

## Investigation of Devonian Unconformity Surface Using Legacy Seismic Profiles, NE Alberta

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### Summary

The Devonian Grosmont Formation in northeastern Alberta is the world's largest accumulation of heavy oil in carbonate rock with estimated bitumen in place of  $64.5 \times 10^9 \text{ m}^3$ . Much of the reservoir unconformably subcrops beneath Cretaceous sediments, known as Devonian Unconformity (DU). This study described the reanalysis and integration together of legacy seismic data sets obtained in the mid 80's. Standard data processing was carried out supplemented by some more modern approaches to noise reduction. These reprocessed data was then used for construction of time surfaces of some key horizons both above and below the DU. The seismic maps show substantially more detail than those constructed on the basis of well log information only. Although features smaller than about 40 m in radius could not be easily discerned at the DU due to wave-field and data sampling limits, the data does reveal the existence of a roughly E-W trending ridge-valley system. A more minor NE-SW trending linear valley also is apparent. These observations are all consistent with the model of a karsted/eroded carbonate surface. Comparison of the maps for the differing interpreted horizons further suggests that deeper horizons may influence both the structure of the DU and even the overlying Mesozoic formations. This suggests that some displacements due to karst cavity collapse or minor faulting within the Grosmont occurred during or after deposition of the younger Mesozoic sediments on top of the Grosmont surface.

### Introduction

The Grosmont Formation is a carbonate platform that encompasses an area of about 13% of Alberta. Of the Grosmont platform region, about  $20,800 \text{ km}^2$  are believed to be prospective for bitumen. The erosional and karsted surface of the Grosmont is important to be known as consequently it may influence the presence and production of hydrocarbon. During the 1980's a succession of seismic surveys (series K, L, M and N) were collected as part of a pilot project in the Grosmont area. To our knowledge, no integrated interpretation of the data was ever carried out. The work presented in this study attempts to provide an overview on seismic data processing, integration and interpretation of well and seismic data with focus on karsted Grosmont surface (i.e. DU).

### Geological setting

During the later parts of the Devonian period a large intracratonic sea existed on the western margin of the current North American Craton (Switzer et al. 1994). This setting of a passive continental margin submerged beneath warm shallow seas provided the conditions for deposition of vast quantities of limestone and shale as well as allowing the growth of series of carbonate reef complexes. These lithologies and what has happened to them in the intervening periods control the present day resource of the Grosmont formation. Two unconformities are seen in this region. The first is the unconformity between the Lower Devonian Elk Point and

the “PreCambrian” metamorphic Canadian Shield (PCU). The second shallower Devonian unconformity (DU) separates the Lower Cretaceous siliciclastic rocks from the Upper Devonian carbonates. This unconformity is a key to the development of the Grosmont resource because the resource abuts the unconformity. The unconformity surface was modified by a combination of erosion and karsting and this raises numerous complexities to the development of the resource as it remains difficult to delineate smaller karst features. The Grosmont formation itself consists of four distinct and major cyclical stratigraphic units that each includes porous carbonates and source and trapping shales, marls, and evaporites. These units named as A, B, C and D.

**Data available and methods**

The obtained data sets employed for this study consist of well-logs and geological formation tops, high resolution seismic surveys and the reported results from a Vertical Seismic Profile (VSP). The relative location of seismic profiles, wellbores, and the well-01 with the VSP data is given in Figure 1. Absolute locations cannot be provided and as such the final interpretations should be considered as illustration of the complex geometries of the DU.

*Well Log Information*

The database accessible to us provided 99 logs and 136 geological formation tops from 31 wells in the study area. Among the well logs, caliper, density, gamma ray and sonic logs are the most important wire-line logs for detecting karst features (Dembicki 1994, Dembicki and Machel 1996, Huebscher and Machel 1997, Machel et al. 2012). Also, sonic and density logs are required for calculation of synthetic seismograms used in well-tie procedure. Unfortunately, most of these wells were drilled for shallow gas production and often only just touch the DU and this reduces the number of wells available to tell us about deeper structures. Further, only a small fraction of the wells have geophysical sonic and density logs that are necessary for proper modelling of the expected seismic responses to allow for the calculation of “synthetic seismograms” that are used as an interpretive tool to assist in assigning the geology to the seismic section.

*High resolution seismic surveys*

Four separate high-resolution seismic surveys of K, L, M and N were obtained for this study. These high resolution surveys at the time of acquisition in the early to mid-1980 were unique, closely spaced receivers and sources have not been employed until more recently. Dynamite was used as a source in most of these surveys and the group interval varied from 10 to 22.5 m. The locations of these surveys and the well with VSP data are shown in the map of Figure 1. A tremendous amount of work was involved in data preparation such as re-formatting, organizing, editing, and merging of field geometry before the application of processing workflows. This work was also all done

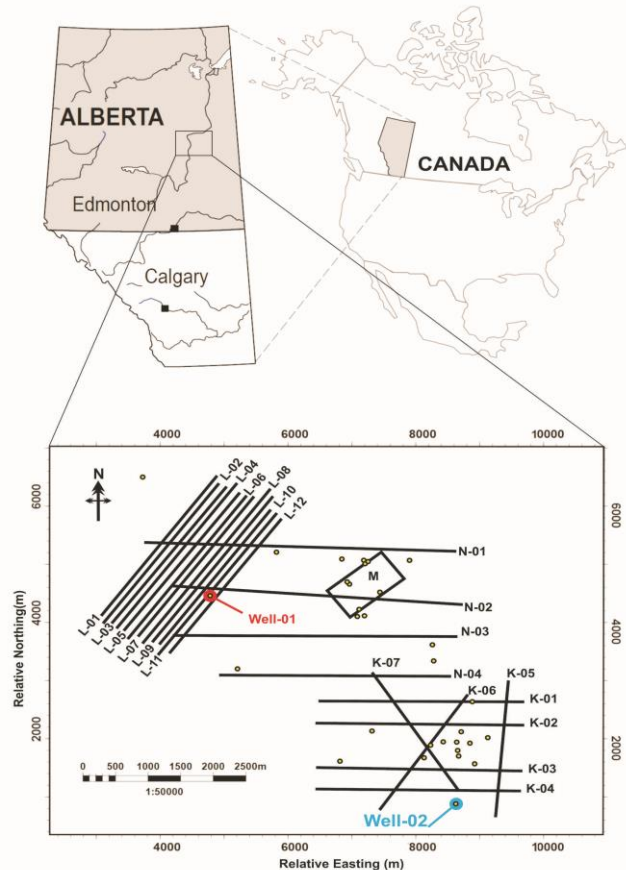


Figure 1: Map from the study area showing the approximate locations of the wellbores and seismic profiles. Exact locations cannot be provided.

with an eye to the eventual integration of the disparate data sets and necessitated assigning an appropriate reference datum from which all of the reprocessing was carried out.

### Data integration and interpretation

The tying of geological structure to the seismic data occurred at well location W-01 where well logs of sonic and density were available (Figure 2). A few prominent seismic reflection events have been picked for interpretation and these are assigned to the various geological tops on the seismic profiles. However, the general lack of appropriate logs as well as the paucity of boreholes penetrating deeper than the Grosmont complicates this interpretation. The VSP data was critical to obtaining approximate lithological ties above the DU horizon while lithologies deeper in the seismic section were confirmed by comparison to the regional geology knowledge. Figure 2 shows these events on the profile L-11 with the synthetic seismogram used for well tie. The events used for mapping and further interpretation are ClearWater, the Wabiskaw, the Grosmont (DU), the Lower Ireton, the Prairie Evaporate, and finally, the PreCambrian crystalline Basement (PCU).

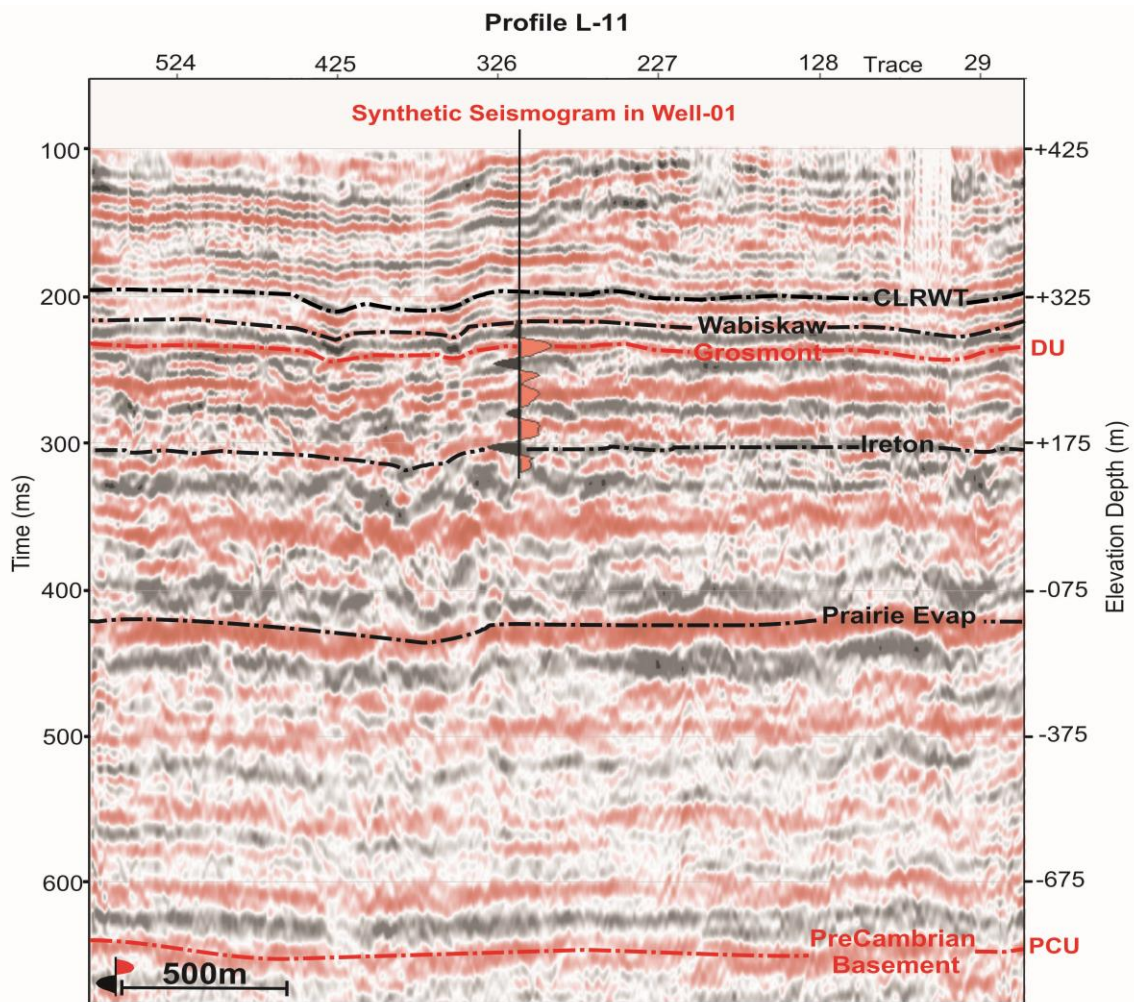


Figure 2: The synthetic seismogram plotted on the interpreted seismic profile L-11 at well-01.

The subcropping Grosmont (DU) is interpreted as a mature karst surface containing karst plain, karst valleys and a ridge (Figure 3). Each of these features is observable in the high resolution seismic profiles. Feature A denoted a ridge, a topographic high in the DU. The valley feature B trended E-W in the southern section of the local area and is notice to encompass the majority of smaller dissolution features such as dolines. It is reasonable that this area also developed cavities and small conduits for the drainage of water at the time of erosion. Feature C was a distinct karst valley that was mapped trending NE-SW near the western edge of the local area. Moreover, this NE-SW orientation of feature C may be sub-parallel to the expected joint trends in the Grosmont formation (Jones 2010). Everywhere else is considered Karst plain and showed minimal evidence of dissolution features.

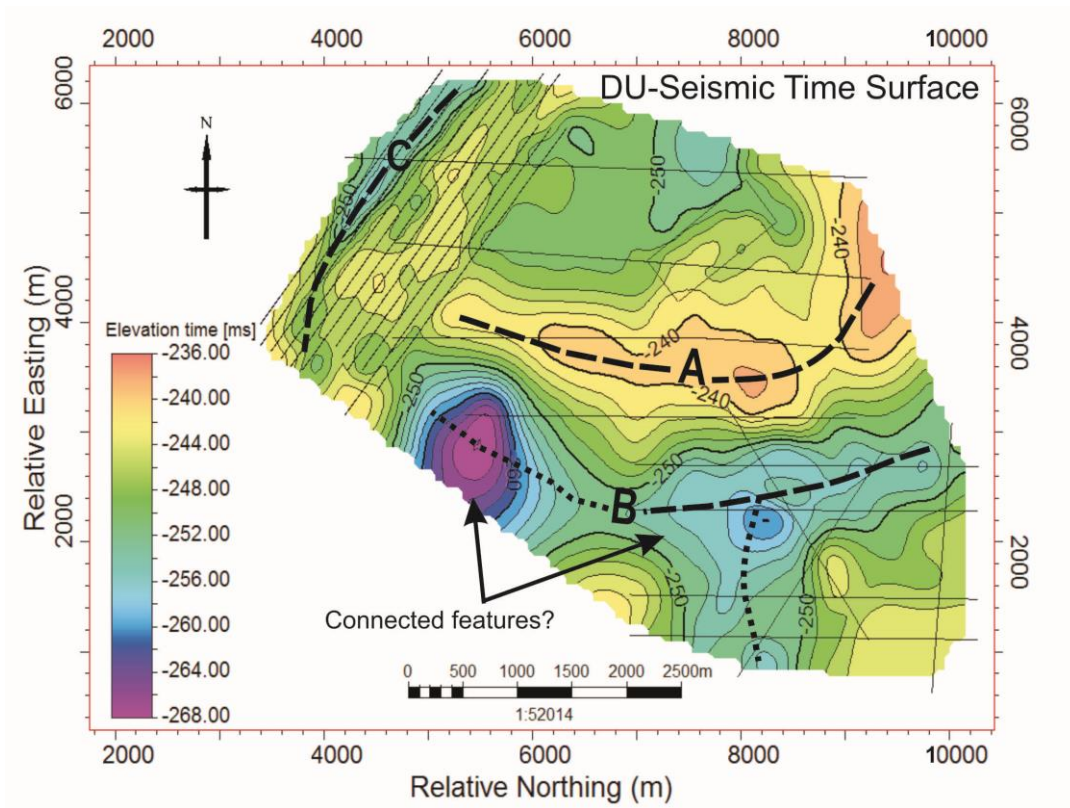


Figure 3: The seismic time surface for the DU. Curved lines A and B highlight the axes of a detected ridge and a valley running roughly E-W across the study area. Axis C highlights the location of a smaller valley running in a NE-SW direction.

A comparison of surface structure of DU against other five interpreted time surfaces is shown in Figure 4 in sequential order from shallow to deep. Both the Mesozoic ClearWater (Figure 4a) and the Wabiskaw (Figure 4b) surfaces correlate with the DU (Figure 4c). This suggests that the sedimentation above the DU was influenced by its topography. The reasons for this are not known but could be indicative of collapse of the karsted DU, differential compaction of the Mesozoic sediments, or even fault motions. The metamorphic basement (Figure 4f) does not exhibit the same structure. This implies that Devonian package of rock may have faulted and displaced along the PCU surface, though there is no strong evidential support for this conclusion.

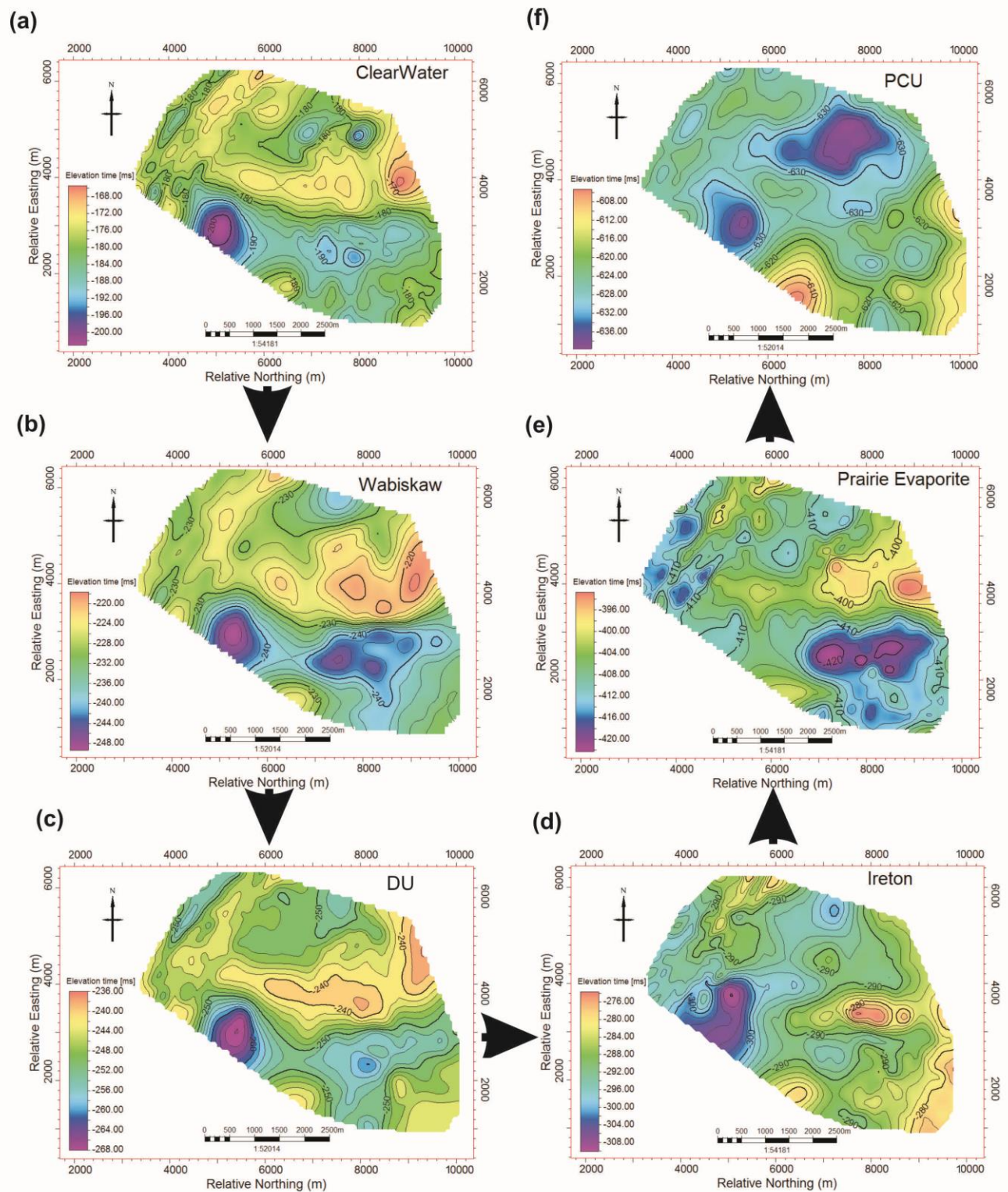


Figure 4: Comparison of the surface maps in time domain for the (a) Mesozoic Clearwater, (b) Mesozoic Wabiskaw, (c) DU, (d) Paleozoic Ireton, (e) Paleozoic Prairie Evaporite and (f) PCU. Arrows denote the progression of the panels with subsequently increasing depth.

## Conclusions

The interpreted time structure maps of the DU and the overlying and underlying formation tops show substantially more detail than those constructed on the basis of well log information only; in fact the use of only well log information would likely result in erroneous interpretations. Although features smaller than about 40 m in radius could not be easily discerned at the DU due to wave-field and data sampling limits, the data does reveal the existence of a ridge-valley pattern. The model like we describe here may occur in any basin that has a deep, relatively thick section of Paleozoic carbonates that underlie major unconformities. Comparison of the structural maps from surfaces below the DU suggests that deeper features may also influence the structure of the DU. Meanwhile the overlying Mesozoic formations represent almost the same structural topography as DU surface. This may be due to collapse of karst features within the Grosmont after Mesozoic deposition, differential compaction of the Mesozoic sediments or even small fault motions. The current re-examination and integration of the legacy Project data sets demonstrates the necessity for geophysical studies of this resource. Additional work would assist in adding value to any modern seismic data obtained in the production of this resource.

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## References

- Dembicki, E. A. . 1994. *The Upper Devonian Grosmont Formation: Well log evaluation and regional mapping of a heavy oil carbonate reservoir in northeastern Alberta*, U of Alberta, Edmonton.
- Dembicki, E. A., and H. G. Machel. 1996. "Recognition and delineation of paleokarst zones by the use of wireline logs in the bitumen-saturated Upper Devonian Grosmont Formation of northeastern Alberta, Canada." *Aapg Bulletin-American Association of Petroleum Geologists* no. 80:695-712.
- Huebscher, H, and Hans Machel. 1997. Paleokarst in the Grosmont Formation, Northeastern Alberta, Canada. Paper read at Core Conference, June 5-7, 1997, at Calgary.
- Jones, B. 2010. Fracture systems in the Grosmont Formation. In *Carbonate Research Program*. Edmonton: Alberta Research Council.
- Machel, H.G., M. L. Borrero, M. Dembicki, E. Huebscher, P. Luo, and Y. Zhao. 2012. The Grosmont: The World's Largest Unconventional Oil Reservoir Hosted in Carbonate Rocks. *Advances in Carbonate Exploration and Reservoir Analysis* (370): 49-81, <http://sp.lyellcollection.org/content/370/1/49.full.pdf+html>.
- Switzer, S. B., W. G. Holland, D. S. Christie, G. C. Graf, A. S. Hedinger, R. J. McAuley, R. A. Wierzbicki, and J. J. Packard. 1994. "Devonian Woodbend - Winterburn Stata of the Western Canada Sedimentary Basin." In *Geological Atlas of the Western Canadian Sedimentary Basin*, edited by G. D. Mossop and I. Shetsen. Edmonton: Canadian Society of Petroleum Geologists and Alberta Research Council.