Introduction

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May 21, 2014

M-OSRP's research objective and goal: identify and address seismic processing challenges

The research objective of M-OSRP is to identify and address outstanding, pressing and prioritized seismic exploration challenges. M-OSRP develops and delivers step-change improved capability to the seismic processing tool-box. That goal delivers new options and processing methods that will be successful and effective when the methods and choices within the current tool-box can and will have difficulty and/or fail. What we provide will not always be the appropriate choice within the toolbox; but what we provide increases the number and types of options, and allows new capability, when needed. That new set of options then facilitates and supports exploring and producing in offshore and on-shore areas and types of plays that are currently too technically challenging, high risk, and unreasonable as investments and to help make those currently difficult or precluded E&P areas, plays and opportunities more reasonable, accessible and manageable.

What's behind seismic processing challenges? Why do we drill dry holes; why do we drill suboptimal development wells? Why do seismic processing methods have problems and fail?

Seismic processing methods are effective and successful when their assumptions and prerequisites are satisfied. When assumptions behind processing methods are not satisfied, these methods can fail. That, in turn, contributes to dry hole drilling and sub-optimal development well drilling decisions.

There are different categories of assumptions, among them are: (1) acquiring the required/adequate seismic data, and (2) required preprocessing, subsurface information, interpretive intervention, needed for methods to be effective.

The M-OSRP strategy and plan

The industry trend to more complicated and challenging offshore and on-shore plays demands more sophisticated and effective seismic processing and imaging methods, with more physically complete and realistic descriptions and concepts. Historically, at every stage of seismic processing and imaging evolution and advancement there has been a concomitant greater demand on providing more detailed and accurate subsurface information (for example, the evolution of seismic migration from post-stack migration, to pre-stack time migration, to pre-stack depth migration, to pre-stack migration-inversion, to RTM for heterogeneous anisotropic media) where each step was, at once, both more complete, effective and more demanding.

The confluence of seismic methods that make increasing demands for detailed and accurate subsurface information, together with the industry trend to regions and plays where providing that level of subsurface information is, in general, increasingly difficult to satisfy, and therefore represents a significant challenge at the present time and for the foreseeable future.

The inability to adequately provide that accurate and detailed subsurface information is a contributing factor to seismic processing, imaging and inversion breakdown and failure and subsequent dry hole drilling. There are two ways to address that type of challenge: (1) remove the assumption violation by finding, *e.g.*, new methods and approaches for satisfying the prerequisites, data acquisition assumptions, and accurate velocity models and other subsurface information, or (2) remove the assumption, by developing new methods that do not make that assumption.

Methods have assumptions and requirements: How does M-OSRP decide whether to advance seismic capability by: (a) developing new methods/approaches to provide what a current method requires or (b) developing fundamentally new methods that do not have those requirements/assumptions?

M-OSRP adopts one or the other of these attitudes and approaches for different assumptions, requirements, steps, and links in the seismic processing chain that's under stress and duress and is in need of attention and improvement.

We describe here the basic strategy that M-OSRP adopts in deciding between: (a) finding a better way of satisfying a current method's assumptions and requirements, and (b) developing new and more effective methods that do not require those assumptions.

If the method requires, *e.g.*, adequate data collected or a better description of the seismic experiment (*e.g.*, the source signature and radiation pattern and deghosted data) then find an approach and method to satisfy those requirements. However, if the method requires detailed subsurface information, or interpretive intervention, to be effective and successful then develop a direct method that doesn't require that subsurface information.

Why the aversion to providing subsurface information?

As the petroleum industry trend world-wide moves to ever more complex and challenging plays, the ability to provide subsurface information has become (and will continue to become) an increasingly serious impediment to effectiveness. That fact, explains the reasonableness and (in fact) the necessity of seeking new methods that can be more effective than current capability, and without subsurface information.

A central purpose of M-OSRP has been, and remains, to provide a consistent and comprehensive set of seismic processing methods, for every link in the processing chain, that are direct and do not require any knowledge of subsurface information.

The tools

The methods M-OSRP develops to satisfy prerequisites, *e.g.*, (reference wave prediction separation, source signature and radiation pattern, and source and receiver deghosting) benefit from forms of wave field separation methods derived from Green's theorem (the extinction theorem). Recent papers on this subject can be found in
`http://mosrp.uh.edu/news/recent-published-papers-deghosting`

Those preprocessing methods do not require subsurface information. All ISS subseries require these preprocessing prerequisites (provided by variants of Green's theorem) to achieve ISS processing objectives.

The inverse scattering series communicates that <u>all</u> processing objectives are achievable directly and without subsurface information. Isolated task ISS subseries are identified that directly and without subsurface information achieve free surface and internal multiple removal, depth imaging, target identification and Q compensation without Q.

The combination of Green's theorem preprocessing and ISS processing provides every link in the processing chain with methods that are direct, and do not require subsurface information.

M-OSRP and Multiples

The early history of multiple removal methods required at every step a more detailed and accurate velocity model (for example, stacking, to FK filters, to Radon, and high resolution Radon or 1D earth and statistical assumptions concerning primaries and multiples (Deconvolution)). A sea-change in multiple removal capability arrived with methods that to one extent or another didn't require subsurface information or interpretive intervention. Methods from the Delphi consortium depended on either subsurface information and/or interpretive intervention, whereas the inverse scattering series (ISS) methods from M-OSRP did not. That is the reason that the ISS internal multiple attenuator has assumed a mainstream industry status and recognition as the high water mark of internal multiple capability. There is ample evidence to support the latter claim, including the 2013 SEG (Thursday, September 26, 2013) Internal Multiple Workshop where 9 of the 10 presenters showed ISS internal multiple results as the state of the art available capability for that seismic internal multiple goal and objective. ISS internal multiple attenuation has become fully mainstream.

Challenge we face

However, we also recognize, report and emphasize that the current industry portfolio/trend and focus today (and for the foreseeable future) makes it clear that there is a large and significant gap between the current challenge for the removal of free surface and internal multiples, where the specific issues are that: (1) the multiple generators and the subsurface properties are ill-defined and complex and (2) *the multiple can too often be proximal to or interfering with primaries.* That type of challenge of removing multiples proximal to, and/or overlapping with, primaries (without damaging primaries) is well beyond the collective capability of the petroleum industry, service companies and academic research groups and consortia—in their ability to effectively address that issue today.

There is a need for new basic concepts, and fundamental theory development that will first need to take place, and following that delivery the practical application issues will need to be addressed.

The plan

At the 2013 SEG, we proposed and described a three pronged strategy (please see the link and slides below) to address that challenge, that M-OSRP will pursue—with the potential to provide the step-change increased and necessary capability. That strategy and plan responds to this outstanding, pressing and prioritized challenge. That level and magnitude of challenge (and the potential opening and delineation of new petroleum reserves and the scale of the opportunity that overcoming it represents) resides behind our commitment to develop and deliver fundamental new concepts, algorithms with step change increased capability, and has returned multiple removal (from its being viewed as a relatively mature subject and project that helps "pay the rent") back to center stage as a major research project and focus within the Mission-Oriented Seismic Research Program. We feel that our background and experience gives us a good chance to develop, and to deliver, the next level of required capability.

Below please find links for the 2013 SEG abstracts/posters/presentations and slides that relate to this communication.
`http://mosrp.uh.edu/events/event-news/seg-annual-meeting-2013`
`http://mosrp.uh.edu/news/seg-annual-meeting-2013`

In the table of contents, we have divided the contributions to this Annual Report into categories:
(1) (a) Prerequisite satisfaction and ISS multiple removal, (b) case studies
(2) Beyond internal multiple attenuation: (a) Removing artifacts/spurious events, (b) internal multiple elimination
(3) ISS depth imaging without the velocity model: update
(4) Analysis and tests of amplitude information at the image point from asymptotic and wave equation migration: implications for RTM.

2014 SEG Expanded Abstracts that relate to these topics can be found in the link:
`http://mosrp.uh.edu/research/publications/seg-abstracts-2014`

What is asymptotic and wave equation migration amplitude analysis <u>with</u> a velocity model doing in an M-OSRP report? What are our objectives, what have we contributed and what are our plans?

While deriving preprocessing methods (described above), and one-way-wave Stolt pre-stack wave equation migration (WEM) from Green's theorem, for our class at UH in Seismic Physics, it was natural to consider how to derive a wave equation migration for two way propagating waves (for RTM) from Green's theorem. That produced the first WEM RTM.

Please see the link
`http://mosrp.uh.edu/news/wave-equation-migration-RTM`

Wave equation migration (WEM) consists of predicting a source and receiver experiment at depth, and then a coincident source and receiver experiment at time equals zero. There are two other original and classic migration imaging conditions, (1) the space and time coincidence of up and down going waves and (2) the exploding reflector model.

These three migration/imaging conditions are not equivalent, with the latter two representing asymptotic approximations of the WEM concept and algorithms. There are several advantages to WEM compared to asymptotic forms of migration: (1) a definitive answer as to whether a subsurface point is an image point; (2) the amplitude analysis at the image point, and (3) the ubiquitous wave coverage and illumination of WEM compared to asymptotic ray based methods. Those advantages and differences between asymptotic and WEM are present for both one way and two-way (RTM) methods.

The first definitive examination and comparison of WEM and asymptotic (Kirchhoff) migration, for one-way-waves, and their respective amplitude information and analysis at the target is reported in this Annual Report. The asymptotic approximate image is useful for structure maps, but doesn't provide an angle dependent reflection coefficient. WEM provides both structure and amplitude information at the image point.

Asymptotic (Kirchhoff) approximate migration doesn't provide an approximate experiment of a predicted coincident source and receiver at time equals zero at an image point.

Asymptotic migration loses that definiteness and meaning of WEM at the image point and provides instead a fixed travel-time curve with "candidate" image points. The physical meaning and amplitude benefits of the WEM experiment at the image point are lost in asymptotic migration, whether for one way waves or for RTM (all current RTM methods are asymptotic migration).

This has important implications for all current RTM methods, which are asymptotic migration, and suggests and encourages a look at the first WEM RTM that M-OSRP has pioneered, and will keep developing. There are also implications for those looking at increased *illumination* by imaging primaries and multiples separately, since all current approaches to that problem use asymptotic RTM methods, which are intrinsically illumination challenged to begin with. Once again, that's an opportunity for WEM RTM.

M-OSRP doesn't plan to be involved long term in the RTM business, because it's a velocity dependent method.

Every year those pursuing RTM methods describe their need for a yet more complicated and accurate set of heterogeneous and anisotropic velocities. We have no special concept, or idea (or interest) to compete in that "provide the velocity" arena, where many capable and resourceful and hard-working researchers now reside. Our goal is to examine and define the potential and the added-value of WEM RTM compared to asymptotic RTM, in some simple but meaningful two dimensional examples, and then encourage others to pursue the further development, where their experience and expertise will expedite that continued development, application and delivery. That's our current plan for RTM.

ISS depth imaging without the velocity model

In this Report, HOIS, a ISS direct depth imaging algorithm without a velocity model is applied to the Marmousi model.

The results are very encouraging and the computer run time is 30% longer than a single Stolt pre-stack water speed migration.

Our prediction for the future is that ISS depth imaging will enter the seismic imaging tool box with stand-alone imaging capability in the next 5-10 years. Our first published field data test of ISS imaging on the Kristin North Sea data set demonstrated concept and method viability.

The technical steps needed between viability and providing a new and more effective seismic imaging option within the seismic toolbox are understood, and will be taken. ISS depth imaging will in the future have the same mainstream role for depth imaging under the most challenging and daunting subsurface complexity that ISS multiple removal plays today, and will be the new and necessary option available for exactly those same daunting circumstances. Those who understand the derivations and logic behind the ISS free surface and internal multiple attenuation methods, will have no problem with the logic that leads to ISS depth imaging. The ISS multiple removal methods and the ISS depth imaging and inversion algorithms derive from the same single set of ISS equations.

Summary/Focus

M-OSRP is pleased to see the mainstream usage and application of the ISS internal multiple attenuator.

However, the current challenges frequently faced with on-shore plays and complex off-shore plays to remove multiples of different orders, and, proximal to, or interfering with, primaries, and without damaging primaries, raises the bar on needed multiple removal capability. That new level of multiple removal challenge is currently beyond the collective capability of the petroleum industry to address. M-OSRP has a three pronged strategy and plan to address that challenge and to develop and deliver an effective response. That is currently (and near term will remain) our central and principle focus and resource allocation. That new algorithmic strength and capability developed within M-OSRP will have a commensurate higher level of compute demand. Our collaboration/cooperation/partnership with IBM connects the "what to compute" for more effectiveness from M-OSRP with new visions of "how to compute" from IBM. That combination of "what" and "how" are essential for providing a new, more effective and relevant capability to our sponsors.

We plan to continue our research in WEM RTM (with a velocity model) and ISS direct imaging (without a velocity model).

For the near future, these imaging projects, will move forward, but with somewhat less resource allocation in comparison to the serious and unfinished business of removing multiples.

There are several reasons for this relative emphasis of projects within M-OSRP: (1) there are numerous regions in the world (*e.g.*, the Middle East, Central North Sea, . . .) where without more capability and effectiveness in removing multiples, making advances in imaging (that depend on multiples having been removed) are irrelevant or useless; and (2) there is often a resistance among researchers in seismic imaging to recognize and acknowledge an imaging challenge as existing, beyond the one that they are currently able to address.

M-OSRP has a portfolio of projects that takes ownership of all the links in the seismic processing chain. Some of our projects are embryonic, whereas others are more "mature" and help "pay the rent". M-OSRP is very aware that some of the concepts we develop and methods we pursue, and messages we communicate, are at variance with the conventional, the consensus view and mainstream concepts and thinking. To provide fundamental new step change capability requires the ability to be resolute and to flourish and to succeed in the face of considerable doubt and skepticism.

No real advance in science ever occurred without running into issues and obstacles from the "consensus view"

It wasn't too long ago that a statement like "multiples can be predicted directly and without subsurface information" was greeted with eyes rolling and disbelief. Now that idea and methodology have become mainstream. Today, saying it will be possible to "directly depth image without a velocity model" generally elicits that same incredulous response.

We are enormously fortunate and deeply grateful for your encouragement and support. Your support and confidence allows us the opportunity to perform fundamental directed "mission-oriented" seismic research that will continue to deliver effective responses to pressing and prioritized seismic processing challenges.

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May, 2014