Deep Cardamom Discovery Enabled by Multi-azimuth Seismic and Anisotropic Imaging*

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Abstract

Shell's Auger TLP near field exploration is focused on the deep potential at Cardamom. Difficult extended reach wells around the Auger salt dome are required (Figure 1). Seismic imaging is impaired by the prospect's proximity to salt. Steeply dipping seismic events and velocity uncertainty makes well positioning difficult. The application of multiple azimuth seismic data and anisotropic imaging reduced targeting uncertainty and resulted in the discovery of a deep hydrocarbon reservoir at Cardamom.

Well positioning uncertainty and improvement of the seismic image is discussed through the use of modern Wide Azimuth (WAZ) streamer seismic in combination with existing Narrow Azimuth (NAZ) streamer seismic. The use of multiple seismic azimuth data for anisotropic velocity model building and pre-stack depth imaging resulted in a reduction in lateral and vertical well positioning uncertainty. To further understand positioning uncertainty and improve surface seismic calibration, drilling was executed using Logging While Drilling (LWD) measurements and Vertical Seismic Profile (VSP) data was acquired.

Implementing these geophysical methods contributed to the Deep Cardamom discovery and provided data to drill a successful up dip side track well. Additional geophysical efforts (updating velocity models, acquiring Ocean Bottom Sensor (OBS) seismic data) have been initiated with the objective of yielding higher quality seismic images to be used for the development phase of the Deep Cardamom accumulation.

The technologies used to overcome the challenges at Cardamom are:

1) Wide azimuth (WAZ) streamer seismic provides full azimuth coverage to about 4200 m offset and +/- 30 degree azimuth coverage for the ~8 km offsets important for accurate anisotropic velocity model building at depth. This azimuth range was augmented with the NAZ data, providing a 90 degree azimuth component.

2) Velocity model building combined new WAZ seismic and existing NAZ data, providing an additional azimuth. Vertical and Tilted Axis Anisotropic velocity models from WAZ and NAZ seismic data processing were key for imaging and subsurface/well positioning.

3) Use of Logging While Drilling (LWD) provided real time depth calibration. Sonic and density logs were used to generate seismic synthetic data for depth calibration as the well was drilling. A high pressure zone immediately below the target sand presented a drilling risk and required accurate depth calibration. Offset VSP acquisition, using a receiver tool pumped in drill pipe, provided additional positioning calibration and up dip side track targeting for a completion location. Pumping the seismic receiver tool through drill pipe reduced VSP acquisition time and reduced the risk of sticking tool.

4) A highly coordinated effort of Shell processors and interpreters utilized multiple data sets, multiple seismic velocity models and migrations, and real time updating using LWD sonic velocities resulted in successfully penetrating the target.

Seismic imaging using WAZ and NAZ seismic data, acquiring LWD and VSP borehole data, and updating the anisotropic velocity model real time resulted in successfully drilling the deep target and the discovery of hydrocarbons at Cardamom.

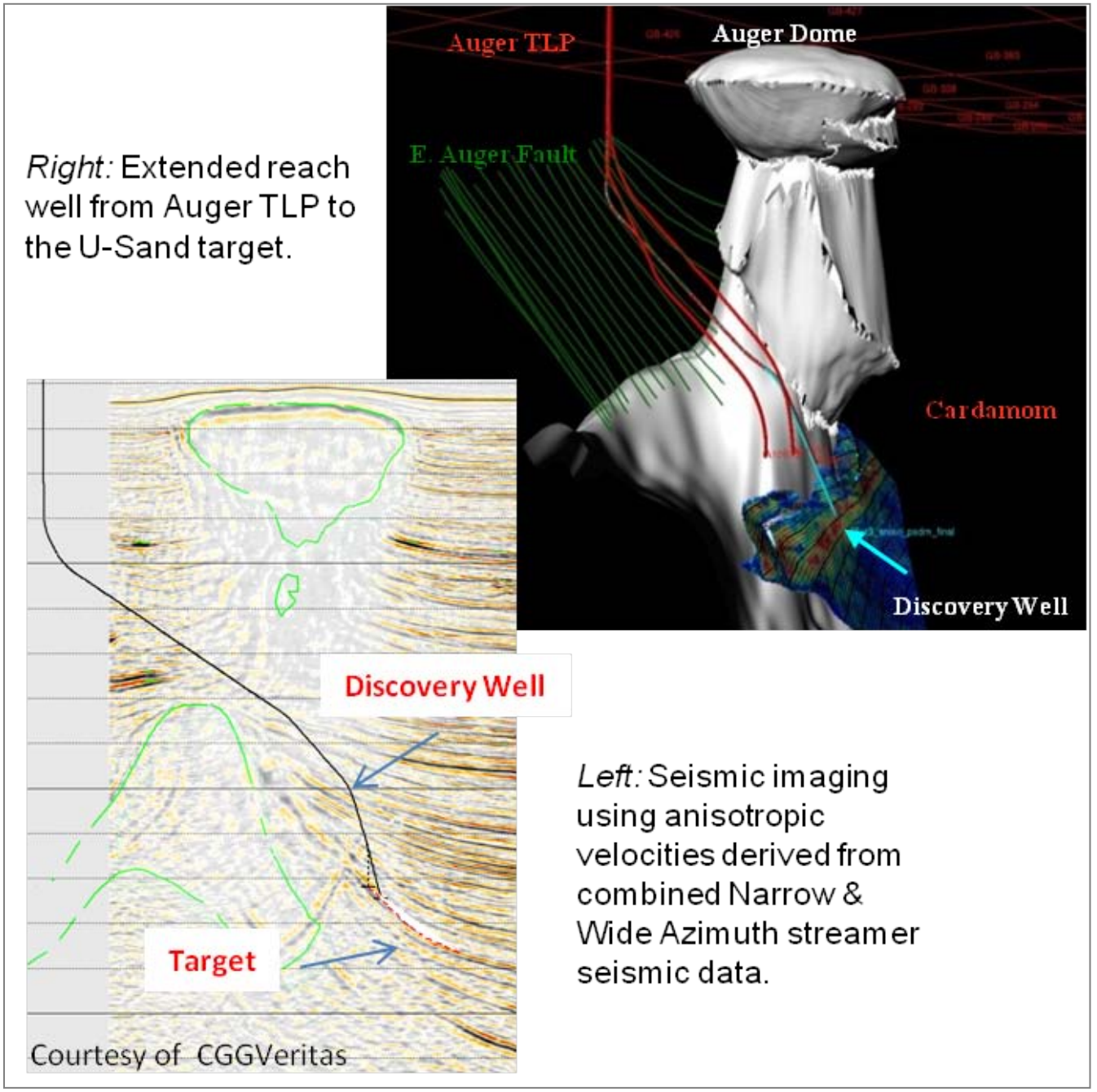

Figure 1. Right: Extended reach well from Auger TLP to the U-Sand target, and Left: Seismic imaging using anisotropic velocities derived from combined Narrow and Wide Azimuth streamer seismic data.