VectorSeis® – Initial Results from a New Multicomponent Sensor

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Abstract

While the concept of multicomponent seismic has been around for many years, cost and quality concerns have limited its use in conventional exploration. Recent technology advances, such as reductions in sensor size and weight, while maintaining or improving performance and reliability, are helping to address these problems. Silicon accelerometers have been available for over a decade, yet only recently has technology allowed these miniature accelerometers to be manufactured with a noise performance compatible with seismic requirements. Input/Output have adopted this technology in the design of a unique micro-machined digital accelerometer specifically targeted at the seismic acquisition industry.

The new VectorSeis® digital sensor provides several advantages over coil analogue geophones. The working principals and spectral characteristics of VectorSeis®, and data comparisons with conventional 1C and 3C geophones will be presented. This new technology and associated recording equipment are also helping to improve the cost structure of multicomponent surveys. This paper explores multi-component data recording using VectorSeis® equipment. Acquisition issues such as operational efficiencies, recording with single sensor vs. field arrays, and leveling/orientation requirements will also be discussed.

Digital Seismic Sensor

Input/Output's, digital sensor has two principal components, a micro-machined silicon accelerometer with a small inertial mass, suspended by miniature springs and a custom designed, mixed-signal ASIC control chip. Force re-balanced feedback operation provides a 24 bit digital output directly from the sensor unit obviating the need for A/D converters in the recording system. The acceleration-proportional output shows a flat transfer- and phase-response from very low frequencies up to 500Hz (Figures 1). Implementation of the digital sensor is in an orthogonal 3-component arrangement forming the core of the VectorSeis® recording system. Data is acquired on a VRSR platform, 6 x 3C stations per box. Sensor design started as early as 1986 with the first prototype field tests in 1998 following extensive laboratory testing. A significant development milestone was achieved with the re-recording of the Pan Canadian, Blackfoot 3C3D survey in 1999 with Veritas DGC. 2001 saw the regular operation of a 1500 station, multi-component pilot crew, again operated by Veritas in N. America.

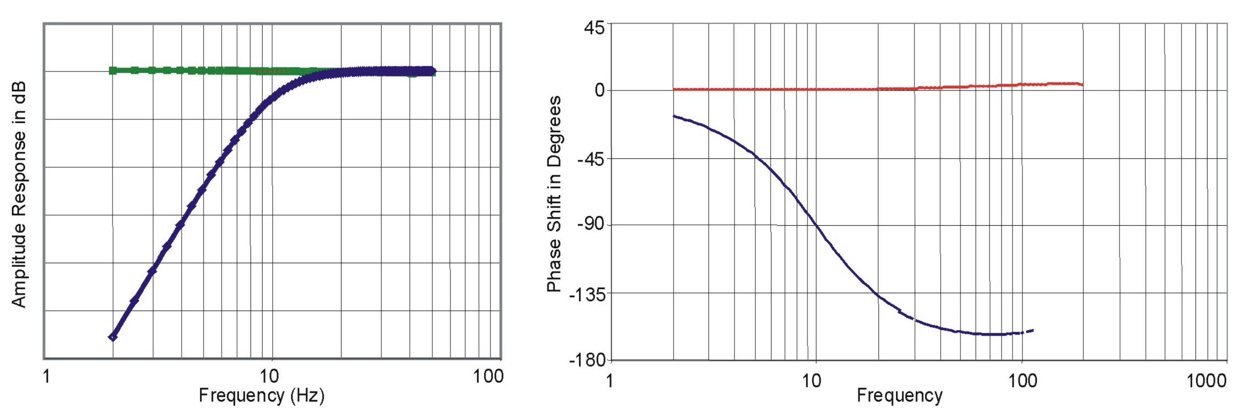

***Figure 1**: Shaker table response for both a geophone and VectorSeis. The dark curve in 1a is the amplitude response for the geophone showing a drop-off of amplitude below the natural resonance frequency and the light curve showing the flat response for VectorSeis. Figure 1b shows the impulse response for the geophone (dark line) and the flat phase response for VectorSeis.*

Operational Considerations (Acquisition)

For standard P-wave exploration, the analogue coil geophone has served the industry well for over 70 years. They are relatively inexpensive, rugged and reliable and they allow for flexible array designs. On the other hand, the natural resonance (for example, 10 Hz) limits the recorded signal fidelity at lower frequencies. Furthermore, the advent of 24-bit recording, improved processing options and cost constraints have lessened the concern if not the need for careful array design. For multicomponent applications the geophone's limitations become more noticeable. The vector fidelity and response of one vertical and two horizontally deployed coils is severely impacted unless the geophone is planted within a few degrees of perfectly level. Even then, vector fidelity is a concern, since the horizontal and vertical coils have significantly different response characteristics.

The operational advantages of recording multicomponent data with these new purpose built multicomponent sensors are substantial; They require fewer connections and less cable so, the overall weight of the equipment is reduced The sensors do not have to be levelled in the field, since this can be corrected for in processing. Figure 2 illustrates the reduction in weight, amount of cable and number of connections as compared to standard 1C and 3C systems.

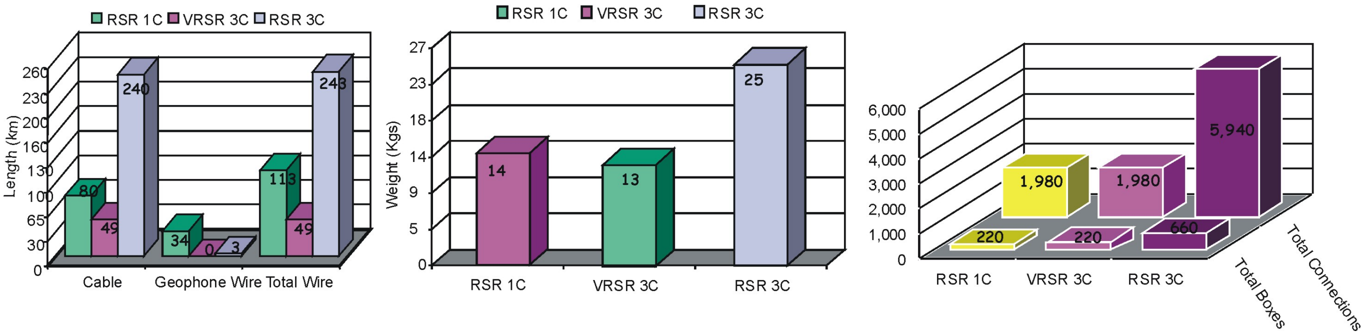

***Figure 2**: Total wire (2a, geophone plus cable), total weight (2b) and total number of connections and boxes (2c) for the RSR 1C, VRSR 3C and RSR 3C respectively.*

The ability of the sensor to work at all orientations increases the acquisition rate and improves coupling since the sensor is not adjusted for leveling purposes. The VRSR recording system utilizes a transcription process that separates the different components into individual files thus reducing processing time and uncertainty. The final result is more accurate and more affordable multicomponent acquisition.

Conventional P-Wave Data vs VectorSeis P-Wave Data

Veritas has acquired, processed and analyzed six programs with side by side comparisons of VectorSeis® sensors to conventional coil geophones. The comparisons have included climatic variations from -30 °C to 40 °C, geographical variations from Northern Canada to the US Gulf Coast, geological settings including carbonates and clastics at depth ranging from 100's of meters to 4000 meters in both structurally complex and stratigraphically complex regimes. We have made single sensor comparisons, array versus single sensor comparisons and arrays in the field versus array forming in processing. We have considered the differences between recording in velocity units for the geophones versus acceleration units for the VectorSeis® data. We have also taken into account the geophone impulse response effects in these comparisons. Furthermore, we have investigated different source configurations in order to maximize the energy for converted-waves and compressional waves. And finally we have considered acquisition design configurations that are optimal for both the converted-waves and the compressional waves.

Figures 3-5 are side by side comparisons of vertical geophone array data versus single sensor VectorSeis® data. Figure 3 shows data that were acquired in SE Saskatchewan, Canada, Figure 4 shows data that were acquired in the Alberta Foothills of Western Canada and Figure 5 shows data that were acquired in the US Gulf Coast region. These examples clearly illustrate the similarity in sensitivity and data quality for conventional geophone arrays versus single sensor VectorSeis® measurements. However, this does not mean that we are universally recommending replacing geophone arrays with single sensors. There will be environments where arrays are necessary. Furthermore, array forming in the field is not possible with digital sensors simply because each individual unit performs the digitization onboard. Independent of the efficacy of the ground roll attenuation, a field array always provides √N S/N improvement simply due to increased effective fold. With single sensor recording similar array forming, in fact more flexible adaptive array forming, can be applied during processing to get equivalent or better results. Even without such efforts, in most cases routine processing has produced remarkably similar results between 6-element coil array geophone data and single sensor VectorSeis® recording.

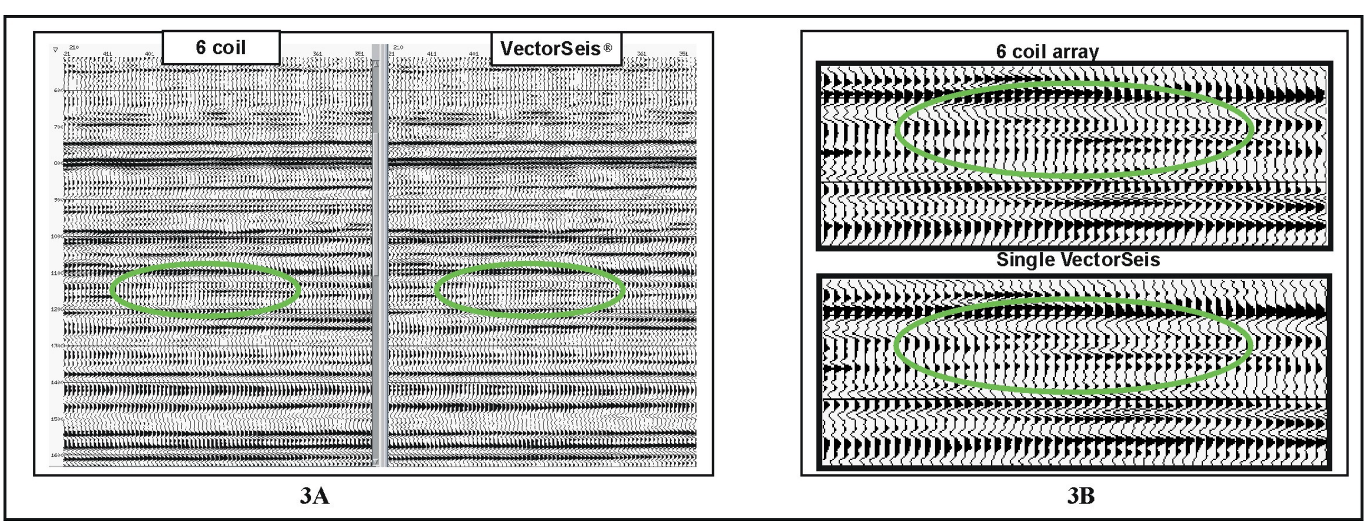

***Figure 3**: Figure 3a shows the p-wave 6 string array data on the left and the p-wave single VectorSeis data on the right, while figure 2b is a blow up of the zone of interest from SE Saskatchewan, Canada.*

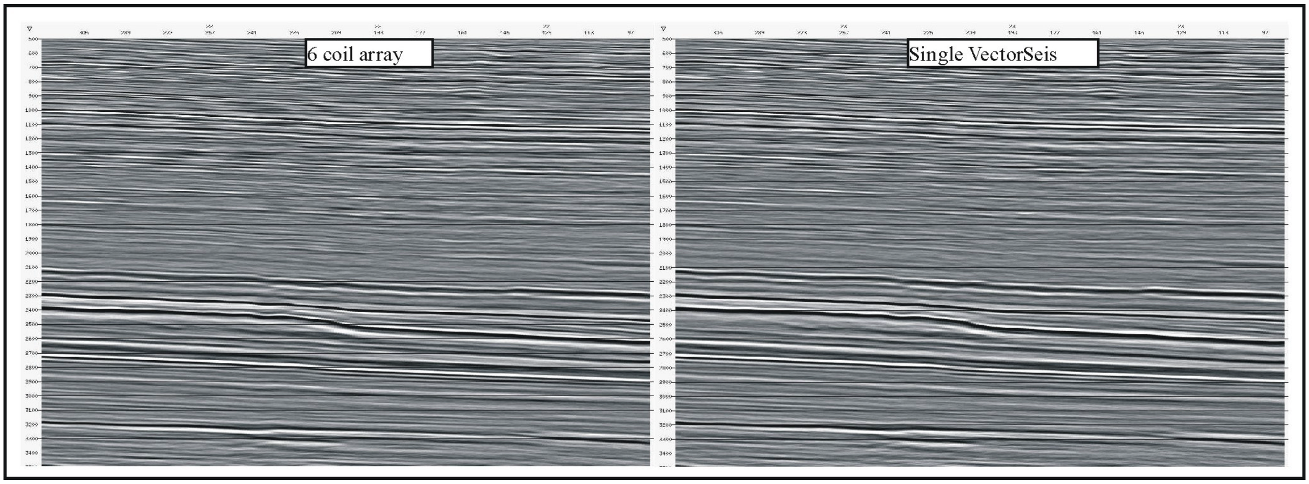

Figure 4: *The p-wave 6 string array data is on the left and the p-wave single VectorSeis data is on the right. These data are from the US Gulf Coast.*

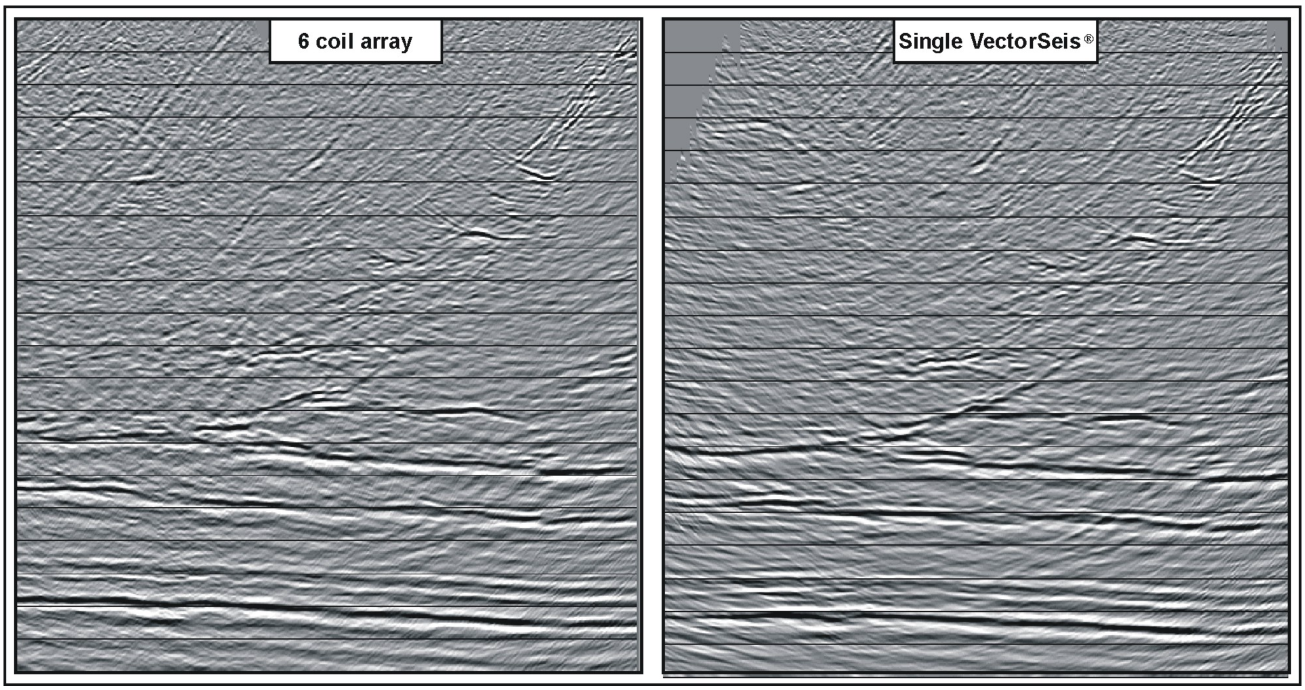

Figure 5: *The p-wave 6 string array data is on the left and the p-wave single VectorSeis data is on the right. These data are from the Canadian Foothills.*

Converted-Wave Data Using VectorSeis®

Veritas have processed numerous converted-wave datasets that were acquired using VectorSeis®. In general, we are finding that these converted-wave data are of better quality compared to conventional 3C data. We believe this is due to the many reasons listed above and in particular due to: the sensors ability to work at any orientation; the reduction in error due to wiring problems; fewer connection errors; separated components delivered from the field; improved vector fidelity and superior coupling associated with the VectorSeis® deployment process. Furthermore, multicomponent recording has typically involved single sensors due to the added complexity of orienting and leveling conventional 3C geophones. Therefore, the single sensor versus geophone array issue is less prominent. Figures 6 and 7 show examples of converted-wave data that were acquired with VectorSeis®. Figure 6 shows the VectorSeis® PS section corresponding to Figure 3 and Figure 7 the corresponding PS section to Figure 5. The interpretation and further discussion associated with figures 3 and 6 can be found in the abstract by Kendall and Pullishy, 2002. Figure 7 illustrates the impressive converted-wave signal strength for a very deep target (4000 m) given a modest charge size (2.2 Kg at 20m) and relatively low fold (1500 %).

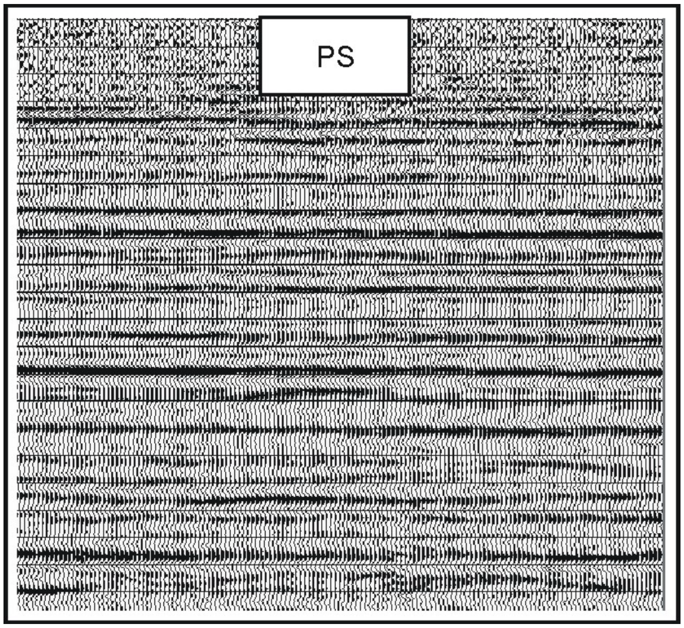

__Figure 6__: The converted-wave data from SE Saskatchewan, Canada.

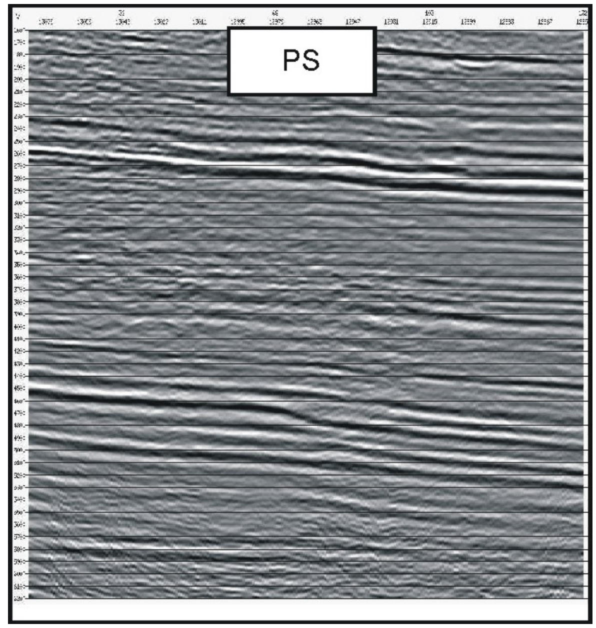

__Figure 7__: The converted-wave data from the US Gulf Coast. Note that the zone of interest is the strong reflection package about two-thirds of the way down (~4000m). These are impressive converted-wave data given the depth to target, the low fold (15 fold) and the relatively small charge size (2.2 Kg at 20m).

Conclusions

The VectorSeis® seismic sensor allows for more accurate and cost effective multicomponent acquisition due to reductions in weight, number of connections and the amount of cable. We have shown, through example, that the sensor performs as well as conventional geophone arrays in numerous geological and geographical environments. Furthermore, we have presented a plausible explanation for the superior quality converted-wave data that is being acquired using these new sensors.