MEMOIRS

This month we feature memoirs of Ruben Martinez, who has been active in our industry for over thirty years. Ruben has been associated with Geophysical Service Inc. (GSI), Halliburton Geophysical Services (HGS), Western Geophysical Company(WGC), Andrew's Group (AGI) and Petroleum Geo-Services (PGS). Author and co-author of many articles, Ruben holds many patents in seismic data processing.

Reflections on Seismic Exploration:

A look at the past reveals a bright future ahead for the next generation of geophysicists

Ruben D. Martinez
Petroleum GeoServices (PGS)

My first contact with geophysics was as a student of geophysical engineering in my native Mexico in the early 70's. As a young geophysicist, I was fascinated by the complexity of the seismic wavefields (Figure 1) that held clues to the mysteries of the subsurface Earth. For many years, these intriguing images have posed a broad range of challenges to the geophysical community from the field geophysicist making decisions concerning survey design, to the processing geophysicist applying sophisticated algorithms to remove unwanted energy (noise) and enhance useful information (signal), to the seismic interpreter utilizing signal information to identify potential oil and gas reservoirs. These wavefields and the challenges they present led me to graduate studies in the United States of America which culminated in an MSc in geophysics and a PhD in geosciences. Since then, I have been associated with several geophysical service companies working in many aspects of geophysics. For three decades I have been focused on seismic exploration for oil and gas reservoirs, and from my experiences I offer these personal reflections on the seismic industry and more specifically on seismic technology development.

My passion has always been seismic exploration and field development technology. This includes the acquisition, processing and interpretation of seismic data. During my career, I have had the great opportunity of working as a field geophysicist, processing geophysicist, seismic interpreter, reservoir geophysicist, and research geophysicist and later as a director of seismic technology development. This spectrum of activities has provided me with an assortment of very rewarding and interesting experiences. I have witnessed many economic changes in the seismic industry and the influences these changes have had on advancing technologies. These changes have correlated somewhat with fluctuations in the oil and gas prices, which have been driving the majority of the technology advances in seismic exploration (Thurston and Stewart, 2005).

Over the years, advances in seismic technology have been traditionally fostered by demands for efficiency, effectiveness and accuracy in acquiring, processing and interpreting seismic data. One example of this is the evolution of marine data acquisition geometries from a single streamer configuration to the eight, twelve or sixteen streamer implementations used today. The sole purpose of these changes has been to achieve high efficiency and effectiveness in data collection. However, these changes in acquisition geometry have posed significant challenges to seismic data processing. Some processing algorithms developed to process seismic data collected with one streamer are no longer useful to process data collected with several streamers. For example, the performance of 3D multiple attenuation and wave equation prestack depth migration algorithms is affected by the multi-streamer geometries, especially when the cross-line sampling is sparse. Additional effects like streamer feathering further complicate the performance of these algorithms. These in turn translate into aliasing problems. In order to overcome these problems, sophisticated survey regularization and trace interpolation algorithms have to be applied.

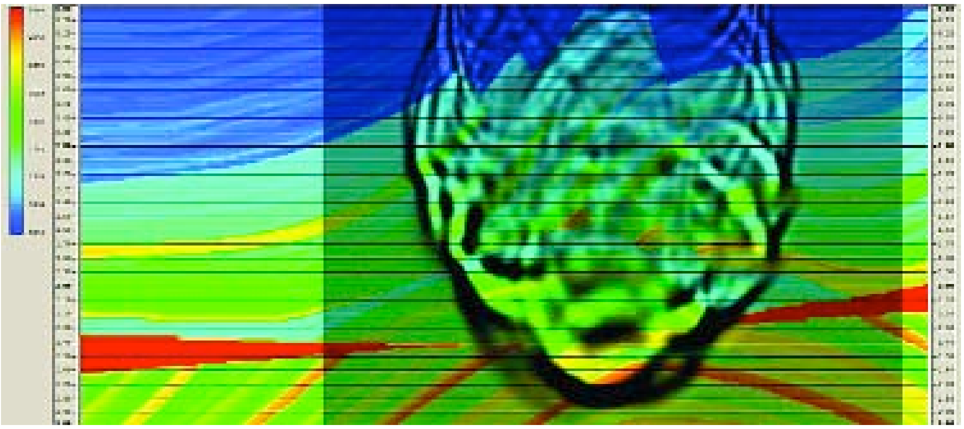

Figure 1. Illustration of a snapshot taken at a given traveltime through the Marmousi model. The wavefronts show the complexity of the wavefield when traveling through this very complex Earth model. The velocity scale in the color scheme is given in kilometers per second. The vertical scale is in depth and in kilometers.

In the example above we see a chain reaction created by the evolution of data acquisition geometries. As a consequence, seismic processing techniques must advance accordingly. This process forces a continuous evolution in seismic processing technology and promises a variety of new challenges for geophysicists in the years ahead.

Continued on Page 43

Continued from Page 42

Scenarios such as these emphasize that to understand the seismic wavefield complexities, it is essential to understand signal and image processing. For example, in seismic data collection, wavefield sampling and antenna theory are essential elements in recording high quality seismic data. Likewise, in seismic data processing, the same concepts used in data collection are vital to ensure a reliable application of seismic signal processing and image reconstruction (migration) techniques.

Over the years, I have observed that some processing technologies evolve in cycles. These technologies were developed in the past and used with limited success, then abandoned. Several years later they were adopted again to address the same geophysical problem. This phenomenon is likely due to the fact that the original problem remains unsolved or partially solved, and this presents a challenge for later generations of geophysicists who become motivated to try and solve it once more. With renewed enthusiasm, young geophysicists are apt to explore new ideas to solve old problems that former geophysicists could not resolve or only partially answered. These young geophysicists revisit theories with the hope of solving the exploration problem at hand. However, sometimes the same obstacles to solving the problem are faced again and again.

One such technological cycle is the seismic attenuation problem, better known as the Q (quality factor) estimation and compensation problem. The solution to this problem has been attempted on several occasions. However, the estimation of Q models to be used as input for Q compensation software is still not fully solved. Current efforts to estimate Q use amplitude spectral ratios obtained from the seismic data. This approach was researched in the 1980's with limited success, and the instability detected in these estimates years ago is the same instability that is observed today (Jacobson et al., 1981). Residual noise and multiples usually prevent the geophysicist from estimating reliable Q values (Sams et al., 1990). This problem (transmission loss and dispersion effects) severely decreases the seismic resolution and reduces our ability to characterize hydrocarbon reservoirs with precision. It is imperative that future generations of geophysicists solve this problem, and I suggest increasing research and development efforts in this area.

My experiences in seismic processing have been related to classical problems such as deconvolution (wavelet processing and seismic attenuation compensation), corrections for the near surface effects (statics), noise and multiple attenuation, survey regularization and interpolation, velocity estimation (in time and depth) and seismic imaging (in time and depth).

Today, a great portion of the budgets dedicated to research and development of new processing algorithms is devoted to develop seismic imaging technology. A relatively small portion of the available financial resources are allocated to R&D projects related to the development of processing techniques to be applied prior to imaging (pre-processing). Recently, I had the honor of presenting the Milton B. Dobrin lecture at the University of Houston (Martinez, 2005). In this lecture, I addressed the issues and challenges that still exist in processing seismic data prior to imaging. The pre-processing steps applied

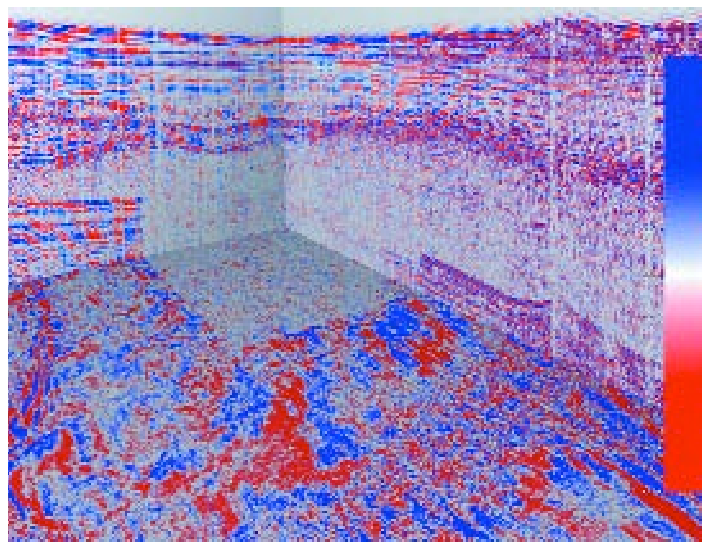

Figure 2. Isometric view of a stacked 3D volume. The attenuated portion of the volume (corner) corresponds to the data after the elimination of surface multiples. The rest of the volume shows the stacked data contaminated by the surface multiples. This figure illustrates the strength of the multiple reflections and the effectiveness of the processing method (SRME) to eliminate the multiples.

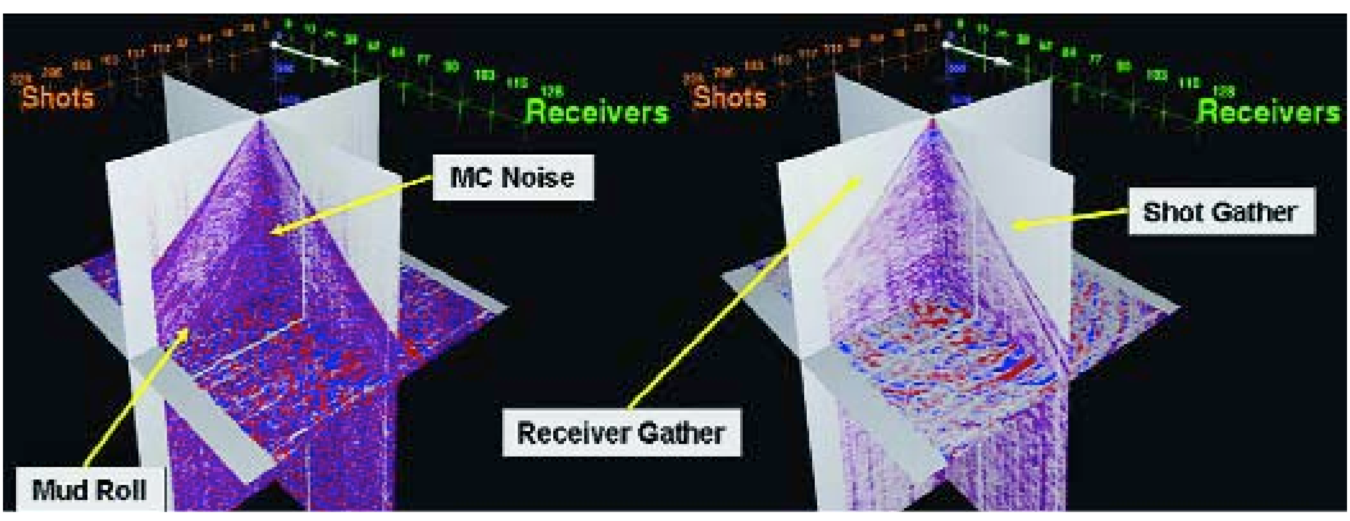

Figure 3. 3D OBS (Ocean Bottom Seismic) data collected with patch geometry and displayed in the source and receiver domains. The left panel shows the data contaminated with noise (mud roll and mode converted noise). The right panel shows the same data but after dual wavefield noise attenuation followed by 3D f-k filtering.

Continued on Page 44

Continued from Page 43

prior to seismic imaging are, in my opinion, key to obtaining a successful result after seismic imaging. The reason is simple. The recorded seismic wavefields are not commonly sampled with the density and survey regularity assumed in the seismic imaging algorithms. These algorithms are designed to produce good results when the data has been collected with adequate trace density and regular geometries (Figure 2).

But why do we see this R&D trend in seismic imaging? One possible explanation is that the university programs today focus on seismic imaging. Another possible reason is that companies that perform R&D (oil and service companies) allocate the largest budgets to seismic imaging algorithm development. And for good reasons, obtaining an accurate image of the subsurface in depth is very valuable from the technical and business point of view. However, as wave equation migration and 3D multiple attenuation algorithms are used more often, the problems associated with the lack of proper pre-processing will need to be addressed with more resources, both human and financial. This trend is illustrated by the current efforts being made in noise attenuation, survey regularization and trace interpolation to improve the performance of multiple attenuation (e.g. 3D SRME) and imaging algorithms. Their poor performance is commonly attributed to the use of irregular and sparse geometries in data acquisition, poorly attenuated noise, etc.

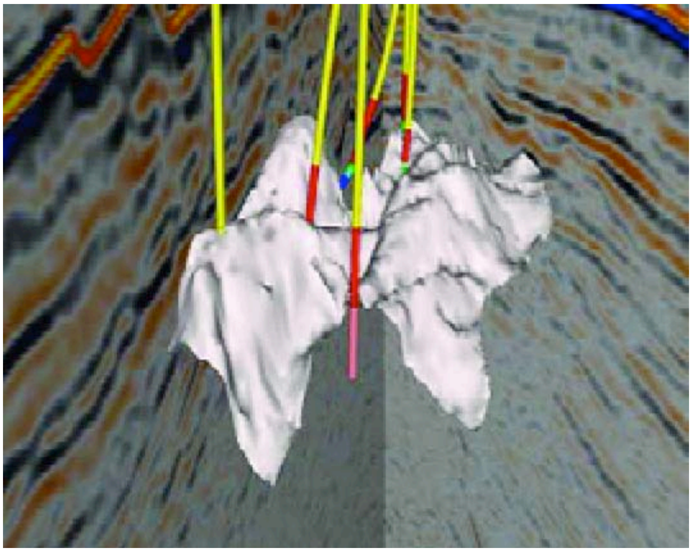

Figure 4. 3D prestack depth migrated data showing a salt body in a geologically complex area with wells posted.

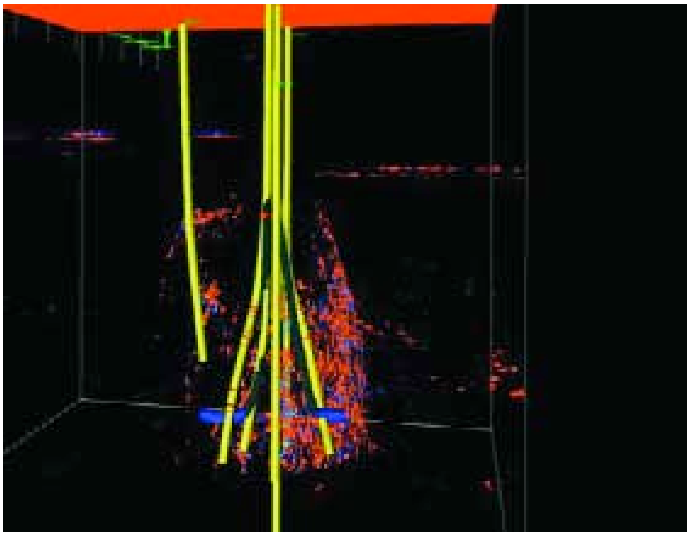

Figure 5. 3D view of seismic attributes extracted from the seismic amplitudes with wells posted.

Velocity estimation for seismic imaging is a key but difficult task; however, another important challenge in processing is signal recovery from noisy data.

After working with seismic data for about thirty years, I have learned that seismic velocities control the accuracy of the traveltime calculations and the validity of the seismic amplitudes so they can be related, in the relative sense, to the reflection coefficients. Therefore, velocity estimation is, in my opinion, the biggest challenge in seismic processing and interpretation. There is no doubt that the geophysical community has made significant advancements in velocity estimation, but at the same time the search for oil and gas reservoirs has become more difficult. The reservoirs are deeper and associated with very complex geologic settings, e.g. sub-salt plays. When the geology is structurally complex, the recovery of reliable velocities and therefore accurate event positioning and amplitudes represents a major challenge, and this topic will be the subject of many R&D projects for new geophysicists in the future. To mitigate this problem, several innovations must occur in seismic data acquisition (field geometries) so that processing techniques can work more reliably to produce seismic events positioned in space and high fidelity seismic amplitudes accurately.

There are other geologic settings where the geologic structures are gentle (low relief). Under these conditions the estimated velocities will be more certain and therefore the seismic amplitudes will also be recovered more accurately after migration.

Seismic noise is perhaps the biggest obstacle for the processing geophysicist (Figure 3). The extraction of signals from noisy data is still considered an ultimate goal in seismic processing, since imaging algorithms will not extract signal from noise. Unfortunately, seismic imaging algorithms move the energy, whether it is signal or noise, as dictated by the velocity field. Over the years I have learned to have respect for seismic noise. Many times, I have seen the lack of noise understanding cause unsuccessful results after a sophisticated processing sequence has been applied. Many geophysicists ignore seismic noise or simply assume that current noise attenuation portfolios are so broad that they will offer techniques to attenuate almost any kind of noise. Nothing is farther from the truth. As the data acquisition geometries become more complex in an effort to increase productivity in data collection, the ability to attenuate noise in the processing center diminishes, and problems like spatial aliasing or ray parameter aliasing prevent any transform based noise attenuation technique from being effective. Thus a great deal of effort is required to recover signals with high fidelity from noisy measurements.

As it is well known, the seismic image obtained as a final processing product has two components; the seismic events in space and their recovered seismic amplitudes (pre or poststack). The seismic image is commonly used for detailed structural interpretation and reservoir characterization using the poststack migrated amplitudes or AVO attributes derived from prestack

Continued on Page 45

Continued from Page 44

migrated amplitudes. After obtaining the final seismic image (post or pre-stack), reservoir geophysics is commonly used for interpreting seismic attributes (e.g. amplitudes) to produce estimates of rock properties (Figures 4 and 5).

The time I spent working in reservoir geophysics was one of the most exciting periods of my career. My job was to apply and perform reservoir geophysics research and development. I found this work the most challenging because the seismic data is ambiguous and the meaning of the seismic amplitudes and traveltimes may be interpreted in many different ways. I enjoyed developing constrained inversion methods to extrapolate rock properties derived from well data at vertical resolution much greater than the seismic data. Rock properties such as P-wave acoustic impedance and S-wave acoustic impedance were used, when reliable AVO (amplitude versus offset) analysis was performed. The resulting products were maps of lithology and fluid distributions in the subsurface. These rock property estimates were averaged models since the seismic data has lower resolution than the well data. This is true even assuming that we can correctly estimate the seismic wavelet and remove its bandlimiting effects.

As a reservoir geophysicist, I found that the main challenge was achieving data integration (seismic, geologic, well and reservoir engineering data) to produce a consistent reservoir model. I believe that the process of building reservoir models (static and dynamic) will continue to be a challenge to future geoscientists and engineers.

Alongside the seismic software evolution, computer technology has advanced at an overwhelming rate over the last three decades. This evolution in hardware technology is vital for computer intensive algorithms like wave equation prestack depth migration. In this case, the theory and algorithms have been known for years, but their commercial use is now possible due largely to the availability of today's powerful computers. This means that future seismic technology development depends on two aspects. One is the talent of the geophysicists to develop new ways to acquire, process and interpret seismic data. Another is the geophysicist's ability to capitalize on the advances of hardware technology that enable us to collect high fidelity data, use complex algorithms to process data, and quickly interpret large volumes of seismic data.

Today, my work as director of seismic processing technology development has given me a much wider vision of seismic technology. Managing technology development is yet another exciting area of the seismic industry and presents challenges that are varied and rewarding. When developing new seismic processing solutions, there are three basic ingredients required to generate a useful piece of geophysical technology. The first one is to develop the right technological vision. The second ingredient is to follow the right project management steps to achieve the desired results, such as commercialized technology. This involves managing an idea all the way from inception to the finished product, such as designing and manufacturing a geophone, streamer or computer program to process data. But the third and most important ingredient is to choose the right people to perform the tasks required to generate the technology. With these three ingredients, success is guaranteed. It is very simple! Ultimately, the foundation of successful seismic processing development rests upon the geophysicists and the quality of their contributions.

Being an exploration geophysicist is very rewarding. The opportunities that this profession offers to a geophysicist are broad and exciting. I have had the opportunity to enjoy many aspects of this profession, and I am delighted at what the future holds. There are great rewards to be gained from generating useful seismic acquisition, processing and interpretation technology. There is nothing more satisfying to a scientist or an engineer than seeing the outcome of his or her work functioning well and producing results that are useful in finding hydrocarbons, as is the case in our industry.

For the young geophysicists coming to the professional life, I believe that they have a wealth of opportunity in front of them. Many fascinating technical problems remain to be solved in the seismic industry, and new problems are arising as a result of the technology evolution. This evolution in seismic technology creates new challenges as fresh geophysicists strive to acquire, process and interpret seismic data more effectively, efficiently and accurately.

References

Jacobson, R. S., Shor, G. G., Jr. and Dorman, L. M., 1981, *Linear inversion of body-wave data - Part II: Attenuation versus depth using spectral ratios:* Geophysics, Soc. of Expl. Geophys., 46, 152-162.

Martinez, R.D., *Some Salient Issues in Seismic Data Processing Prior to Imaging:* Annual Milton B. Dobrin Lecture in Geophysics, University of Houston. February 2005. http://www.gshtx.org/en/cev/?137

Sams, M. and Goldberg, D., 1990, *The validity of Q estimates from borehole data using spectral ratios (short note):* Geophysics, Soc. of Expl. Geophys., 55, 97-101.

Thurston, J.B. and Stewart, R.R., 2005, *What drives innovation in the upstream hydro - carbon industry?* The Leading Edge, Vol.24, No.11, pp 1110-1116.

Acknowledgments

I am grateful to Pamela Lucia for her help to edit and improve this article. Also, I would like to thank Matthew Karazincir, John Brittan and Joel Starr for providing some of the data examples shown in this article. R