A shift in time: time-lapse detection using interferometry

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Introduction:

Time-lapse seismic studies are used to ***detect*** and ***analyze*** changes in the rock properties of a subsurface rock layer caused by ***changes in fluid content*** of that layer. ***Two or more seismic surveys*** are performed over a target zone where ***hydrocarbon production*** or ***fluid injection*** are active; ideally, with one survey performed before any fluids are displaced (called the ***'baseline'*** survey). If appropriate care is taken to ***duplicate acquisition and processing***, seismic images can be formed whose subtraction yields ***'anomalies'*** related to the ***fluid change***.

The most frequently-sought anomaly is a ***reflection amplitude difference*** associated with a boundary between the fluid-bearing rock and a neighboring formation. This difference is due to the change in reflectivity of the boundary, caused ***by fluid-related rock property changes.***

A second type of anomaly, less frequently considered, is a ***'time sag***' anomaly associated with the reflecting layers beneath the fluid-bearing rock. This anomaly is caused by ***the change in velocity of the fluid-bearing zone***, and is often quite small and hard to detect.

Detecting very small shifts:

In this project, we employed a novel surface-correction method called ***'raypath interferometry'*** to precisely register two CMP stack images and detect event time shifts or 'time sag' smaller than a sample interval. We attribute the success of this method to using the ***same 'reference wavefield'*** for the two images to precisely register them, and to the fact that raypath interferometry is ***non-stationary,*** making corrections applied to shallow events independent of those for deeper ones.

Model example:

While doing a ***model study*** in 2012 of time-lapse seismic acquisition and processing, we noticed, by accident, that a ***CMP difference image*** whose data were surface-corrected with ***conventional maximum-stack-power autostatics*** and manually aligned before subtraction tended to emphasize the ***reflection amplitude anomaly*** caused by fluid injection (Figure 1),

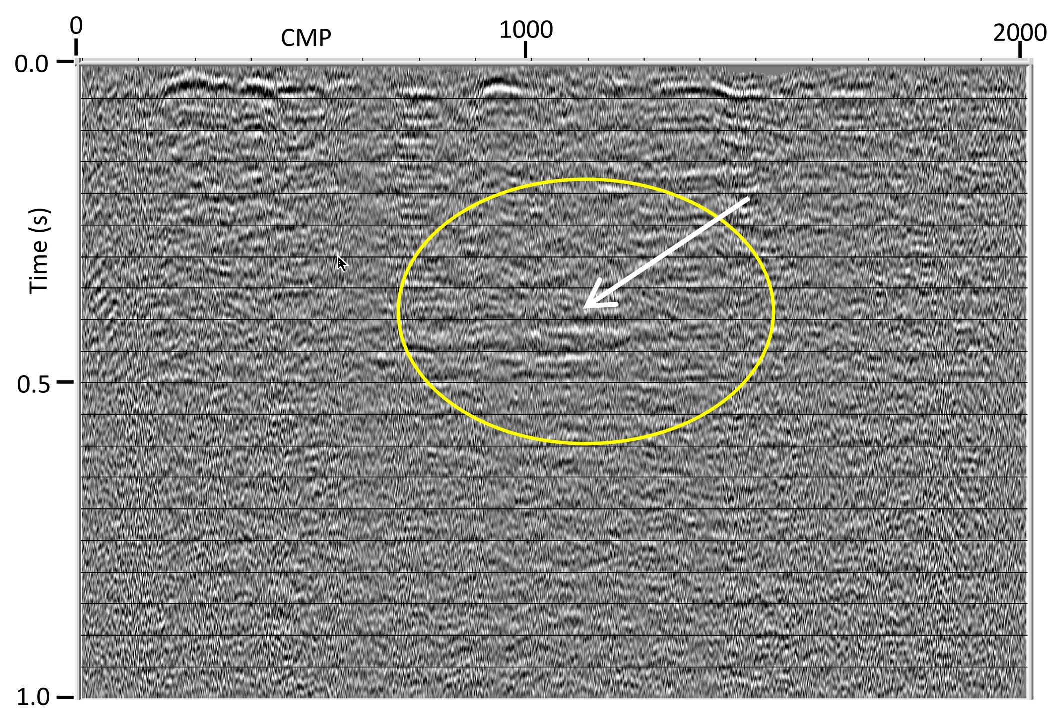

FIG. 1. CMP difference image between a time-lapse CMP stack image and a baseline CMP stack image after conventional autostatics applied independently to each survey. The reflection amplitude anomaly (white arrow) is easily seen; time sag anomaly beneath is less prominent.

while a ***CMP difference image*** whose data were surface-corrected using ***joint raypath interferometry*** (with a common reference wavefield) tended to emphasize the ***time-sag anomaly*** caused by the lowered velocity in the injection zone (Figure 2).

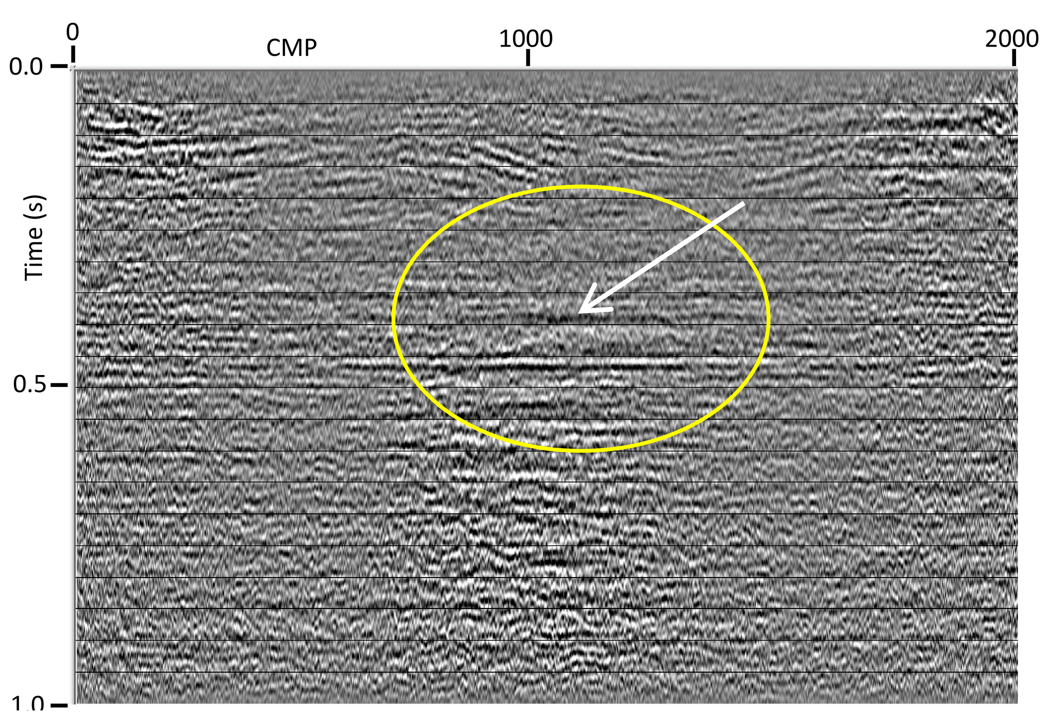

FIG. 2. CMP difference image between a time-lapse CMP stack image and a baseline CMP stack image after surface-correction of each data set using raypath interferometry. The amplitude anomaly (white arrow) is still visible, but the time sag anomaly is much more prominent.

A detectability test:

In order to investigate the ***detectability*** of very small time shifts between portions of two similar images, we created a synthetic CMP stack based on the Violet Grove time-lapse survey, then created an identical CMP stack in which a contiguous block of traces was ***shifted by 0.5ms***. As can be seen in Figures 3, 4, and 5 this very small time shift is detectable, even in the presence of a high level of additive random noise.

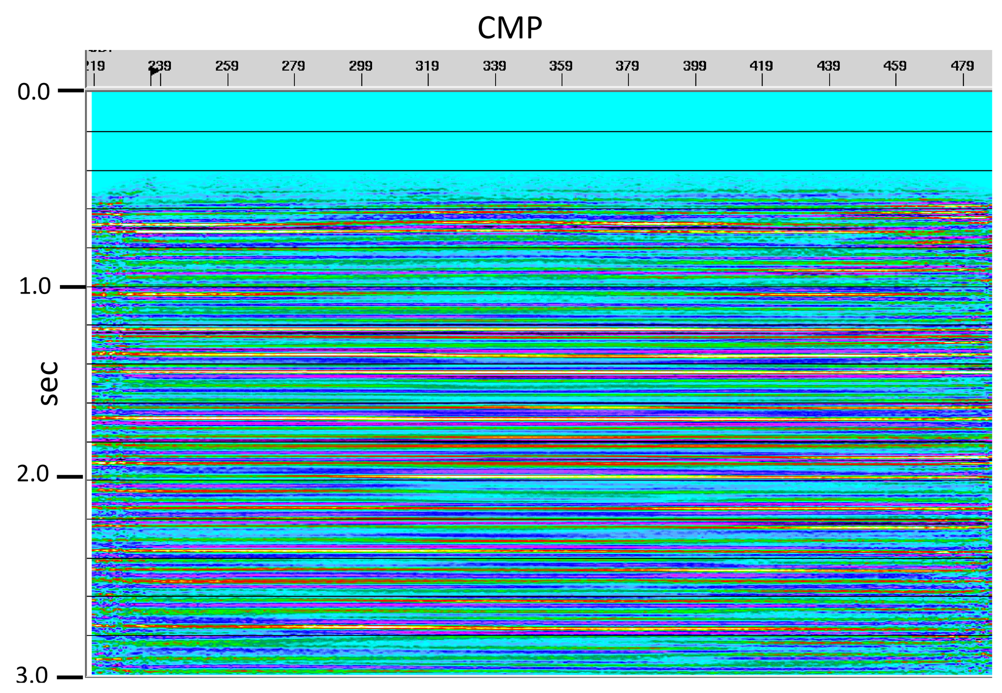

FIG. 3. CMP stack of Violet Grove source gathers with added random noise

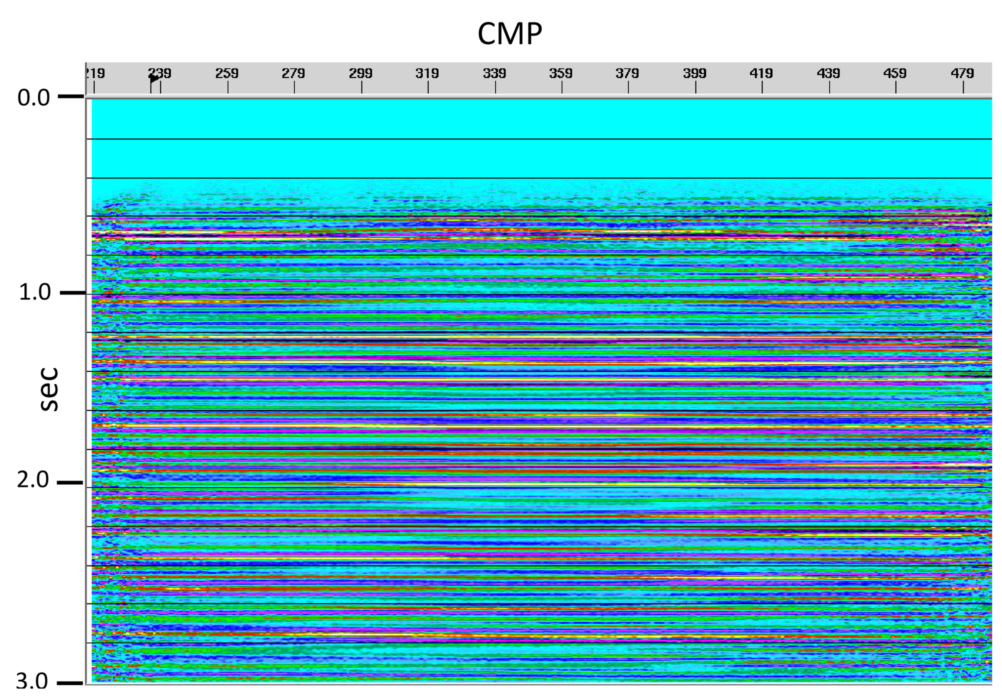

FIG. 4. Same as Figure 3, except 0.5ms time shift applied to traces at CMPs 325-375. Differences between Figures 3 and 4 are almost imperceptible.

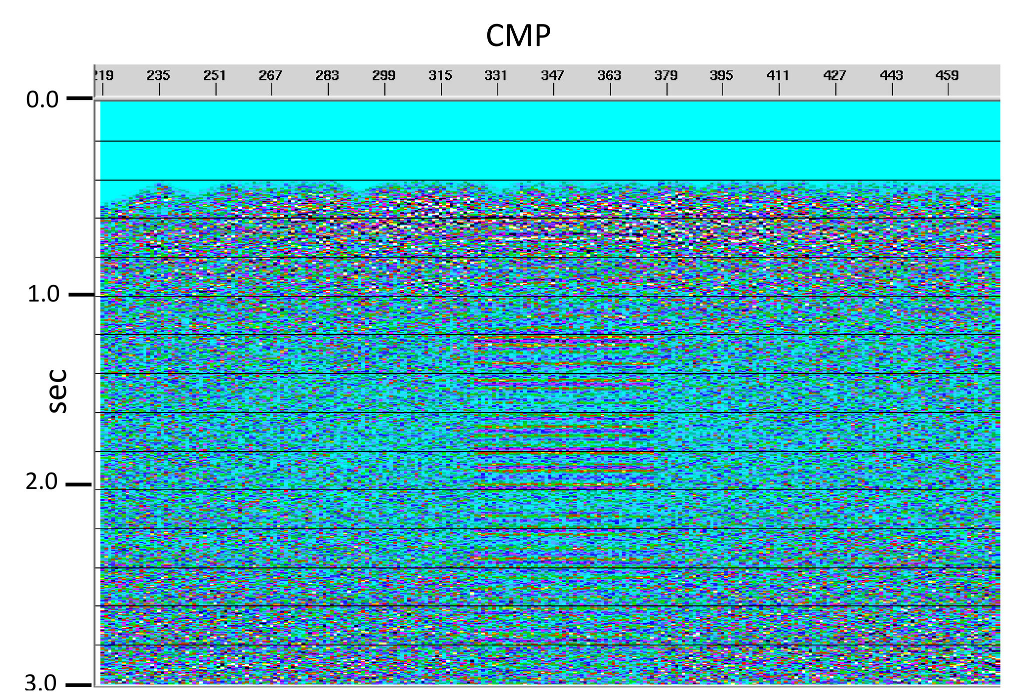

FIG. 5. Figure 4 image subtracted from Figure 3 image—0.5ms time shift is immediately obvious in spite of random noise.

Violet Grove time sag:

Seismic data from the ***2005 baseline survey*** and the ***2007 time-lapse survey*** at Violet Grove were carefully processed as described in our written report, including ***joint raypath interferometry*** to apply surface corrections before CMP stack, and ***amplitude normalization*** after CMP stack. Figures 6 and 7 show, ***interferometrically***, that the amplitude differences in the ***difference image*** are due primarily to time sag.

As Figure 8 shows, ***if the injection zone at Violet Grove is actually asymmetric, the time sag anomaly actually fits better!***

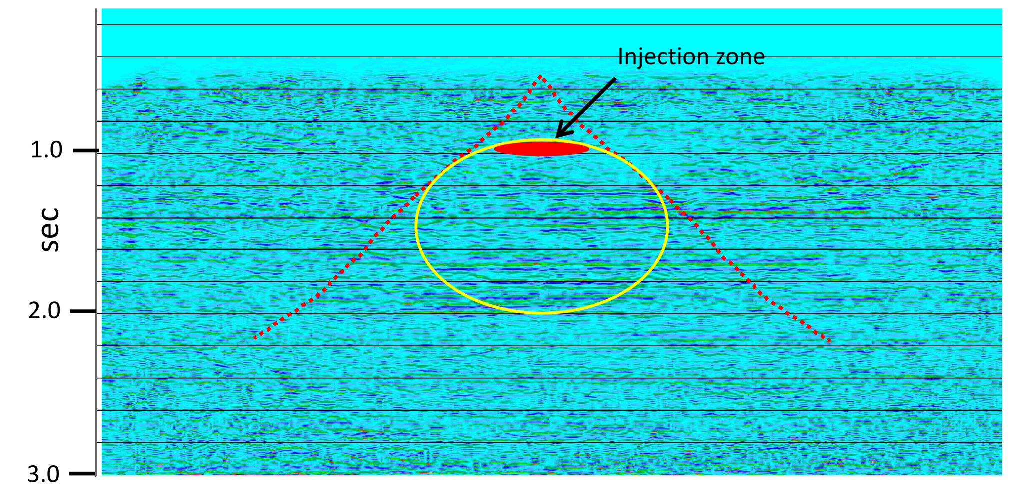

FIG. 6. Time sag beneath the presumed injection zone at Violet Grove, when 2005 baseline image is subtracted from 2007 time-lapse image.

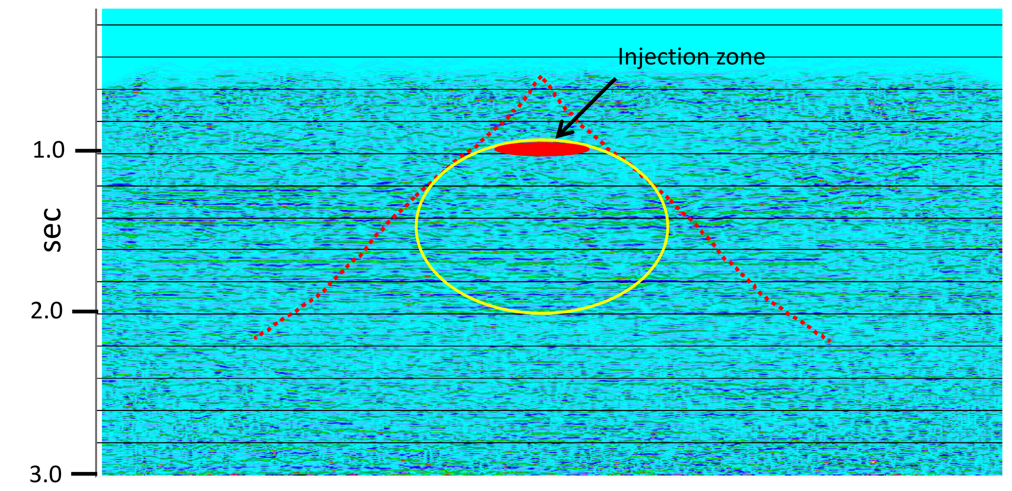

FIG. 7. To confirm that the **amplitude differences** in Figure 6 are due primarily to **time shifts**, the baseline image was shifted by 1.6ms before subtraction (***an interferometric comparison***), whereupon much of the amplitude anomaly moves laterally away from the injection zone.

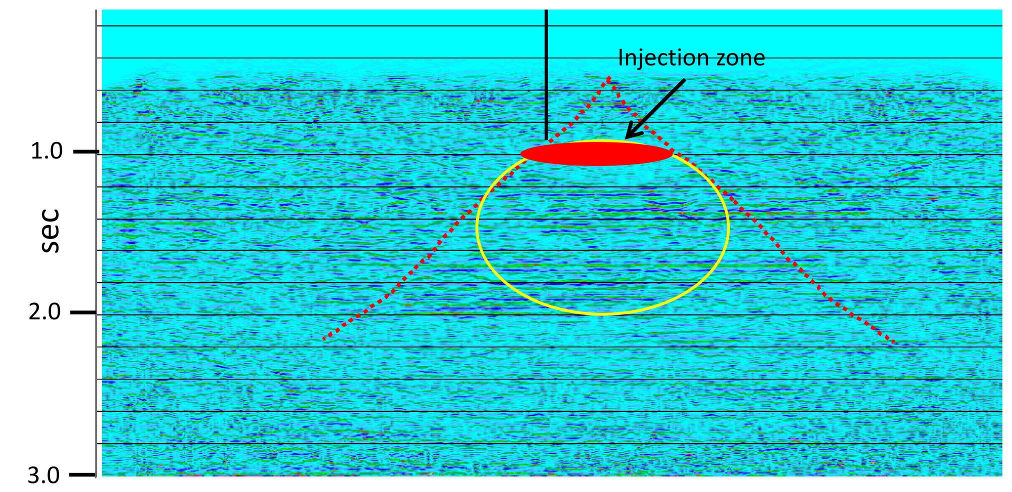

FIG. 8. If the actual injection zone extended asymmetrically from the borehole, the time sag anomaly would fit our preconceived notions even better!