Seismic methods in reservoir monitoring – with applications to heavy oil production

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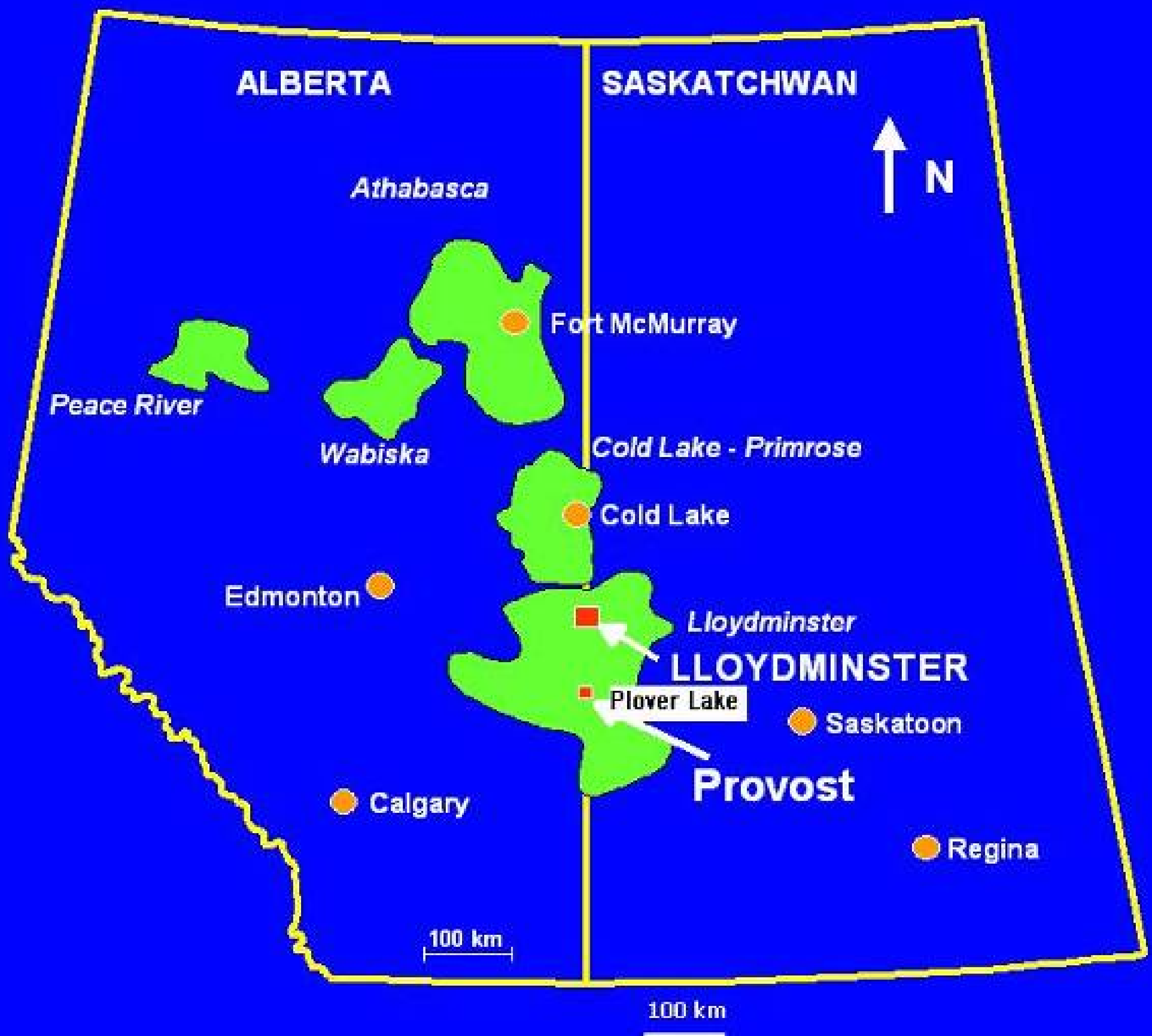
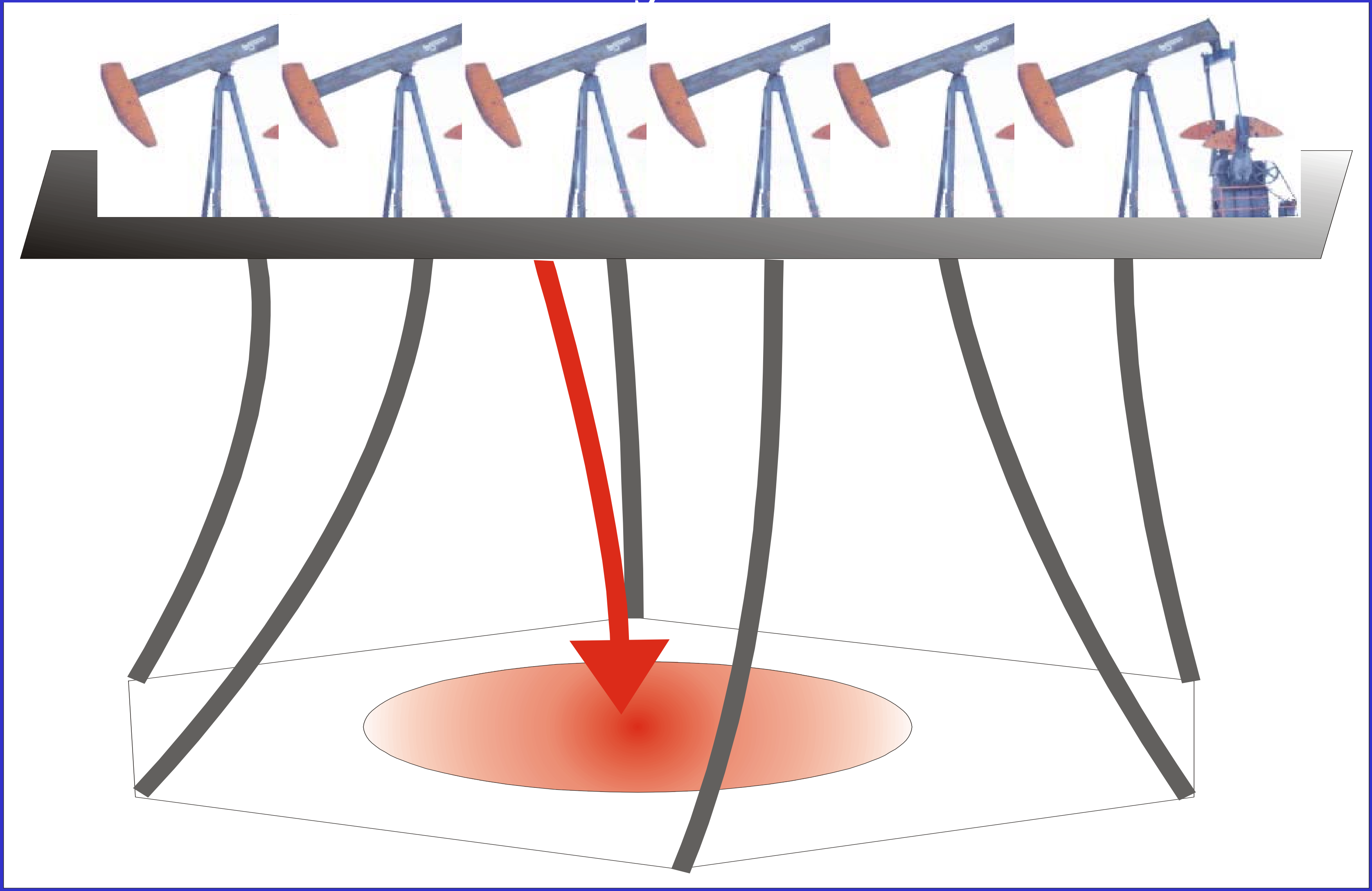
Introduction - Location of Provost BB Pool



Time-lapse Seismology

Seismic monitoring is an important tool in heavy oil reservoir characterization.

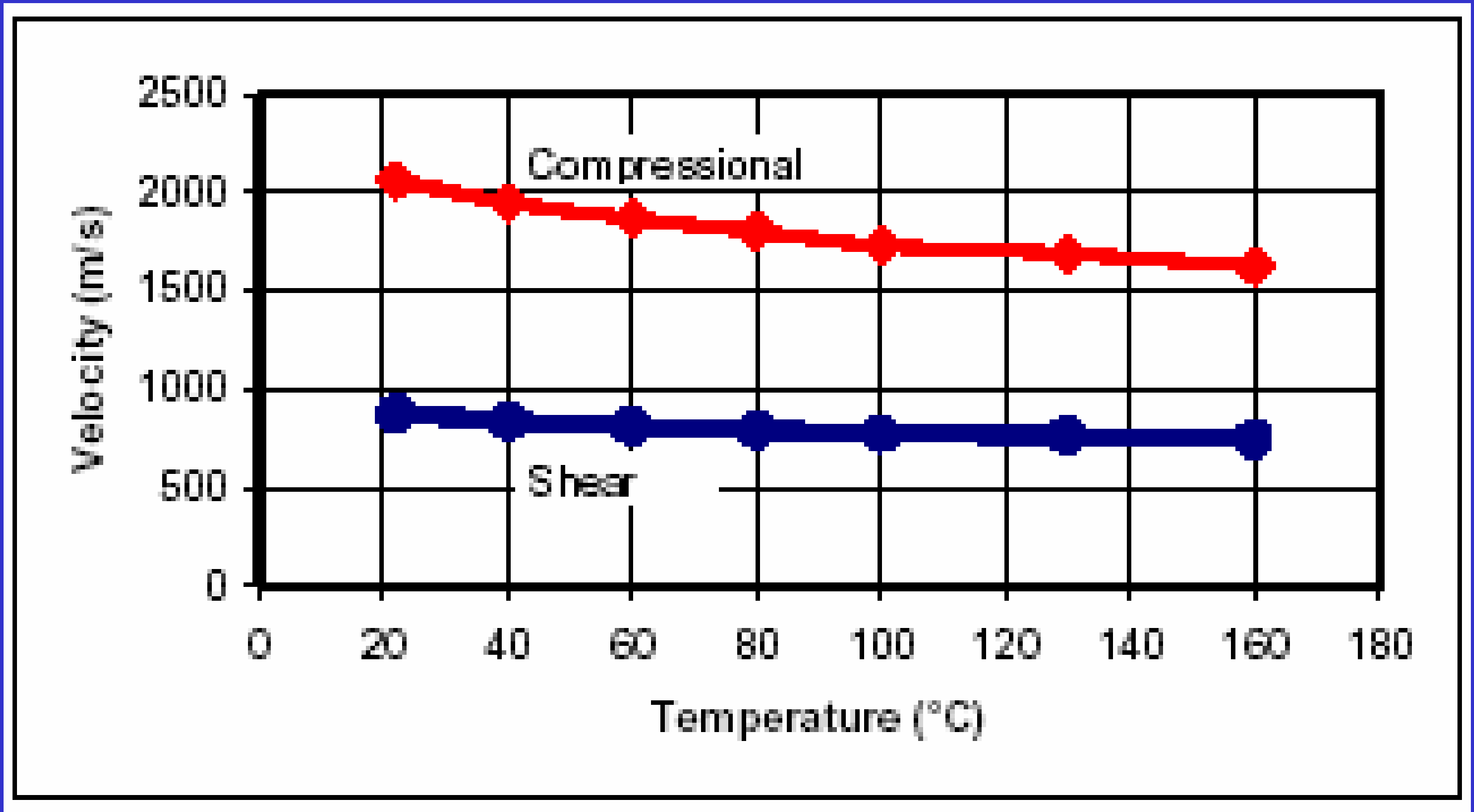
Steam Drive Production Can Be Seismically Monitored



Core Sample from Heavy Oil Sands

- Core samples of Waseca sands were used in velocity measurements (photo from R.R. Stewart).

Rock physics study



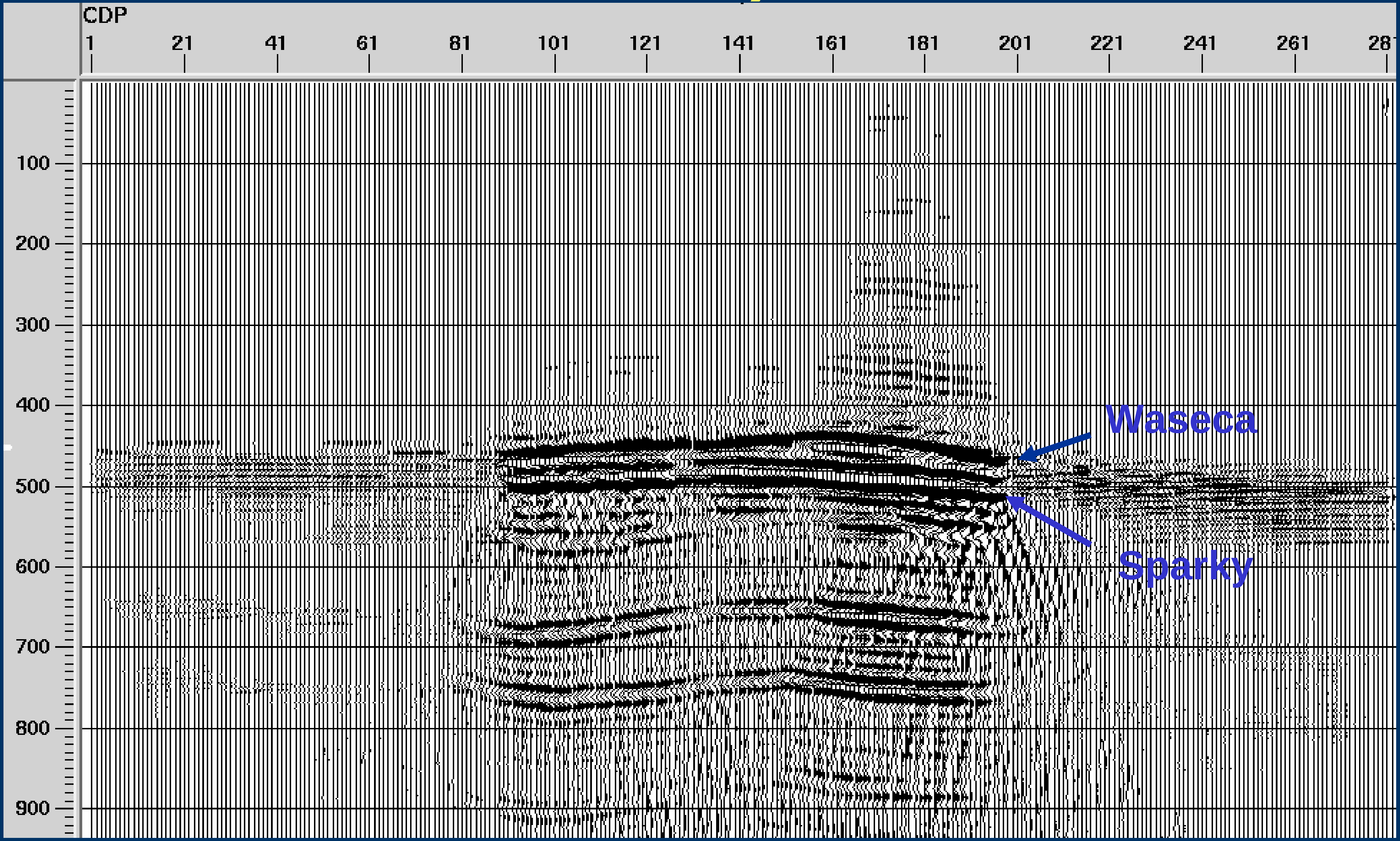
(Watson et al, 2002)

Time-lapse seismology: Data are recorded periodically in producing oil fields

In time-lapse seismology, viva la difference!

- Difference of migrated time sections for repeated surveys
- Difference in impedance inversion estimates
- Difference in AVO responses
- Difference in seismic traveltimes
- Changes in seismic attenuation
- Changes in VP/VS ratio

model responses gave an excellent agreement to real seismic data (Zou et al., 2003):



Use of attenuation

(Quan and Harris, 1997)

$$H(f) = e^{-f \int_{ray} \alpha_0 \, dl}$$

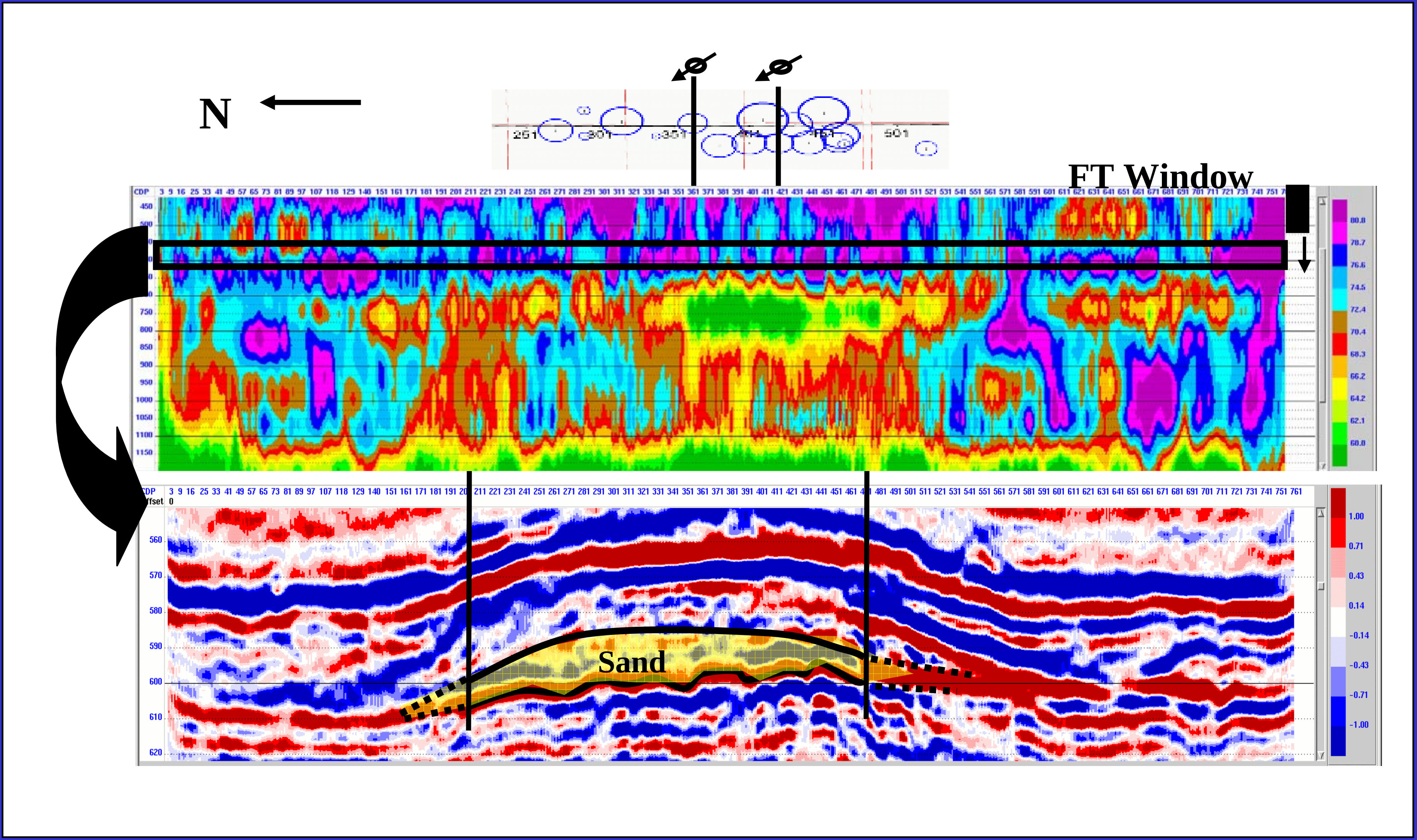
$$\alpha_0 = \frac{\pi}{Qv} = attenuation\_coefficient$$

Mapping the Centroid Frequency (Hedlin et al., 2002)

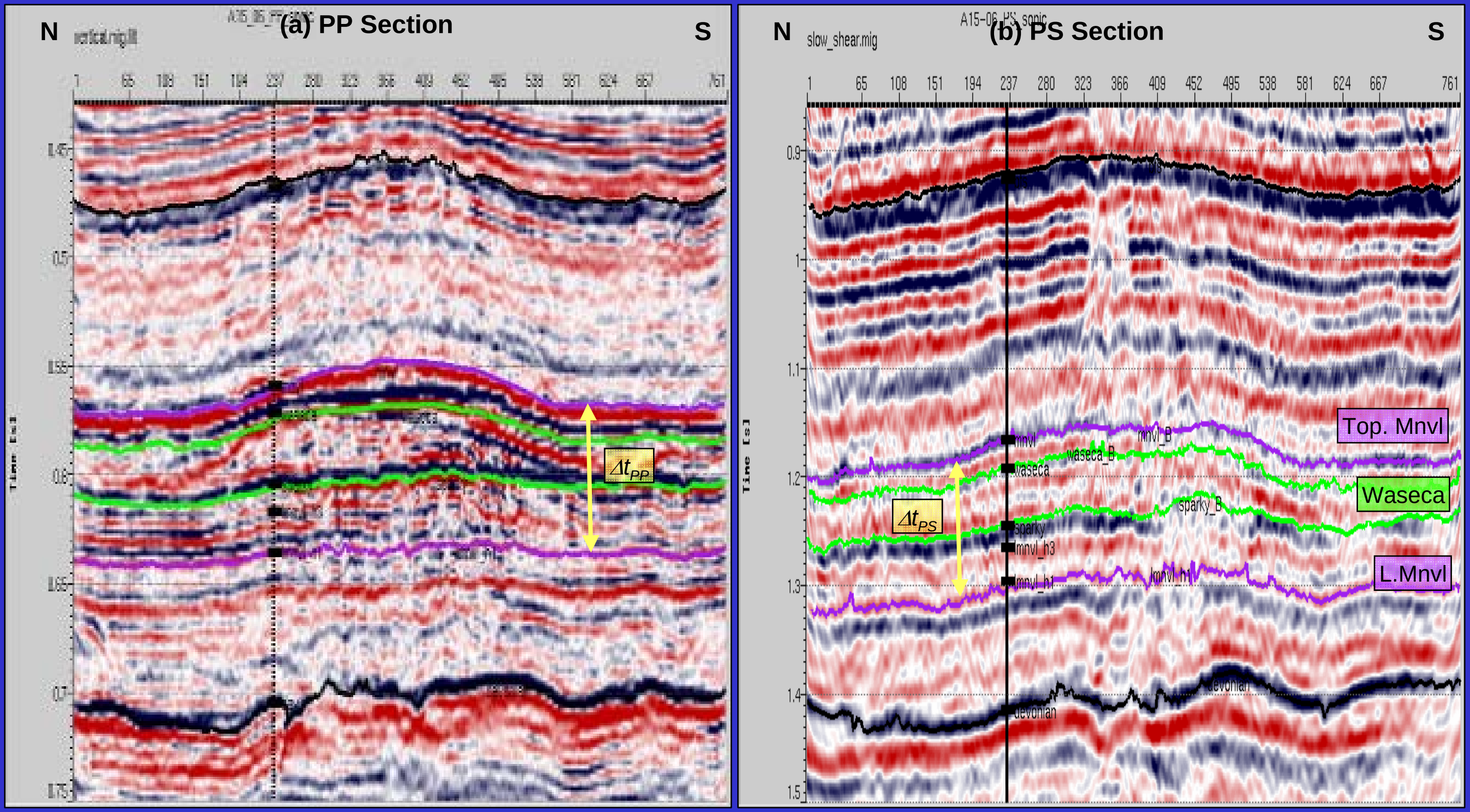
$$f_c = \frac{\int_0^{\infty} f A(f)\,df}{\int_0^{\infty} A(f)\,df}$$

Slide from CSEG 2002 talk by Hedlin et al.

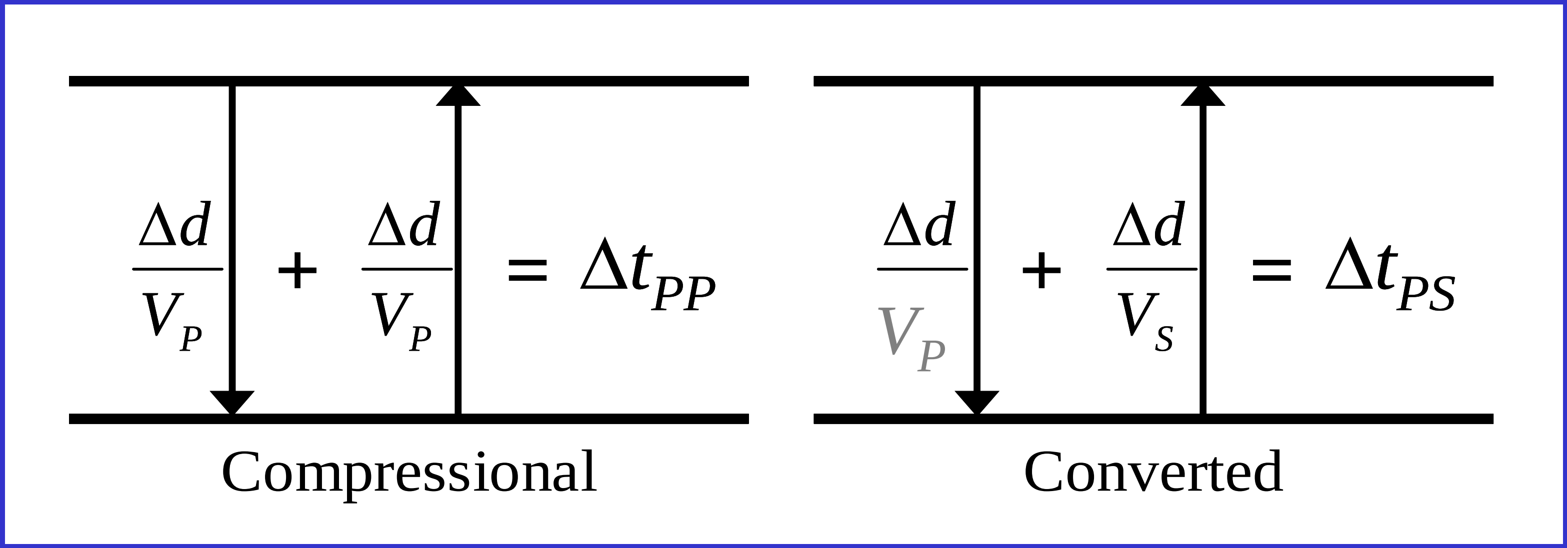
Seismic Section and Centroid Frequency Compressional Data 2000



PP+PS interpretation (Watson et al., 2002)



V_P/V_S Ratio



$$\frac{V_P}{V_S} = \frac{2\Delta t_{PS} - \Delta t_{PP}}{\Delta t_{PP}}$$

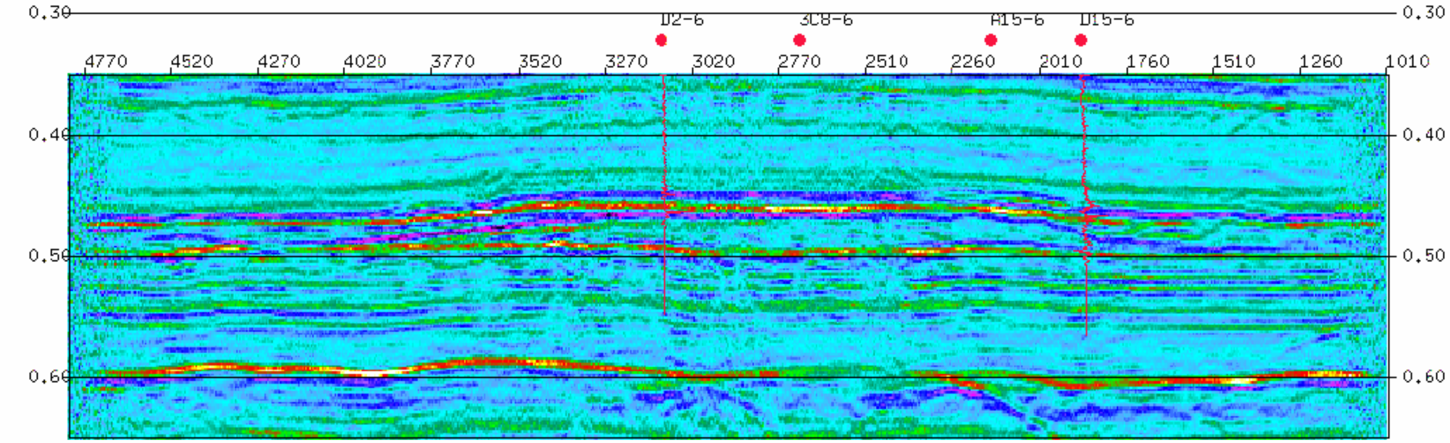
VP/VS Ratio Diagnostics

- VP/VS will decrease with thickening sand.
- VP/VS will decrease with temperature increase.
- VP/VS will decrease will increased gas saturation.

AVO Sections – Another Reservoir Characterization Tool (from Jon Downton)

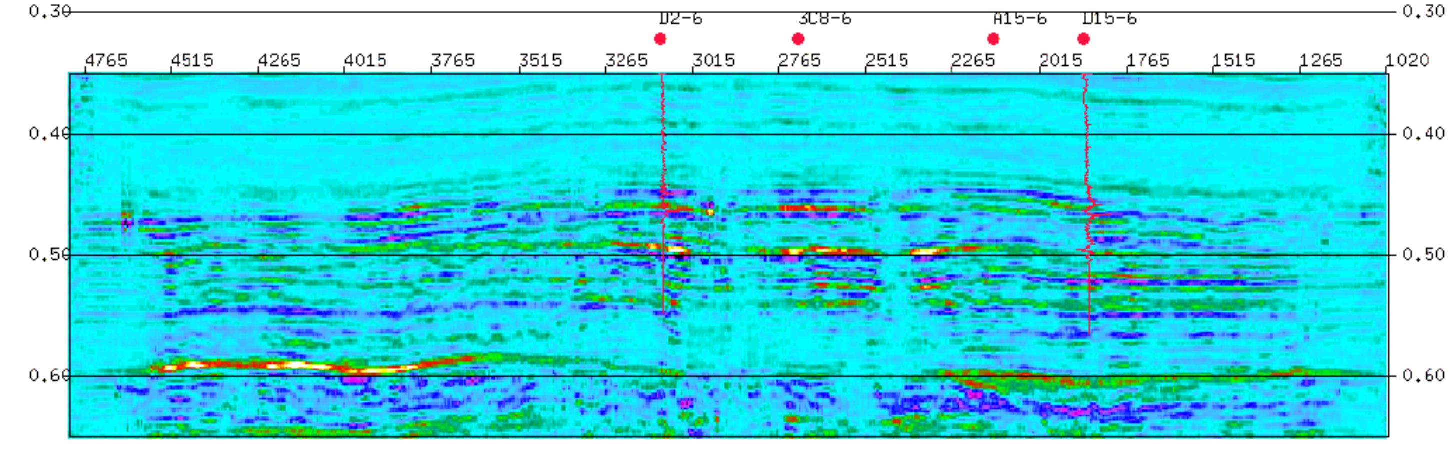
Full offset stack

Channel



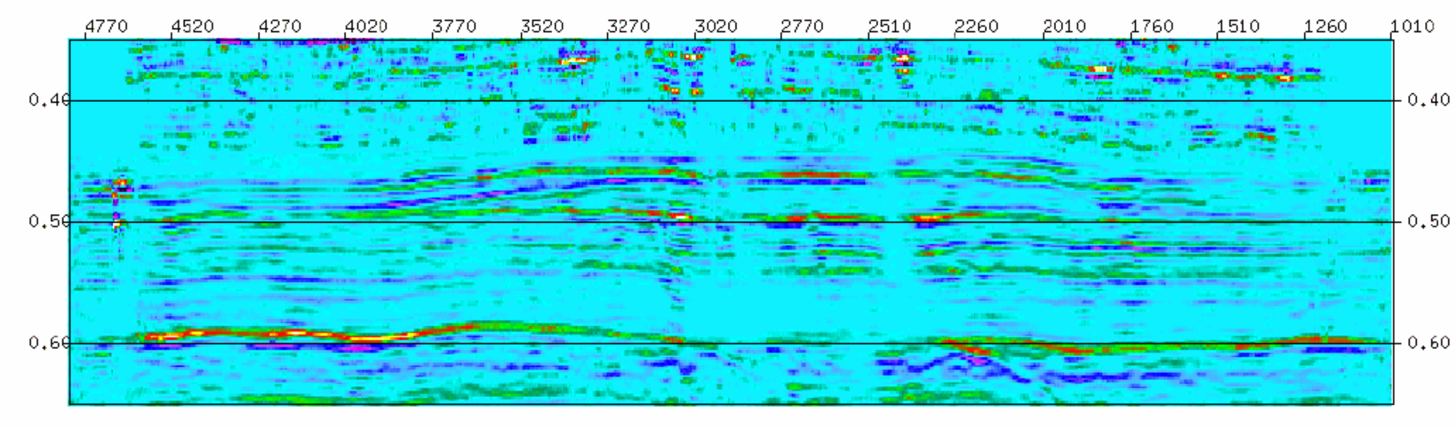
Delta-Lambda section

Channel



Fluid stack

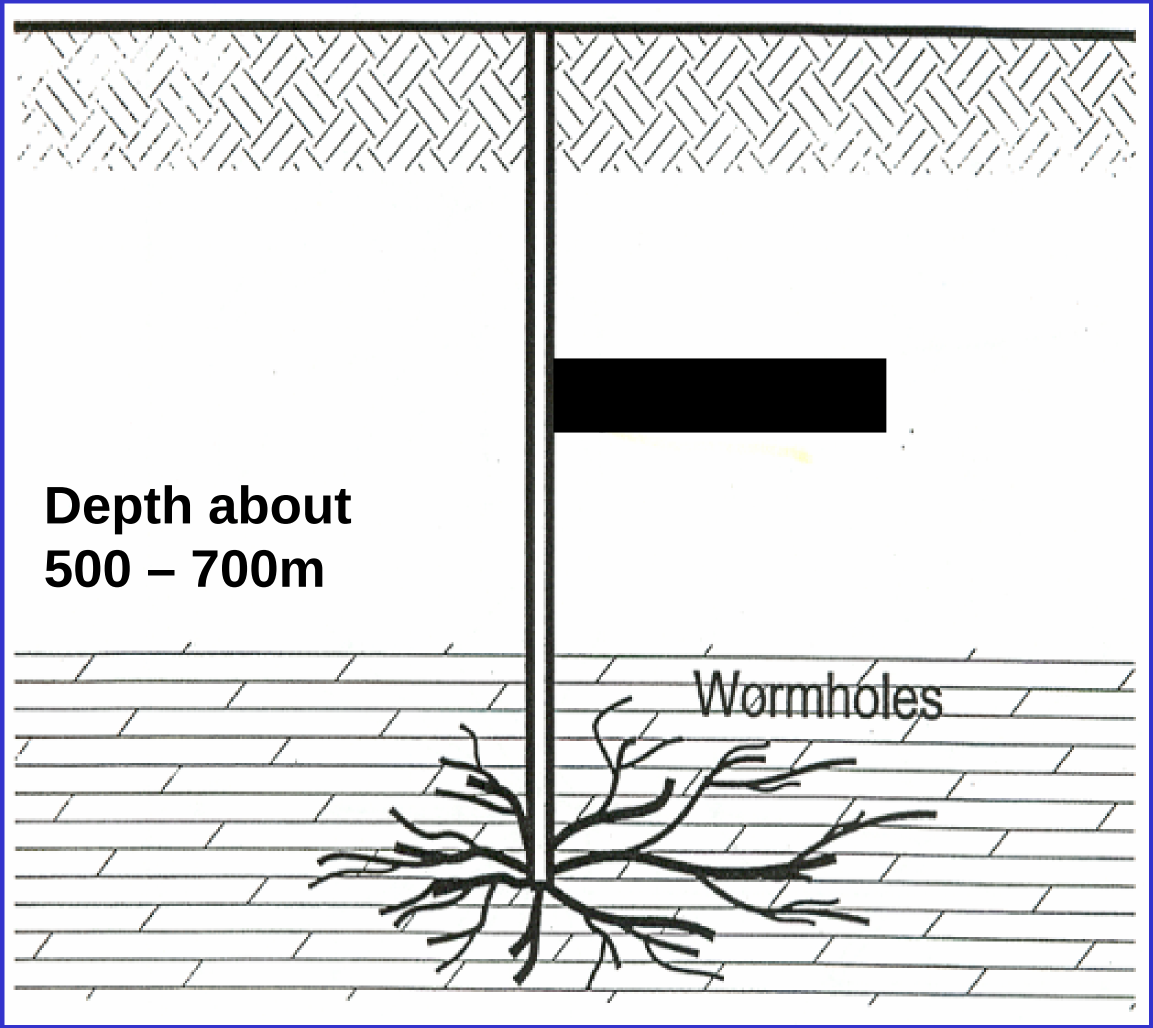
Channel



“Cold Flow” Monitoring

- Several oil fields in Alberta and Saskatchewan involve production of heavy oil sands without use of steam injection.
- There are zones of very high porosity created by production termed “wormholes”, along with the creation of “foamy oil”.
- Question: Can these cold production effects be detected by seismic monitoring?

Wormhole network



Wormhole growth pattern

(adapted from Miller et al., 2001)

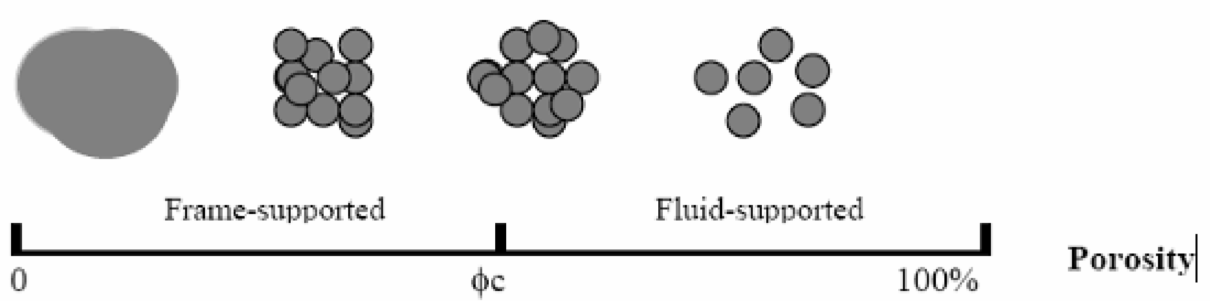
Courtesy of KUDU Oil Well Pumps

Wormholes – high permeability & porosity channels

- small (on the order of centimeters)
- high porosity (>50%)

“wormhole” created in reservoir lab simulation (Tremblay et al. ARC,1998 SPE/DOE symposium & EAGE Symp., 1999)

Physical meaning of critical porosity (from *Nur,et al., Critical porosity : a key to relating physical properties to porosity in rocks, March 1998 TLE*).

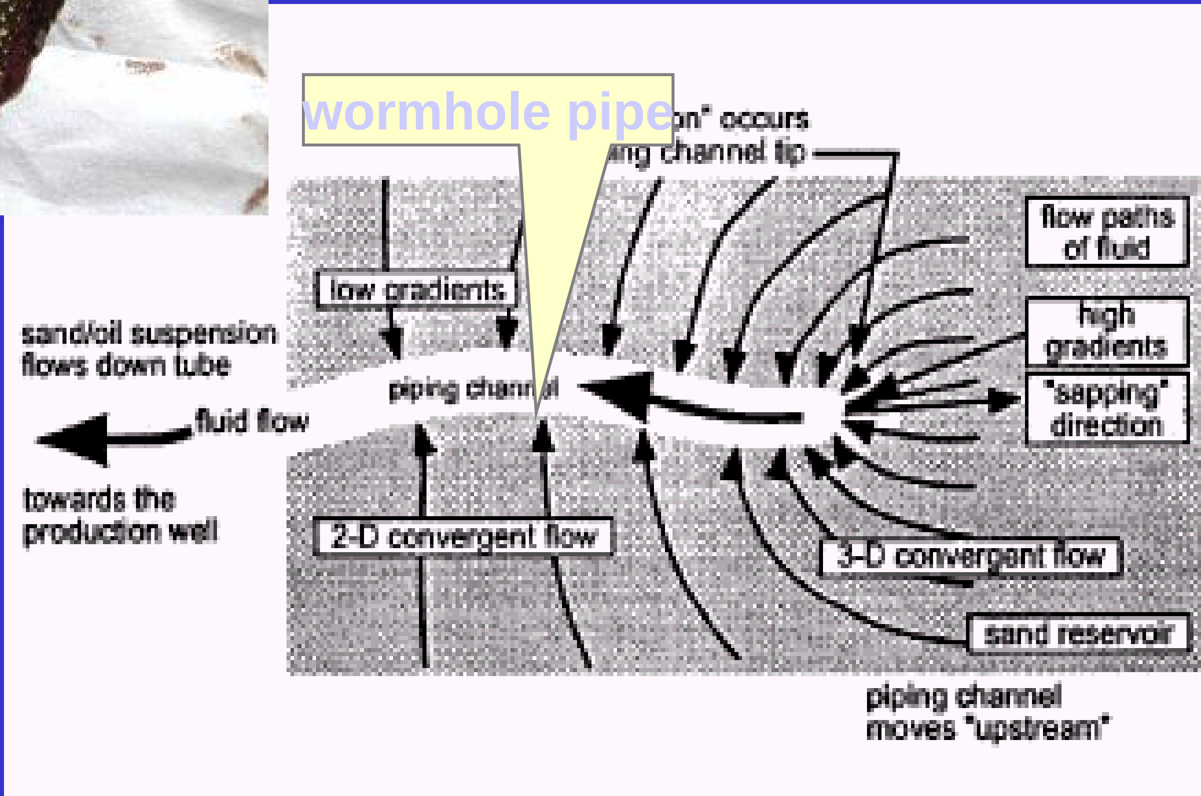


Critical porosity
(35-40%)

Foamy oil drive

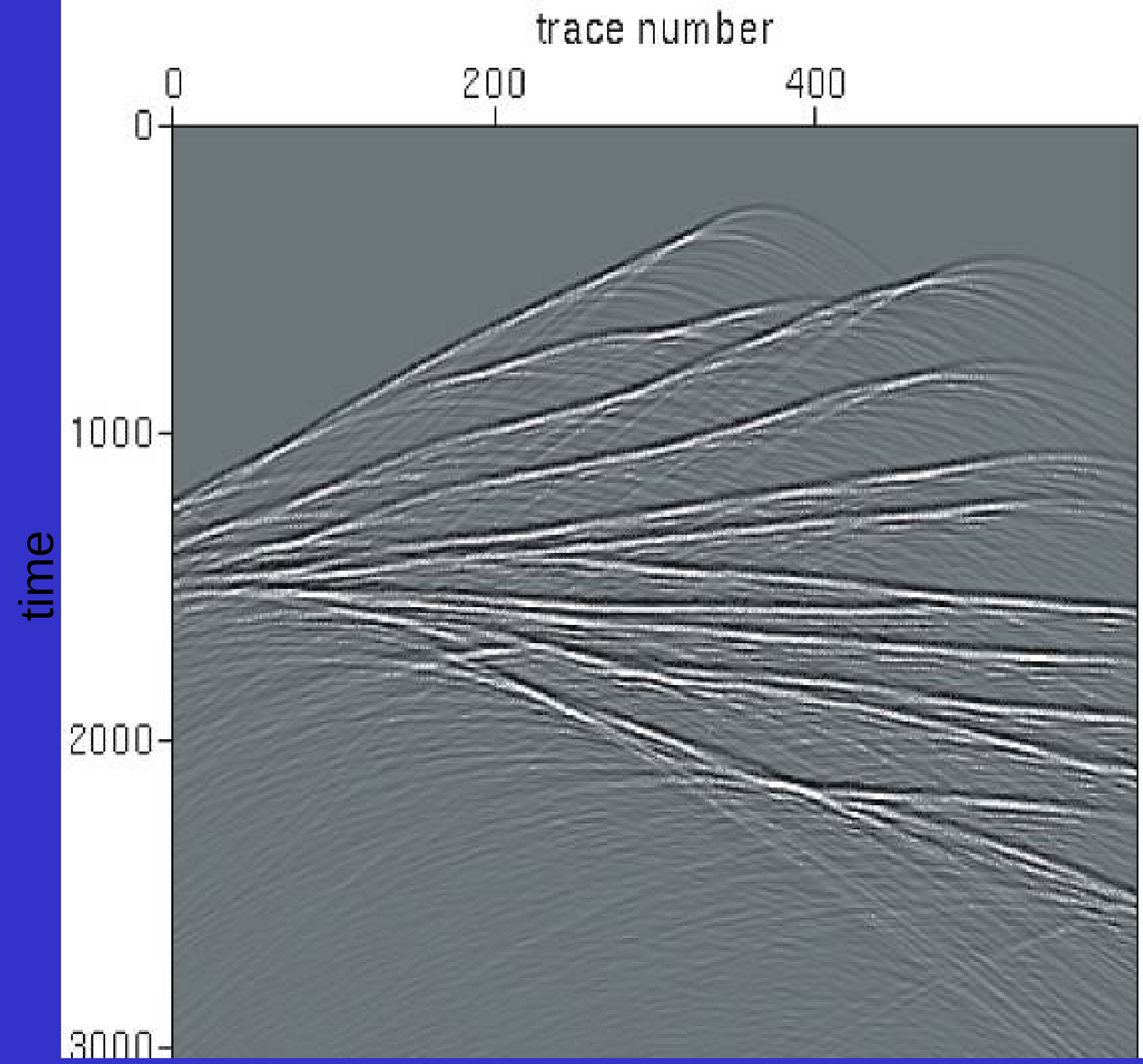
Foamy oil mechanism

(D. Greenidge, Imperial Oil Resources)



In a wormhole, foamy oil provides the pressure to sustain the high production rates **(Dusseault,1994)**

Seismic response at f=3000 Hz

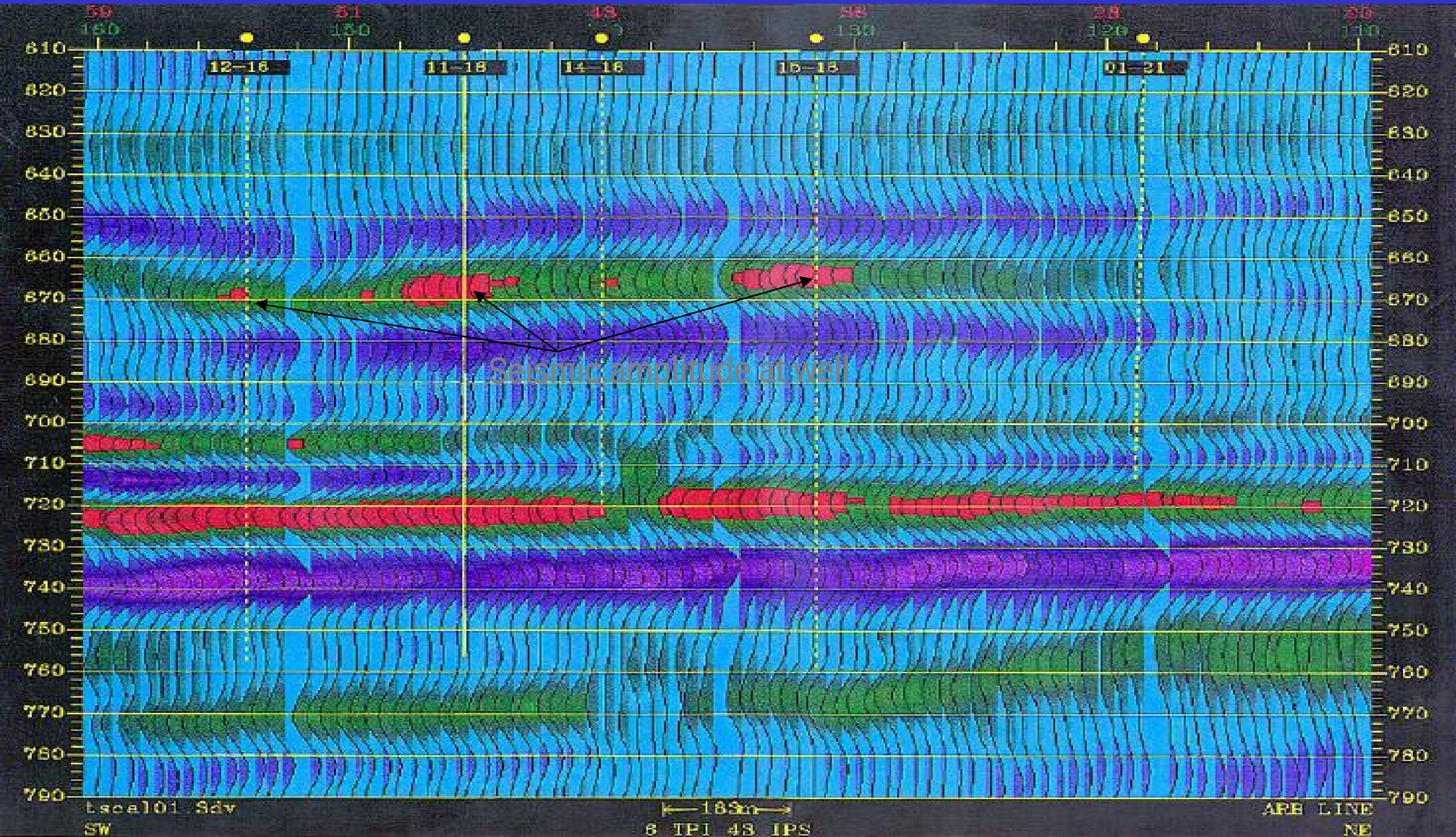


Seismogram 60 metres in x and 30 ms in time

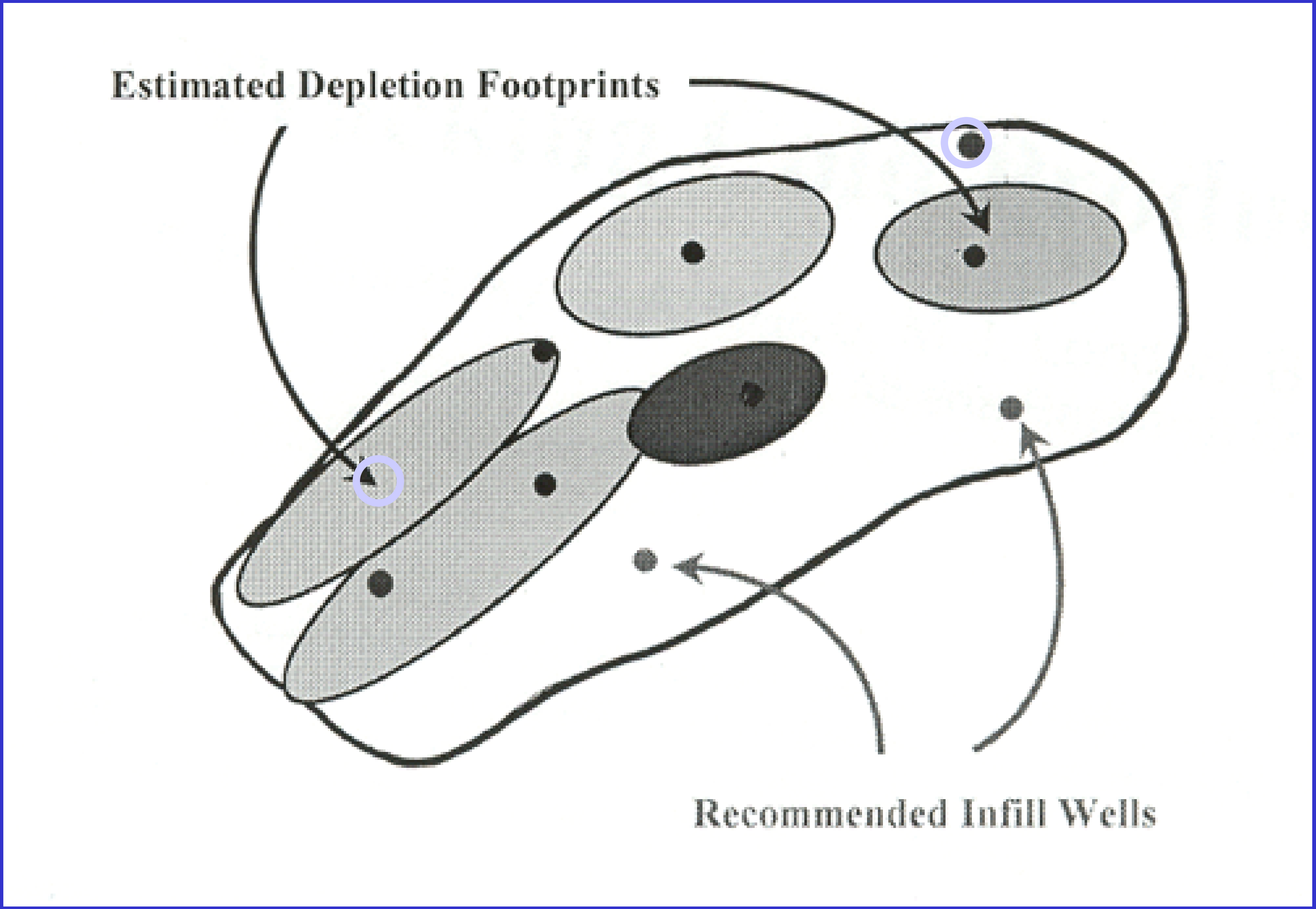
Detection of Wormhole Effects

- Detection of individual wormholes at the 10cm – 1m scale would require ultrahigh frequency information, which is possibly found in cross-borehole surveys and almost never in surface data.
- Can we detect the presence of wormholes and foamy oil in an effective medium?

Seismic line across Provost Upper Mannville BB Pool
howing higher amplitudes at producing wells, from Mayo

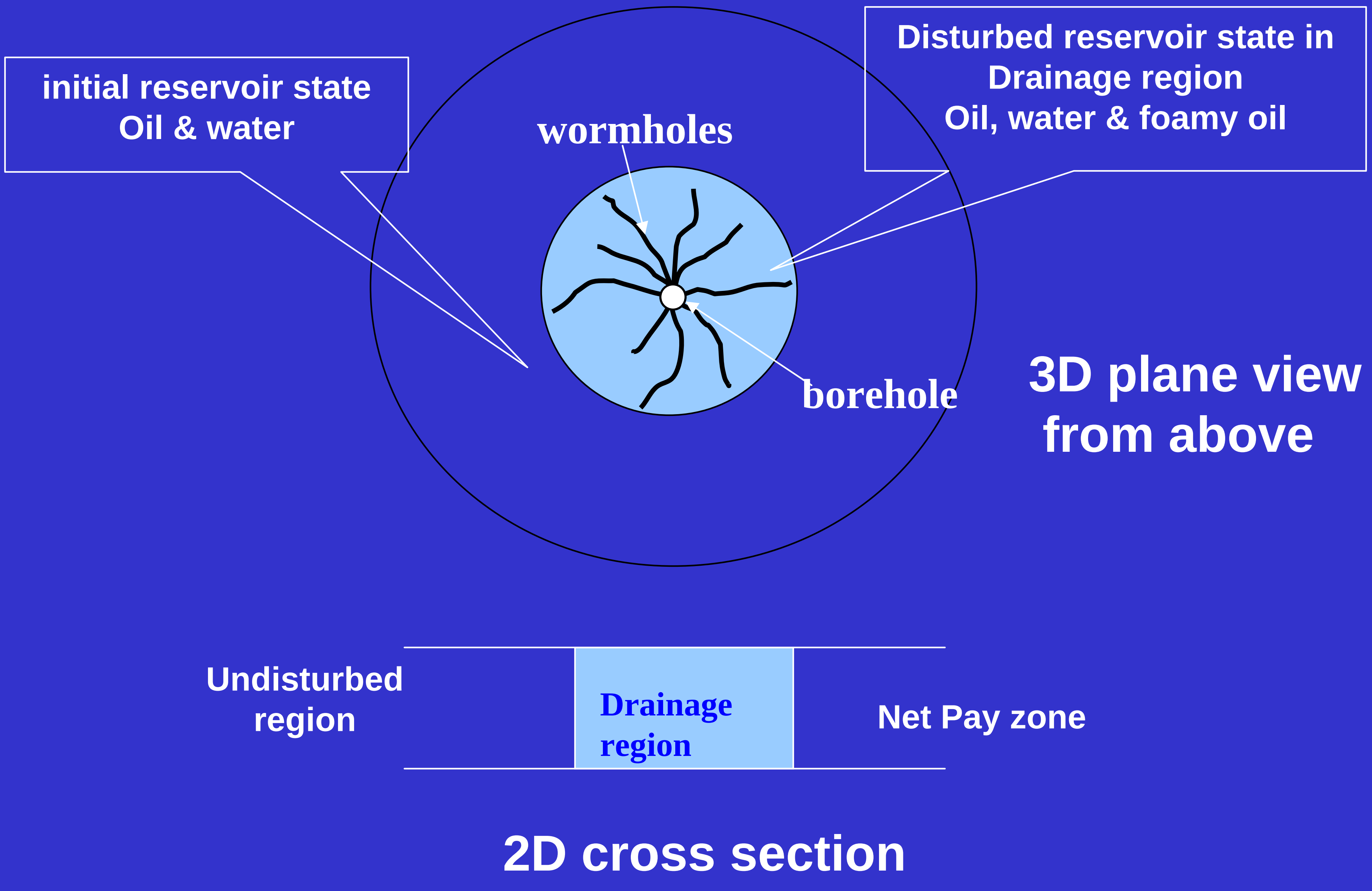


It is useful for engineers and geologists to know the size and distribution of drainage regions

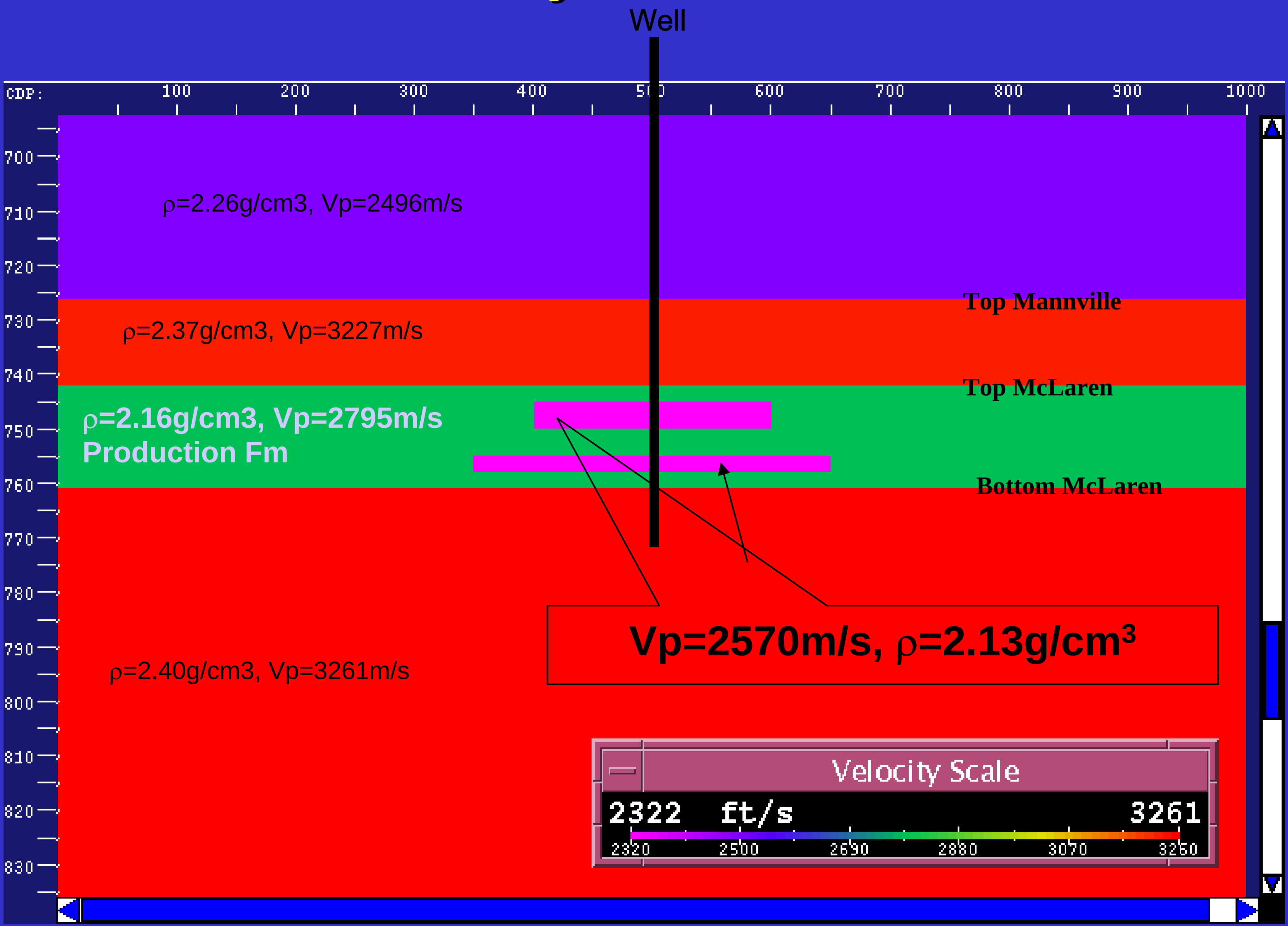


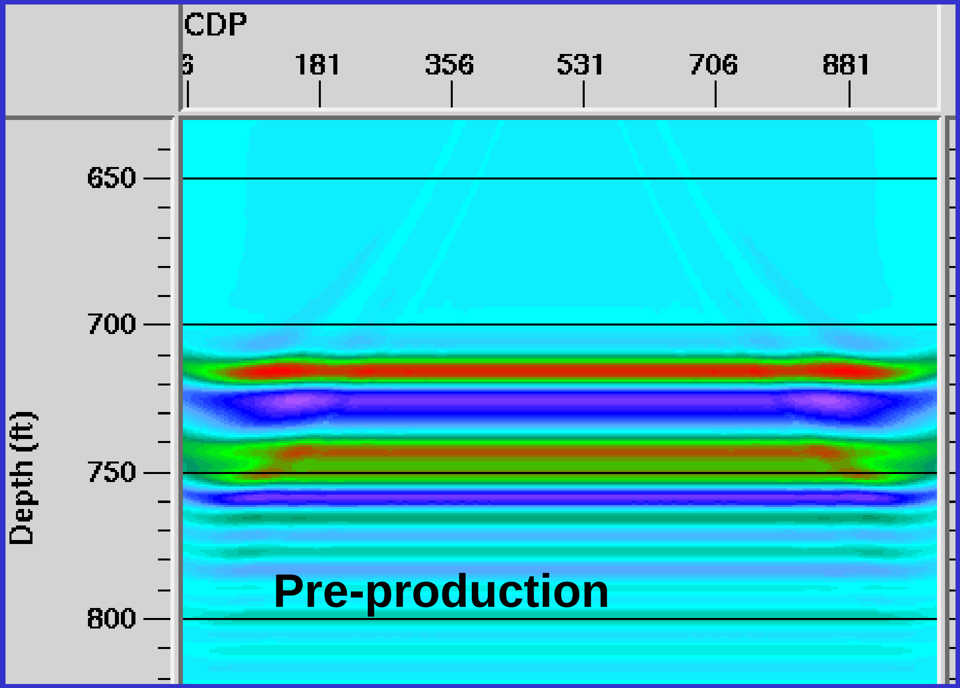
Drainage footprint scenario for the cold production wells in a small southwest Saskatchewan heavy oil pool (Sawatzky, 2002)

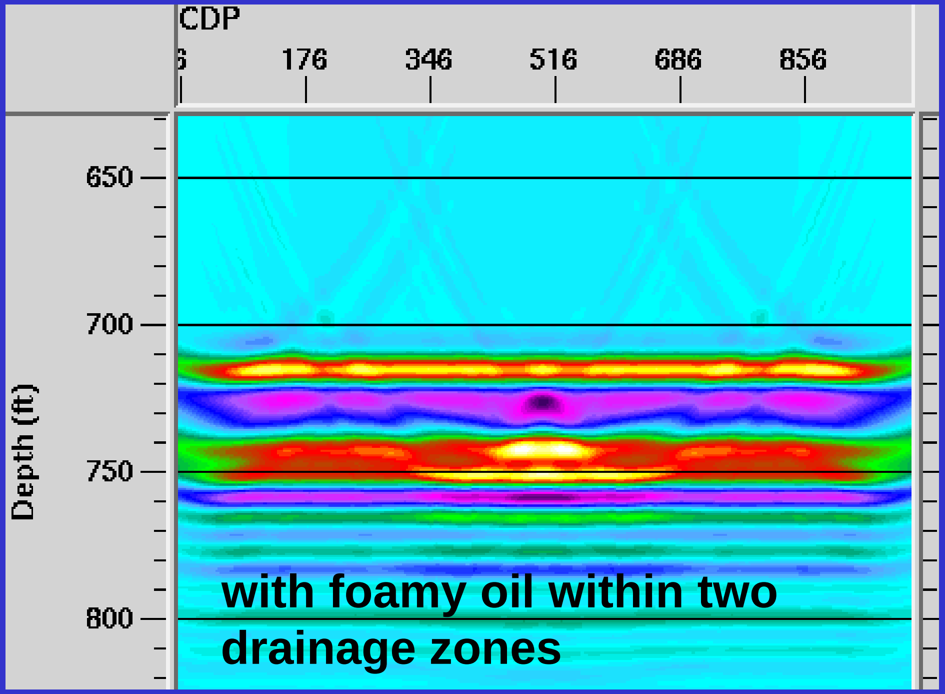
Simplified drainage model with foamy oil effects (vertical wellbore) – from Chen (2004)

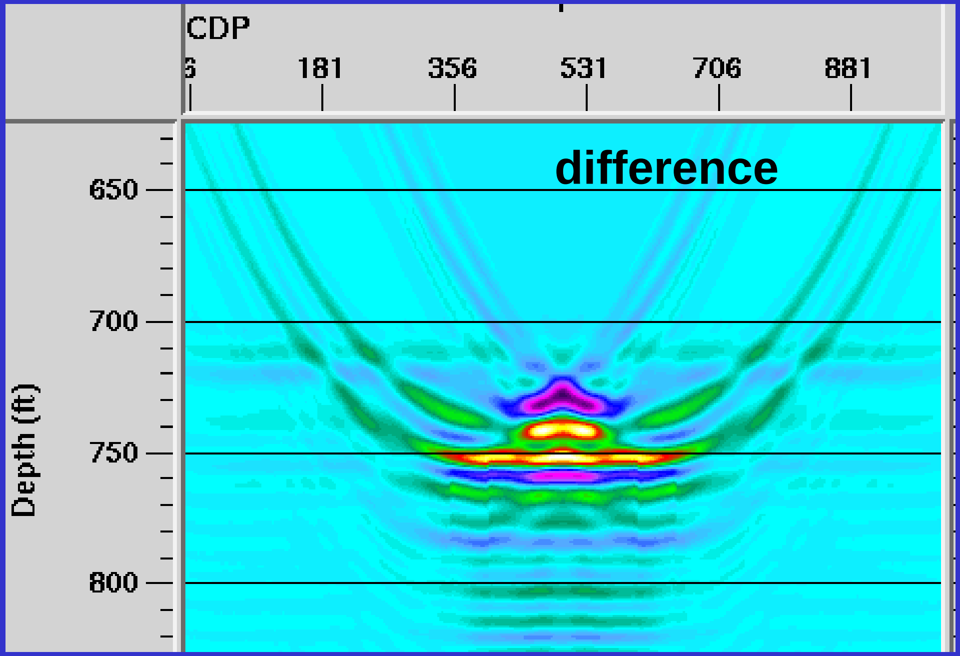


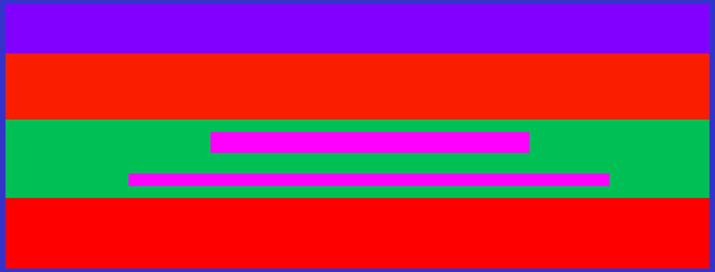
Post-production model of drainage region with foamy oil effects





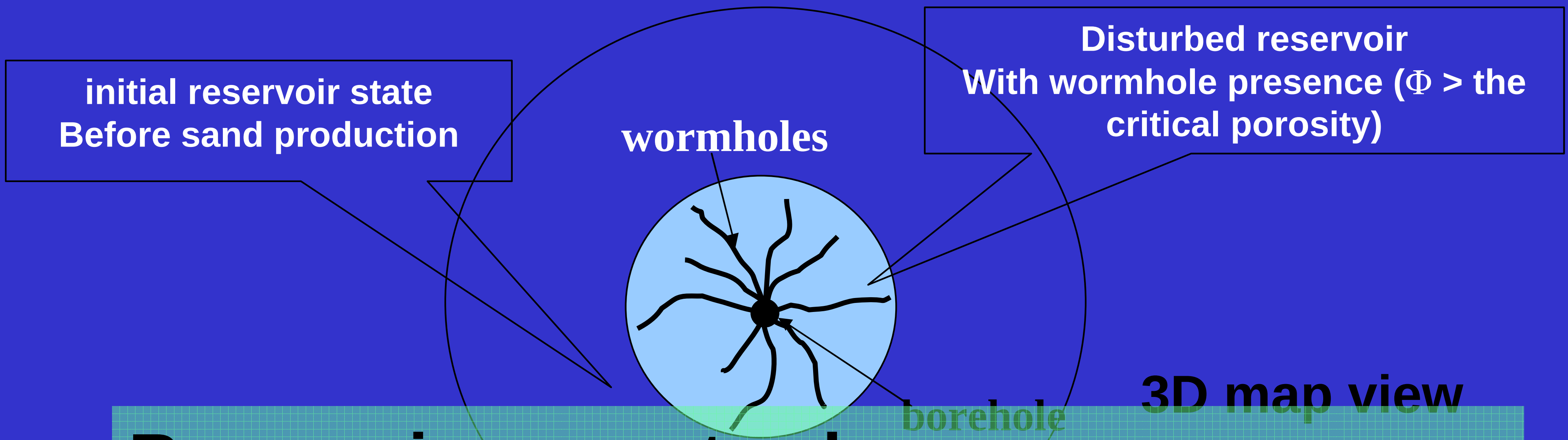






Zero-offset seismic sections frequency bandwidth 200Hz (reverse display), from Chen, 2004.

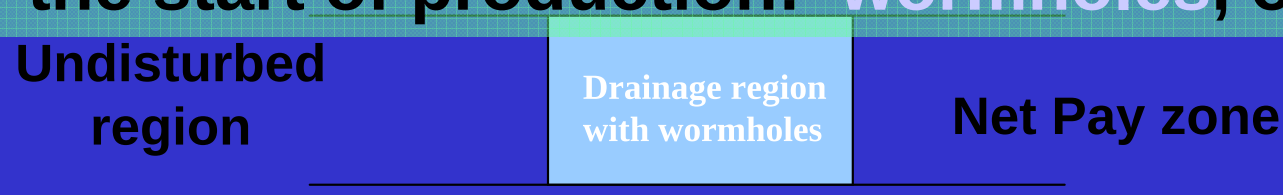
Simplified drainage model with wormhole effects, Chen (2004).



Reservoir property changes

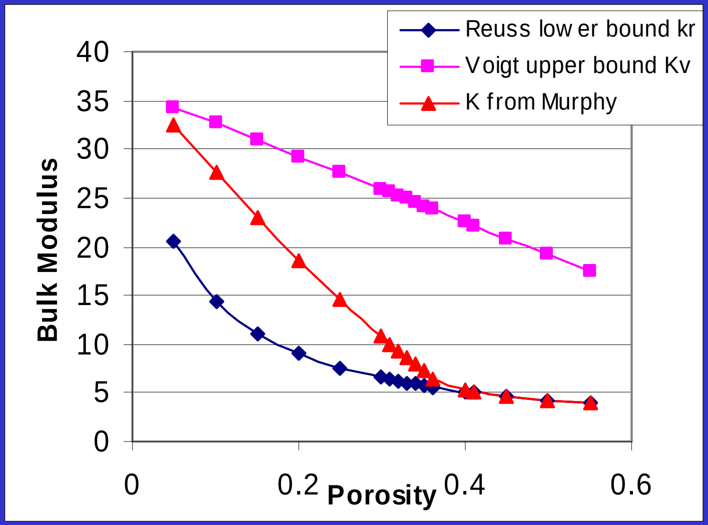
Before production: oil & water

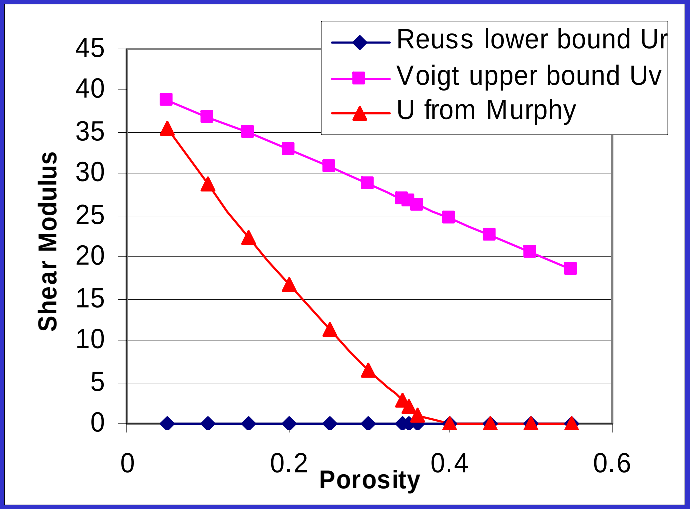
After the start of production: wormholes, oil & water

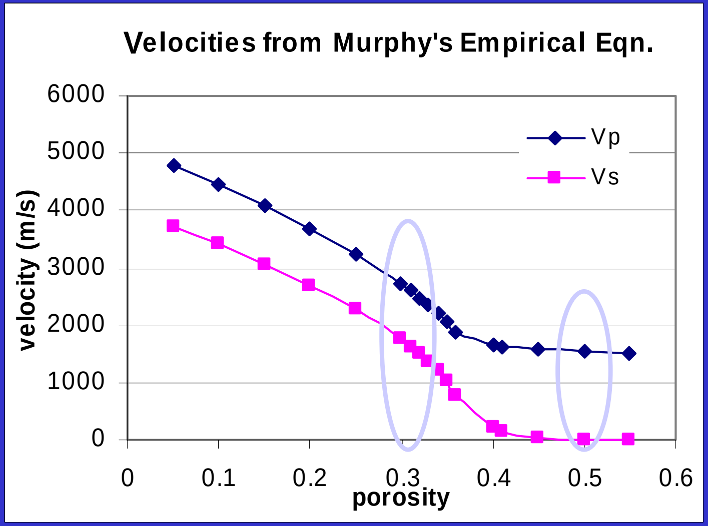


2D cross-section

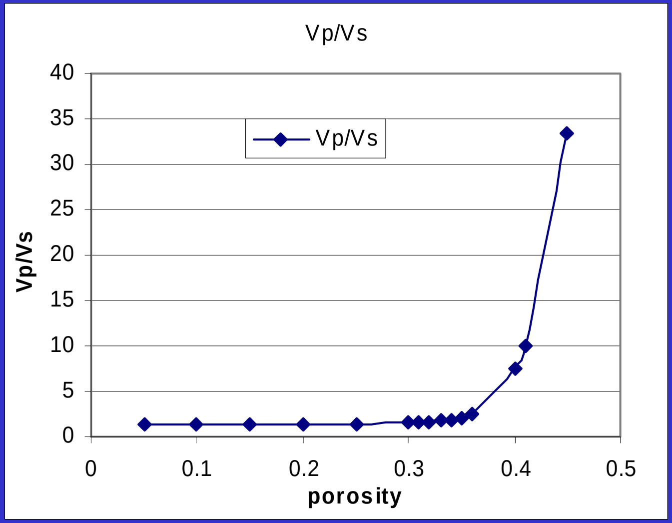
Moduli & Velocities vs Porosity, Chen et al., 2004



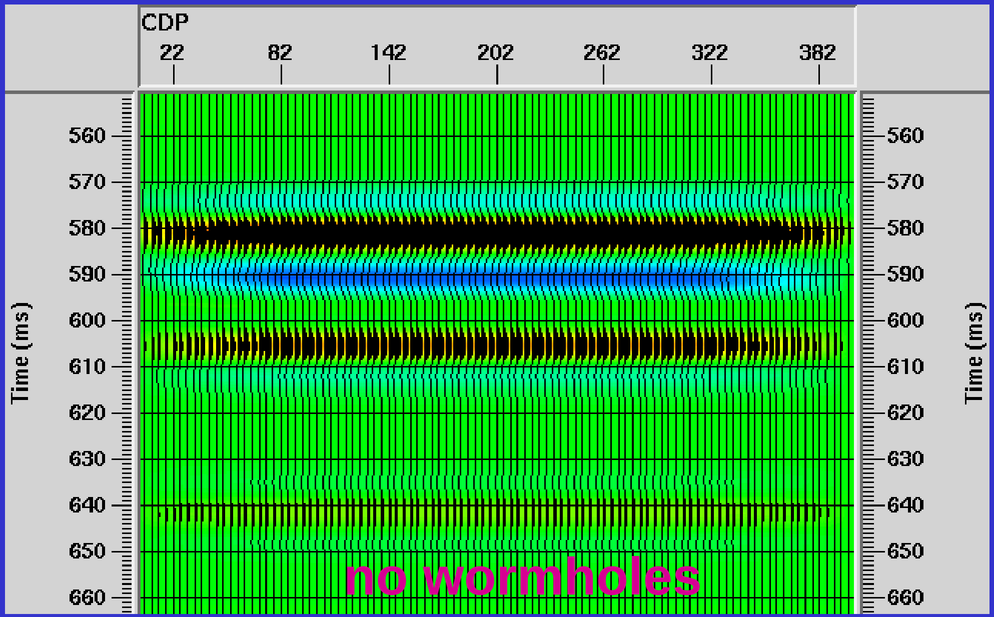




Applied to the Gassmann Equations



PP stack sections using 60Hz Ricker with wormhole effects, Chen (2004).



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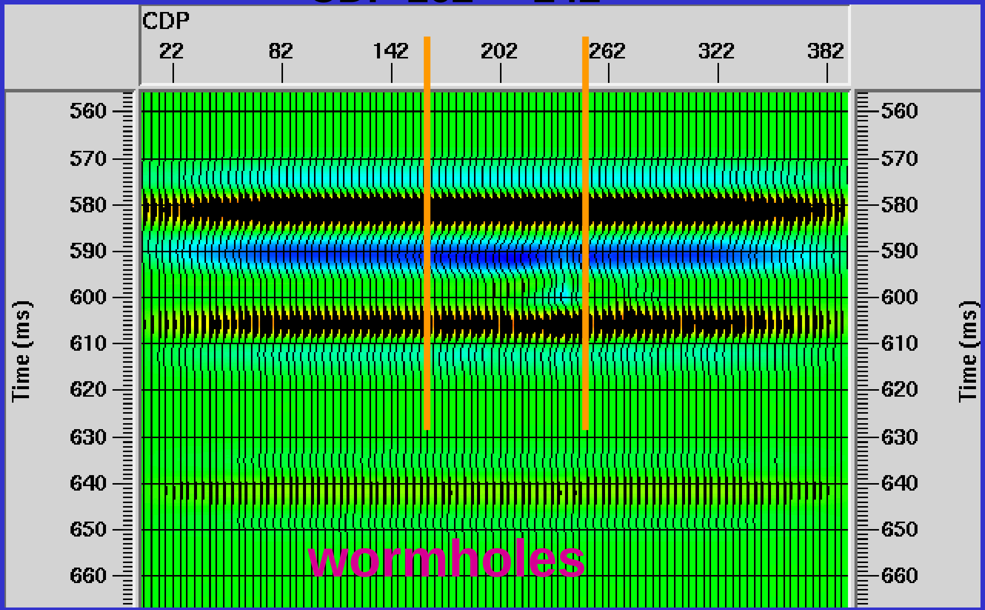
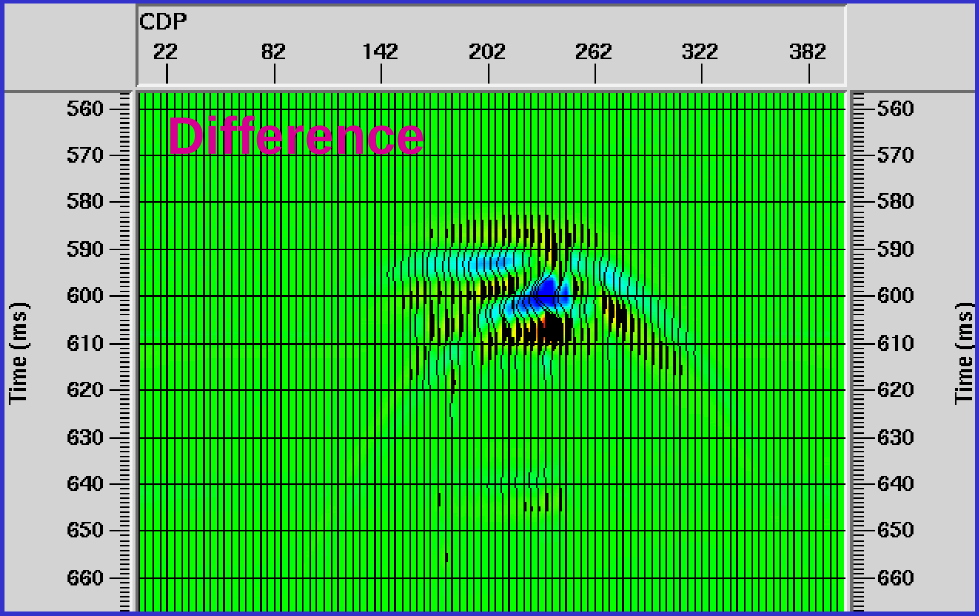
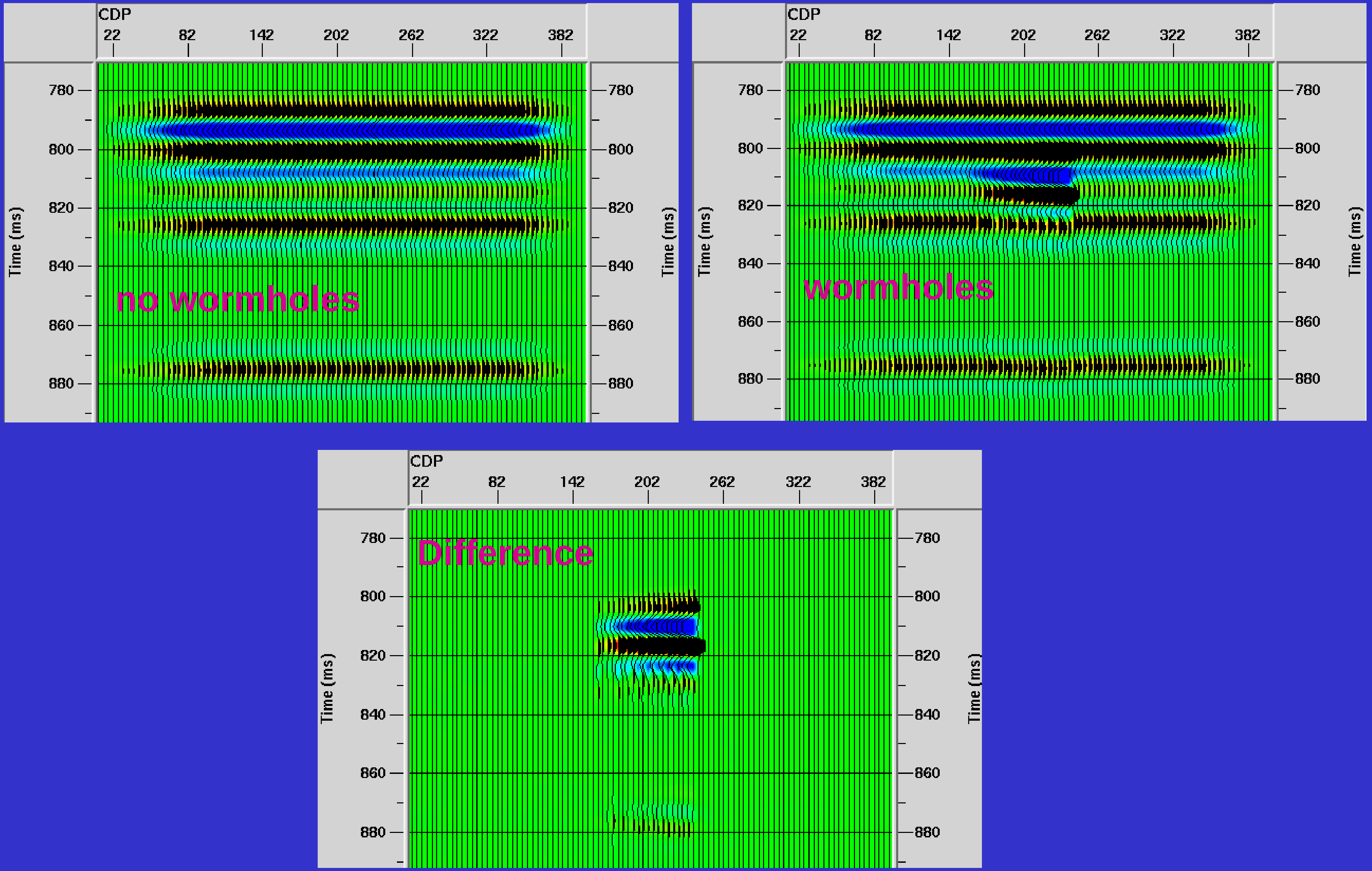




PS stack sections using 60Hz Ricker with wormhole effects, Chen (2004).



VP/VS Ratios in Cold Production

- **Effects of sand thickening and gas saturation can be similar to hot production surveys and would decrease VP/VS.**
- **Wormholes would tend to increase VP/VS -if they were big enough and critical porosity was exceeded.**

Conclusions

- **In "hot flow", seismic monitoring tools include differencing of reflectivity, impedance, AVO, and VP/VS ratios.**
- **In "cold flow", we can see the cumulative effects of wormholes and foamy oil. Promising reservoir monitoring tools include amplitude differencing, Vp/Vs ratios, AVO, and Q effects.**

Contributors of Slides to the Hot Flow Talk

- Katherine Brittle
- Sandy Chen
- Pat Daley
- Jon Downton
- Joan Embleton
- Ken Hedlin
- Brian Hoffe
- Larry Lines
- Larry Mayo
- Brian Russell
- Rob Stewart
- Ian Watson
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Acknowledgements

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Look forward to future possibilities