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# Imaging Vertical Faulting on a WCB 3D using Duplex Wave Migration

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## Summary

Conventional pre-stack depth migration (PSDM) is capable of imaging vertical boundaries provided the geology has strong vertical velocity heterogeneity and the seismic is recorded with a very large surface aperture. This paper describes a Kirchhoff implementation of Duplex Wave Migration (DWM) that removes these limitations and we illustrate how DWM can provide an entirely new methodology for determining more accurate depth models. A 3D data set from the WCB will be used to illustrate the ability of DWM to image a well known normal fault, a vertical dyke that is detectable using an aeromagnetic survey but invisible on 3D seismic data and additional parallel and orthogonal vertical faulting that is invisible to both aeromagnetic surveys and 3D seismic surveys. The new knowledge about these vertical faults is used to explain unusual well results in the area and to indicate alternative sources for the hydrocarbon flow.

## Introduction

The imaging of vertical boundaries has become extremely important for solving a whole host of exploration and production challenges. These include salt wall imaging, zero or near zero throw faults within the reservoir (fault compartmentalization), zones of fracturing, locating diagenetic reservoirs formed by basinal hydrothermal fluid flow along vertical faults (Hickman and Kent 2005), identification of bypassed reserves (enhanced recovery) and the delineation of the edge boundaries of oil (or gas) to water interfaces.

Marmalevsky et al. (2005) presented a Kirchhoff method for DWM that successfully imaged vertical boundaries from salt walls and subtle zero throw faults within the sedimentary section while at the same time automatically attenuating all energy other than the duplex wave energy (DWE). In this paper we will present an example of 3D DWM on a 3D data set from the WCB to identify otherwise seismically invisible vertical boundaries.

**Method**

We have developed a Kirchhoff depth migration that is based on the Green's function using the kinematics of DWE. A primary event (that must be deeper than the vertical boundaries we wish to image) is defined in depth by the user. It is assumed that a conventional PSDM has been run prior to running DWM, therefore we use the depth model generated from that process as a starting point. The depth model can be either isotropic or TTI anisotropic. The TTI travel time calculations are generate using an Eikonal solver as described by Roganov (2006).

The DWM algorithm is designed to image the DWE that will arrive at a time greater than that of the primary base boundary. A beam tube construction eliminates the migration noise that would result from including the base boundary primary reflections in the migration summation. Tight control of the aperture is also key to suppression of artifacts from primary reflections. Each DWM run produces four separate and distinct views of the vertical boundaries based on two possible bounce orders – base boundary then vertical boundary or vice versa and traces input to the migration are either to the right of the shot or to the left of the shot.

This means that in the case of a vertical boundary we can examine the reflections from the same boundary using data that has bounced off of each side of the boundary. If the velocities are too slow then the vertical boundary will be positioned too close to the shot and if they are two fast then the positioning of the vertical boundary will be too far from the shot. Since we have an image of the same vertical boundary from both sides of the boundary they will only focus at the same location in 3D space if the velocities are correct. This means we no longer have to rely solely on the flatness of migrated gathers criteria for velocity model building. It is hoped that further research will indicate that this is a powerful method for obtaining more accurate anisotropic parameters.

This method for the suppression of artifacts can be used without restrictions on the geologic structure of the medium through which the DWE travels. This method enables the identification of all types of vertical boundaries including salt walls, subtle vertical faults within the reservoir, vertical zones of corrosion that exist above the oil to water contacts etc. The fact that we use a Kirchhoff implementation means that the data need not be regularly sampled in space. Also, the Kirchhoff implementation allows for efficient and targeted velocity analysis by generating a series of migrated DWM 3D view cubes. Modern 3D visualization technology is used to integrate the additional information about vertical boundaries into the pre-existing PSDM depth model. If the changes in structure or velocities are significant then we may wish to rerun the PSDM.

**Real 3D Data Example from the Western Canadian Basin**

It is well known that NW to SE trending lineaments, and a near orthogonal set of NE to SW trending lineaments exist throughout the WCB (K.S. MISRA et al., (1991)). These vertical faults originate from block faulting in the Precambrian basement and they often have little or no vertical throw, therefore they are generally invisible to conventional seismic imaging. In some areas the faults have been intruded by igneous lava flow that in some cases outcrops at the surface. A NW to SE linear dyke has been revealed by an aeromagnetic survey in the north half of the example 3D survey. The dyke is invisible on the coherency cube of the conventional PSDM product.

Figure 1 shows two cross sections from the interpreted 3D PSDM data cube. Five horizons are interpreted and several wells were drilled in this area into a thin gas sand play above horizon 2 and a few wells were also drilled into an oil play above horizon 3. We ran 3D DWM on horizons 2 through 5. The DWM images generated from all four horizons showed faulting that matched the known normal fault (which was clearly identified on the PSDM coherency cube), and the

aeromagnetic evidence of a dyke (which was invisible on the same coherency cube). Also, a set of faults parallel to the dyke was revealed and a set of parallel faults in the NE to SW direction was identified.

Figure 2 shows vertical boundary imaging in a 3D DWM data cube 100 meters above horizon 5 and Figure 3 shows the structure map of horizon 5 generated during conventional PSDM model building. Figure 4 shows the vertical boundaries identified in the interval 100 meters above horizon 2 and figure 5 illustrates that the only producing gas well from this interval is at the crossing point of high amplitude orthogonal faults.

## Conclusions

3D DWM is a practical tool to delineate vertical boundaries that are invisible to conventional PSDM. Vertical faulting and fracturing is thought to be much more prevalent than we realize today. Diagenetic reservoirs that develop where hydrothermal flow is vertically directed were previously found only by accident but now we have a direct imaging technology to aid in a targeted search for these traps. Corrosive plumes above oil to water contacts can now be used to delineate reservoir boundaries. Perhaps the most significant potential of this technology is enhanced recovery through accurate delineation of fault compartmentalization, fault characterization, fault seal analysis and the identification of bypassed hydrocarbons within the reservoir.

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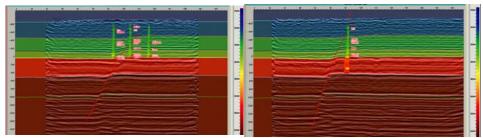
**Figure 1.** PSDM Stack Section with Velocity and Horizon: Xsline80 (left), Xsline190 (right)
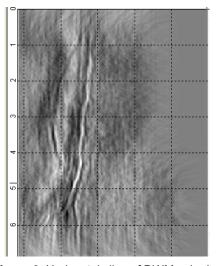


**Figure 2.** Horizontal slice of DWM cube by 100 meters above horizon 5.
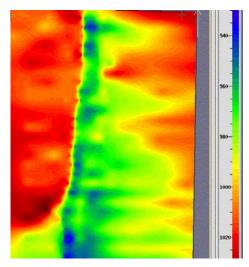Blue arrows – known regional fault.
Yellow – subtle fault



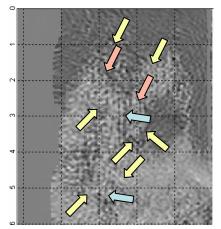**Figure 3.** Structural map by horizon 5 from PSDM model building.



**Figure 4.** Horizontal slice of DWM cube by 100 meters above horizon 2.
Blue arrows – known regional fault.
Yellow and red – faults imaged by DWM only.
Red arrows – fault corresponding to dyke, delineated by aeromagnetic survey data.



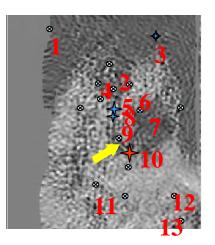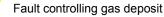**Figure 5.** Same as Fig 4 but with marked well positions.

Well with industrial gas production

Oil wells

⊗  Dry wells

Fault controlling gas deposit