The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, chief geophysicist for Arcis Seismic Solutions, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.

Preconditioning of Seismic Data Prior to Impedance Inversion

By SATINDER CHOPRA and RITESH KUMAR SHARMA

The calibration of seismic data with the available well control is an important step that provides the link between seismic reflections, their stratigraphic interpretation and subsequent prediction of reservoir and fluid properties.

The standard practice to do this has been to produce synthetic seismograms from well logs with a bandwidth similar to that of the seismic data. The synthetic traces are produced by picking up the sonic and density logs for a well and calculating the reflection coefficients. These reflection coefficients are then convolved with a suitable zero or minimum phase wavelet and choosing a frequency response similar to that of seismic.

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The wavelet could also be extracted from the seismic data. Thereafter, the synthetic seismogram is displayed in the same polarity as the seismic and either overlaid or inter-fixed on the seismic data at the location of the well, after making a shift adjustment in time. Such a correlation helps to quickly identify individual reflections, which can then be interpreted on the seismic data.

The frequency content of surface seismic data varies with time due to attenuation or other effects, so generally we see higher frequencies in shallow intervals that are gradually lowered with increasing times. In figure 1 we show a seismic section over a 1s interval, but higher frequencies in the upper 500ms and lower frequencies in the lower 500ms are seen. This can be seen on the wavelets that are extracted in the upper and lower intervals and the frequency spectra generated for the two intervals, as shown in the insets.

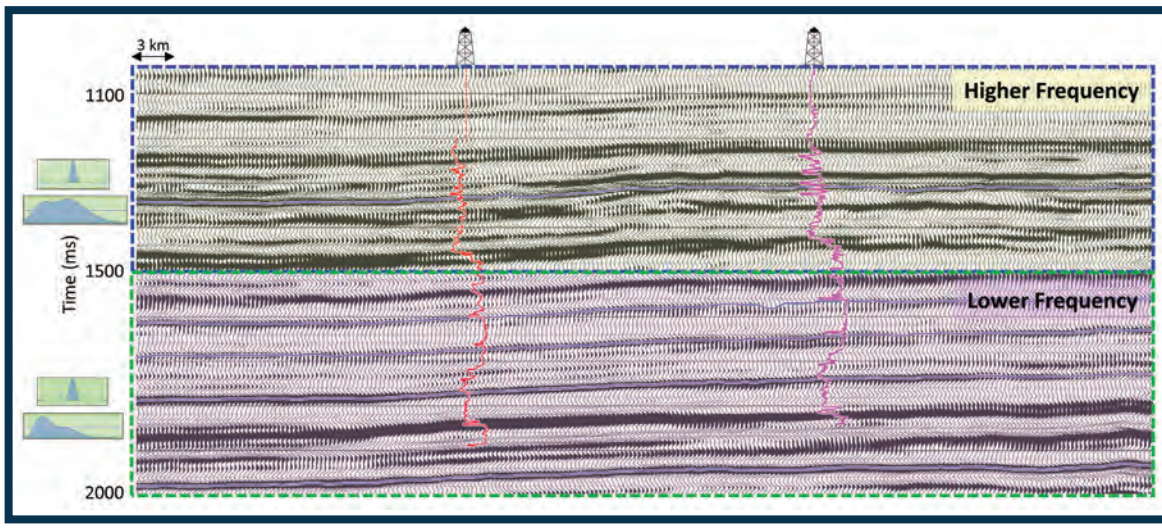

Figure 1 – Figure shows a segment of a seismic section passing through two wells, wherein the upper half exhibits higher frequency and the lower half shows lower frequency. The frequency spectra and the extracted wavelets from the two intervals are shown to the left. The impedance logs at the location of the wells are shown overlaid.

Synthetic Seismograms

A synthetic seismogram generated using the wavelet from the shallower interval would exhibit a reasonable frequency match in the upper interval, but will show a higher frequency content for the lower interval as compared with the seismic data. We show this in figure 2, where in (a) we have the P-velocity and density logs used for generating the synthetic traces in blue. These are compared with the real seismic traces in red, and the correlation coefficient between them is 0.723. Notice in the shallow portion highlighted with the black dashed box, the frequency content between the synthetic and the real traces seems similar. However, in the lower portion highlighted with the blue dashed box, the synthetic traces seem to exhibit a somewhat higher frequency (HF) content. As mentioned above, this is because the wavelet extracted from the upper interval was used for generating the synthetic seismogram.

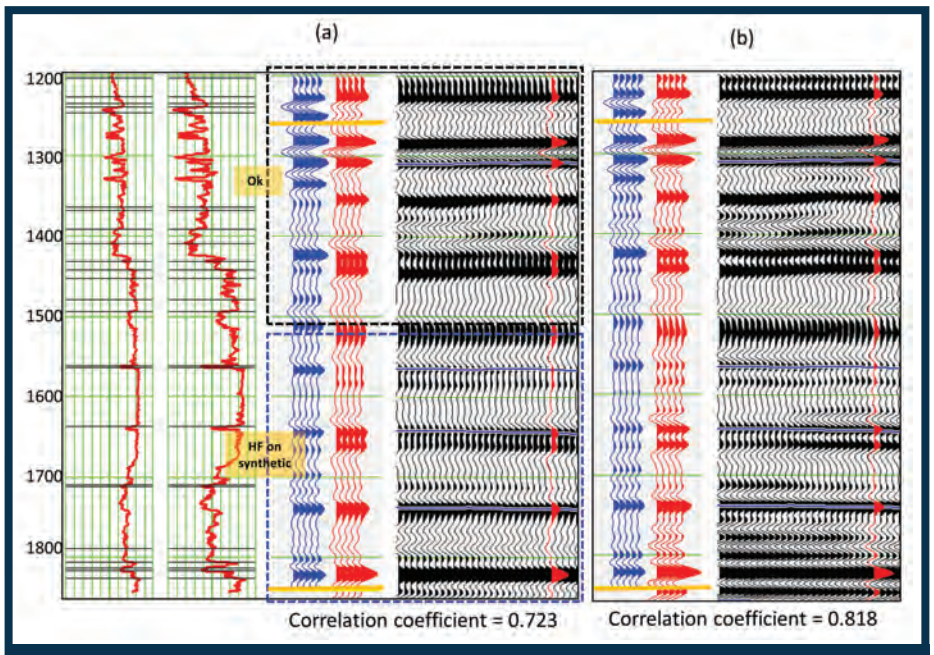

Figure 2 – (a) Creating a synthetic seismogram using the wavelet extracted from the upper half of the seismic section shows a good correlation with the real seismic data for the upper window. We do however notice higher frequency on the lower half of the synthetic seismogram. (b) Generating a synthetic seismogram using a wavelet extracted from seismic data after running thin-bed reflectivity inversion. The correlation coefficient calculated between the synthetic and the real seismic data traces, before and after thin-bed reflectivity inversion on seismic data between the windows indicated with the yellow bars is shown to increase from 0.723 to 0.818.

One way to address this problem would be to extract an average wavelet over the full window and then generate a full-window synthetic seismogram that could be correlated with the seismic. However, this would have a lower resolution in the upper window and a higher resolution in the lower window, something that is contrary to what we expect.

Another way that could be adopted is that separate wavelets are extracted in the upper and the lower windows and separate synthetics are generated and compared. As well, the inversions would need to be performed in separate windows, which is time-consuming. In such an exercise, we can expect to see lower resolution in the lower window compared to the upper window.

If we go back and examine the input seismic data, we see that the bandwidth of the data is somewhat narrow, with the peak frequency at 12 or 15 Hz and noise after 60 Hz. Also, the frequency spectrum shows a roll-off after 30 Hz. In figure 3a we show a segment of a seismic section from the input data, and the frequency spectrum is shown in the inset. To be able to extract some more information from the data, we should at least be able to make the frequency spectrum look flatter.

We achieve this with thin-bed reflectivity inversion, a process that extracts time-varying wavelets from

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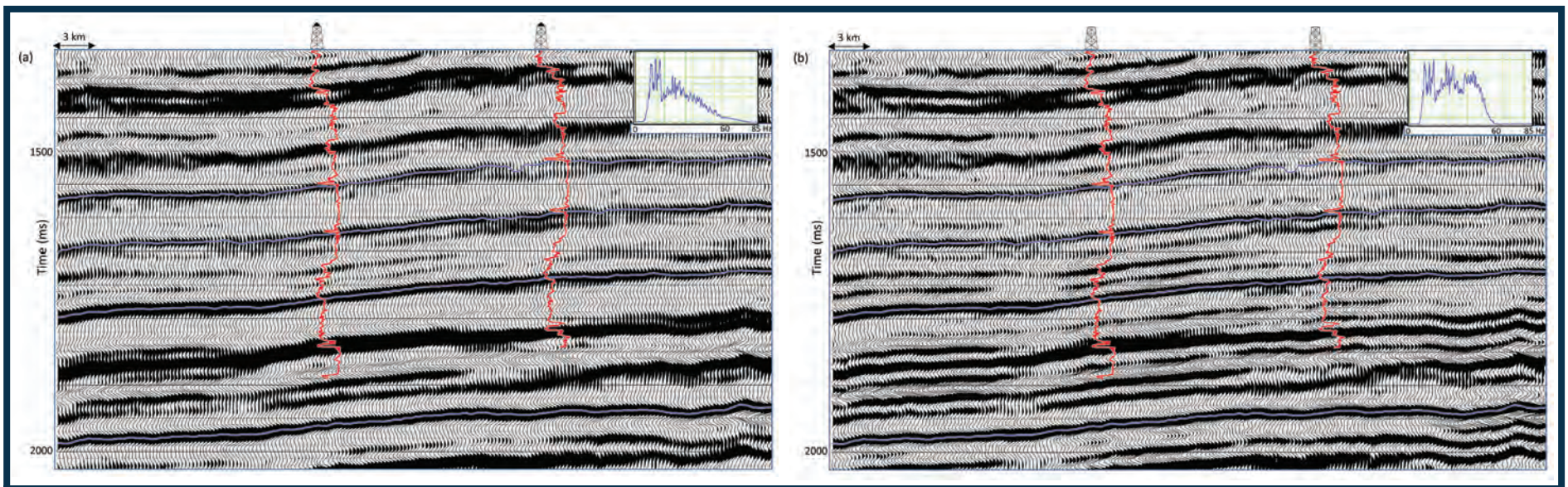

Figure 3: Segment of a seismic section from the (a) input seismic data, and (b) input seismic data with thin-bed reflectivity inversion and filtered to the same bandwidth as the input seismic data. The frequency spectra in the insets show the bandwidth of the seismic data as 5-10-50-60 Hz but that of the filtered thin-bed reflectivity inversion is now seen as flatter.

Continued from previous page

the seismic data and using principles of spectral inversion produces sparse reflectivity estimates. The advantages include being able to pick up more reflection detail, to perform more accurate interpretation on seismic volumes obtained by convolving reflectivity volumes with wavelets of higher bandwidth than the input data, and to visualize subtle anomalies when some attributes are run on thin-bed reflectivity inversion output. More detail on this method and its applications can be picked up from the Geophysical Corner columns in the May 2008 and July 2009 issues of the EXPLORER.

Enhancing Bandwidth

We put the input seismic data through thin-bed reflectivity inversion and derive the reflectivity volume. In principle, once the reflectivity volume is derived from the seismic data, it is possible to filter it back to a frequency bandwidth higher than the input seismic data. But there are some seismic interpreters in our industry who are not comfortable with the idea of enhancing the bandwidth of the data beyond the recorded frequencies. Keeping that in mind, here we filter the derived reflectivity volume to the same bandwidth as the input seismic data (i.e. 5-10-50-60 Hz).

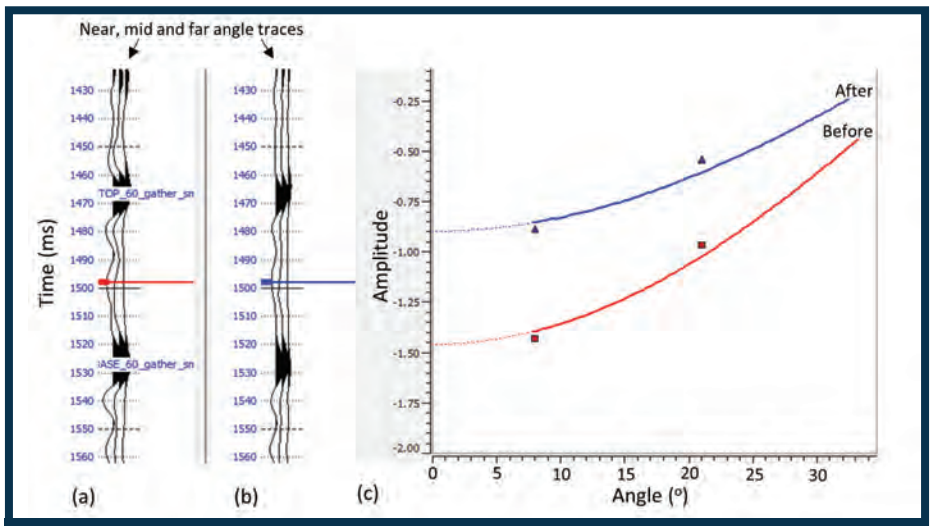

Figure 4: The angle stack traces for a short time window, created for data before (a) and after thin-bed reflectivity inversion (b) are shown to the left, where the red and blue bars mark similar events. The amplitudes of these similar events are plotted as a function of angle to the right in (c). Notice that while there is a small change in the amplitude of the events after thin-bed reflectivity inversion, the relative amplitude variation with angle is very similar.

The seismic section equivalent to the section shown in figure 3a is shown in figure 3b. Notice the improvement in the resolution detail, which is also seen on the frequency spectrum shown in the inset. The amplitudes of the frequencies beyond 25 Hz have been enhanced so that the spectrum now looks flatter. The correlation with the impedance logs also looks much better. We show a section of the data after thin-bed reflectivity inversion in figure 2b, where the synthetic seismogram generated from the well log data shows a better correlation with the seismic data. The correlation coefficient is now seen increased from 0.723 to 0.818.

The preservation of amplitude variation, both in the post-stack and the pre-stack seismic data, is usually a mater of concern for seismic interpreters. This is important for all AVO analysis work as well as impedance inversion performed on the seismic data. We picked up the pre-stack seismic data for a data volume from central Alberta, and after

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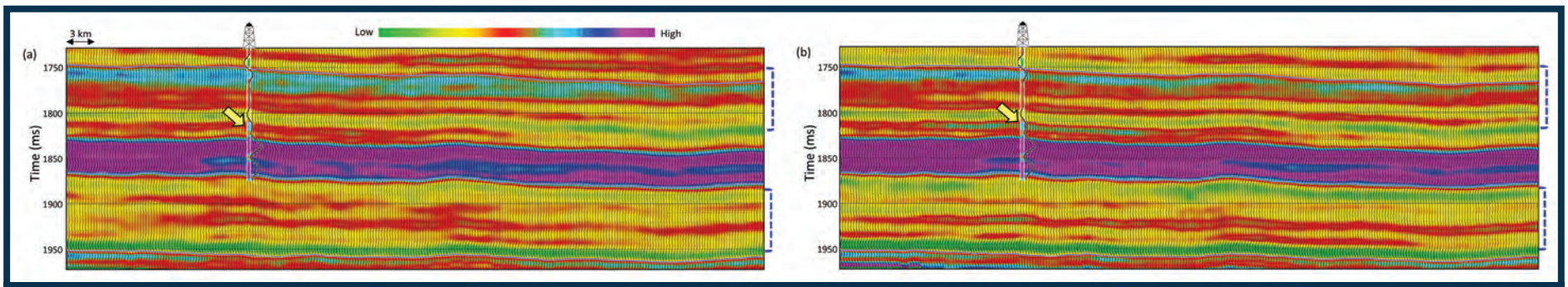

Figure 5: Segments of P-impedance sections generated using (a) the input seismic data, and (b) the data with thin-bed reflectivity inversion. The impedance log at the location of the well is shown as a curve, as a color strip. Notice the yellow arrows indicating the mismatch between log and the inverted impedance in (a) and a much better match in (b). Also, the intervals indicated to the right with dashed blue braces indicate the zones that show more well-defined events in terms of impedance in (b).

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Palaeozoic Plays of Northwest Europe

26-27 May 2016

The Geological Society, Burlington House, Piccadilly, London

Palaeozoic hydrocarbon plays in NW Europe remain relatively under-explored, both on- and offshore, despite the great success of local plays such as the Carboniferous and Permian in the southern North Sea. There is renewed momentum to understand and explore these plays further, including for example the joint-industry Palaeozoic Project, part of the UK Industry/Government's "21st Century Exploration Roadmap" initiative.

This Petroleum Group conference is intended to bring together new and existing knowledge about the Palaeozoic in NW Europe. Themes will include, but are not limited to:

- Palaeozoic exploration plays
- Palaeozoic source rocks
- Existing oil and gas field examples
- Outcrop analogues
- Palaeozoic shale oil and gas
- Pre-Mesozoic fractured plays

For further information and registration please contact:

Laura Griffiths The Geological Society, Burlington House, Piccadilly, London W1J 0BG.
T: +44 (0)20 7434 9944 or email: laura.griffiths@geolsoc.org.uk or visit the conference webpage: www.geolsoc.org.uk/PG-Palaeozoic-Plays-of-Northwest-Europe

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Call for Abstracts – 29 February 2016

Mesozoic Resource Potential in the Southern Permian Basin

7-9 September 2016

Burlington House, Piccadilly, London

The Southern Permian Basin covers a large geographic area of northern Europe including the UK, Netherlands, Germany, Poland, Denmark and Sweden. For many operators it has, and continues to be, a heartland for hydrocarbon production from Permian reservoirs. However, in this mature basin many opportunities remain within the overburden and particularly within the Mesozoic succession associated with heterolithic source rock, reservoir and seal facies and complex tectonics. Interest in this interval has also increased due to its geothermal energy and unconventional hydrocarbon potential. In this conference, we aim to bring together academics and industry workers from across the region to share ideas on the following themes:

- Regional cross-border stratigraphic correlation.
- Sedimentology including reservoir/seal extent, facies and diagenesis.
- Structural evolution and styles.
- Regional and local-scale hydrocarbon generation and charge.
- Examples of geothermal developments in the basin.
- Hydrocarbon field-scale observations (including geophysical, petrophysical and production data) and their application to further exploration, hydrocarbon/geothermal development within the Mesozoic.

There will be two days of oral and poster contributions from the 8th to 9th of September 2016 including sessions on regional overview/tectonics, the Triassic, Jurassic and Cretaceous.

Pre-Conference Activities (optional):

7th September 2016: Field excursion to the Lower Cretaceous of Surrey and Sussex led by Dr. Martin Wells, BP. Details to follow, should you wish to receive updates please register your interest with Laura Griffiths (laura.griffiths@geolsoc.org.uk) and Ben Kilhams (b.kilhams@shell.com).

Evening of the 7th September 2016: Evening Icebreaker Wine Reception at Burlington House.

Confirmed Keynotes:

Prof. Ralf Littke (RWTH Aachen University)
Dr. Mark Geluk (Shell)
Prof. Grzegorz Pienkowski / Prof. Piotr Krzywiec (Polish Geological Institute/Polish Academy of Sciences)
Prof. Jonas Kley (Georg-August-Universität Göttingen)

Call for Abstracts:

Please submit abstracts for oral and poster contributions that cover any of the above themes to laura.griffiths@geolsoc.org.uk and b.kilhams@shell.com before 29 February 2016

For further information please contact:

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GTWs

We were pleased to run several Geoscience Technical Workshops this year. Of particular interest was a GTW in Sicily (a first for AAPG) chaired by Raffa de Cuia, Davide Casabianca and John Cosgrove on fractured reservoirs, which also allowed for four fascinating field trips, including a guided trip up Mount Etna, in the snow, in April.

APPEX Regional 2015

We also recently held our APPEX Regional conference in Nice, France. This was an opportunity to focus regionally on exploration opportunities and prospects. This event was organized in cooperation with the AAPG Africa Region.

I mentioned at the beginning of this piece the importance we place on students, so, apart from the AAPG Imperial Barrel Award competition, which we see as the backbone of our student educational programs, the Europe Region Council have also granted $40,000 to 10 universities who have in turn included another 30 universities in their educational events and field trips. These programs allowed over 400 students to take part in AAPG-funded events in 2015 and we are very keen to ensure an even spread of opportunities to universities throughout Europe, rather than just accepting grant requests from the closest universities or those with higher profiles.

We are looking forward to Tony Dore, the latest Distinguished Lecturer, embarking on a tour in Europe next May and we are busy putting together a program for him.

Our thanks go to Keith Gerdes, AAPG Europe president whose term ended in June 2015. He brought great insight and experience to the Region leadership and we are very appreciative of the time he spent with the AAPG. He handed the leadership baton to Jonathan Craig, whom we all are very excited to work with over the coming two years.

Finally, mention needs to be made of the passing of our friend, colleague and a great former president of the Region, Vlasta Dvorakova. She is deeply missed as she was taken so suddenly from us in June. She worked tirelessly for the AAPG and was always on the end of a phone or Skype to help and support in any way she could.

Here's hoping for a slightly better 2016 for everyone. If you would like more information on any of the AAPG Europe activities please let us know.

INMEMORY

Eric Ericson, 87
Santa Fe, N.M., Oct. 24, 2015

Richard H. Lane, 73
Washington, D.C., Oct. 16, 2015

Babatope Olaleye, 60
Lagos, Nigeria, Nov. 2, 2015

Robert Ragsdale III, 90
Benbrook, Texas, Nov. 5, 2015

John Shaw (Member 1962)
San Marcos, Calif., Oct. 22, 2015

Ernest Szabo, 91
Rio Rancho, N.M., Jan. 5, 2015

James Prentice Walker, 78
Oklahoma City, Aug. 24, 2015

(Editor's note: "In Memory" listings are based on information received from the AAPG membership department. Age at time of death, when known, is listed. When the member's date of death is unavailable, the person's membership classification and anniversary date are listed.)

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conditioning of the gathers, generated the near-, mid- and the far-angle stacks.

Simultaneous Inversion

This is the input required for simultaneous inversion, which we have discussed earlier in our article published in the June 2015 issue of the EXPLORER. In figure 4 we show the amplitude variation of the near-, mid- and far-angle traces for one such gather for two equivalent events, before and after thin-bed reflectivity inversion. We notice, that though there is a small change in the amplitude of the events after thin-bed reflectivity inversion, which is expected, the relative amplitude variation with angle is very similar.

Finally, simultaneous inversion was run on the pre-stack data after preconditioning and thin-bed reflectivity inversion run on angle stacks. The result of the impedance inversion in the form of P-impedance sections, before and after thin-bed reflectivity inversion are shown in figure 5a and b. The overlaid impedance logs are shown as curves as well as colored strip logs. Notice the mismatch indicated with the yellow arrow between the log and the inverted impedance values in figure 5a, whereas it shows a reasonably good match between the two in figure 5b. Also, in the intervals indicated by the dashed blue braces to the right, many of the events are seen better well-defined and more focused in figure 5b than figure 5a.

We thus conclude from the above exercises that the varying frequency content in seismic data can pose problems while carrying out synthetic seismogram correlation to seismic data. The roll-offs that are seen on the frequency spectra of input seismic data can be flattened out with the application of thin-bed reflectivity inversion. This application is a post-stack process but can be fruitfully run on the near-, mid- and far-offset stacks, which then can be put through simultaneous impedance inversion. The results of such exercises can lead to more accurate interpretations, which obviously help the bottom-line.

We thank Arcis Seismic Solutions, TGS, for allowing us to present this work.

AAPG FOUNDATION

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Important 2016 Award Deadlines

Teacher of the Year Award *NOW OPEN!*
DEADLINE: JAN 15

The Foundation will award $6,000 to a U.S.-based K-12 Teacher for Excellence in the Teaching of the Earth Sciences. **Nominate a teacher who had a tremendous impact on your choice to enter the geosciences, or apply today!**

Grants-in-Aid *NOW OPEN!*
DEADLINE: FEB 15, 2016

The Grants-in-Aid Program provides financial assistance to graduate students (M.S. or Ph.D.) whose thesis research has application to the search for and development of petroleum and energy-mineral resources, and/or to related environmental geology issues. **Grants range from $500 to $3,000 each.**

Professorial Award *NOW OPEN!*
DEADLINE: FEB 15, 2016

The Foundation will award $1,000 in 2016 to a college or university professor for Excellence in the Teaching of Natural Resources in the Earth Sciences. **Nominate a professor who impacted your career in geology today.**

L. Austin Weeks Undergraduate Grant Program
OPENS: JAN 15, 2016 | DEADLINE: APRIL 15, 2016

The L. Austin Weeks Undergraduate Grant program provides $500 grants to undergraduate students and geoscience student associations (student chapters and clubs) worldwide to help with tuition, books, field trips and conferences.

Military Veterans Scholarship Program
OPENS: JAN 15, 2016 | DEADLINE: APRIL 15, 2016

The Military Veterans Scholarship Program (MVSP) is designed is designed to support veterans pursuing geoscience education programs at a four-year college or university. Grants range from $2,000 to $4,000 each and are intended provide financial assistance to veterans who are studying undergraduate level geoscience.

Learn more. Visit: **foundation.aapg.org**

Mimi Do, 2015 L. Austin Weeks grant recipient, Southern Utah University.