.5 D in nature, implies that we can achieve the exploration objective through strike oriented acquisition. We then proceeded to investigate and analyze the 3D simulated shot gathers to set other key parameters such as streamer length, source point interval, migration aperture, recording length and group interval. Many "interpolation" and "decimation' tests were preformed to assess the consequences of changing these parameters, especially as they related to important processing algorithms and strategies, and thereby final acquisition parameters were set for field execution.

Conclusions

Several key issues should be addressed in the design of a 3D seismic acquisition program. We present a method that we consider useful in the 3D survey design process. The method relies heavily on the veracity of the input model, the wave equation modeling implementation and a detailed and thoughtful geophysical analysis of the results.