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Applying the phase congruency algorithm to seismic data slices – A carbonate case study

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Introduction

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- A common problem in seismic interpretation is the search for discontinuities such as faults.
- The usual approach to identifying these features is the coherency method (Bahorich and Farmer, 1995).
- The phase congruency algorithm was designed to detect corners and edges on two-dimensional images (Kovesi, 1996) and we have implemented this algorithm to search for seismic discontinuities.
- We will discuss the theory of phase congruency and first apply it to a simple image example.
- Finally, we will illustrate the phase congruency algorithm with several fractured carbonate examples.

The phase congruency method

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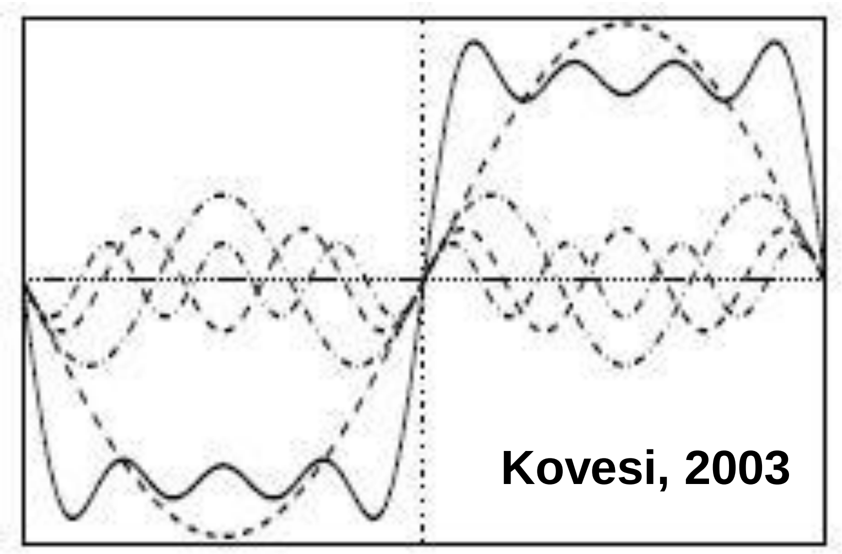
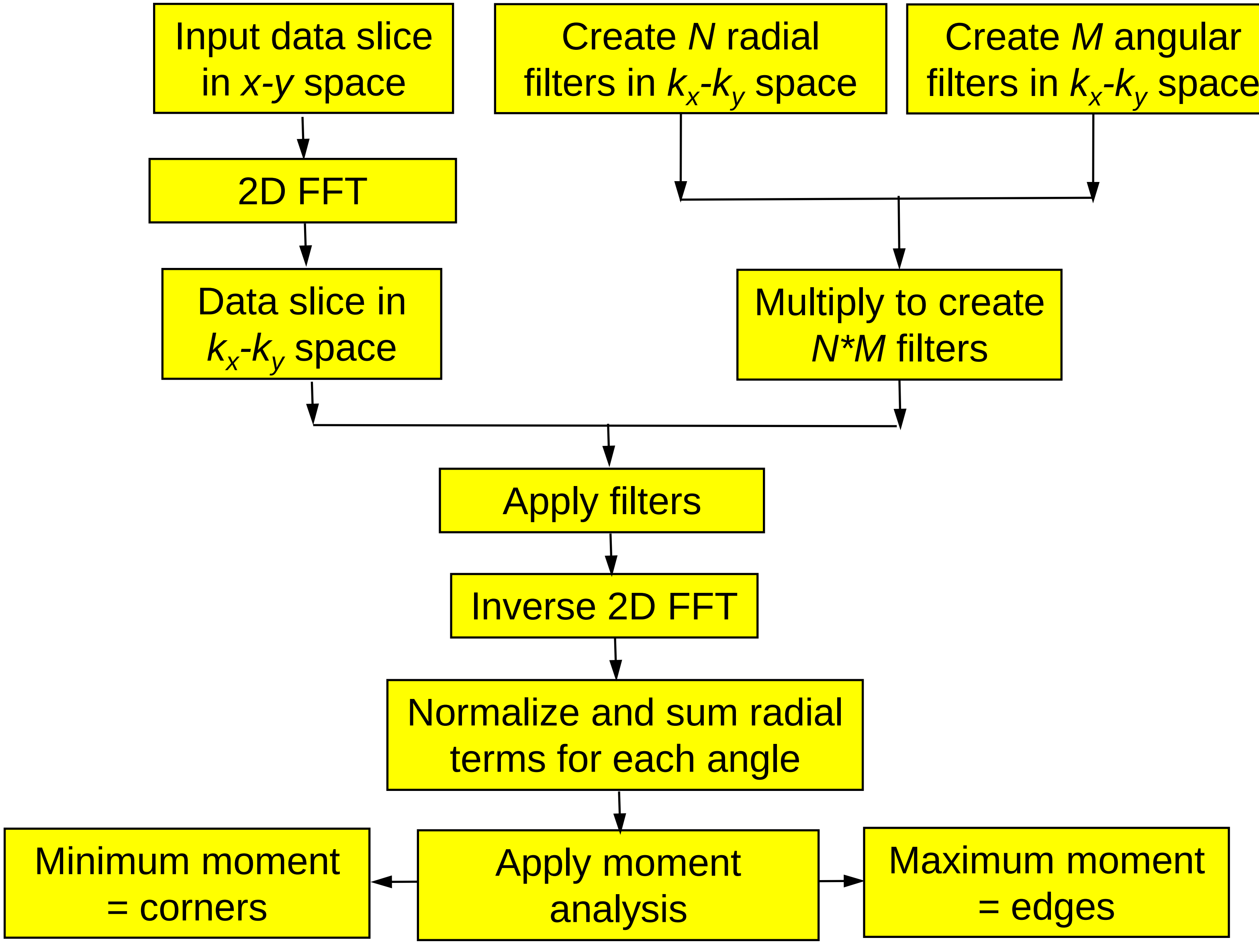
- The Fourier components in the figure are all in phase for a step. 1D phase congruency is found by finding the deviation of each phase component away from the mean.

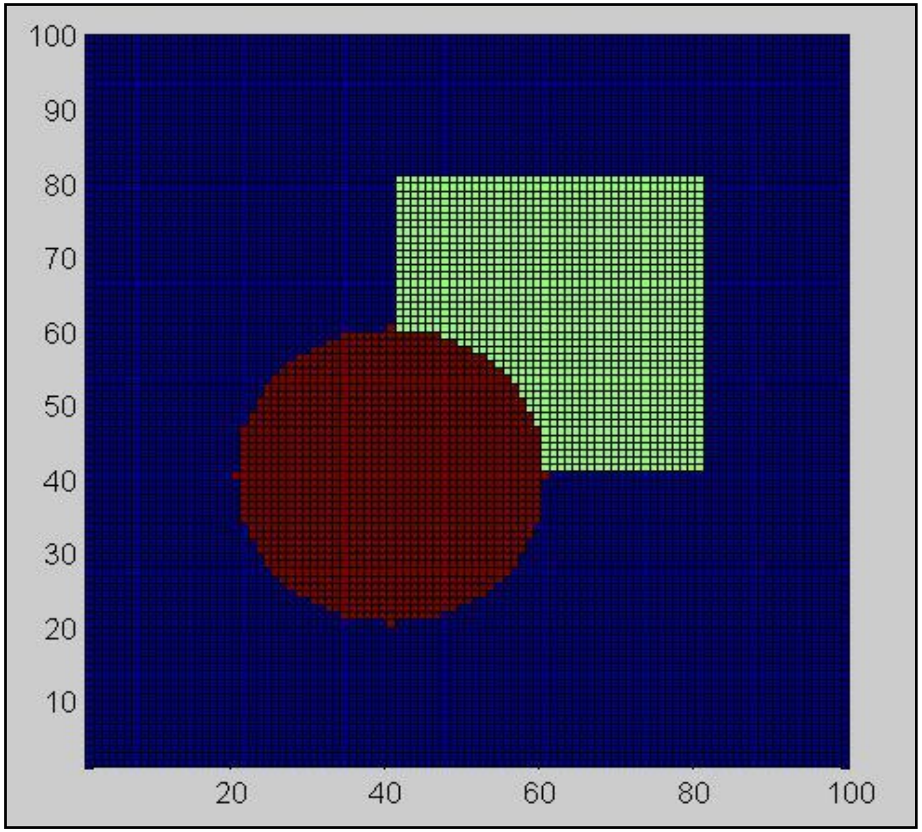


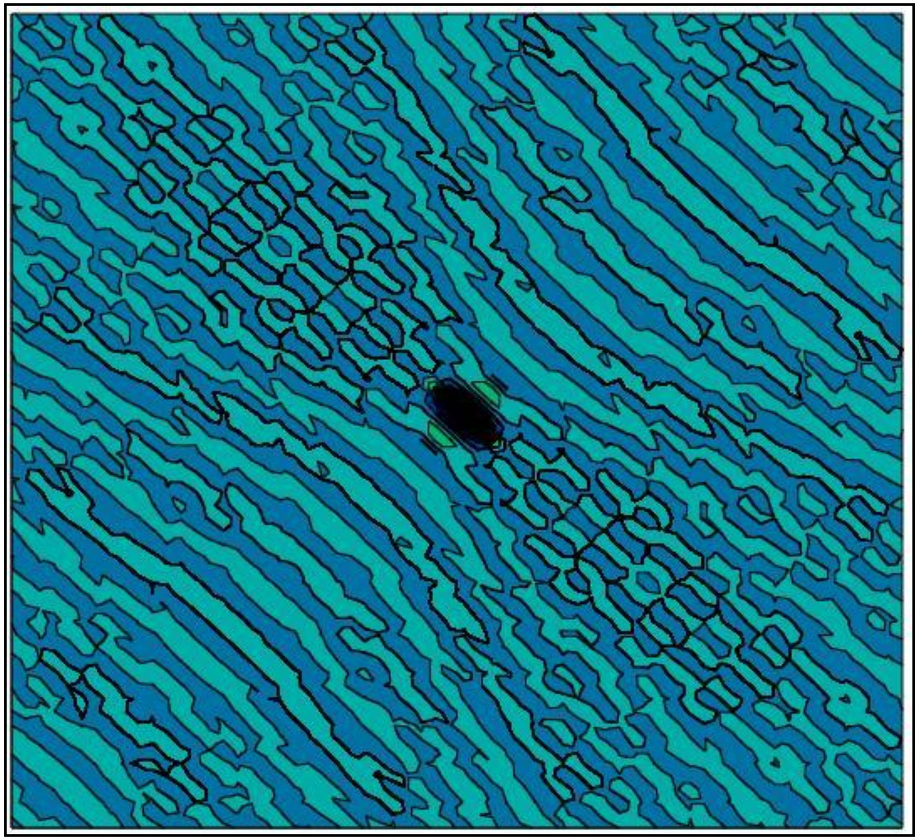
- For images and maps, phase congruency is computed in the 2D spatial frequency domain.
- This involves filtering with angular and radial filters, using the log Gabor transform.
- The final computation is done using moment analysis.
- The basic flowchart is shown on the next slide.

Phase congruency flow chart



Simple example





(a)

(b)

Here is an example with a circle of amplitude 2 over a square of amplitude 1, showing (a) the input and (b) its spectrum, in both map and perspective view.

The filters

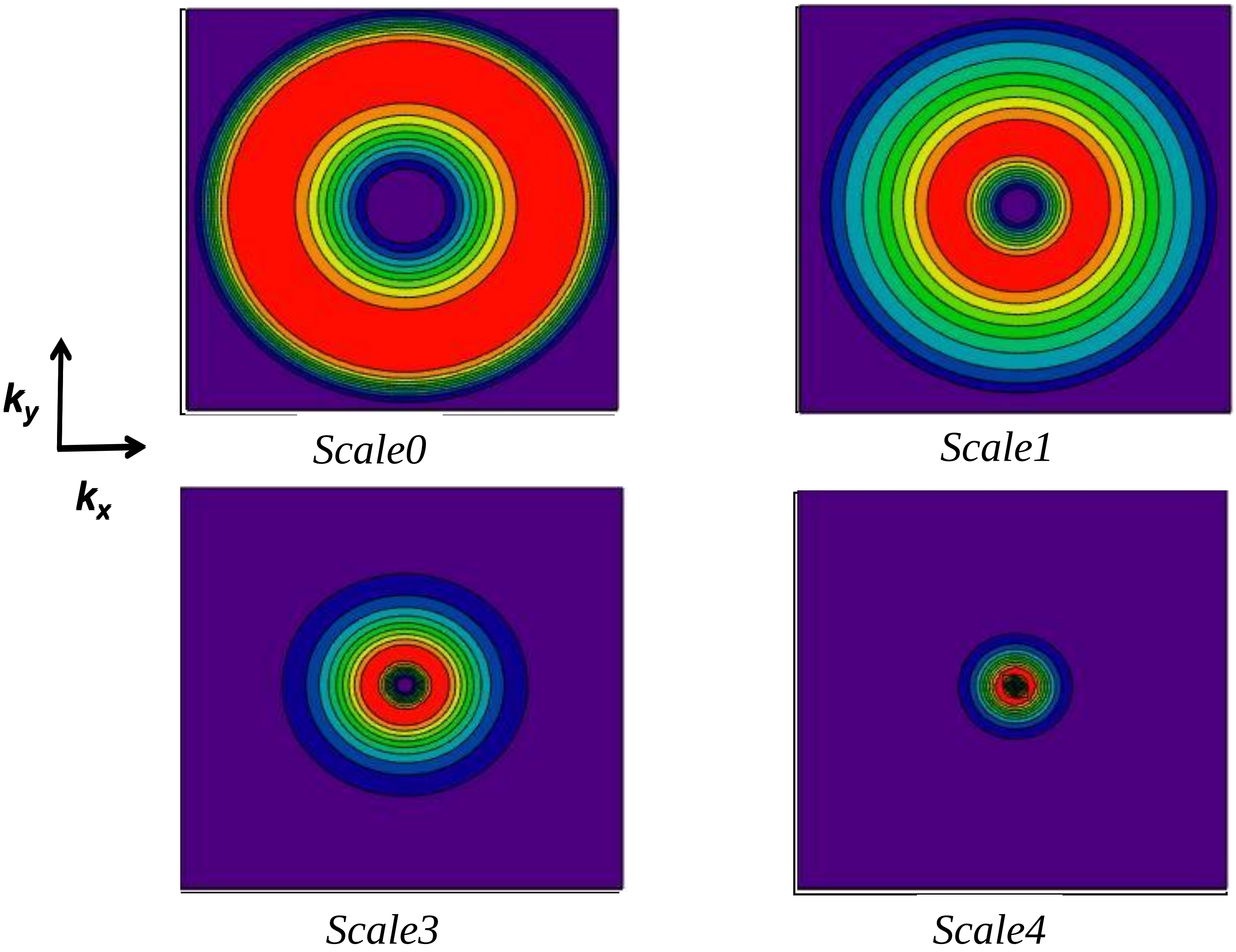
- The log Gabor transform (Field, 1987) is Gaussian on a logarithmic scale and thus has better high frequency characteristics than the traditional Gabor transform.
- The key parameters in the log Gabor transform are the scale value in the exponent, and the number of scales. We will use N = 4 scales, from 0 to 3.

$$\log Gabor_S = \exp\left[\frac{-\ln(r \cdot \lambda_S)^2}{\sigma}\right] \cdot lp,$$

$$\lambda_S = 3m^S,\ m = 2.1,\ \sigma = 2\ln(0.55)^2.$$

- The angular filters are over M angles. In our example M = 6, with angles from 0^o to 150^o in increments of 30^o.
- We then show the final result after application of the filters, inverse 2D FFT and moment analysis.

The radial (log Gabor) filters



The angular filters

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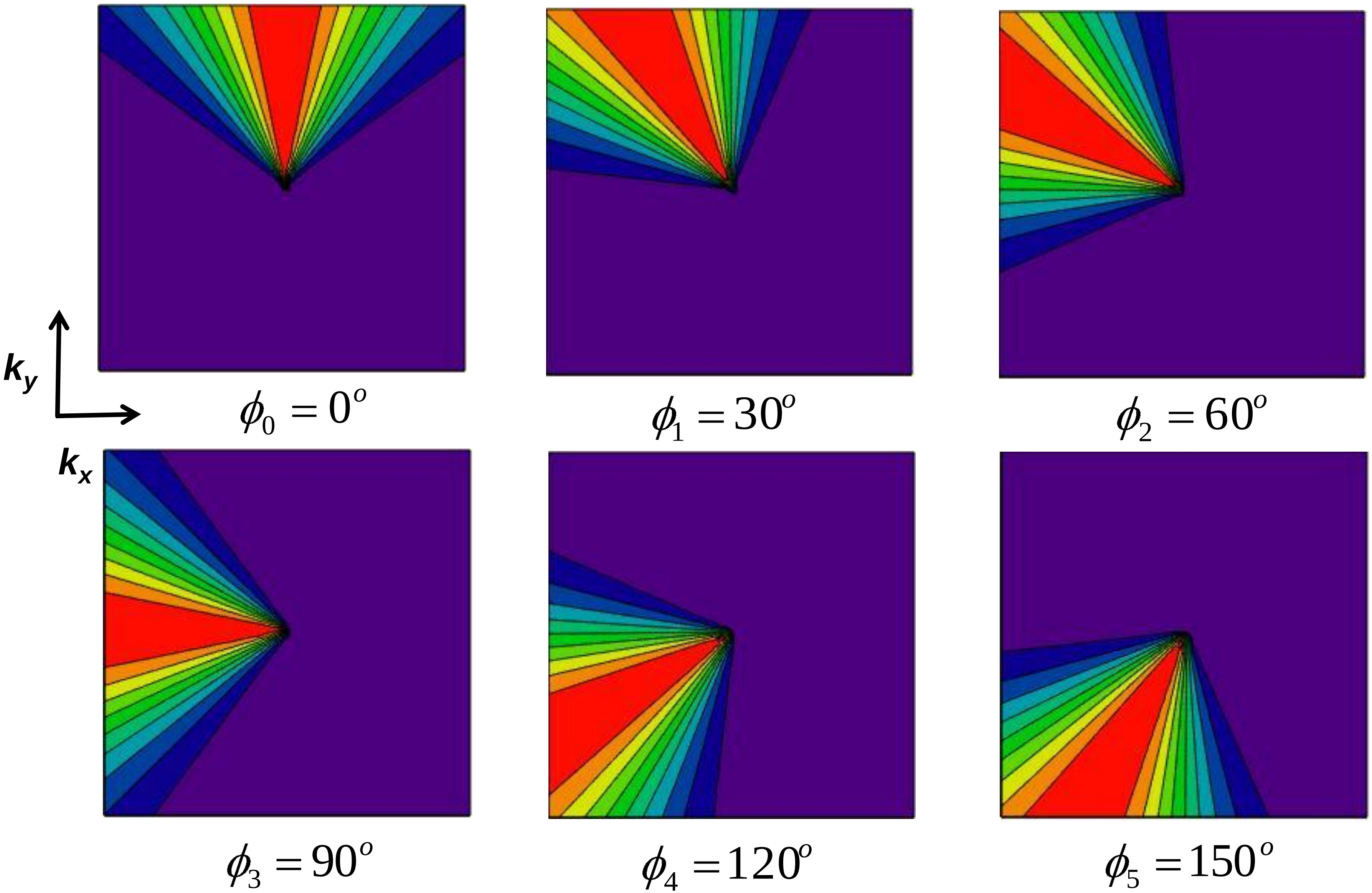
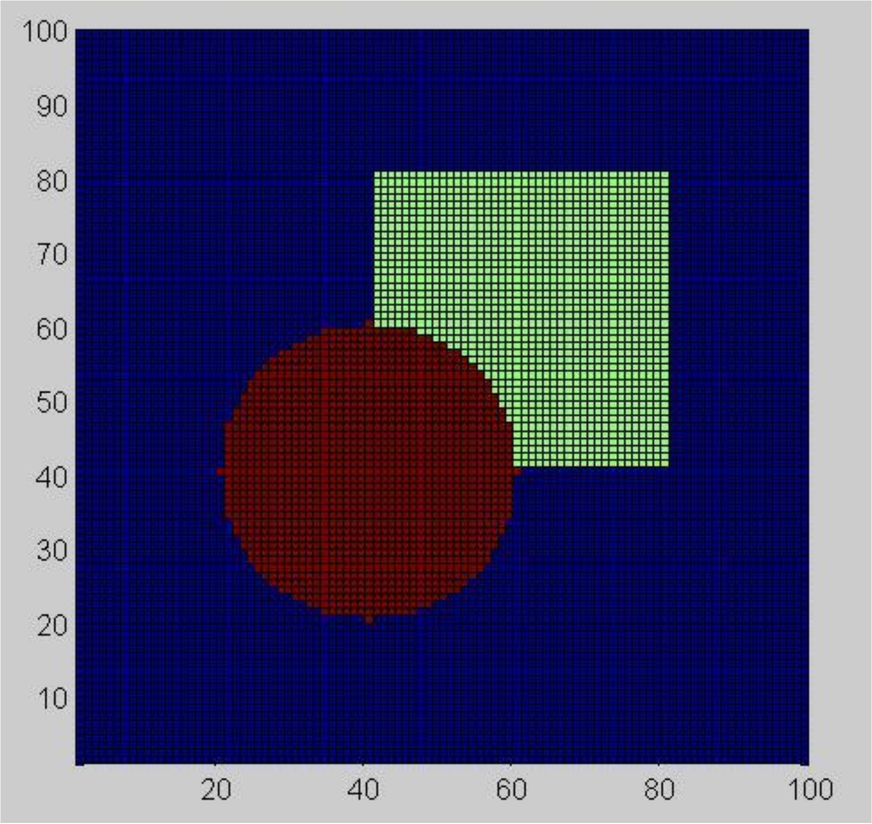
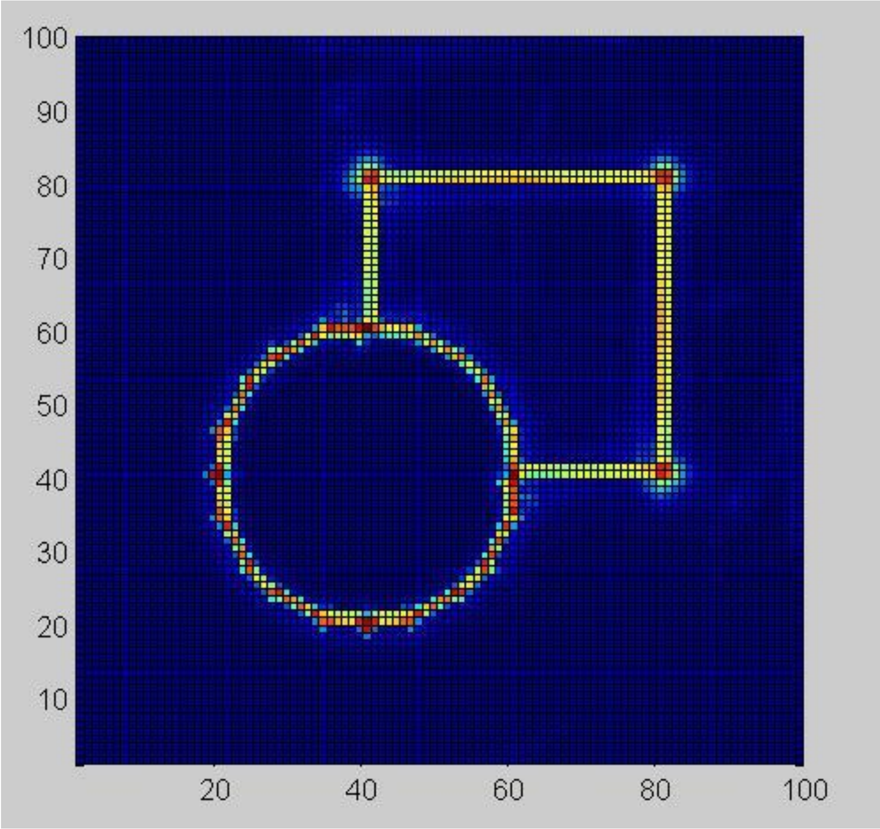


Simple example

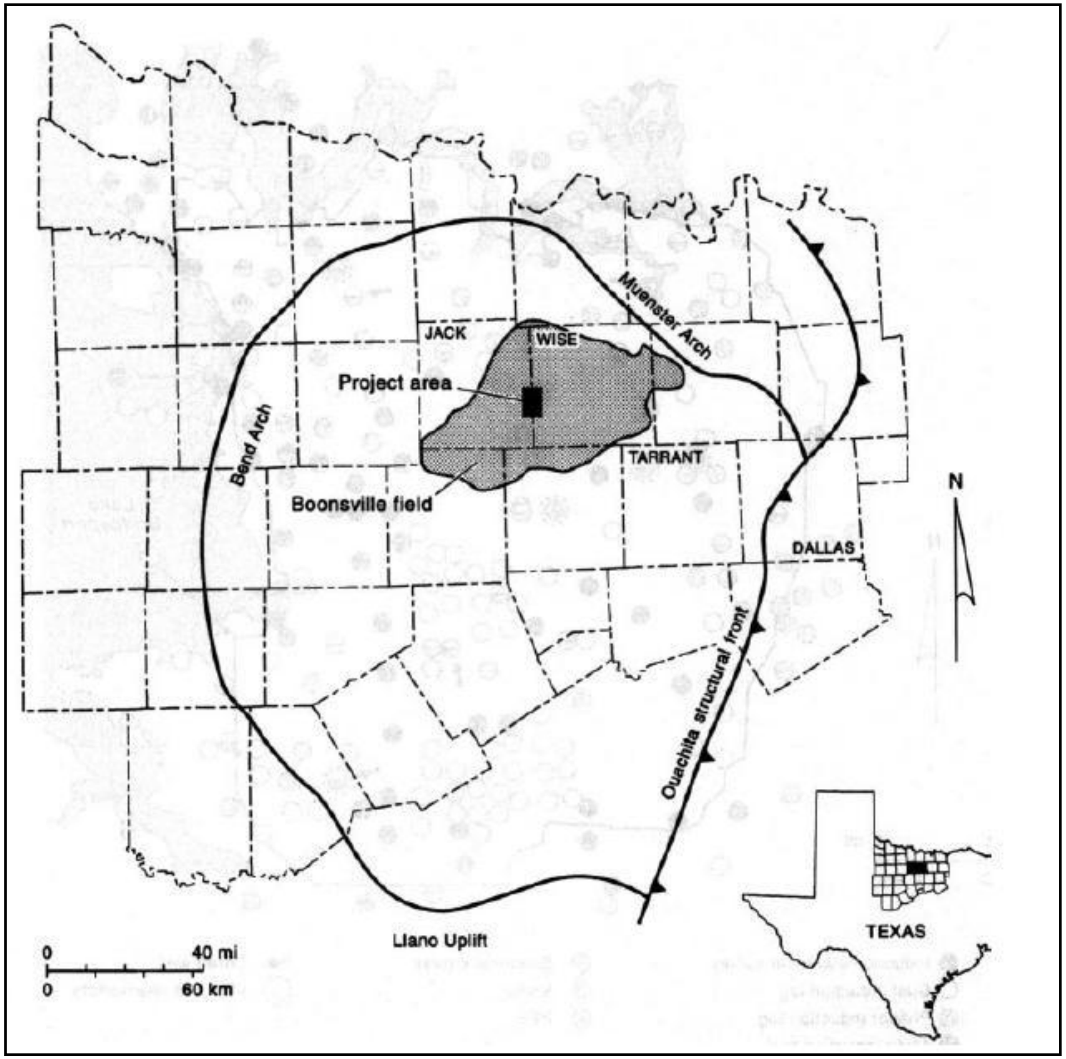




(a) **(b)**

Here is our circle of amplitude 2 over a square of amplitude 1, showing (a) the input and (b) the output.

Boonsville study



Hardage et al., 1996

Next we will apply the phase congruency method to seismic slices.

First, we will examine a karst collapse study from the Boonsville gas field in Texas (Hardage et al., 1996), using a dataset made available by the Texas Bureau of Economic Geology.

The study area is shown on the left.

Boonsville Geology

- In the Boonsville gas field, production is from the Bend conglomerate, a middle Pennsylvanian clastic deposited in a fluvio-deltaic environment.
- The Bend formation is underlain by Paleozoic carbonates, the deepest being the Ellenburger Group of Ordovician age.
- The Ellenburger contains numerous karst collapse features which extend up to 760 m from basement through the Bend conglomerate.
- Hardage et al. (1996) demonstrate, using measured pressure data, that these karst collapse features created reservoir compartmentalization within the producing Bend formation.

Seismic cross-section

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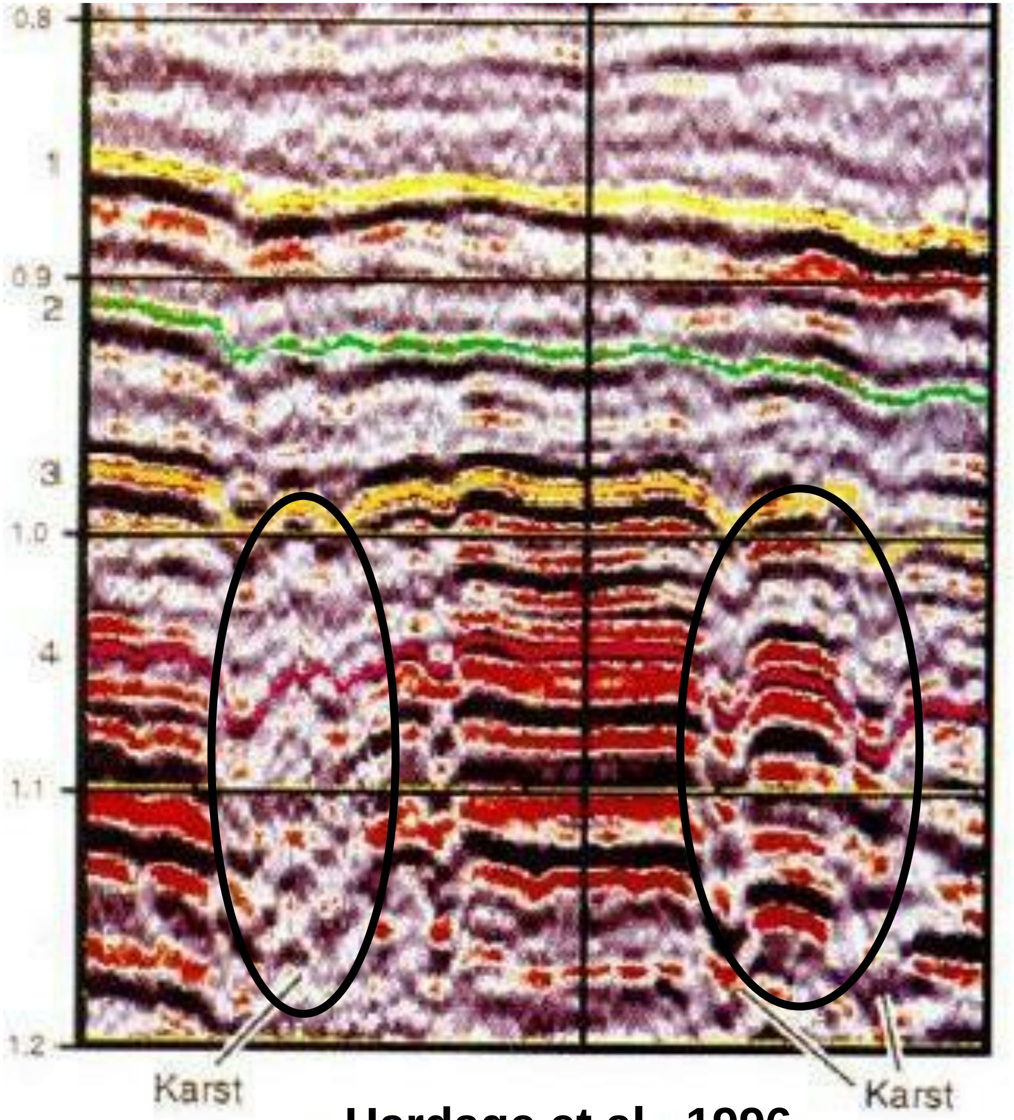
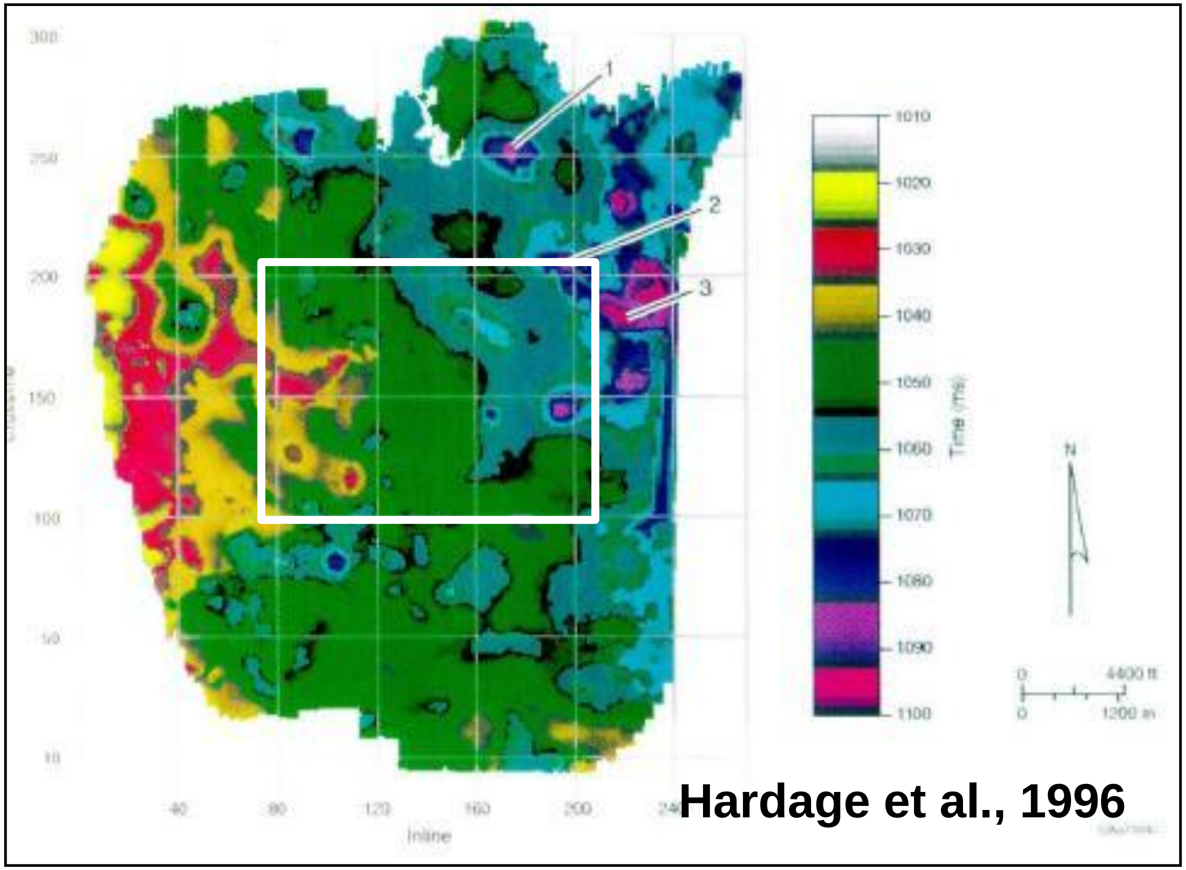
Production from the Bend Conglomerate

Here is a reconstructed seismic cross-section from the Boonsville survey showing the producing zone and the karst collapse features.



Hardage et al., 1996

Boonsville area

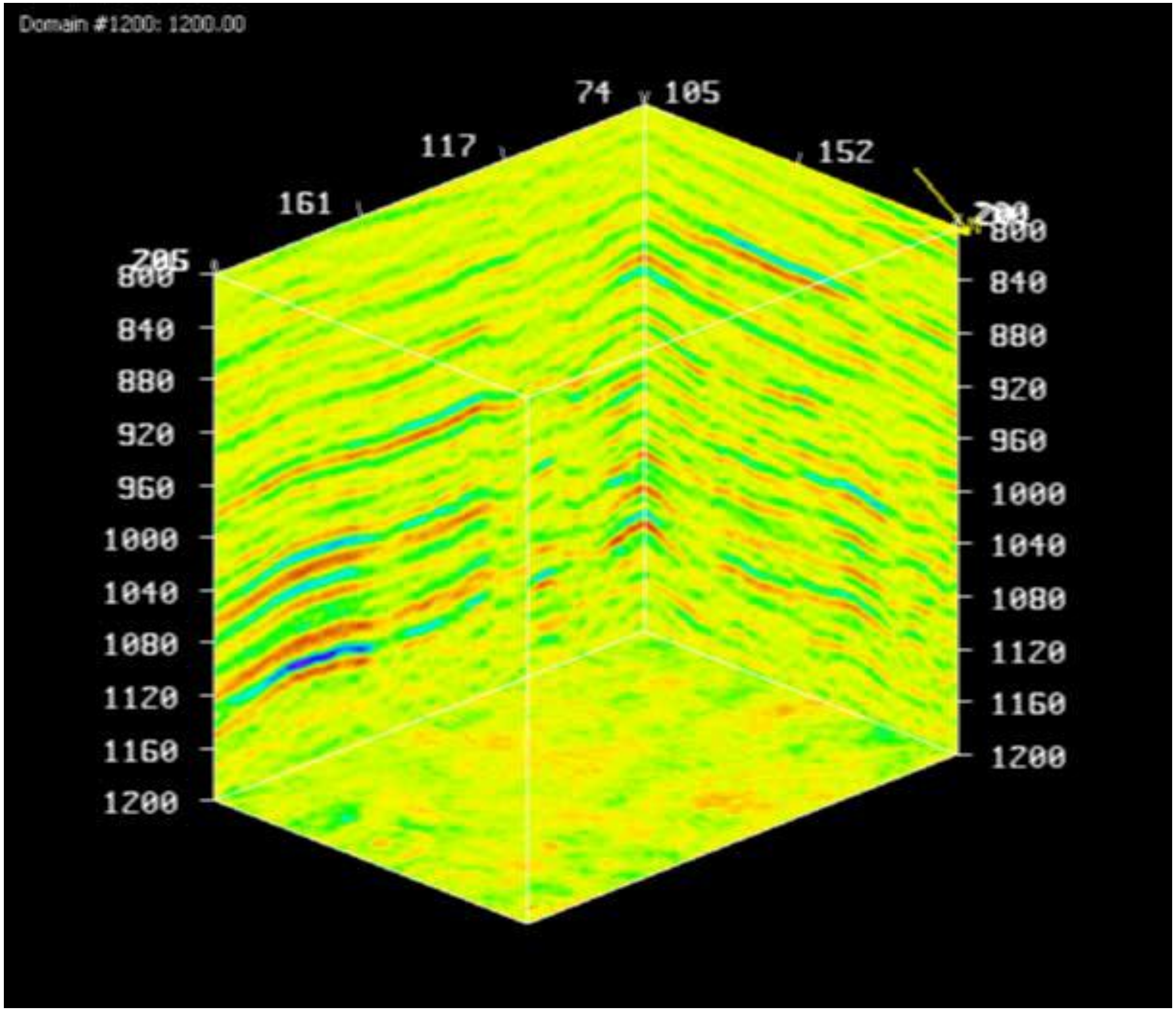


Hardage et al., 1996

The interpreted time structure map for the base the Bend conglomerate (Vineyard formation). The karst features are the circular features. The area of the survey used in this study is shown as the white outline.

- The next two slides are movies of slices through the volume, showing horizontal time slices through the seismic and phase congruency volumes.

Movie of seismic time slices



Movie of phase congruency

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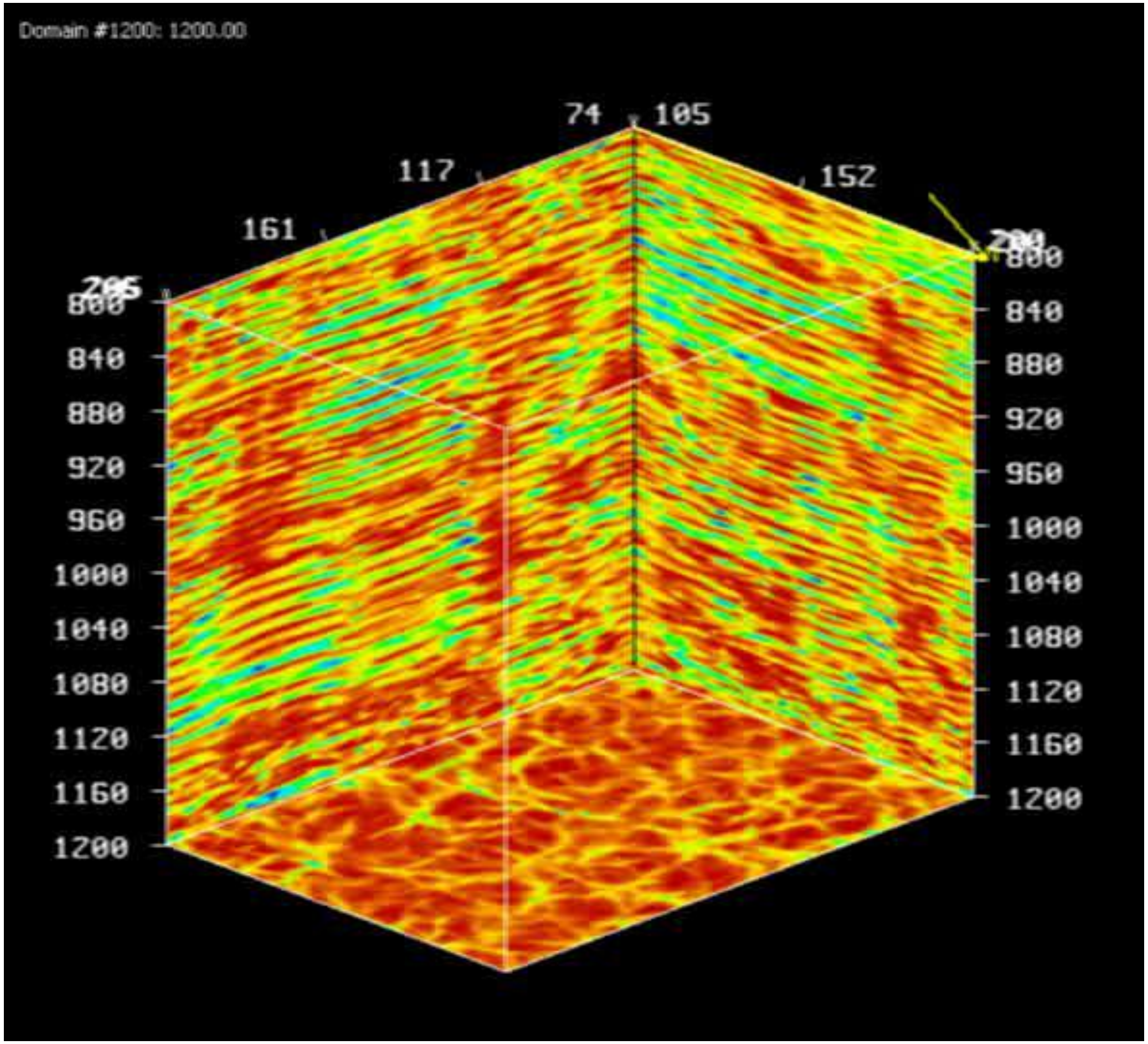

Seismic vs Phase Congruency

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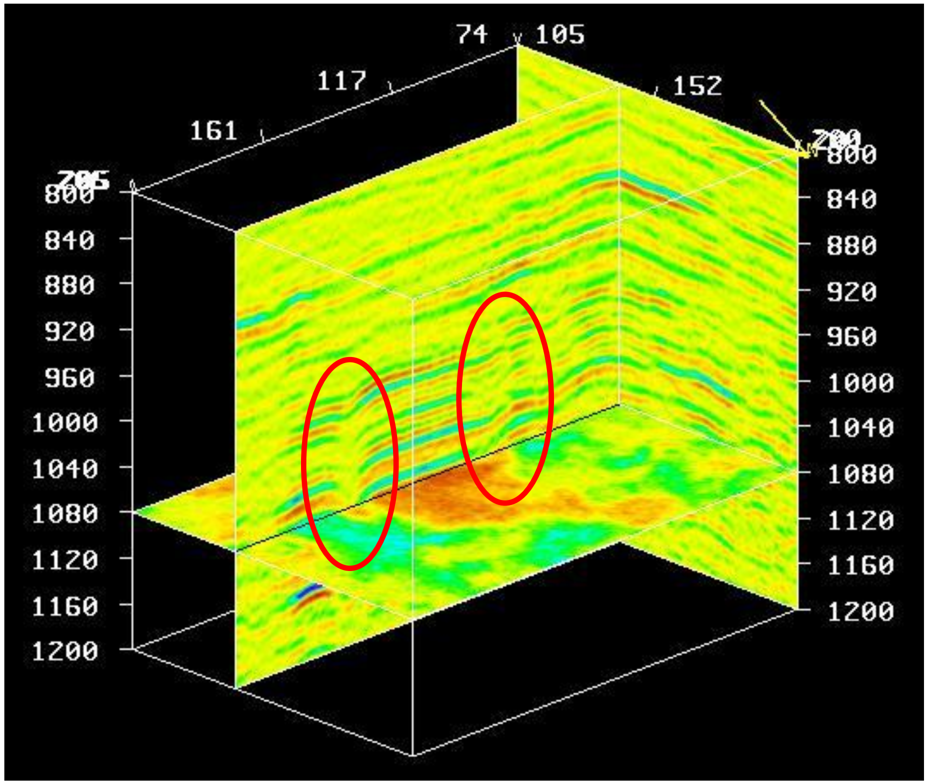
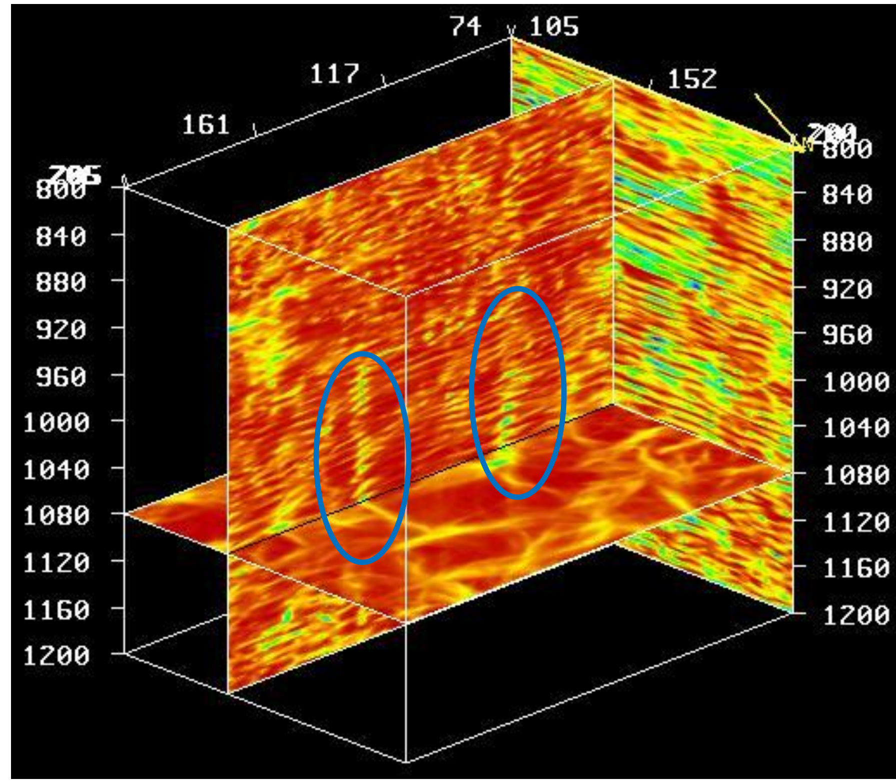


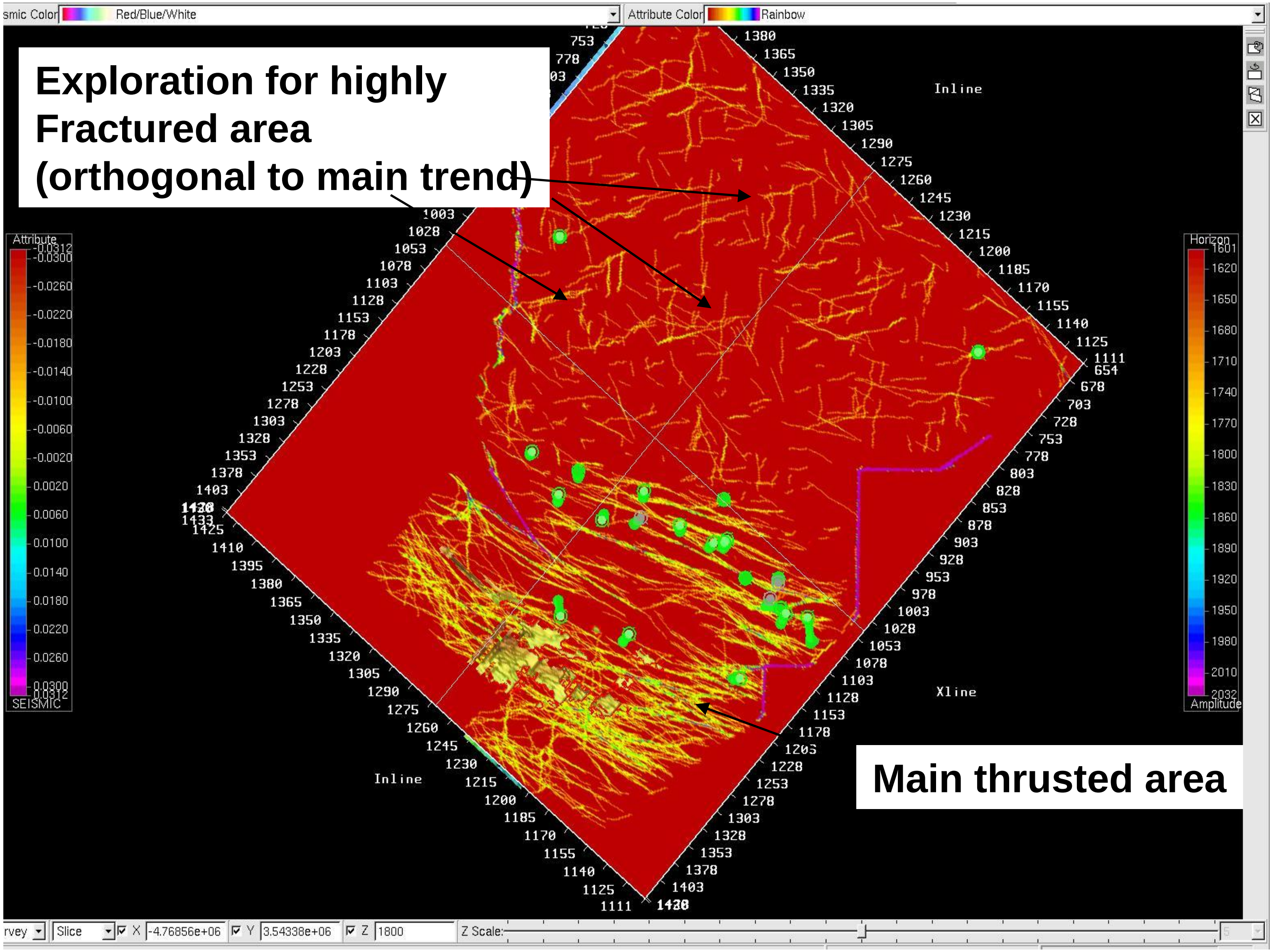


- A vertical slice superimposed on a horizontal slice at 1080 ms, roughly halfway through the karst collapse. The seismic is on the left and the phase congruency on the right.
- Note the good definition of the collapse feature.

Fractured carbonate case study

- Our second case study is a fractured carbonate reservoir from Alberta.
- We will look at both a time slice and a vertical slice through a computed phase congruency volume.
- First, note the difference in density between the fractures in the north versus south sides of the survey, which correlates with the number of wells.
- Second, note the correlation with the FMI logs.
- Finally, we will show a slide that correlates initial production vs amplitude of phase congruency and show a reasonable linear fit.

Fractured carbonate example



Fracture Identification Test

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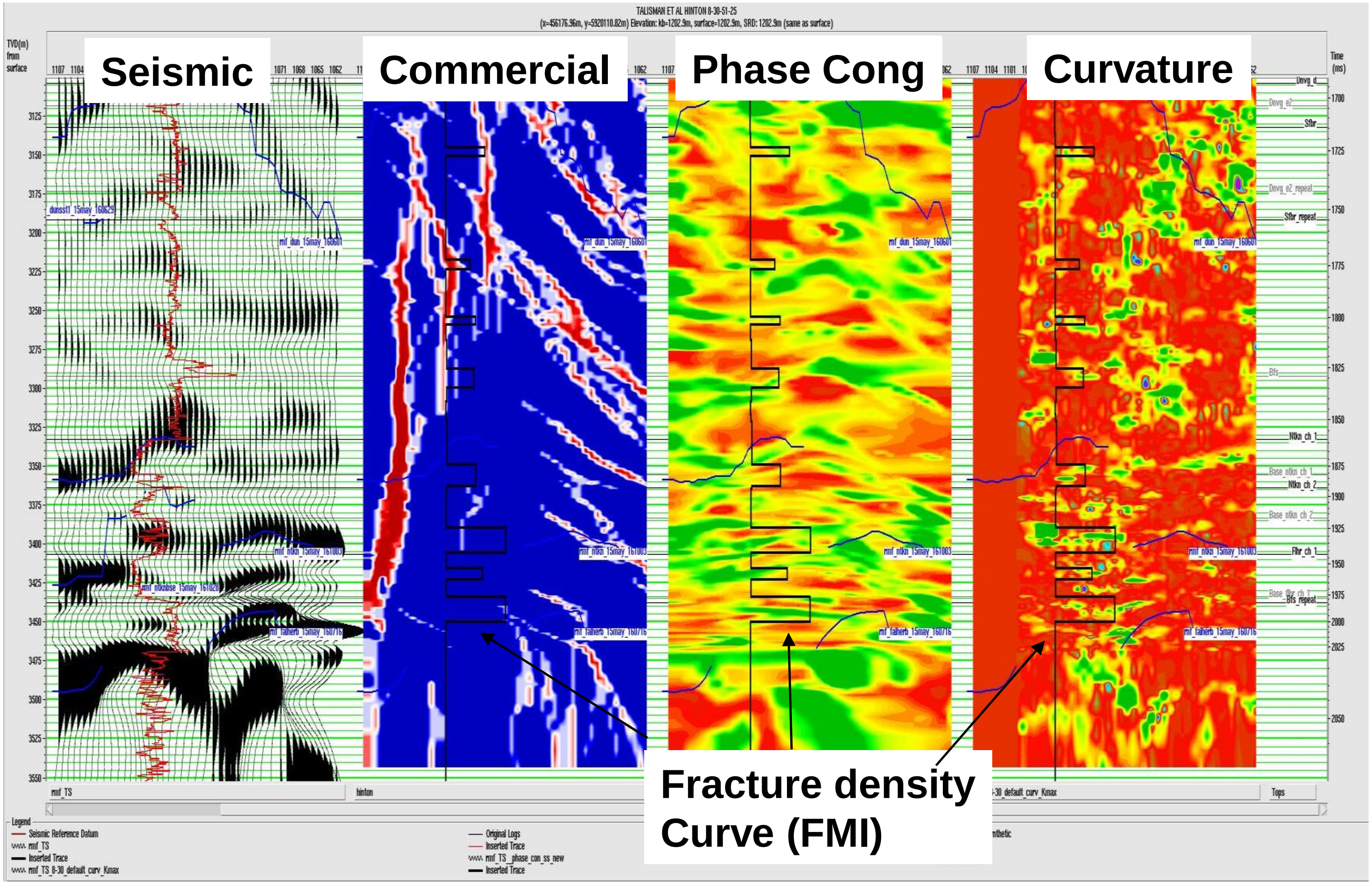
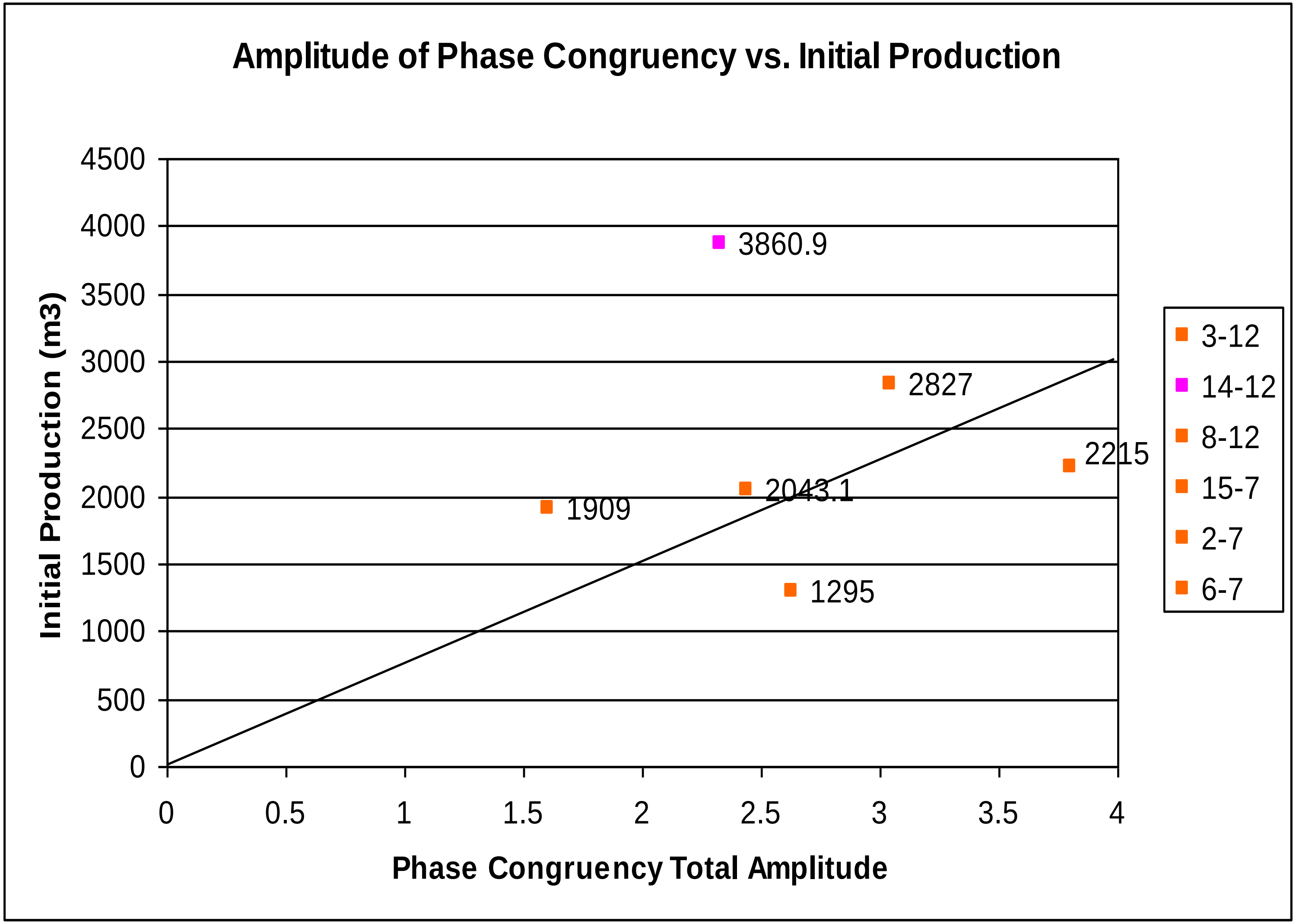


Areas of fracturing are identified at maximums in curvature, and Phase Congruency. (Where the rock is bending and edges are detected)

Phase Congruency vs Initial Production



As can be seen above: more fractures lead to more production

Conclusions

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- This has been an overview of the phase congruency algorithm applied to seismic time slices.
- We first discussed the theory of this approach and applied it to a simple example.
- In our first case study, we identified karst collapse features which affected the compartmentalization of the overlying reservoirs.
- In our second case study we showed that when integrated with regional stress fields, faults and fracture trends can be isolated and mapped.
- Thanks go to our colleagues at CREWES, Hampson-Russell and Talisman, and also to the CREWES sponsors.