Introduction to this special section—Seismic Noise

As hydrocarbons become more difficult to find and produce, the need for better seismic data quality increases. Currently, we are exploring and producing in areas with weaker signal and stronger noise. Today, noise is an increasing challenge that demands more of the geophysicist.

With this in mind, SEG's Research Committee sponsored the 2007 summer research workshop, "Seismic Noise: Origins, Prevention, Mitigation, Utilization" in Antalya, Turkey. Some of the presenters have written articles for this special issue; we also have included some noise articles that were not presented at the workshop. In their papers, Brittan et al. and Gulunay present methods to attenuate seismic interference noise on marine data. Crider et al.'s case history describes the impact noise attenuation had on the interpretation of the Horn Mountain Field in the Gulf of Mexico. The signal-to noise improvements possible with over/under streamer acquisition are shown by Özdemir et al. Reilly et al. apply a novel approach to processing 2-C OBC data to a 3D survey from the Arabian Gulf, while Karsli et al. discuss ground-roll attenuation with Wiener filtering.

Halliday et al. use active and passive source seismic interferometry to estimates surface waves, and results from an acquisition method designed to attenuate power line noise are shown by Özkan and Özer. Broadhead examines the effect of random noise on wavelet estimation. Wiener filters are used by Wang et al. to attenuate coherent noise recorded on seismic arrays designed for passive monitoring. Curvelets are used by Neelamani et al. to attenuate noise on a poststack 3D data set. Belfer et al. and Eisenberg-Klein et al. use multifocusing and CRS, respectively, to improve the signal-to-noise ratio of some example data sets.

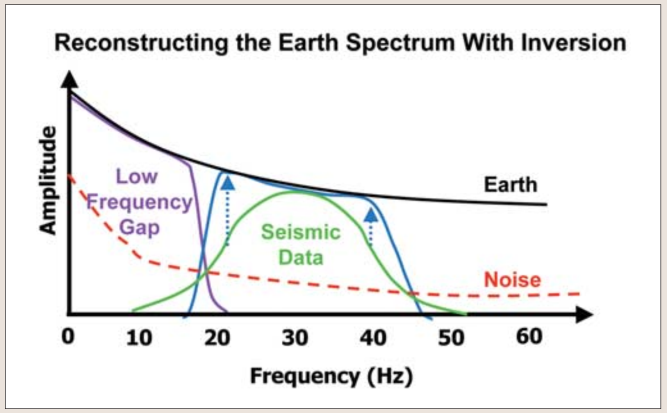

Figure 1. This illustration shows the reconstruction of the Earth's spectrum by reservoir property inversion. The extent of the Earth spectrum that can be recovered (blue curve) is limited by the frequency range in which the seismic signal amplitude (green) is above the noise amplitude (red). The zero-frequency information can be estimated from imaging velocities, and the higher-frequency information can be obtained from the seismic reflection data. There is a gap (purple) in the seismic information at the lower frequencies. Obtaining low-frequency information is particularly challenging because of increased noise at low frequencies.

Why is this topic important now? In the past, when the major seismic application was simple structural imaging, large field arrays were used to suppress ambient noise and surface waves. In data processing, common midpoint stacking along with AGC were employed to beat down the noise. Additional standard processes included deconvolution, *f-k* filters, and Radon filters to reduce strong surface-related multiples and ground roll. As acquisition systems improved, the number of channels increased, and offshore hydrophones in streamers provided data with higher signal to noise ratio. Geophysicists could get more than traveltimes and structure information out of seismic data. Today, seismic applications are more demanding and need better

Figure 2. Attendees of the SEG Research Workshop in Antalya, Turkey explore the nearby Termessos amphitheater dating from 300 B.C.

noise mitigation. Reservoir property estimation and inversion require better amplitude and phase fidelity for broader bandwidth prestack data. Furthermore, single-sensors provide better resolution and better economy and S-wave data provide complementary information for reservoir property inversion. However, single-sensors and S-wave data are nosier than conventional data from groups of receivers. Finally, we are exploring in more difficult environments with much poorer signal-to-noise ratios. Today, the noise challenge is the critical factor in our ability to reach these more demanding applications.

Reservoir property inversion requires broader bandwidth than structural imaging, and bandwidth can be defined as the frequencies for which the processed signal amplitude is greater than that of the noise. Therefore, the definition of bandwidth depends on the quantification of the noise. Figure 1 is a diagram that illustrates the bandwidth needs of reservoir property inversion. The solid black curve is the desired Earth spectrum, which can be modeled from well logs. The green curve shows a Ricker wavelet spectrum for the seismic data, and a red dashed curve illustrates the noise floor. The Ricker wavelet is an optimal imaging wavelet in terms of the shortest wavelet for the broadest frequency spectrum. In inversion, the wavelet is removed to obtain the blue curve, but note that the extent the Earth spectrum can be recovered is limited by the noise. The lack of low-frequency signal above the noise is a particular problem for the inversion, and this low-frequency information must be supplied from geological models of the area. The inversion would be better constrained if low-frequency seismic information above the noise could be measured. Unfortunately, the environmental noise is not flat, but increases dramatically at the low frequencies resulting in considerable challenges in recording and utilizing these low frequencies.

Along with more demanding applications, we are exploring in more difficult environments where signals are small (deeper targets, targets under basalt, salt or artic ice, or generated with weaker sources) and where noise is huge (more seismic surveys being acquired nearby, producing fields, sur-

2007 Summer Research Workshop
Seismic Noise: Origins, Prevention, Mitigation, Utilization

Organizing Committee:
Chris Krohn (ExxonMobil)
Necati Gulunay (CGGVeritas)
Shuki Ronen (CGGVeritas, now Chevron)

Technical Committee:
Ali Ozbek (WesternGeco)
William Abriel (Chevron)
Peter Pecholcs (Saudi Aramco)
Eric Vershuur (Delft)
Ken Matson (BP)
Ali Tura (Shell)
Joseph Paffenholtz (Fairfield)

face scattering, shallow multiples, low-frequency environmental noise). Since large arrays can limit the signal's bandwidth, there are advantages to using point multicomponent single sensors. Also, due to high deployment costs, a small number of these point receivers are often used in noisy environments, such as on the ocean bottom, in shallow water, and in producing fields. Our newer recording systems have a larger dynamic range to record both weak signals and strong noise without arrays, but the signal-to-noise ratio on raw single-sensor data is low. We often use smaller sources which contribute to a low signal-to-noise challenge. In addition, we are acquiring more and more data in noise-producing oil fields—either to monitor production or to explore deeper targets under the producing fields. Offshore seismic crews share the ocean with seismic interference—an increasingly common problem. Greater effort is required to produce the desired high-fidelity data, especially for broadband, prestack needs such as reservoir property estimation.

What is seismic noise? All geophysicists working with seismic data have their own definition of seismic noise. At the start of the workshop, noise was defined relative to signal. Basically, seismic signal is the recorded energy utilized by the application from which the seismic data were acquired. Therefore, seismic noise is any recorded energy that interferes with this seismic signal. In other words, what one wants is signal and what one does not want is noise. With this definition, signal for one application, such as P-waves for conventional reflection imaging, would be noise for a different application, such as the P-waves recorded on the horizontal geophones for the application of P-S converted-wave imaging.

There are many types of seismic noise, each with its own characteristics and behaviors. It is helpful to separate the noise origins into three basic types: ambient or background noise (wind, swell, nearby seismic acquisition, production); source-generated noise (direct and scattered surface waves, air waves, multiples); and instrument noise. Within these noise origins, we often classify the data as being either coherent from trace to trace or random, and our mitigation methods typically exploit the coherency or randomness of the noise. However, in the latter case the event may only appear random because sampling in the proper data domain is inadequate for its coherency to be apparent (i.e., the coherence length is short). In addition to the noise observable on raw gathers, processing and imaging combined with acquisition geometry limitations can produce noise on the final images.

How do we meet these challenges? Understanding the origin and source of the noise along with its propagation behavior could uncover better ways to either prevent recording the noise or to mitigate it. But noise can include information about the subsurface; can it be utilized? Ground roll is a strong noise that must be removed for subsurface imaging, but it also can be utilized to invert for the near-surface shear modulus for engineering applications. An improved near-surface characterization could supply S-wave velocities for static corrections for the reflection data. Also, water-bottom multiples have been utilized in combination with the primary reflections for subsurface imaging. Such approaches need an improved characterization of noise.

The 2007 SEG Summer Research Workshop. One of the purposes of the research workshop was to explore synergies between different experts working different aspects of seismic noise. Topics included interference noise, imaging and noise, transforms, ground roll, multiples, deconvolution and wavelets, near-surface and scattering, point and multicomponent receivers, and environmental noise. Afternoon excursions (Figure 2) to ancient ruins and spectacular waterfalls facilitated interaction between participants and provided time to discuss ideas and experiences.

The Organizing Committee—Chris Krohn, Necati Gulunay, and Shuki Ronen—decided to hold the workshop in Antalya not only because of its beauty, but also because of the severity of the seismic noise problems in the Middle East. This was one of the first workshops sponsored by the SEG Research Committee to be held outside of the United States or Canada. By having the workshop in Turkey, we attracted geophysicists and students from Middle Eastern universities and national oil companies, some of whom had never attended an international society meeting. This in turn helped satisfy SEG's goal of facilitating greater participation by its international members.

The workshop began with a keynote talk by Cem Tarik Menlikli of Turkish Petroleum Corporation (TPAO), who showcased not only the antiquities of the Turkish oil and gas regions but also their exploration challenges and noise issues. The organization committee is grateful to Chevron for sponsoring the students and ExxonMobil for sponsoring the icebreaker.

—*Chris Krohn, Houston, USA*
—*Shuki Ronen, San Ramon, USA*
—*Jeff Deere, Calgary, Canada*
—*Necati Gulunay, Cairo, Egypt*