Inverse Scattering Series Internal Multiple Attenuation: A Western Canada Case Study

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Summary

This work shows a multiple attenuation results based on the application of the Inverse Scattering Series (ISS) method to predict internal multiple models. The ISS multiple modeling procedure is data-driven and does not assume a priori subsurface information such as known velocity field and generating horizons. Adaptive subtraction is employed to match the predicted model with the internal multiples present in the data set. A case study using the one-dimensional prediction ISS method was applied to a poststack field data set located in western Alberta, Canada, where the interval between the Duvernay formation and the shale/basin contact is dominated by strong internal multiples. The workflow attenuated most of the internal multiples present in the target zone, improving the overall resolution and highlighting weak events previously hindered by multiples, yielding a more interpretable section.

Introduction

With many new oil and gas exploration and development fields focusing on deeper reservoirs, internal multiple contamination is becoming an increasingly important problem. Strong internal multiples overlaying with weak primary energy can considerably compromise the quality of the surface seismic data set. These multiples are observed frequently on land data, making the interpretation, fracture characterization and inversion ambiguous over the zone of interest.

Common data-driven multiple attenuation techniques based on velocity discrimination and periodic operators are generally not adequate for this type of phenomena, especially in areas with a relatively flat geology. Methods based on Radon transform are not capable of attenuating the internal multiples due little or no moveout velocity differentiation when compared with primaries. The many different modes and periods of internal multiples that are present in the data make the design of suitable operators based on the multiple periodicity ineffective.

Internal multiple prediction and subtraction schemes were developed to overcome the limitations of the aforementioned methods. Research and case studies have shown successful multiple attenuation outcomes over the past years. Field case studies from El-Emam *et al.* (2005), El-Emam *et al.* (2011), Ras *et al.* (2012), and Sonika *et al.* (2012) showed that the prediction method based on the research from Jakubowicz *et al.* (1998) and further improved by Wu *et al.* (2011), contributed to the attenuation of a significant amount of internal multiples from land field surveys located in the Middle East. For all these cases, the study, identification and interpretation of the set of interfaces responsible for the generation of most internal multiples are mandatory. This task is not straightforward and can become virtually impossible in the absence of borehole information.

In contrast, the ISS prediction framework for the attenuation of internal multiples (Araújo *et al.*, 1994; Weglein *et al.*, 1997) does not require prior identification and interpretation of the major generating

horizons. Instead, it computes all internal multiples from all possible combinations of events from a given interval (Fu *et al.*, 2010). This method gives the data analyst more freedom to assign the zone that generates the multiples that are interfering at the reservoir level, thus allowing a reduced turnaround in horizon interpretation and testing. Adaptive subtraction methods are required after the ISS prediction to match the multiple model to the input field data.

ISS multiple attenuation workflow

The workflow employs the ISS algorithm to predict internal multiples in the field data. This method is completely data-driven: it does not require a priori information about the subsurface, such as major interfaces generating the internal multiples or velocity field (Fu *et al.*, 2010). Starting from a given downward multiple generation zone, the algorithm predicts all the internal multiples originating from this interval at once. The prediction starts computing the first term in a subseries of the ISS, followed by the traveltime and amplitude prediction of all internal multiples (Weglein *et al.*, 1997). Figure 1 shows an example of a given internal multiple being predicted by the construction of three primary events. The preferred ISS prediction method varies according the data set geological setting, source and receiver geometry, searching for a better trade-off between compliance with the algorithm assumptions and computational cost.
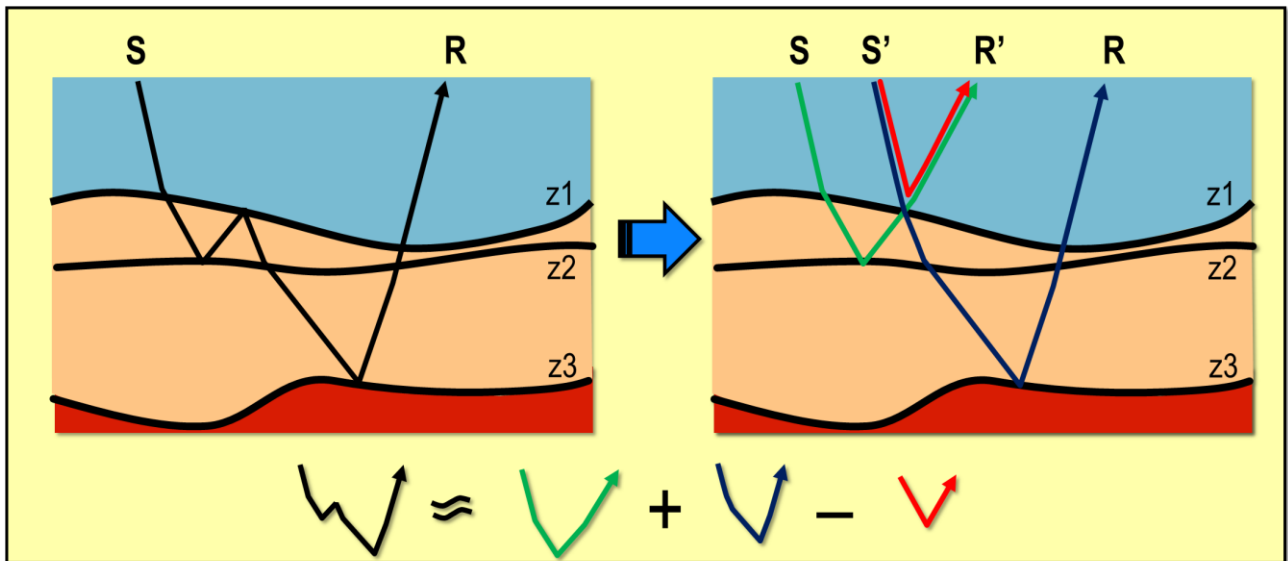

Figure 1 – *A given internal multiple (left) can have the traveltime constructed using three primary events (green, blue and red) from the subsurface that satisfies the higher-lower-higher relationship of $z3 > z2 > z1$.*

Similar to requirements of most data-driven prediction methods, the ISS framework assumes that background noise is addressed prior internal multiple prediction. More details about the theory, assumptions and applications can be found in Weglein *et al.* (1997) and Fu *et al.* (2010).

Adaptive subtraction is employed to overcome imperfections in the predicted multiple model. Errors in the model arise due diverse reasons such as geometry of the generating reflections, sampling imperfections, limiting assumptions of the ISS algorithm, low signal-to-noise level of the data, complexity of the geology, among other reasons. This requires adaptive matching of the multiple model to the input reference data before subtraction.

Analogous to the prediction task, a number of adaptive subtraction methods should be considered. Each of these methods will match differently with the input data set and all available methods should be tested and assessed across the target survey to define the best adaptive subtraction strategy. This strategy might include (and is not limited to) different types of filters and parameters according the frequency spectrum bandwidth, sorting order and transform domains (e.g. frequency-spatial, frequency-wavenumber and curvelets). The workflow derived to address the matching between the input field data and the ISS internal multiple models underwent to a comprehensive testing over a selected area of several adaptive subtraction techniques and workflows.

Workflow example

The workflow was applied to the poststack time data set covering the total area of the Lobstick II 3D survey located in Alberta, Canada, as shown in Figure 2. The main target zone of this area was initially focused over the Pembina field, but the exploration target moved toward deeper targets, from the Duvernay formation down to basinal deposits (between 1.5 and 3.0 seconds in the time section). Internal multiple contamination is severe in this zone, directly interfering with conformable overburden formations (potential multiples generators) and masking the contrast response at the shale/basin contact. At the basin zone, most of the events that conform with shallower formations are internal multiples and the primary reflection event of interest are obscured.
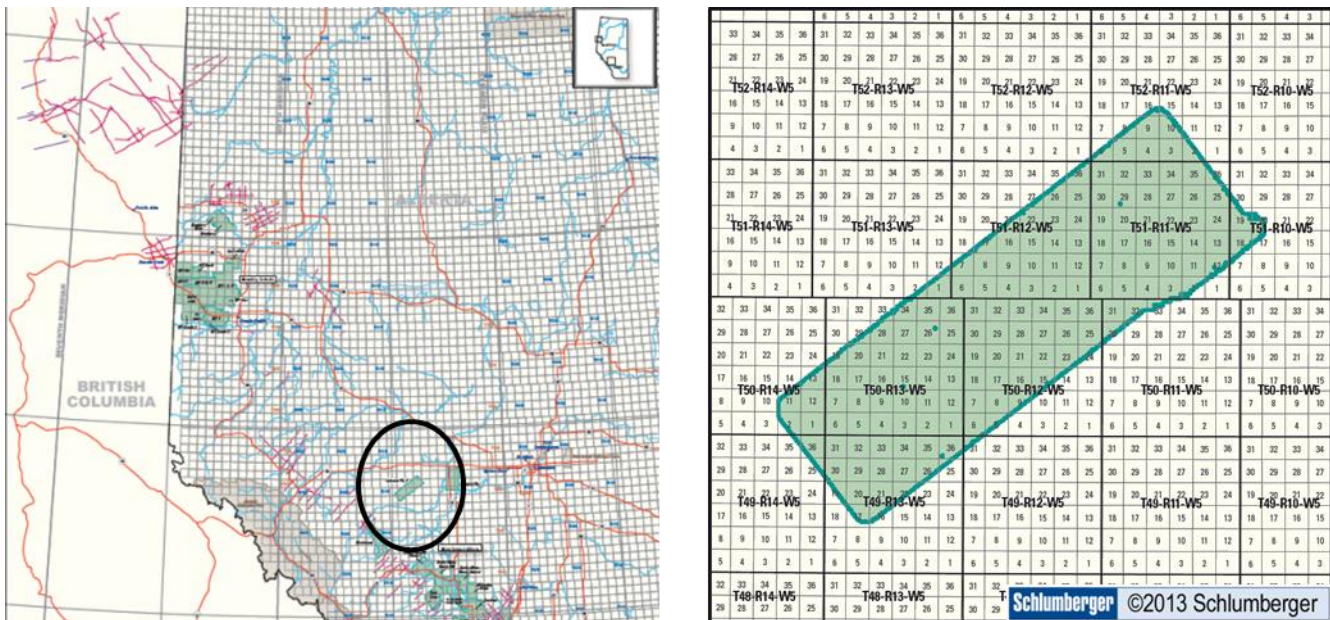

Figure 2 – *Lobstick II 3D survey location in Alberta, Canada.*

This survey was recently reprocessed to address most of the noise contamination present in the data, including this multiple attenuation workflow. Borehole information was not deep enough to aid in the assessment of major internal multiple generators and no mapped interfaces/horizons were available, making the ISS method a suitable choice for internal multiple prediction. The normal incidence ISS prediction (one-dimensional earth model) was used to derive an internal multiple model from the poststack cube covering the entire survey.   The one-dimensional prediction assumption was not violated due relatively flat structure with little overburden dip present across the whole data set. The prediction was carried out using a downward multiple generating window between 1.2 and 2.0 seconds, predicting most of the internal multiple present in the target zone.

The adaptive subtraction step was defined based on two distinct structural and environment of the geology between multiples and primaries present in the post-stack data. Internal multiples over the Duvernay zone (between 1.2 and 2.1 seconds) do not present structural discrepancies with the underlying primary events. Adaptive subtraction under this circumstance must be mild (restrict the adaptive matching variation in a temporal and spatial sense) so that the matched model does not remove primary events. In contrast, there is a clear structural change between primaries and internal multiples at the shale/basin contact zone (below 2.1 seconds), allowing a harsher (allowing more temporal and spatial adaptive variation) adaptive matching focusing on the removal of all events non-conformable with the depositional basin events.

Figures 3 and 4 show the comparison of inline and crossline stacked (no migration) sections before and after the multiple attenuation workflow. The mild subtraction between 1.2 and 2.1 seconds shows a general continuity and resolution improvement of weak reflections over both figures, indicating that the interfering multiple events are being consistently attenuated across the whole cube. Figure 5 shows a selection of two time slices, covering the Duvernay (at 2 seconds) and the shale/basin (2.5 seconds) zones. Results of the adaptive subtraction in the shallow slice corroborates with the results on Figures 3 and 4, improving the lateral resolution over major channels and revealing weak events over the northeast area of the section. The adaptive subtraction performed in the deep zone (below 2.1 seconds) shows a remarkable improvement, cleaning up the strong internal multiples crossing the stacked section and improving the shale/basin contact overall picture.

Conclusions

Previous experience has shown that multiple contamination is one of the major challenges for land data. In such a scenario, internal multiples cannot be easily attenuated using conventional methods based on periodicity, velocity or dip discrimination, leaving prediction and subtraction methodologies as the only option is such cases. This work showed a workflow using the normal incidence ISS internal multiple prediction followed by a fit-for purpose adaptive subtraction on a poststack volume. Results from this survey showed a significant and consistent improvement over the entire cube, where strong internal multiples were effectively attenuated and the overall data set resolution was improved. Current work is being conducted on prestack multiple attenuation workflow for this data set, allowing the multiple removal prior to imaging, and the application of inversion algorithms less dependent on borehole information.
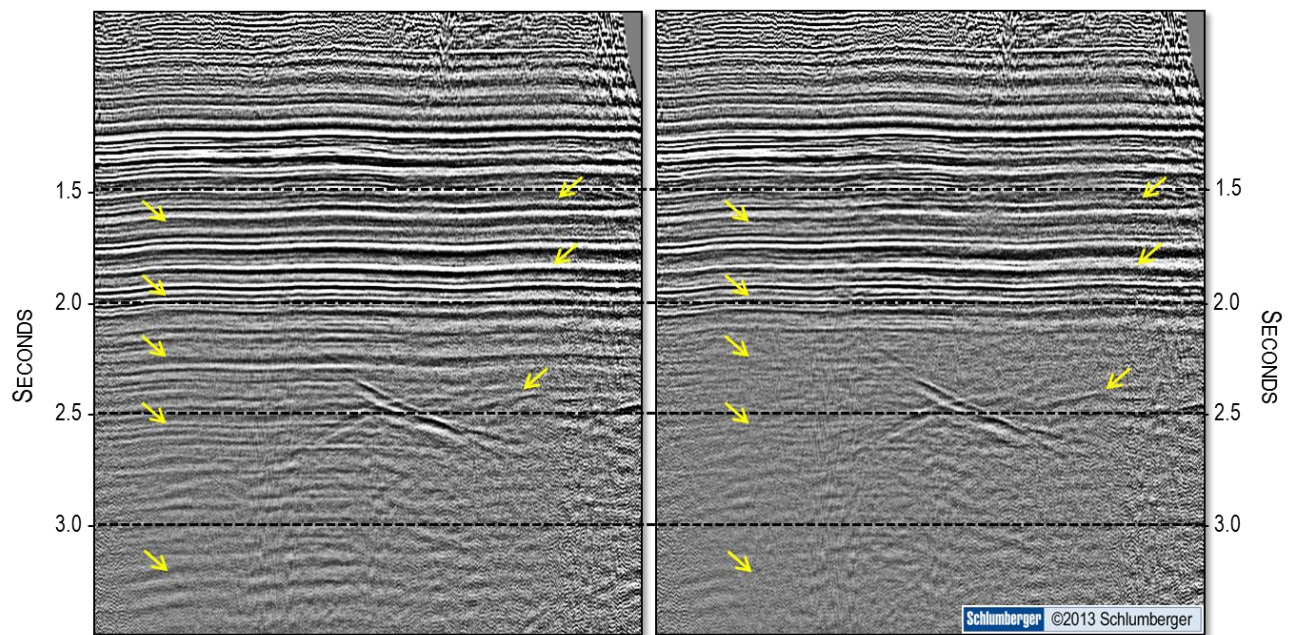
Acknowledgements

Figure 3 *– Inline stacked section before (left) and after (right) the multiple attenuation. Arrows show places where there was a clear improvement of the data set after applying the workflow.*
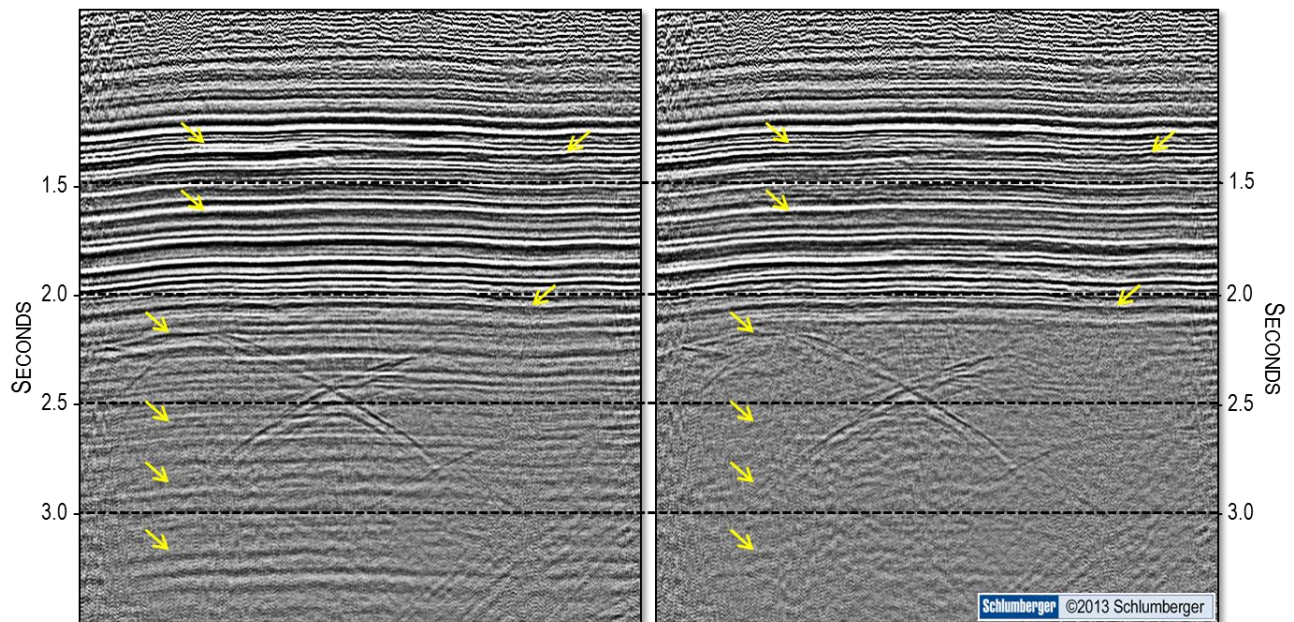

Figure 4 *– Crossline stacked section before (left) and after (right) the multiple attenuation. Arrows show the data set improvement after applying the workflow.*
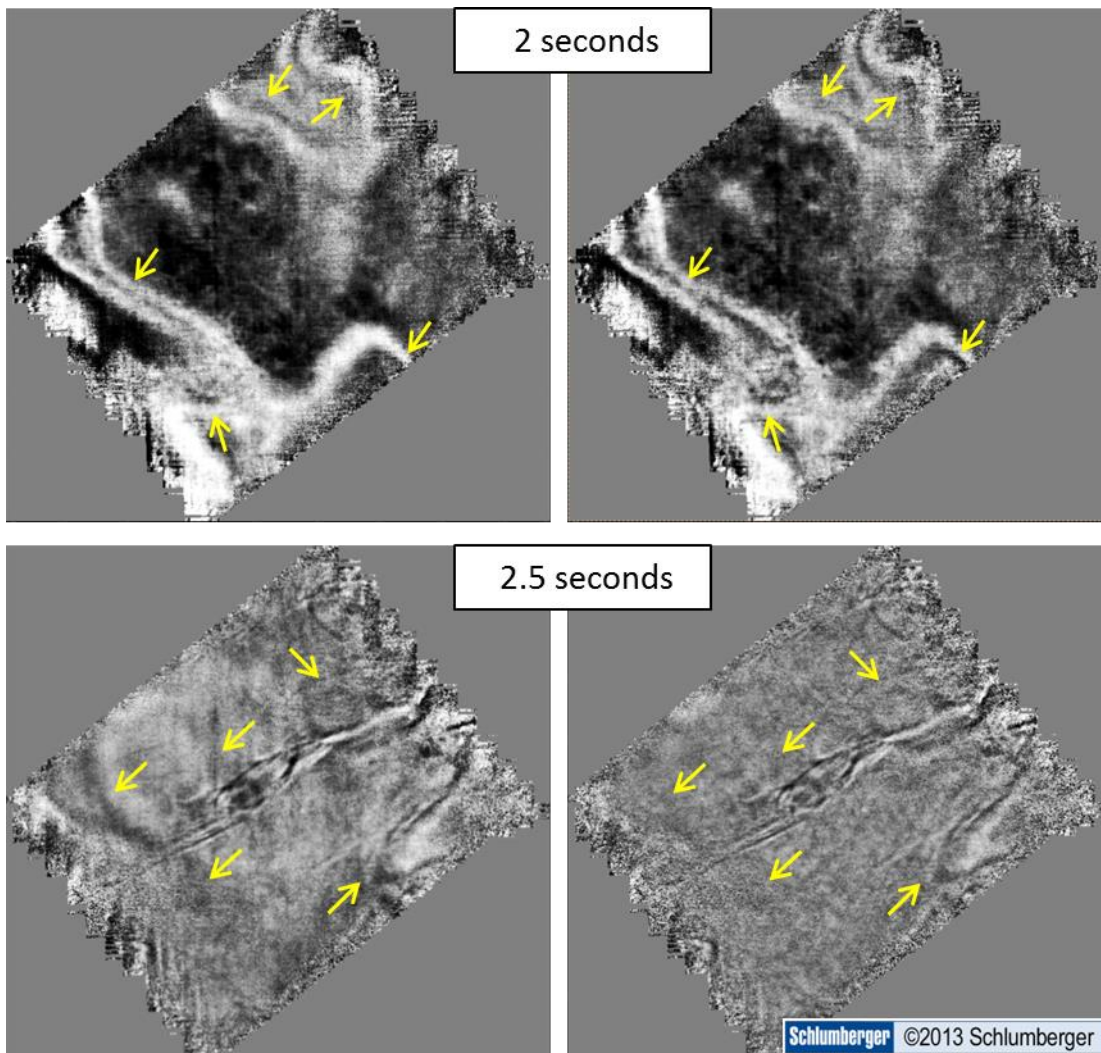
Figure 5 – *Time slice displays at 2 and 2.5 seconds before (left) and after (right) internal multiple attenuation. Yellow arrows in the 2 seconds plot show improvement of the overall resolution; whereas, most of multiple interference (shadow from overburden multiple generating formations) was removed in the 2.5 seconds plot.*

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