Attempts to Understand Reservoir Communication using Inter-well Chemical Tracers and the Coherence Cube

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Introduction

This paper will endeavor to show, with mixed results, the potential value in combining two distinct and separate technologies to help in understanding preferential flow in reservoirs.

Chemical Inter-well Tracers

Chemical inter-well tracers provide the *only direct means* of tracking fluid movement in a reservoir, thus allowing the determination of reservoir heterogeneity. Chemical tracers allow for the determination of the magnitude of any flow, whether it is radial or uni-directional flow, in the reservoir formation. In this way, not only the communication between the injector(s) and the producer wells is established, but also the extent of the communication. Although it is useful, this method does not yield the actual pathways followed by the fluids. This information is usually crucial for the understanding of fluid flow in formations that contain flow barriers, low permeability pockets or lateral variation in porosity within the formations. Obviously, seismic data possibly provides another way for achieving this. However, the resolution of seismic data is usually too low to see any meaningful detail that would help explain the fluid flows.

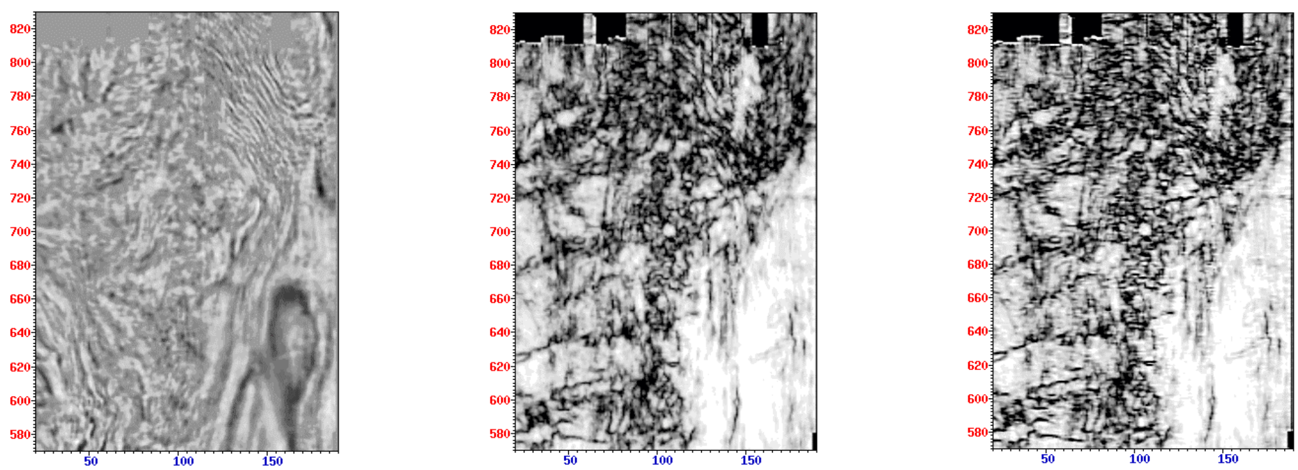

FIGURE 1: Coherence slice not only shows up faults with clarity but also the intensively fractured region to the top

Coherence Cube^{TM} Imaging

Coherence Cube is essentially a cube of coherence values generated from the input 3D seismic data volume, using some statistical measure. Coherence measurements in three dimensions represent the trace-to-trace similarity and therefore produce interpretable changes [1,2,3]. Similar traces are mapped with high coherence coefficients and discontinuities have low coefficients. Regions of similar traces cut by faults for example, result in sharp discontinuities of trace-to-trace coherence, producing delineation of low coherence along fault planes. Since the three-dimensionality is an essential ingredient of coherence computation, faults or fractures in any orientation are revealed equally well. Fig.1 (a) and (b) depict an example from Cook Inlet area in Alaska where faults, apparently difficult to interpret on the seismic slice show up clearly on the coherence slice.

Sharpened Coherence

It is possible to apply edge enhancement operators to the Coherence Cube [4], and get a 3D cube of sharpened coherence coefficients. Comparison of the same set of slices from the coherence and sharpened coherence volumes, shows the crisper appearance of different features on the latter, which prove to be helpful in interpretation. Fig.1 (c) shows the sharpened coherence slice. Evidently, there is sharp and accurate detail visible on this slice.

Since the Coherence Cube offers a much higher lateral resolution, it would afford a more accurate way of detecting discontinuities which may then accordingly be interpreted as flow barriers or possible fluid flow pathways and/or barriers within producing reservoir formations. Appropriately, the original seismic data was reprocessed, augmented with a frequency enhancement technique and submitted to Coherence Cube generation.

Application of the Two Technologies to a Producing Field

The field under study is located in southern Alberta. The discovery well drilled in 1993 started the process of development drilling and the pool started producing in 1994. Presently, more than 20 wells have been drilled in the pool. The daily production, which peaked at 1200 m^3/day in 1996, had dropped to less than 500 m^3/day. The target reservoir is a Devonian Lower Nisku dolomite formation, about 35 m (115 feet) thick. It was deposited as a widespread carbonate bank in a shallow, open marine environment. The porosity is primarily vuggy within the oil reservoir but ranges to intergranular beyond. Overlying the Nisku reservoir rock is the primary dolostones and the laminated impermeable anhydrites formed in the subtidal to supratidal environment of a regressive often hypersaline shelf. Below the Nisku are the Ireton and Leduc formations. The Ireton, an argillaceous dolomite, is very thin in the area. It is underlain by thick porous Leduc dolomite, which is generally regarded as a regional aquifer.

Observations

1. The tracers injected in the north western part of the field (vertical wells INJ-1, INJ-2 and INJ-3, which are color-coded blue, Fig.2) have not been detected in any of the producers after a two year period. This suggests there is a flow barrier between the three injectors in the north end of the field and the producers to the south.
2. Tracers injected in well HZ INJ- 4 (blue) reach well PRO-1 (light blue to the South) in 8 days, a distance just over 2 kms. Wells closer than PRO-1 and wells to the east (shown in pink) took 61 days to reach breakthrough.
3. Tracers injected in well HZ INJ- 4 (blue) reach wells in the North East. Tracer reached well PRO-3 (green) faster than either in closer wells PRO- 4 (green) or PRO-5 (green) and PRO-6 (green) wells.
4. Tracers injected in well HZ INJ- 4 (blue) reach the wells in the cluster (orange) to its right (EAST) so fast (1 day), that there seems to be a high permeability pathway leading from this injector to the wells in this area.

Explanations based on Coherence Cube interpretation

Horizon slices were produced from the Coherence Cube at levels just at and below the reservoir formation and are shown in Figs. 3-5.

As seen in Fig. 3, wells INJ-1, INJ-2 and INJ-3 are seen located on the NW side of an almost NE-SW linear trend seen in the upper left corner. This trend is interpreted as flow barrier that prevents the tracers injected in the three wells to travel through it.

The tracer injected in well INJ- 4 reaches well PRO-1 (indicated with arrow) in just 8 days. Obviously, one would expect this to take place via faults and fractures at this level. Fig. 3 shows a fracture mesh of low coherence, which may be interpreted as being responsible for this tracer flow. However, the seismic data in this part of the survey has a poor signal-to-noise ratio. This aspect of the data though valid brings in an element of uncertainty and demerits the above interpretation. Nevertheless, Fig. 3 offers an explanation for the observation of tracers injected in INJ- 4 and detected in PRO-1.

Fig. 4 shows the horizon slice at 66 ms below the tracked horizon. The tracer injected in INJ- 4 is detected in wells PRO-3 and PRO-2 after 3 days and in well PRO- 4 after 27 days. Examining the coherence slices in Fig. 4, one notices a low coherence pathway for the tracer to follow starting from well INJ-4 and traveling to wells PRO-3 and PRO-2. Well PRO-4 is located away from this low coherence pathway and so takes a longer time.

Fig. 5 shows a horizon slice at 70 ms below the horizon. The tracer from well INJ-4 reaches the wells in the pocket marked in red in virtually no time (one day). It was expected that this pocket has high permeability and so the reservoir formation has high connectivity.

Conclusions

Tracer results were able to depict flow boundaries, directional flow, problem injectors and producers, and heterogeneity of the field within the reservoir into three distinct areas. However, tracers cannot show the flow path of the fluid movement. Coherence Cube is a method of determining discontinuities which may be interpreted as flow barriers or fluid flow pathways. Sharpened coherence cubes were generated for the reprocessed 3D volume for a producing field and horizon slices just below the reservoir level interpreted to understand the inter-well tracer observations. These slices offer an explanation for the tracer results. An important conclusion that has been drawn from this exercise is that there is potential value in combining two distinct and separate technologies, *viz.* Coherence Cube and inter-well chemical tracers, to understand reservoir communication. Needless to say, the success of such an endeavour would depend to a large extent on the quality of the seismic data being used.

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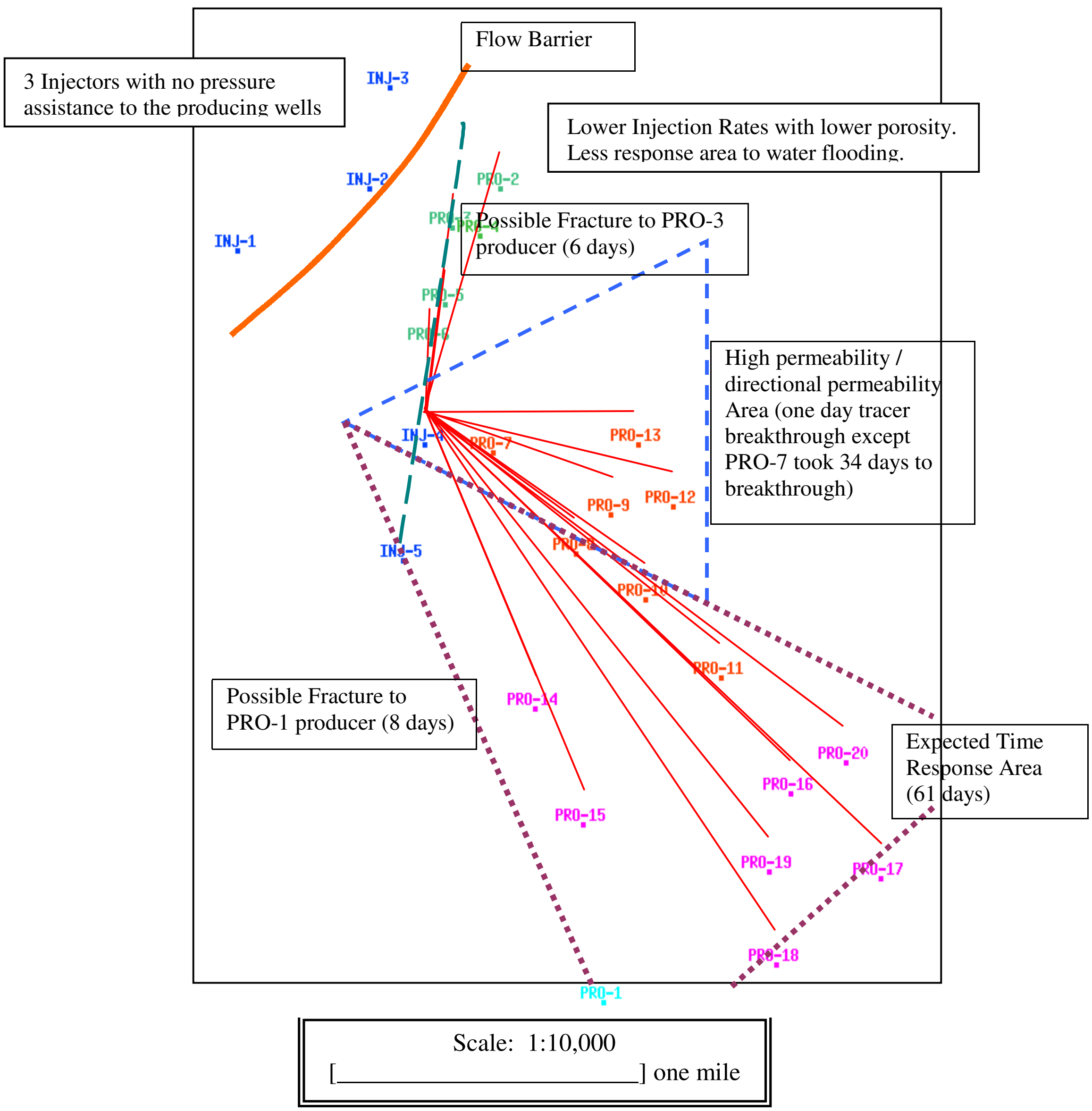

FIGURE 2: Summary map of chemical tracer response – three signature delineation areas

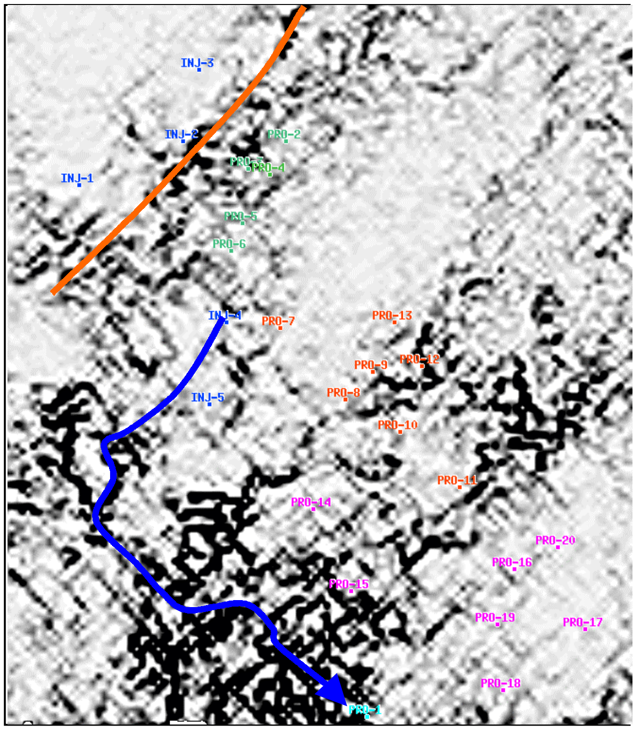

FIGURE 3: shows clearly a NE-SW low coherence trend in the upper left corner. This is interpreted as the flow barrier preventing fluid movement (tracers) from these wells to flow through to the right hand side (Graphically shown as an Orange Line). The quick breakthrough to PRO-1 (light blue) in the south is explained by the darker lines that depict the potential channel pathway for the tracer to arrive from INJ-4 in such a short time (Graphically depicted by dark blue line as the potential pathway).

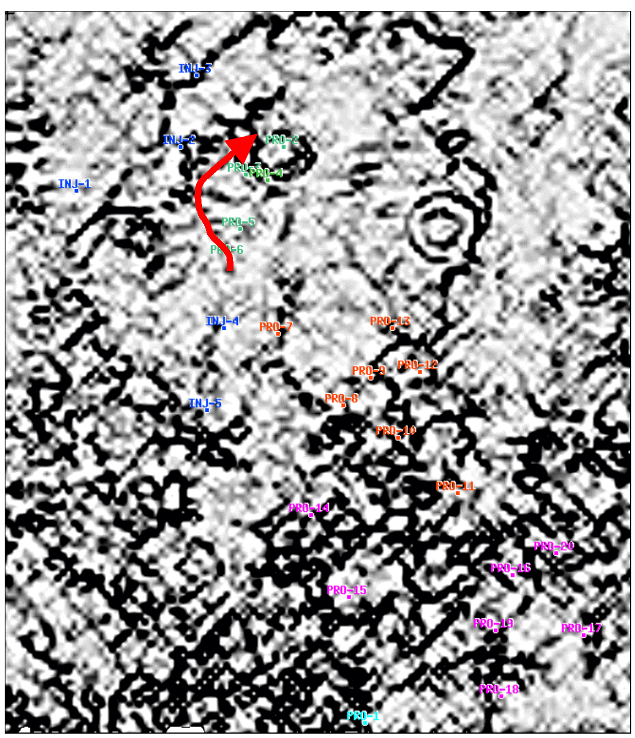

FIGURE 4: Horizon coherence slices70 ms below the horizon representing the reservoir top. Red arrow depicts potential pathway (low coherence) for early breakthrough (6 days), and by-passing two wells that are closer to the injector but with considerably longer breakthrough time (60 days) in area of high coherence.

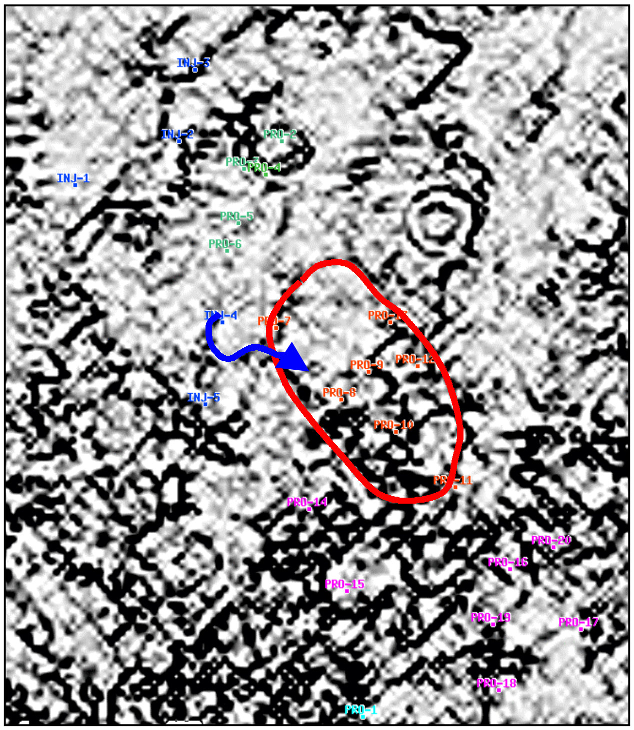

FIGURE 5: Horizon slices from coherence volume 68 ms below the horizon representing the reservoir top. Wells inside red area had one (1) day to breakthrough.

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