APPLICATION OF REFLECTION SEISMOLOGY TO MISSISSIPPIAN CARBONATE POROSITY AND DIRECT HYDROCARBON DETECTION

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Abstract

Studies from the Claresholm area of Alberta indicate that "Bright Spot" technology may be directly applicable in the exploration for Mississippian gas at depths of up to 2100 metres. Amplitude and velocity anomalies are the fundamental indicators of the presence of gas-filled porosity. Interval velocity variations of 10 to 20% are readily detectable within the Mississippian Turner Valley Formation. The presence of gas-filled porosity decreases the Mississippian Upper Turner Valley interval velocity to near that of the overlying Jurassic and Lower Cretaceous section. The effect of the decreased velocity contrast is to give rise to a "dim spot" plus attenuation of amplitude and frequency of events immediately under the reservoir. Zones of gas-filled porosity, water-filled porosity and tight water-filled carbonates can be differentiated on the basis of amplitude and velocity analysis. Gas-filled porosity of 10 to 15% is differentiated on the basis of a 20% interval-velocity change with respect to tight (3-5% porosity) water-filled carbonates of 19 to 20 ft /msec (6-7 km/sec). The Mississippian Upper Turner Valley reflection dims and events beneath the gas-saturated zone are attenuated. Water-filled porosity (11-15%) illustrates a 10% interval-velocity differential with respect to the tight carbonates and little or no attenuation beneath the water-filled porosity zone. Oil saturation cannot be distinguished from water.

Introduction

The purpose of this paper is to examine the reality of applying "Bright Spot" or hydrocarbon-indicator technology to Mississippian carbonate prospects in the Western Canada basin.

As yet bright spot technology works best in young (Tertiary) clastic sequences in a continental margin framework. Within Alberta it is generally acknowledged to work well in shallow stratigraphic gas settings, *e.g.*, Cretaceous Colony Sands.

Within the Paleozoic section of the western Canada basin, a prime exploration target has been the Mississippian carbonates. Porosities within the Mississippian commonly range from 5 to 15%. Because of the low primary porosity, the complexity of structure and/or unconformity relief and the depth to the Mississippian in many prospects, most explorationists would hold little hope for direct hydrocarbon indications within the Mississippian.

This paper examines the validity of Mississippian direct hydrocarbon detection. The results indicate that a potential does exist under certain conditions for porosity and direct hydrocarbon detection in Mississippian carbonates.

Mississippian Direct Detection Techniques

The Claresholm field was chosen as a model for Mississippian direct-detection techniques (Fig. 1). Figure 2 shows synthetic seismograms derived from sonic logs run in three wells (one dry, one marginal, one producing) in the Claresholm field area. Note the importance in delineating the Mississippian signature, and observing its amplitude and character change from the dry to the producing well. The dominant "event" that many would assume represents the Mississippian top comes from the Jurassic shale and Lower Cretaceous interbedded clastics and coal a few hundred feet above

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The author wishes to thank Teledyne Exploration, Uno-Tex Petroleum and Canexeco for providing the seismic data used in this study. The study was funded by the University of Calgary research operating grant #1577.

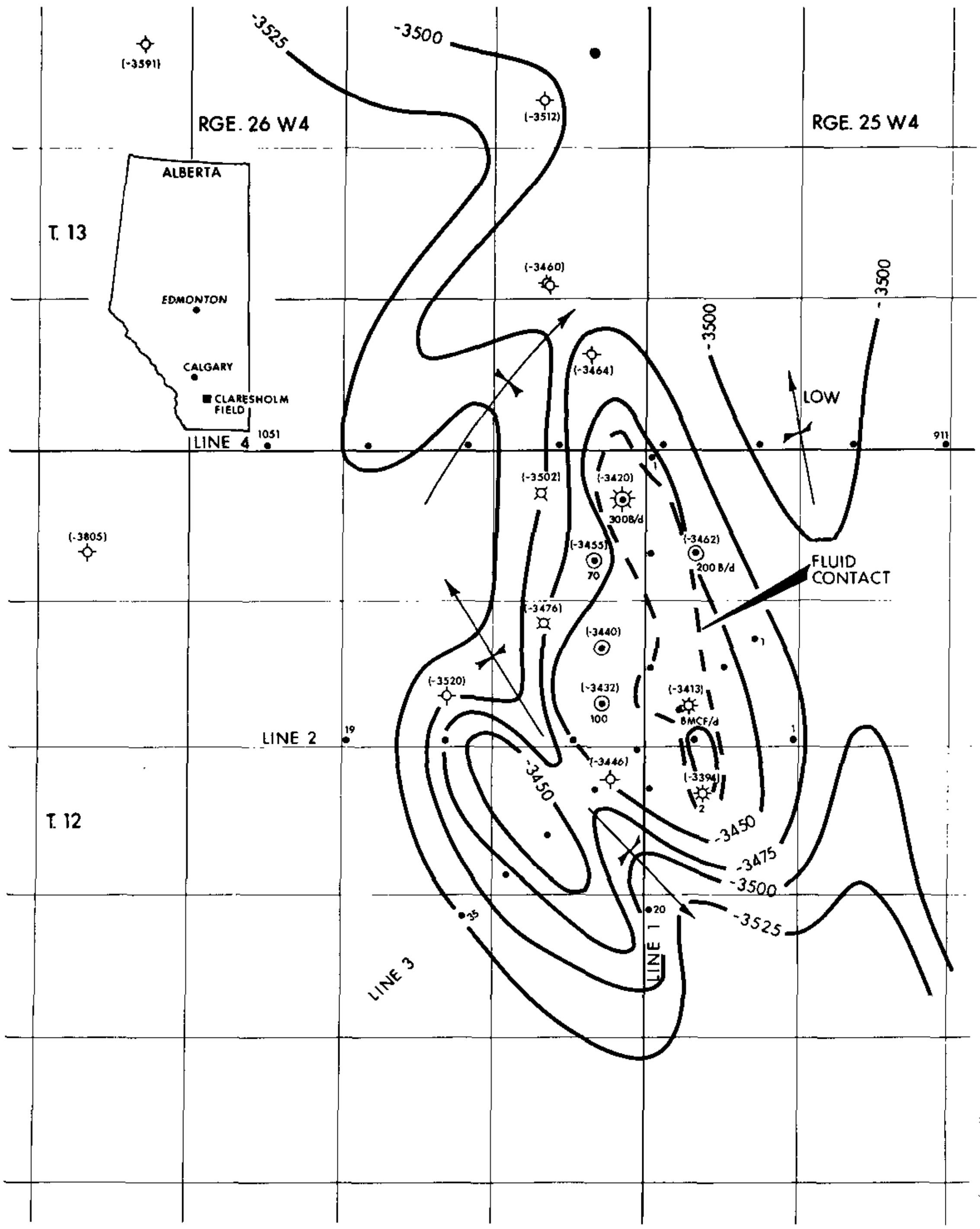

Fig. 1. Top of Mississippian Turner Valley structure map derived from well and seismic control.

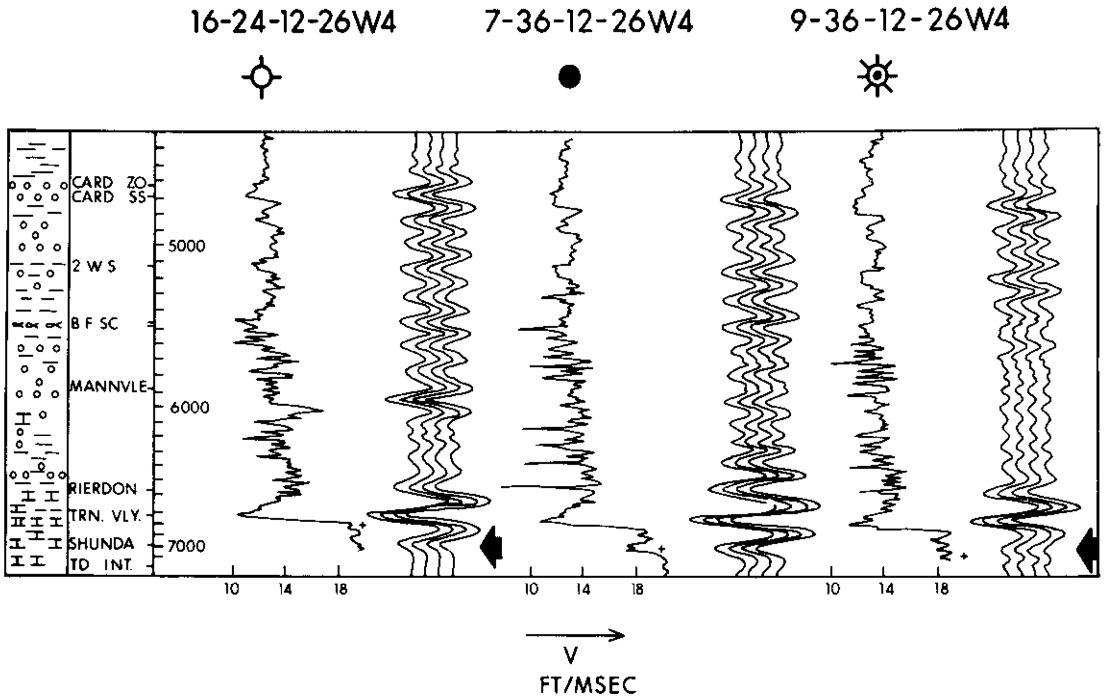

Fig. 2. Synthetic seismogram section illustrating the stratigraphic section and its seismic expression. Note the Mississippian signature change from the dry hole to the producing well.

the Mississippian. Identification of the top of the Mississippian Upper Turner Valley event and the total Mississippian signature is critical in direct-detection analysis. If porosity develops and hydrocarbons occur in the Mississippian, the Mississippian interval velocity decreases by a factor of 10 to 20%, thereby reducing the contrasting velocities between the Mississippian and the overlying Jurassic shale. A dimming of the top of Mississippian reflection amplitude, plus attentuation of events immediately beneath the Mississippian top, is noted on Figure 2. Criteria for direct indication of hydrocarbons within the Mississippian Upper Turner Valley at depths of 1500 to 2100 m in the Claresholm field are a "dim spot" plus a decrease of Upper Mississippian interval velocities of 10 to 20%.

Figure 3 illustrates an Upper Turner Valley (Upper Porous) isopach map. The trap is a combination structural and stratigraphic feature formed by truncation of the Mississippian Turner Valley Upper Porous unit superimposed on a Mississippian structural high. Figure 4 illustrates that the Mississippian structural high coincides with a basement structural high. Mississippian structural and stratigraphic features may have been controlled by basement tectonics. Note the drape of the Paleozoic section over the basement fault block. Seismic sections that do not delineate the basement configurations, or are arbitrarily "flattened" on the Cambrian or near-Cambrian event at approximately 1.5 seconds, are structurally deceiving and are of little use other than showing differential relief at the top of Mississippian level.

Figures 5 through 7 illustrate portions of Claresholm seismic lines, 1, 2, and 3, which show the Turner Valley "dim spot" corresponding to the gas/oil contact. Note the disappearance of a reflection leg corresponding to the top of the Mississippian event on these sections. The disappearance of the leg, plus a general attenuation of the Mississippian signature, is indicative of the presence of gas-filled porosity. The change or transition in the seismic signature marks the limits of the Claresholm gas field (Fig. 1).

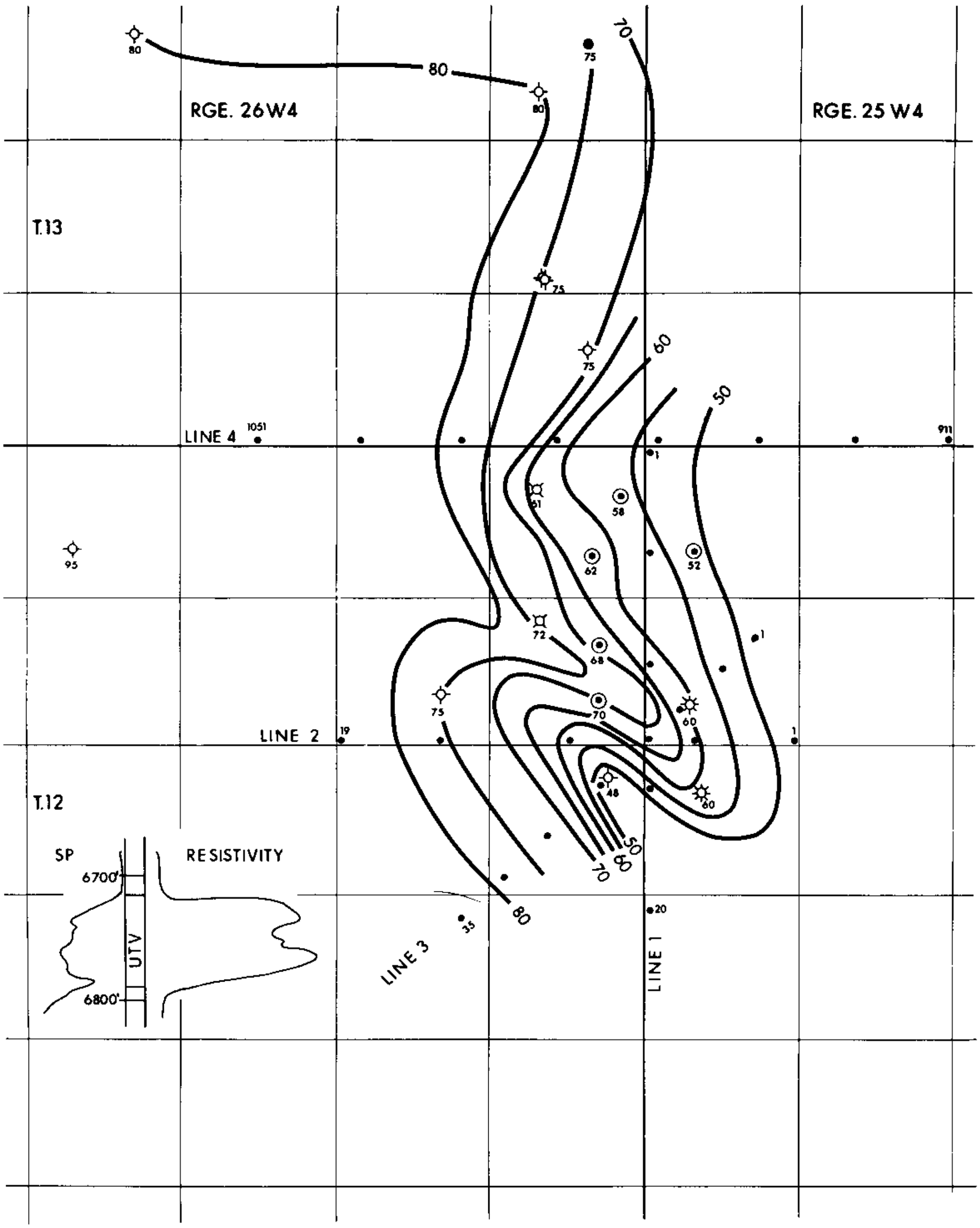

Fig. 3. Upper Turner Valley unit isopach.

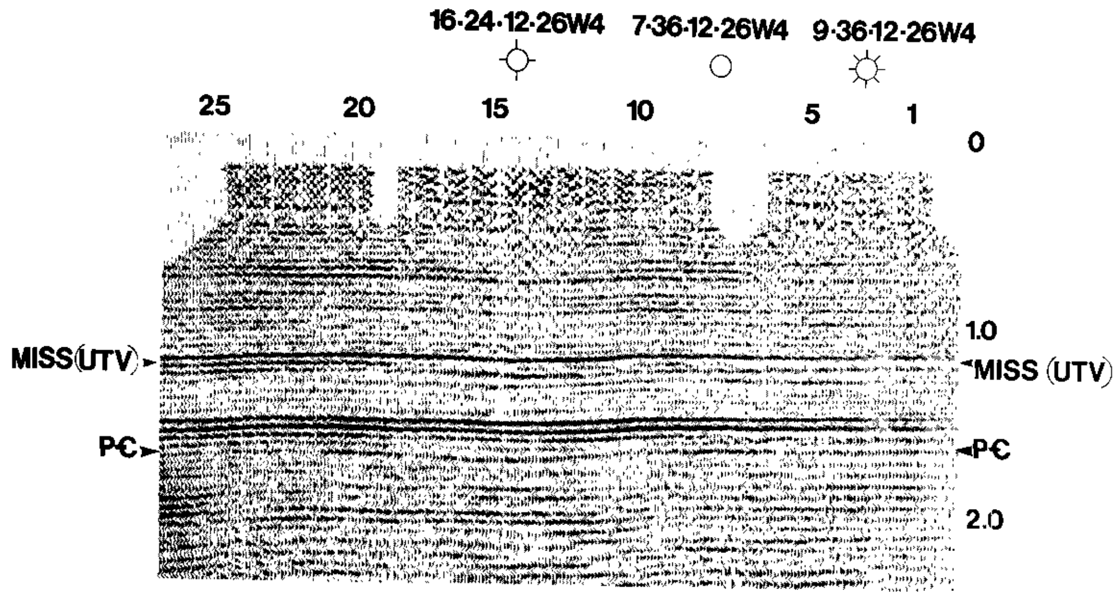

Fig. 4. Claresholm field is located over a basement block fault as evidenced on Claresholm line 1. Note the thinning from left to right of the Mississippian interval.

Table 1 illustrates a velocity analysis of line 1 (Fig. 4). Note the interval velocity drop of 15 to 20% from the tight (low-porosity) Mississippian Turner Valley interval to the porous gas-filled interval. The isovelocity drop of this magnitude indicates the presence of gas-filled porosity. The combination of Mississippian interval-velocity drop, dim spot, and attenuation of events within and below the top of the Mississippian represents Mississippian hydrocarbon indicators (Davis, 1978).

Velocity analyses can be used to arrive at estimates of porosity. Porosity estimates of 10 to 11% are obtained in porous water-filled zones based on Wyllie's time-average formula. Gas-saturated zone porosities cannot be obtained from Wyllie's time-average formula (Anstey, 1977, p. 94). Porosity zonation is readily delineated on the basis of waveform and velocity, as indicated by Table 1. Porosity variation itself can give rise to velocity and amplitude variations. Porosity often varies considerably within the Mississippian, and lateral variations can form traps (Glaister and Thomas, 1960). Figure 8 illustrates a well drilled on a water-filled porosity anomaly.

Shotpoint	Jurassic event — top Devonian	Jurassic event — top Cambrian
1	4800	5700 oil/water filled Φ
6	4200	5100 gas filled Φ
8	4800	5700 oil/water filled Φ
10	4200	5100 gas filled Φ
12	5100	6300 tight
15	5400	6600 tight
17	4800	5700 water filled Φ
20	5400	6000 tight

Table 1. Interval-velocity variations derived from seismic velocity analyses of common depth point (CDP) seismic data of line 1. Interval velocities are in metres/second.

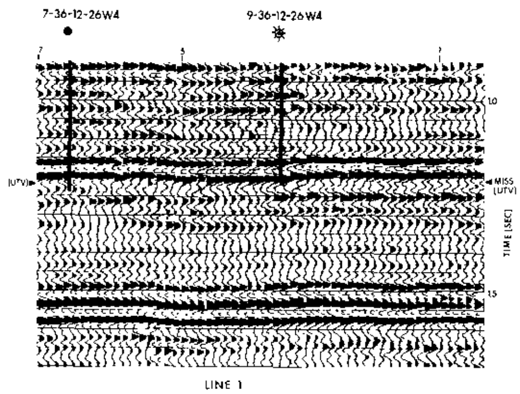

Fig. 5. Claresholm line 1 showing "dim spot" at Upper Turner Valley level.

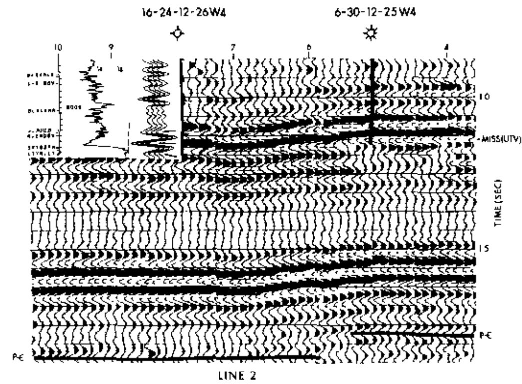

Fig. 6. Claresholm line 2.

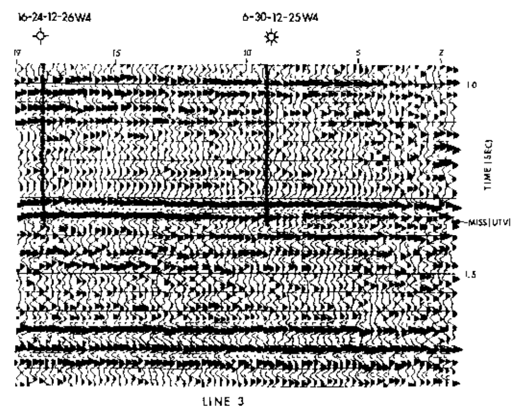

Fig. 7. Claresholm line 3. Section is flattened on the near-Cambrian event at 1.5 seconds.

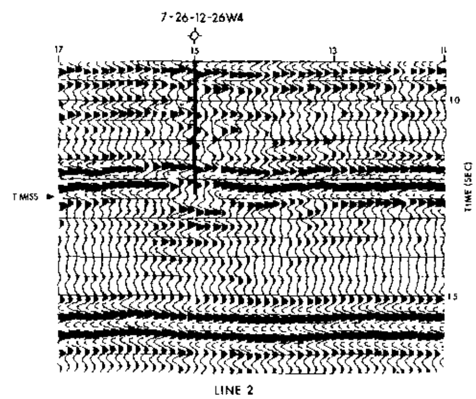

Fig. 8. Well (7-26-12-26W4) location on water-filled porosity zone of line 2. Note lack of attenuation of events under amplitude anomaly at Mississippian level.

Conclusions

From this study the following conclusions are drawn:

— Hydrocarbon indicators exist on seismic records from the Claresholm field area. These Mississippian carbonate hydrocarbon indicators include "dim spots", attenuation of seismic events beneath the top of Mississippian gas-filled porosity zones and interval-velocity variations of 15 to 20%.

— The amplitude anomalies used in direct hydrocarbon detection of Mississippian carbonate porosity are extremely subtle, but still detectable for a unit 15 to 25 m thick at 2100 m depth.

— Amplitude variations must be matched with velocity variations to quantify the cause of the amplitude anomalies; *i.e.*, porosity and/or hydrocarbon content. Differentiation of water and gas-filled porosity is possible on the Claresholm seismic sections. Oil-versus water-filled porosity is not differentiable, however.

— Seismic data acquisition and processing techniques should be adapted toward the goal of enhancing and preserving amplitude and frequency content while maximizing the amount and quality of velocity information derivable from the data.

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