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Seismic Imaging of the Overturned Limb of a Footwall Syncline and its Impact on Exploration in Fold and Thrust Belts

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Summary

LOFF8 is part of a unique experimental seismic program that was shot across the Laramide Structures of the Western Canadian Fold and Thrust Belt expressly to evaluate long offset, high intensity acquisition parameters. It is 52 kilometres long and runs NE to SW across the un-deformed sediments of the Western Canadian Sedimentary Basin, the triangle zone and the fold and thrust belt up to the front ranges of the Rocky Mountains.

The interpretation presented is integrated with numerous wells with samples, wireline logs and dipmeter data. It is currently in an active area for conventional and unconventional exploration and crosses numerous oil and gas pools.

In this interpretation we will show an example of a steep and overturned fold limb imaged in the seismic section. The results of the interpretation clearly validate the use of the acquisition parameters and show a way forward for imaging steep limbs in fold and thrust belts.

Introduction

The hydrocarbon exploration of the Western Canada Fold and Thrust Belt (WCFTB) is over 100 years old. For the last 70 years it has been greatly aided by seismic imaging techniques which have provided an understanding of the deep structures. Even so, this process is still full of surprises as steep dips, fault repeats, detachments, and poor coupling at the surface all contribute to obscuring a clear image of the subsurface.

In an effort to improve our understanding of the WCFTB, a seismic line (LOFF8) was shot across the Brazeau Thrust in the Alberta portion of the WCFTB. The LOFF8 seismic line is part of a unique experimental seismic program that was shot expressly to evaluate long offset, high intensity acquisition parameters (Colombo, 2005). It is 52 kilometres long and runs NE to SW from the un-deformed sediments of the Western Canadian Sedimentary Basin, across the Triangle Zone and the Foothills to the front ranges of the WCFTB.

The interpretations of the seismic line LOFF8 in time and depth are reviewed in this paper. The tools used for the integration of the surface and subsurface geological and geophysical data are described and a new deformation model is presented.

Pre Stack Time Migration (PSTM)

The local surface geology and well data were incorporated into the initial processing of the LOFF8 line in time. Significant value was gained by having a cross section available from the public data base to guide the velocity picking (Fig. 1). (Langenburg et al 2002)

In the early stage of the PSTM work flow, an anomalous area of high-velocity rock was identified by the processor. This area was in the footwall of the Brazeau Thrust where the cross section D-D' had predicted low-velocity Mesozoic formations. The velocities being used in the PSTM were more compatible with higher velocity Paleozoic carbonates.

LOFF 8 long offset high intensity seismic line

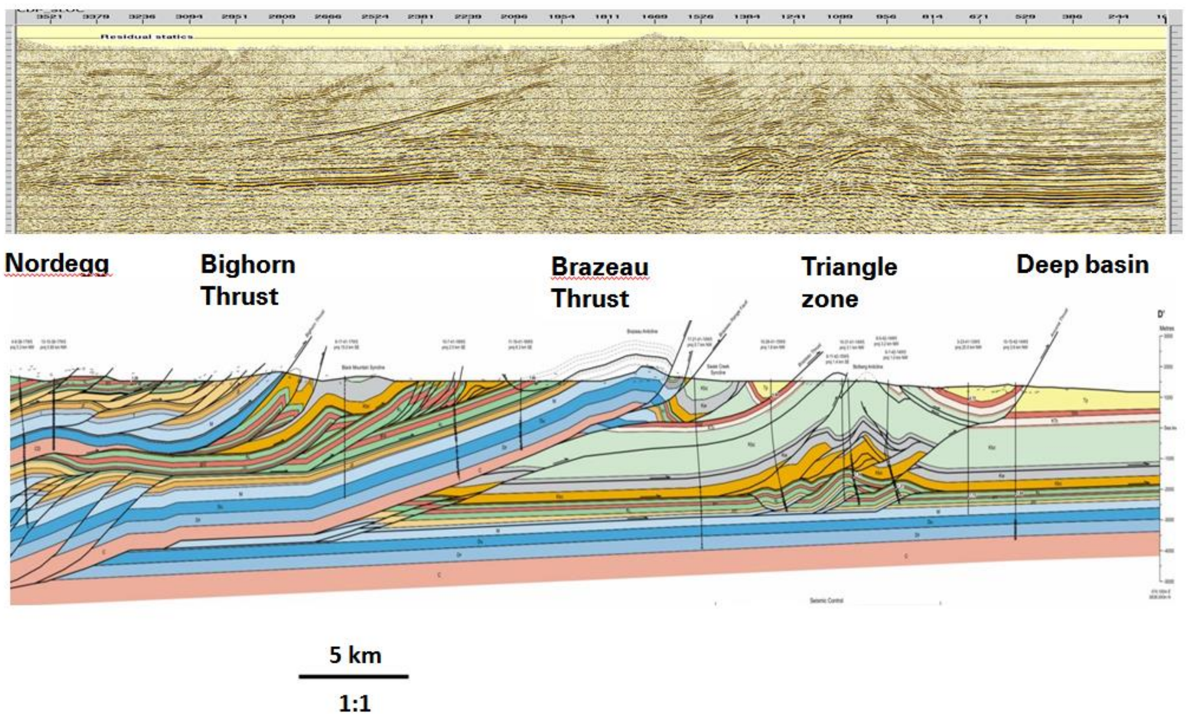

Fig. 1.

Initial time migration on LOFF8 in relation to regional section D-D'. (Langenburg et al 2002)

Pre Stack Depth Migration (PSDM)

As a result of the velocity anomaly it was decided to increase the geological study area and go to a PSDM processing stream. Both the surface geology and the wells were examined in detail over a larger area. In total 82 wells and 1600 square kilometers of surface geology were incorporated into the geological model.

During the review of dipmeters and wireline logs for the expanded area, one well stood out. It was a very deep test with a TD of 5985m. The well's name is AQUIT CDCOG Shunda 7-13-39-15 (7-13) drilled in 1981. In addition to its depth it had an exceptionally good wireline logging suite.

Both the surface mapping and well data show that the Brazeau Thrust sheet is a major structural feature with a very consistent trend and plunge in this area. Based on this information the direction and amount of plunge in two structural domains were determined (Groshong 2008). The northern domain extended from LOFF8 NW for 8 km and the southern one extended from LOFF8 to the SE for 15 km. Within these two domains it was felt that large scale structural features could be safely projected many kilometres.

All the surface geology data and well data (including dip vectors) were loaded into the Move software. This software allowed the data to be analysed and projected interactively onto the plane of section using a variety down plunge projection direction.

The 7-13 well had 5985m of wireline logs, deviation surveys, dipmeter and top data. The entire wireline log data was checked for quality and consistency; this included a detailed review of the dipmeter data. The geological tops were re-picked for consistency with the other 82 wells. This data was loaded into the RDA dipmeter-analysis software.

A detailed dip analysis was carried out on the 7-13 well data. In this process, points were picked in the well bore using the SCAT display (Statistical Curvature Analysis Technique) to highlight dip domains

(Bengston, 1981). These were then interpreted using the gamma correlation log from the wireline logging suite to determine the stratigraphic up direction.

Based on this process the well was divided into three large domains. The dipmeter data and geological tops in the hanging wall of the Brazeau Thrust were designated as an upper domain called BR. This data was imported into the dipmeter analysis package with the stratigraphic top of the dipmeter data pointing up. The data in the footwall of the Brazeau Thrust were found to be in one of two distinct geological domains. Bedding from the Brazeau Thrust down to 4250 m was overturned, based on the gamma correlation log. This domain was called the OT domain and the dipmeter data was loaded with the stratigraphic top of the dipmeter data pointing down. The third geological domain was the data from 4250 m to TD which was called the R domain and it was loaded with the stratigraphic top of the dipmeter data pointing up.

The geological tops, domains, and dip vectors were incorporated into the revised structural interpretation of the formations penetrated in 7-13. The Paleozoic stratigraphy can be seen to be the right way up in the hanging wall of the Brazeau Thrust, overturned in the immediate footwall of the Brazeau Thrust and the right way up again in the regional part of the section.

This data was then projected onto LOFF8 using a down plunge projection. The resulting interpretation in depth clearly illustrates that the velocity anomaly is caused by Paleozoic carbonate in the overturned limb of a fold, in the footwall of the Brazeau Thrust (Fig. 2).

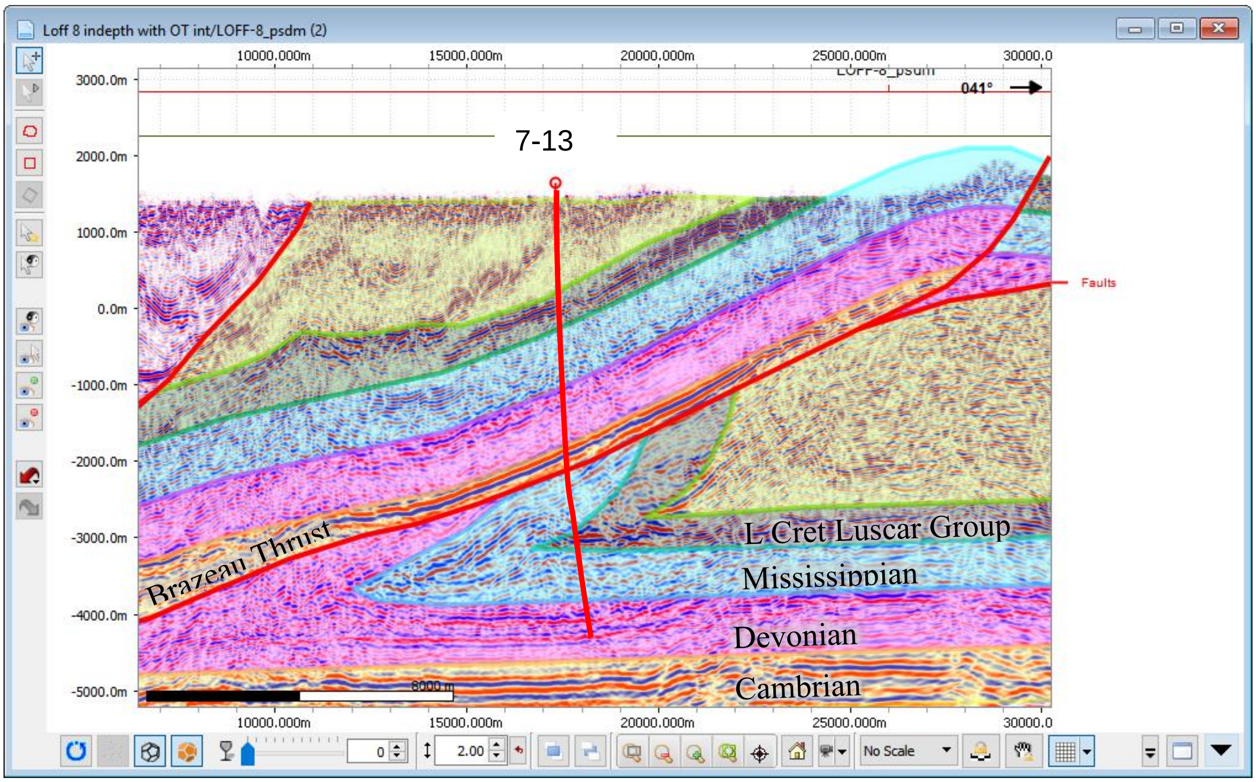

Fig. 2. Final PSDM depth section with 7-13 projected down plunge on to the plane of section.

Revised Velocity Model

Based on the geological modelling from the 7-13 well, the velocity model for the LOFF8 was revised. An overturned limb of Paleozoic carbonates was added into the LOFF8 PSDM velocity model.

Conclusions

There are three main conclusions:

1. The interpretation of LOFF8 provided an ideal platform to illustrate a workflow for integrating geology and geophysics in a processing stream for fold and thrust belts.
2. The long offset, high intensity acquisition parameters of LOFF8 in conjunction with the PSTM and PSDM work flows improved the image of the overturned limb in the footwall of the Brazeau Thrust Sheet. This process has application for other fold and thrust belts, especially where the sub thrust target is obscured by higher velocity geological formations at the surface.
3. In addition this work was successful in identifying a new deformation model for the Brazeau Thrust. It showed that a large fold with an amplitude of 3 km occurred early in the evolution of the structure. This was followed by the initiation of a thrust that carried the back limb of the fold to the NE by 10 km.

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Midland Valley, Glasgow, Scotland, UK, Move and 2DMove geological modelling software.

ResDip Systems, Houston, Texas, USA, RDA dip analysis software.

Seis Ventures Res. Ltd, Calgary, AB, Canada, LOFF8 seismic line.

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