# Joint Impedance & Facies Inversion – inversion driven by facies and per-facies rock physics

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## Introduction

In this paper we introduce a new Joint Impedance & Facies Inversion system (Ji-Fi for short), which gives a significant increase in quality over model-based Simultaneous Inversion, because it incorporates the correct physics of the convolutional seismic inverse problem! We first review Simultaneous Inversion, then introduce Ji-Fi, and compare one against the other, first with a wedge model and then using a case study.

## Simultaneous Inversion review

There are many somewhat different 'flavours' of model-based Simultaneous Inversion, but at a high level they all more or less follow the workflow outlined in Fig. 1.

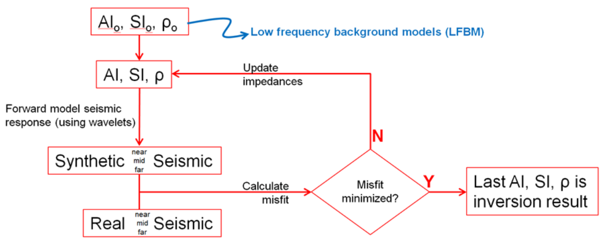


*Figure 1: High level model-based Simultaneous Inversion workflow*

Whilst this can be solved by simple least-squares optimization, some well-known shortcomings to Simultaneous Inversion are:

i. It is very difficult if not impossible to incorporate solid Rock Physics within the simultaneous inversion scheme
ii. The LFBMs (AIo, SIo and ρo in Fig. 1) are difficult to determine accurately.
iii. When you are away from seismic events the impedances (AI, SI and ρ in this case) are forced back to the LFBM values.

Note that seismic events are typically generated when a seismic wave travels from one facies (or Rock-type) into another; we know this already for almost a century as seismic interpreters pick these seismic events as horizons and interpret them as interfaces between different facies. In other words, facies (or facies transitions to be precise) are a primary control on the seismic response, and not inverting for them in simultaneous inversion means that the (convolutional) seismic inverse problem is not being fully addressed.

## Joint Impedance & Facies Inversion (Ji-Fi)

To overcome the issues listed above we have developed a Joint Impedance and Seismic Inversion system, where the AIo, SIo and ρo LFBMs are specified individually for all facies expected! This sounds like more work, but deriving LFBMs for, say, Sand and Shale individually is much easier than deriving one AIo, SIo and Rhoo LFBM for Sand-and-Shale combined as required in Simultaneous Inversion (see ii. in the previous section).

By providing the LFBMs for each expected facies individually, we are able to invert for facies and for impedances-per-facies. So Ji-Fi is a mixed discrete (facies) and continuous (impedances) inversion: the physics of the convolutional inverse problem is captured correctly!

For more information on this new technique, please refer to Kemper & Gunning (2014) and Rimstad & Omre (2010).

## Wedge Model

We have applied both simultaneous inversion and Ji-Fi to a wedge model as shown in Fig. 2 below.

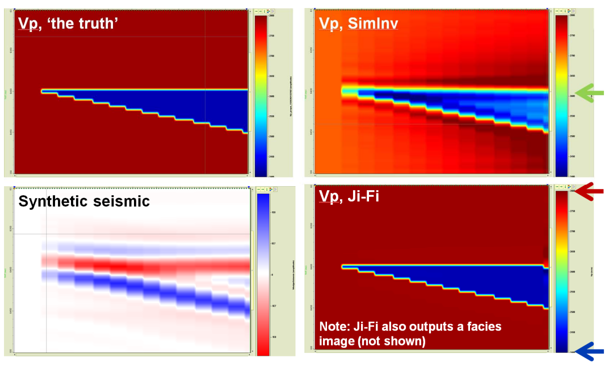


*Figure 2: (top left) A sand wedge Vp 'Truth model' (Vs and ρ not shown); (bottom left) the corresponding synthetic seismic at 10o incidence angle (synthetic seismic at 20o and 30o incidence angle not shown); (top right) Simultaneous Inversion Vp (Vs and ρ not shown; note that the constant Vp LFBM used has the Vp value indicated by the* ***green arrow****); (bottom right) Ji-Fi Vp (Vs and ρ not shown; note that the constant Shale Vp LFBM used has the Vp value indicated by the* ***dark red arrow****, and the*

*constant Sand Vp LFBM used has the Vp value indicated by the* ***dark blue arrow****).*

As indicated in the figure caption, a constant LFBM was used for the simultaneous inversion; clearly a more sophisticated LFBM could have been created which would have led to a better result, but constant LFBMs (one for Shale and one for Sand) were also used for Ji-Fi, where the result is very pleasing.

The tip of the Sand wedge is better modelled in Ji-Fi. It is a well-known problem in geophysics that at tuning, we can determine the Net Pay, but not whether we are dealing with, say, one Sand of thickness H, or with a Sand/Shale package of thickness 2H with a Net-to-Gross ratio of 50% (see Connolly, 2007; Connolly & Kemper, 2007). Hence the thicker tip in the case of simultaneous inversion, with indeed an intermediate impedance value. In Ji-Fi however, the impedances assigned can only be the impedance of Shale or the impedance of Sand (within uncertainty bounds, which for this model are very tight indeed). Clearly Ji-Fi cannot post the impedance of Shale at the tip as otherwise that whole trace would be Shale, the synthetic seismic would be identical to zero, and no satisfactory match with the actual seismic could be established. Therefore Ji-Fi is forced to post a Sand impedance value at the tip, but only for one sample; should Ji-Fi (like in simultaneous inversion) thicken the tip, the synthetic seismic amplitude would be too large, and no satisfactory match with the actual seismic could be established. So we end up with a tip of the correct impedance and the right thickness! In fact, Ji-Fi generated impedances usually show a wider spectral content than simultaneously inverted impedances, which is good news for thin bed detection.

Remarkably, even though from Fig. 2 we see that at the thin end of the Sand wedge the synthetic seismic 'curls upwards' (a well-known phenomenon), Ji-Fi posts the tip at the correct depth! Conversely, the simultaneous inversion result curves up somewhat…

Note that at the very right hand side of the Sand wedge in the Ji-Fi result there is a small inversion anomaly; this is because Ji-Fi is a global inversion scheme, and to the right of the model there are no neighbouring traces, so this is a small edge effect; other than that, the Ji-Fi result is a perfect replication of the Truth model in this case.

Even though the Ji-Fi result in Fig. 2 is demonstrably better than the simultaneous inversion result, few conclusions if any should be drawn from this noise free conceptual experiment.

## Case Study

We applied both Simultaneous Inversion followed by Bayesian Classification (a two-step process) and Ji-Fi (a one step process) to a Triassic Oil and Gas field offshore Western Australia, as presented in Fig. 3.

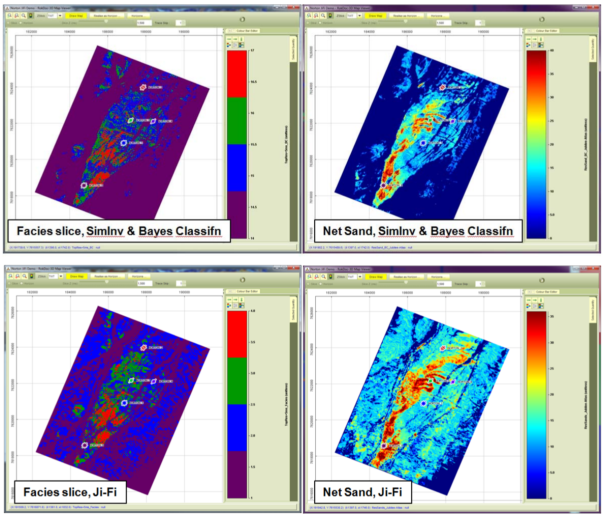


*Figure 3: Simultaneous inversion (followed by Bayesian classification results (top row) and Ji-Fi results (bottom row) on a Triassic Oil and Gas field offshore Western Australia. Left column a horizon slice through the facies cubes (Shale is purple; Water-sand is blue; Oil-sand is green and Gas-sand is red), and right column the net sand map within the inversion window.*

We observe that Ji-Fi gives a better inversion result, in that only Ji-Fi...

- Shows a proper match regards hydrocarbon content to all wells,
- Images the channel as a nice, continuous feature,
- Finds water bearing sands off structure (where you would expect them).

## Conclusions

In this abstract we have explained that seismic inversion is a mixed discrete/continuous problem, which to date is solved continuously only in the great majority of algorithms. Ji-Fi uses the correct physics, i.e. inverts **jointly** for facies (discrete quantities) and for impedances-per-facies (continuous quantities). The result is an increase in inversion quality in our opinion.

Note that reservoir characterisation with Ji-Fi generated results (facies and impedances) is more readily accomplished than with simultaneous inversion generated results (impedances only). With only impedances to hand, a transform from impedances to, say porosity needs to be fitted that is somehow valid for all facies; with also facies to hand (as is the case with Ji-Fi), a transform for each facies can be established (using fundamental rock physics principles, not just fitting) resulting in a better porosity estimate in this example.

Furthermore, a more reliable, Ji-Fi generated facies image may have a positive impact on a number of other subsurface workflows, such a pressure prediction, de-risking of deep offshore prospects, more accurate geological modelling in terms of flow units etc.

**Acknowledgments**

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