Nine-component vertical seismic profile (9C VSP) data were acquired across a three-state area (Texas, Kansas, Colorado) to evaluate the relative merits of imaging Morrow and post-Morrow stratigraphy with compressional (P-wave) seismic data and shear (S-wave) seismic data. 9C VSP data generated using three orthogonal vector sources were used in this study rather than 3C data generated by only a vertical-displacement source because the important SH shear mode would not have been available if only the latter had been acquired. The popular SV converted mode (or C wave) utilized in 3C seismic technology is created by P-to-SV mode conversions at nonvertical angles of incidence at subsurface interfaces rather than propagating directly from an SV source as in 9C data acquisition.

In contrast, 9C acquisition generates a P-wave mode and both fundamental S-wave modes (SH and SV) directly at the source station and allows these three basic components of the elastic seismic wavefield to be isolated from each other for imaging purposes. The purpose of these field tests was to compare SH, SV, and P reflectivity at targeted interfaces. Because C waves were not an imaging objective, we used zero-offset acquisition geometry, which caused C-wave reflectivity to be quite small. We consider zero offset a source-to-receiver offset that is less than one-tenth of the depth to the shallowest receiver station.

VSP was used because VSP images can be constructed in the depth domain with great accuracy. Depth-based P-wave, SV, and SH images constructed from 9C VSP data are ideal for correlation with depth-based geologic and engineering data available across targeted stratigraphic intervals.

Interpretation of P-wave, SV, and SH VSP images created at study wells in Texas, Kansas, and Colorado showed that there is no preferred seismic wave mode for imaging Morrow stratigraphy and shallower strata across the entire Morrow trend. We think that this seismic imaging variability is controlled by the ratio of the P-wave velocity ($V_P$) to the S-wave velocity ($V_S$) across key stratal surfaces, not by the magnitude of the interface change in $V_P$ alone or $V_S$ alone. In one case, P-wave data reacted to a critical Morrow stratal surface better than either SH or SV data. At a second well, the SH mode reacted best to a key Morrow stratal surface. At the third well, the SV mode was the best option for imaging an important Morrow stratal surface. Other reflectivity differences for shallower strata are also demonstrated in our data.

This study illustrated that for Morrow exploration/exploitation, and no doubt for stratigraphic plays in many basins, multicomponent seismic tests should be done at key prospects to determine the optimal wave mode for imaging elusive targets. Explorationists can no longer assume that P-wave seismic data alone are sufficient for imaging some reservoir systems. In some cases even 3C seismic data will not be adequate for optimal well siting because the SH shear mode is not available, and the converted-SV mode (or C wave) utilized with 3C data has a different reflectivity than do source-generated SV and SH modes. In such cases, data will have to be acquired for proper prospect evaluation so all four images ($P$, $SV$, $SH$, and $C$) can be constructed and interpreted.

Morrow stratigraphy and depositional environment. Previous studies have shown that some Morrow incised-valley channels that are elusive as P-wave targets create robust S-wave reflections, suggesting that exploration and field development of Morrow prospects should be done by a combination of P-wave and S-wave seismic imaging. To study and compare P-wave and S-wave reflectivity of Morrow and post-Morrow strata, 9C VSP data were recorded at three locations along the Morrow trend (Figure 1). These data were processed to create both time-based and depth-based P-wave and S-wave images of the drilled stratigraphy, and then analyzed to determine if S-waves offer an alternative to P-waves (and perhaps even an advantage over P waves) in imaging some stratigraphic targets. One study well (A in Figure 1) was in Sherman County, Texas; a second well (B) was in Clark County, Kansas; and the third (C) was in Cheyenne County, Colorado.

A variety of marine and nonmarine environments occurred across the shallow-water, low-dip ramp that existed...
across our three-well study area during Morrow deposition. Sea-level fluctuations caused the relative positions of these environments to shift great distances, with valleys being incised during sea-level lowstands. These incisements then filled with fluvial, estuarine, and bay deposits when sea level transgressed the shallow ramp.

Drilling demonstrates that Morrow valley-fill facies vary over short distances with the bulk of the sediment fill being fine-grained to coarse-grained siliciclastics. Thin coals, limestones, and numerous unconformities are also associated with the sea-level cycles that are sometimes observed across the Morrow stratigraphic interval.

Petrophysical facies consist of marine shale, sandy mudstone, calcareous mudstone, and limestone; fluvial mudstone, siltstone, shale, and sandstone; estuarine sandstone and shale; and coals. All these rock types are influenced by varying degrees of carbonate cementation. In short, there is a wide range of petrophysical properties in the thin-bedded, laterally variable sequences that comprise the Morrow interval and later strata. This is a major reason that it is prudent to determine if one particular seismic wave mode (P, SV, or SH) responds to some facies variations better than do the other modes of a seismic wavefield.

**VSP data acquisition.** The 9C VSP used vertical arrays of 3C downhole geophones and three distinct vector-seismic sources (a vertical vibrator, an inline horizontal vibrator, and a crossline horizontal vibrator) positioned at small offset distance from each vertical well to create a zero-offset recording geometry (Figure 2). In the horizontal-layer stratigraphy at the test sites, these near-vertical raypaths caused the downgoing P mode to generate almost no converted SV (C-wave) reflection events. Thus, C-wave imaging was not considered in this study. The frequency sweep range for the vertical vibrators was 8-96 Hz; horizontal vibrators swept 4-48 Hz.

In Figure 3, vector $F_v$ at the source station indicates the force vector applied by the vertical vibrator in Figure 2; $F_{IL}$ is the force vector applied by the inline horizontal vibrator; and $F_{XL}$ is the force vector produced by the crossline horizontal vibrator. In this VSP data-acquisition program, inline is defined as the direction from the source station to the vertical receiver station. This orientation direction is depicted as vertical plane ABCD in Figure 3 that passes through the surface-source-station and downhole receiver-station coordinates. Crossline is defined as the direction perpendicular to inline (the direction normal to plane ABCD).

Each downhole receiver station was occupied by a 3C geophone consisting of a vertical sensor V and two orthogonal horizontal sensors H1 and H2. For the vertical wells in this study, vertical geophone V was always aligned in plane ABCD. Horizontal geophones H1 and H2 were oriented in different azimuth directions relative to plane ABCD at each downhole receiver station because of the tool spin that occurs when a downhole device such as a VSP sonde is suspended and operated by wireline. Receiver stations were separated vertically by 50 ft. Receiver station depths started at or below the base of the Morrow and extended 2000-2500 ft above the top of the Morrow.

We used the common industry practice of recording a P-wave first arrival from a far-offset vertical vibrator to orient the horizontal elements of the 3C VSP receiver at each depth station. This geophone orientation technique assumes that the P-wave first arrival from a far-offset source travels in the vertical plane that passes through the downhole geophone station and the surface-source coordinates.

**Wave mode separation.** Three fundamental wave modes are required to define the vector properties of a seismic wavefield in a homogeneous medium: the compressional (P)
mode, the horizontal shear (SH) mode, and the vertical shear (SV) mode. To distinguish SH and SV shear modes, a vertical plane should be passed through the source point where a particular S-wave radiation originates and then through the receiver coordinates where that same S-wave radiation is observed. In an isotropic earth, the component of S-wave displacement that is aligned in this vertical plane is the SV mode; the component that is aligned perpendicular to this vertical plane is the SH mode. Figure 4 shows three vertical planes oriented in the YZ coordinate plane—one vertical plane for each fundamental wave mode (P, SH, SV). A plane normal to the YZ coordinate plane is included in each diagram. SS is the source station where each wave mode originates; A is the observation point.

A key distinction among the three fundamental modes (P, SH, SV) is the direction of particle displacement that each mode produces in the propagation medium. These particle-displacement vectors are represented by double-headed arrows in Figure 4. The P-wave mode creates a particle displacement oriented in the same direction that the wavefield is propagating (indicated by the direction of the broad arrow). Both S-wave modes (SH and SV) create a particle displacement oriented perpendicular to the direction of wave propagation. SH displacement is aligned along the X-axis, perpendicular to the vertical plane passing through the source and observation points. SV displacement is aligned in this vertical plane.

Because P and SV displacements are in the vertical YZ
propagation plane, both displacements (P and SV) have a Y component and a Z component when the incident angle at A is not 0 or 90°. Neither the P nor the SV mode has an X component of displacement (in an isotropic earth). As a result, the P mode and SV mode can transfer energy from one to the other during reflection/transmission at stratal interfaces. Some P-wave energy can transfer to SV and some SV energy can transfer to P-wave. Because SH displacement is perpendicular to the YZ plane, SH displacement has only a X component and no Y component or Z component. As a consequence, in an earth consisting of horizontal isotropic layers, no SH energy can convert to P-mode or to SV-mode during reflection and transmission. Similarly, no P or SV energy can transfer to SH.

This wave physics means that only one way exists to create a reflected SH shear mode and that is to use an SH source that creates a downgoing SH mode. However, there are two ways to create a reflected SV mode. Option 1 is to use an SV source and produce a downgoing SV mode. Option 2 is to use a P-wave source and then rely on P-to-SV mode conversion at subsurface interfaces where there is a nonvertical angle of incidence for the downgoing P wave. In this latter case, the downgoing wave mode is a P wave, not a SV mode. The SV mode exists on only the upgoing path when a P-wave source option is used to generate S data.

The reason for using 9C VSP data (P-source, SH-source, and SV-source) rather than 3C VSP data (P-source only) in this project was that 9C VSP data allowed all three funda-

Figure 7. Unoriented data, crossline vibrator, well A.

Figure 8. Oriented data, inline vibrator, well A. Compare with Figure 6. Each trace has a different gain function to create a simulated plane wavefield.
mental wave modes (P, SH, SV) to be extracted and used for imaging. In contrast, 3C VSP data created by a P-wave source do not contain SH modes, and SV images must be made from secondary SV data that are produced by P-to-SV mode conversions at nonnormal angles of incidence, not from the direct SV waveform produced by a SV source.

The objective of the receiver rotation described in the preceding section was to orient the three geophone elements at each downhole 3C receiver station so that they pointed, respectively, in the directions of the P, SV, and SH particle displacement vectors in Figure 4.

9C VSP data processing. Zero-offset 9C VSP data acquired in demonstration well A are displayed in Figures 5-7. These figures show data recorded by the V, H1, and H2 geophones for each vector-wavefield source at the near-offset source station.

Vertical component VSP data have reasonably good signal-to-noise character even when not rotated to the P, SH, SV data domain in Figure 4. If P-wave information only is what is desired from VSP data, acceptable P-wave images can be made without doing receiver rotations. This simplified P-wave data-processing approach is often used in VSP applications. As is well known among VSP data processors, a different conclusion about data quality is reached when randomly oriented H1 and H2 data are examined. In each VSP survey analyzed in this study, raw H1 and H2 data have inconsistent first arrivals with amplitudes and waveshapes varying from trace to trace. Examples of this behavior at well A are illustrated in Figures 6 and 7. Trace-to-trace variations in these data are caused by tool spin and the random orientation of the horizontal geophones that result from this tool rotation as the VSP sonde is moved from depth station to depth station.

Oriented versions of the horizontal geophone data at well A are shown in Figures 8 and 9. All three geophone channels have improved data quality, with the data improvement being more obvious for the horizontal receivers. After these data rotations, a P-wave image can be made from the V-geophone (or vertical receiver) data in Figure 5; an SV-wave image can be constructed from H1 and H2 data after they are transformed to an inline receiver response (Figure 8); and an SH-wave image can be produced from the H1 and H2 responses once they are combined to create a crossline receiver response (Figure 9).

After these receiver rotations were done at wells A and B, we used standard wavefield-separation and deconvolution techniques and conventional front-corridor summation to create P, SV, and SH images. After transforming H1 and H2 data to form inline and crossline receiver responses, some energy remains on the crossterm wavefields (inline vibrator/crossline receiver in Figure 8, and crossline vibrator/inline receiver in Figure 9). This crossterm energy can be produced by anisotropy within the propagation medium, imperfect estimates of H1 and H2 orientations, inconsistent coupling of H1 and H2 receivers, and crosstalk between H1 and H2 data channels. We checked the data for evidence of only anisotropic-media effects in the crossterm wavefields. At well C, we had to include Alford rotation in the data-processing sequence because a modest amount of anisotropy-induced S-wave splitting occurred at that study site.

VSP is a seismic data-acquisition technique that records seismic reflection events in two simultaneous data domains: seismic traveltime and stratigraphic depth. As a result, a VSP image can be constructed so that the vertical axis of the image is either stratigraphic depth or seismic image time. No other seismic measurement allows images to be made directly in the depth domain. Depth-based VSP images are essential when integrating seismic reflectivity with depth-based geologic and engineering data; time-based VSP images are required to calibrate subsurface stratigraphy with time-based seismic data volumes. We emphasize depth-based images in this study.

Vector-wavefield reflectivity physics. The P, SV, and SH wave modes that comprise the three fundamental components of a vector wavefield exhibit different reflectivities at a stratigraphic interface. These differences in reflectivity are the reason that some reservoir stratal surfaces are better
imaged with P-waves than with S-waves, and other reservoir interfaces are better imaged with S-waves than with P-waves. Geophysical literature repeatedly documents the principles of vector-wavefield reflectivity. Examples from some of these reflectivity studies are used in this section to summarize key concepts that need to be kept in mind when interpreting spatially coincident P-wave, SV, and SH images.

**P-wave and S-wave reflectivities.** An insightful comparison of P-wave and SH reflection behavior was made by McCormack and others (1984). Their analysis was limited to normal incidence conditions, the raypath geometry involved in the zero-offset VSP data acquisition in this study. Their key finding is illustrated in Figure 10, a set of curves relating P-wave reflectivity ($R_{i,p}$) and S-wave reflectivity ($R_{i,s}$).

For vertical raypaths incident on horizontal interfaces, there is no distinction between SH and SV shear modes, and the term S-wave reflectivity (not SH reflectivity or SV reflectivity) is appropriate for the quantity $R_{i,s}$ used as the vertical axis in Figure 10. The horizontal axis is a parameter $\beta_i$, defined as

$$\beta_i = \frac{(V_p/V_s)_{i+1}}{(V_p/V_s)_i},$$

where $V_p$ is P-wave velocity, $V_s$ is S-wave velocity, $i$ is an index signifying the rock layer above the reflecting interface, and $(i+1)$ is an index assigned to the rock layer below the interface. The P-wave reflection coefficient $R_{i,p}$ is constant for each curve and the value of $R_{i,p}$ is labeled on individual curves.

Visual inspection of curve $R_{i,p} = 0$ shows that even though the P-wave reflection coefficient is zero at an interface, the S-wave reflection coefficient can be positive, negative, or zero at that same interface depending on the value of $\beta_i$, the ratio of $(V_p/V_s)$ across the interface. If $R_{i,p} = 0$ and $\beta_i$ is not 1.0, the stratigraphy related to that interface is invisible to P waves but can produce a significant S-wave reflection.

Visual inspection of horizontal line $R_{i,s} = 0$ shows a different story. That is, the S-wave reflection coefficient can be zero at an interface yet the P-wave reflection coefficient $R_{i,p}$ can be positive, negative, or zero, depending on the $(V_p/V_s)$ ratio between rock layers $i$ and $(i+1)$. In this case, if $R_{i,s} = 0$ and $\beta_i$ is not 1.0, the stratigraphy related to that interface is invisible to S waves but may generate a robust P-wave reflection.

Further inspection of the figure shows that at any given interface, that is for any specific value of $\beta_i$, P-wave and S-wave reflection coefficients may have the same algebraic sign or opposite algebraic signs depending on how $(V_p/V_s)$ varies across the interface. Four data points (A, B, C, D) are labeled on Figure 10 to illustrate the following relationships that can exist between P and S reflectivity at a stratal surface: A = $R_{i,p}$ is negative, $R_{i,s}$ is positive; B = $R_{i,p}$ is negative, $R_{i,s}$ is negative; C = $R_{i,p}$ is positive, $R_{i,s}$ is negative; and D = $R_{i,p}$ is positive, $R_{i,s}$ is positive.

The physics of P-wave and S-wave reflectivity thus demonstrates that there can be wide differences in P-wave and S-wave reflection behavior at certain stratigraphic interfaces. It should not then be a surprise that some reservoir targets may be better imaged with P-wave seismic data whereas other reservoirs may be better imaged with S-wave seismic data.

The key point developed here is that P-wave and S-wave reflections can be different at many targeted stratigraphic interfaces even for the simple case of normal-incidence reflection. This fundamental difference in P-wave and S-wave reflectivities remains true for the more complicated mathematical expressions of P-wave and S-wave reflectivities that have to be used when nonnormal angles of incidence are considered. The intent here is not to quantify numerical differences in P-wave and S-wave reflectivities for all ranges of incidence angle. The intent is to use real field data to establish the principle that P-wave and S-wave reflectivities differ at some interfaces, which is the reason for the interest in using S-wave images to reveal targets that cannot be seen in P-wave images.

**SV and SH reflectivities.** Having established the principle that P-wave and S-wave reflectivities differ at many interfaces, we now compare SH and SV reflectivities to determine if SH and SV modes can create different images of subsurface strata. Consider Figure 11 where the offset behavior of SV and SH reflection coefficients are compared at an interface between two different rock-layer sequences. In one case, the SV and SH reflection coefficients are positive at
small incidence angles; in the other case, these coefficients are negative at normal incidence. At true normal incidence ($\theta = 0^\circ$), SV and SH modes have the same reflection coefficient in both cases. The equivalence of SV and SH reflectivities at zero incidence angle supports the claim in the preceding section that SV and SH modes cannot be distinguished along vertical raypaths. However, for nonzero incidence angles, SV and SH reflection coefficients differ, with this difference increasing as the incidence angle increases (Figure 11). This behavior means that SH and SV images constructed from data involving a large range of offsets will not be identical and will provide two diverse suites of attributes for interpreting sequence architecture and lithofacies distributions. Because the incidence angles involved in the zero-offset VSP data were $10^\circ$ or larger at some interfaces spanned by the large vertical array of VSP receiver stations, the SV and SH images constructed from these VSP data will differ at certain stratigraphic depths because of the slight divergence of the SV and SH reflection coefficients at small nonzero incident angles (Figure 11). These image differences should be sufficient to determine if large-offset SV and SH data, which would involve significant differences in SV and SH reflectivity behavior, should be acquired across a prospect to evaluate stratigraphic reservoirs.

**Implications.** Some important vector-wavefield interpretation principles are demonstrated by these reflectivity behaviors. First, there can be major differences between P-wave and S-wave images constructed from zero-offset VSP data (Figure 10). Second, SV and SH reflectivities differ slightly when SV and SH modes arrive at an interface at small incidence angles that barely exceed $5^\circ$ (Figure 11), and these differences should be apparent in SV and SH images constructed from zero-offset VSP data. Realizing the importance of these differences in P-wave, SV, and SH reflectivities, the objectives of this study were to construct the best possible P-wave, SV, and SH images of stratigraphic targets at VSP wells A, B, and C and then to interpret these images to determine which wave mode (P, SV, or SH) provided optimal stratigraphic information at each study site.

**S-wave splitting.** All rock systems are anisotropic to some degree, meaning that one or more physical properties of the rock vary as those properties are measured in different directions through the rock medium. Fracturing is one of the more common anisotropic properties of a rock because fracturing causes several rock properties, such as permeability, shear strength, and seismic velocity, to have values parallel to the fracture planes that differ from the values of those properties perpendicular to the fracture planes. Other examples of anisotropic rock parameters are thin-bedded strata, laminae, and even elongated matrix grains (or pores) that are oriented in a preferential direction by deposition or tectonic stress.

As S-waves propagate through an anisotropic medium, they do not behave as do P waves. The major difference is that the incident S-wave that impinges upon a fractured rock volume splits into two S-waves that continue to travel through the anisotropic material in the same direction as the incident S-wave. In contrast, a P-wave does not separate into two distinct daughter P-waves when it encounters fractured rocks.

If both SV and SH modes enter a fractured interval, each mode splits into $S_1$ and $S_2$ components. The physics of this wave propagation concept is quite important, because the particle displacement orientation (that is, the polarization) of the faster S-wave component (the $S_1$ component) can be measured if three-component receivers are used to record the propagating wavefields. The orientation of the principal axis of anisotropy can then be inferred from that measurement.

Any seismic measurement that defines the polarization plane of either $S_1$ or $S_2$ therefore defines the azimuth directions of the anisotropy axes and symmetry planes that exist in the propagation medium. When S-wave splitting occurs, data processing needs to focus on creating $S_1$ and $S_2$ images, not SV and SH images. S-wave splitting was observed only at well C in our study. A time delay of 8 ms occurred between the $S_1$ and $S_2$ events at the top of the Morrow at this site. No S-wave splitting occurred at wells A and B.

**Comparison of P and S images with stratigraphy.** Figures 12-14 compare the P-wave and S-wave images created at each well with log data. S-wave splitting was observed at
well C only. Thus, the SV and SH images at this well were processed through the additional step of Alford rotation to create S1 (fast-S) and S2 (slow-S) images. Because S-wave splitting was not observed at wells A and B, data processing at these wells stopped when SV and SH images were produced.

The Morrow stratigraphy penetrated by each VSP well is labeled in each display. Examination of the figures leads to the following observations:

1) Both P-wave and S-wave reflections are generated throughout the Morrow interval at each site. This interval is marked by the short, bold arrows that identify the “target” boundary.

2) S-wave reflections often occur at different stratal surfaces than do P-wave reflections. Examples within the Morrow are identified by letters; examples in post-Morrow strata are identified with numbers. Thus, improved and more detailed models of reservoir architecture should result by combining P-wave and S-wave seismic reflection data because a greater variety of stratal surfaces can be mapped. This has important implications in seismic stratigraphy. Examples of P-waves and converted SV-waves imaging different stratal surfaces associated with channels and incisements have been published by DeAngelo and others (2003).

3) In some instances, S-wave reflections are more robust than P-wave reflections. Examples are the SV and SH responses near depth coordinate 6500 ft in well A (A and B in Figure 12), and the SH response between the Cherokee and Lower Morrow in Well B (A in Figure 13). This suggests that S-wave seismic technology should be considered for any stratigraphic prospect that is difficult to image with P-wave seismic data.

4) The frequency sweeps of the vibrators were set to create equivalent P and S wavelength spectra (8.96 Hz for the vertical vibrators; 4.48 Hz for the horizontal vibrators). Thus, when analyzed in the depth domain, the wavelength resolution of S-wave images constructed from 9C VSP data is equivalent to the resolution of P-wave images. This observation establishes the key fact that surface-recorded S-wave data can provide a spatial resolution of rather deep targets that is equivalent to the resolution achieved with P-wave surface-recorded data (Figures 12 and 13).

5) SV and SH reflection character differs across the Morrow interval and across several other shallower stratigraphic intervals. Some differences are labeled in Figures 12 and 13. Until the rock and fluid implications of these differences are better understood, it seems prudent that operators should consider 9C seismic data acquisition whenever possible so the SH mode can be utilized for prospect evaluation and not rely on all S-wave information being provided by mode-converted SV data produced by 3C seismic technology.

6) S-wave splitting can occur at some prospects (Figure 14). Further data collection and study have to be done to determine how much of this S-wave splitting phenomenon is associated with the overburden above stratigraphic targets, how much is related to the target interval, and to what extent S-wave splitting is an indicator of reservoir quality.

7) Different wave modes generate optimal images of the Morrow and its related stratigraphy at various locations across the Morrow trend. At well A, the SV mode provided the most robust intra-Morrow reflection (A in Figure 12). At well B, the SH mode created the best image (A in Figure 13). At well C, the P-wave mode was the best choice for imaging (A in Figure 14).

Conclusions. This study showed that S-wave reflections often occur at different stratal surfaces than do P-wave reflections. This reflectivity behavior means that the combination of P-wave and S-wave reflection images should result in improved stratigraphic interpretations of prospects. This fact from physics—that P-wave and S-wave reflections may at times follow different stratal surfaces—implies S-wave data can sometimes provide a better image of stratigraphic reservoirs than do P-wave data. The choice as to which wavefield, P or S, will yield the better image will depend on the specific type and sequence of stratal surfaces that exist across a prospect. Because operators may not know what stratal surface sequences exist at a prospect and what petrophysical variations, particularly \( V_p / V_g \), occur across these stratal boundaries, this study suggests that all stratigraphic prospects should be evaluated with both P-wave and S-wave seismic data if a multicomponent seismic program can be justified by prospect economics.

Perhaps the most obvious conclusion provided by this study is that 9C VSP data should be recorded at prospects whenever possible to determine the relative imaging value of P-wave and S-wave data at those sites. The P-wave and S-wave images extracted from 9C VSP data provide a definitive and relatively low-cost answer to the question, “Do S waves see stratigraphy better, or differently, at this particular prospect than do P waves?”

A principal shortcoming of this work was that there was insufficient subsurface control at the study wells to establish the petrophysical conditions across stratigraphic interfaces that caused one particular seismic wave mode to image some stratigraphy better than did the other two wave modes of the elastic wavefield. The three study wells where the 9C VSP data were acquired were wells of opportunity that became available for multicomponent seismic research. VSP surveys were done even though limited well logs and no cores existed at the wells.

Operators who follow the practice recommended here and do multicomponent VSP testing to determine which seismic wave mode provides optimal imaging of stratigraphic relationships are encouraged to conduct such VSP surveys in new wells rather than in old wells that have limited subsurface control. By using new wells, cores can be acquired over critical intervals and full suites of modern logs can be
recorded. It will be important to acquire dipole sonic log data in these wells because the manner by which the velocity ratio $V_p/V_s$ varies across a rock interface appears to be a critical control on P-wave and S-wave reflectivities at that interface (Figure 10).


Acknowledgments: This research was done by the Exploration Geophysics Laboratory (EGL) at the Bureau of Economic Geology as a part of that laboratory’s effort to demonstrate applications of multicomponent seismic technology. The SH/SV reflectivity curves and VSP data-processing examples shown here were created by James L. Simmons Jr., former EGL researcher now at GX Technology. Funding for this study was provided to Visos Exploration, an industry sponsor of EGL, through DOE solicitation DE-PS26-99BC15146. Visos subcontracted EGL to process and interpret the 9C VSP data in this study.

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(FTOS, from p. 712)

both new Internet systems to be suspect, it must be obvious that the research, design, production, testing, and installation involved, financed by huge government subsidies, would help progress toward the full employment goals of our flagging economies.

“In the event that both systems fail, the Internet via Waterpipe Grid has a distinct advantage in that it could be demobilized by simply flushing the data parcels of the entire project down our well proven waste pipe/sewer complex; while much of the staff and equipment of the Internet via Power Grid would remain up the pole.”

Thanks, Ken. But I don’t understand why you stop with the waterpipe grid. Oil and gas pipelines are also available plus they are more regionally distributed. Think of the Alaskan pipeline and email to the North Slope. On the other hand, the power line grid might give my mundane email an added jolt.