Let there be light: illuminating physical models from the surface

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Summary

In order to obtain useful seismic images of the subsurface, the various features of the structure must be adequately illuminated by seismic energy. Physical modeling is a useful technique for studying effective seismic illumination. Recently, an interesting physical model was constructed in the CREWES physical modeling facility and thoroughly surveyed using not only surface sources and receivers, but transducers embedded in both horizontal and vertical boreholes, as well.

In this work, we study the illumination obtained only from surface sources and receivers in order to see how much we can learn about subsurface features of an "unknown" prospect using only the data from surface surveys. Interestingly, we can obtain a surprising amount of information about unseen subsurface features using the simplest of all surveys; a zero-offset "sonar" survey.

Method

A physical model is often one of the best ways to study various aspects of field exploration. One of the most important considerations for any seismic survey is that of illuminating subsurface features well enough to form images conveying the maximum information about the geometry and material composition of the target. Recently, a physical model was constructed in the CREWES physical modeling facility (Wong et al., 2019), whose purpose was to explore seismic illumination, not only that arising from surface sources and receivers, but also from subsurface transducers, as deployed in vertical and horizontal boreholes. In addition to various structural features at depth, the model included a shallow 'masking' structure comprising a high-velocity sill and dike. The model was subsequently thoroughly surveyed using several different acquisition geometries. Figure 1 shows a schematic of the model, with various combinations of source and receiver configurations.

Of the various data sets created during the modeling surveys of the model in Figure 1, we selected only the multi-fold CMP survey (101 surface shots into 1001 surface receivers) and the single-fold zero-offset survey (992 surface shots into a coincident receiver). To create displays for comparison, each survey was reduced to an image of the subsurface, using as little 'extra' knowledge as possible. The idea for the comparison was to consider each survey a 'reconnaissance', performed solely to provide information for more detailed subsequent surveys, including the possible placement of boreholes, with buried sources/receivers. Hence, processing of each survey was minimal, consisting mainly of removal of coherent noise (Henley, 2003), and Gabor deconvolution (Margrave et al, 2011) to sharpen the wavelet. In the case of the CMP survey, water velocity was used to apply NMO (since water was the predominant model material) and the multi-fold traces stacked according to common CMP, for a maximum stack-fold of 100, and an effective scaled lateral resolution of 2.5m. The zero-offset survey is unstacked, with a lateral resolution of 5m.

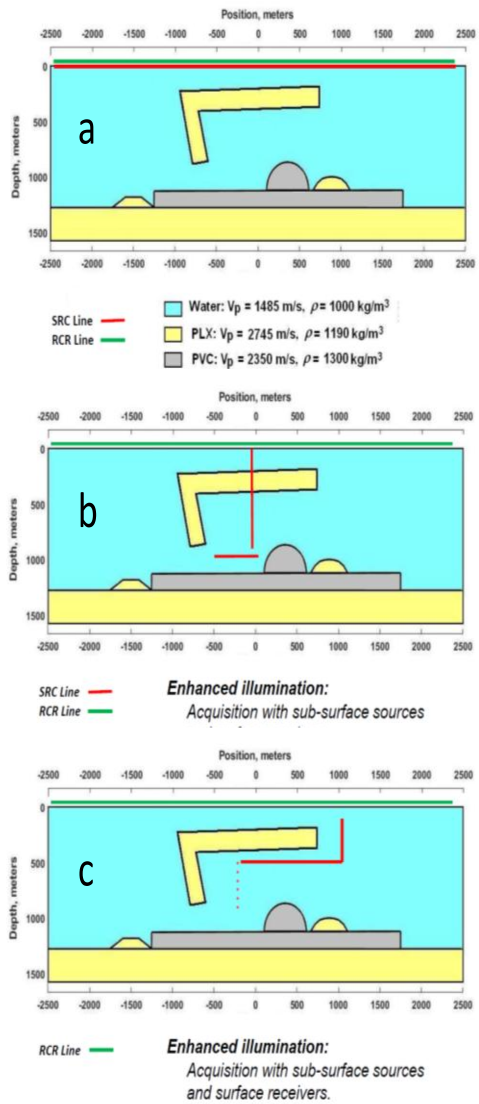

Fig. 1. Physical model schematic. a) Basic model with surface survey geometry shown. b) New source positions shown. c) Further possible source geometry.

Figure 2 shows the CMP stack of the multi-fold survey, after coherent noise removal and deconvolution. Superimposed on the stack is the schematic of the model, as well as an arrow indicating a ‘mystery’ event, not immediately correlatable to a structural feature. Some residual reflection from the tank sides is also present, having not been totally attenuated. Figure 3 is the zero-offset survey after coherent noise attenuation and deconvolution. Figures 4 and 5 are the colour versions of Figures 2 and 3, respectively, without the schematic overlays.

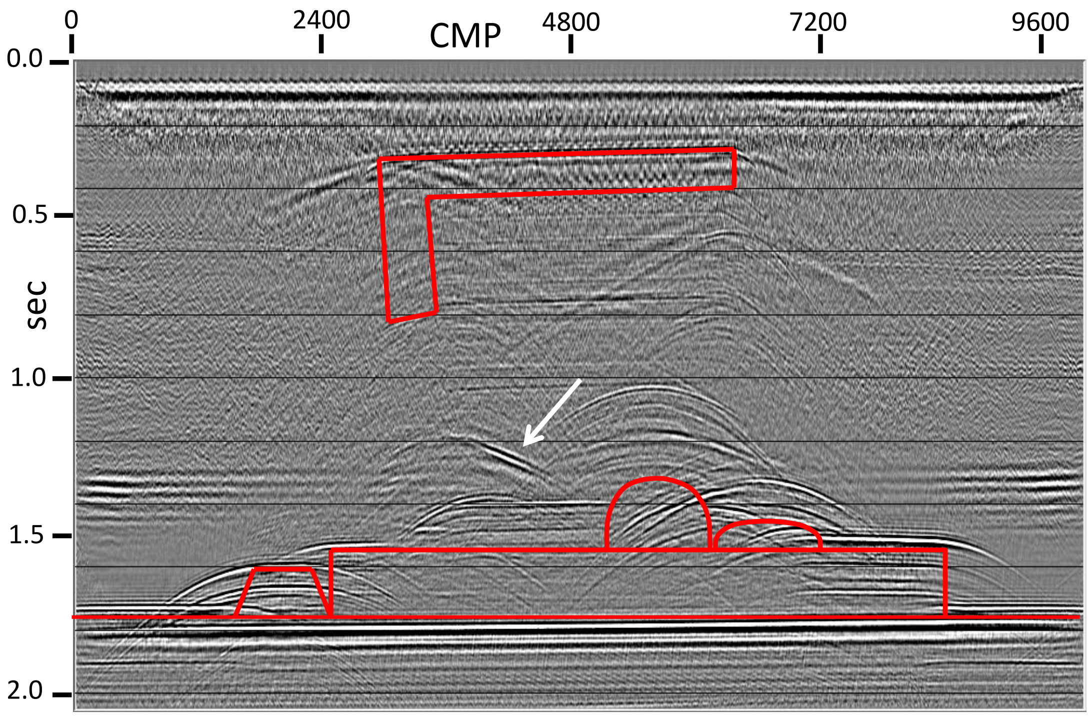

Fig. 2. Full CMP stack for the multi-fold survey, model schematic superimposed.

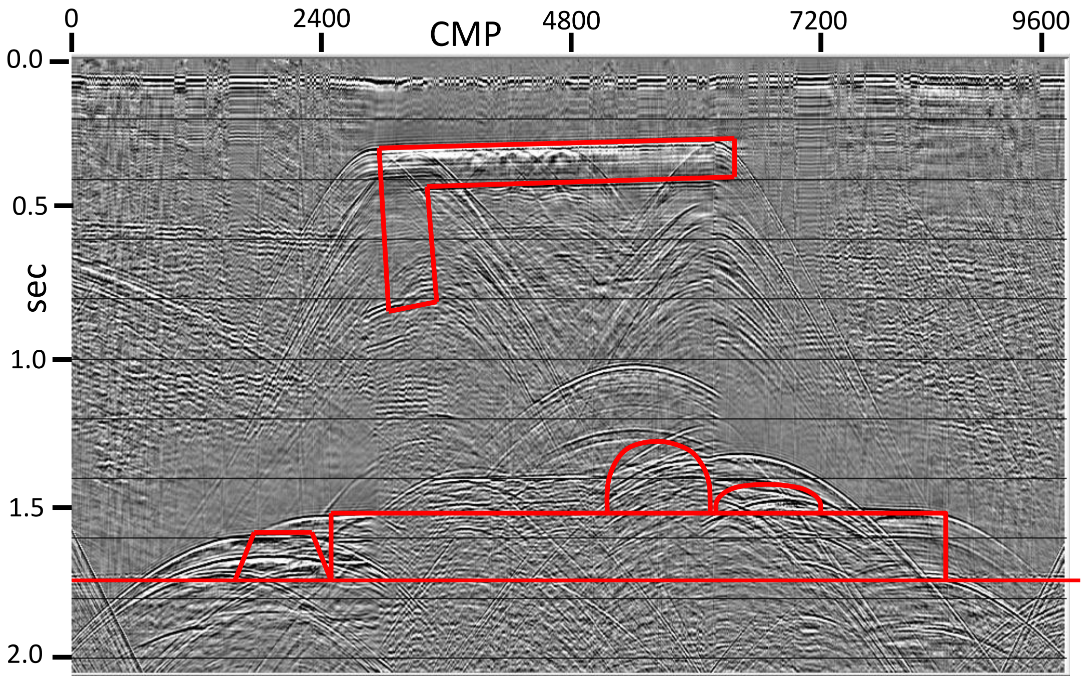

Fig. 3. Zero-offset survey after noise removal, deconvolution.

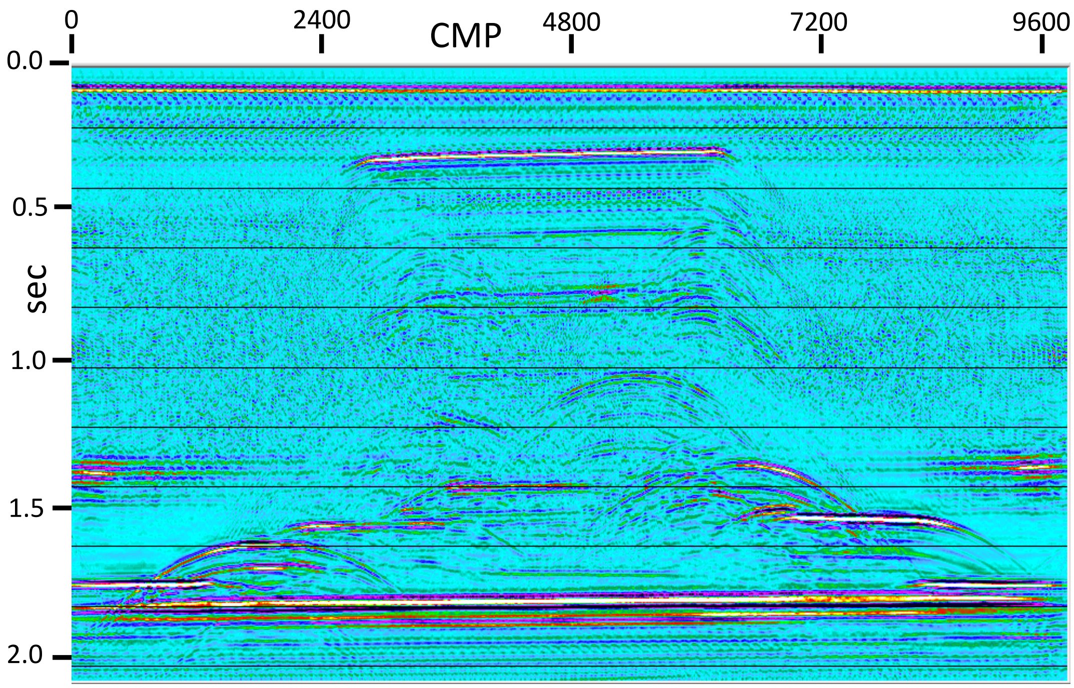

Fig. 4 Fully processed CMP survey.

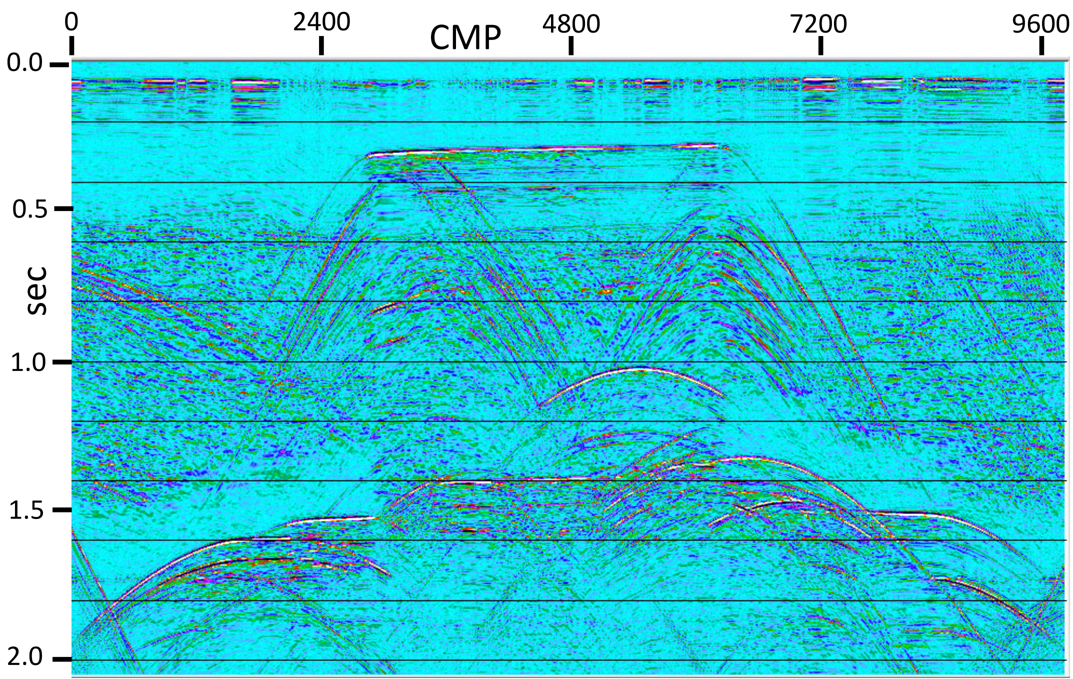

Fig. 5. Fully processed zero-offset “sonar” survey.

Results and analysis

Considering the multi-fold CMP stack images in Figures 2 and 4, some reflections are strong, but others, like the bottom of the sill or the dike are indistinct. In addition, unwanted reflections from tank sides and bottom persist, in spite of being specifically attenuated in the common-offset domain, and further attenuated in the CMP stack. The high-velocity dike has led to a “mystery event” that was only identified by studying the pre-stack data in detail. If we were to apply a pre-stack depth migration to the data, in all likelihood, the image would improve, and the mystery event would disappear; but this would require detailed knowledge of subsurface velocities, not available for a reconnaissance survey.

The zero-offset survey, on the other hand, may actually provide more knowledge of model details than the CMP survey, even though its lateral resolution is only half that of the CMP survey, and it is only single-fold. While we most often use only reflections to identify rock layer boundaries and structural features, we can use other attributes and artifacts in our interpretation. In Figure 5, we note that all sharp corners (both inside and outside) have associated diffractions, which locate them precisely. Interestingly, as well, because the illumination for a zero-offset survey emulates a single parallel beam, unlike the fan-shaped illumination patterns of the individual shots of the CMP survey, the sill and dike each cast distinct shadows, which reveal their vertical boundaries. Furthermore, uplifted segments of the deeper model reflections (due to short transit times in the sill and dike) can be identified unambiguously, with no confusion caused by ‘mystery’ events. Since there are no non-vertical raypaths in the zero-offset survey, events like the ‘mystery event’ in the CMP stack, caused by combined oblique raypaths through the sill and dike structure do not appear. Finally, coherent noise attenuation is more effective than in the CMP survey.

Novel Information

In a low-noise environment like a marine survey or modeling tank, sometimes more information can be obtained from a single-fold sonar survey, with 1% of the effort, than from a full CMP survey, unless much additional information is supplied, like a detailed velocity model.

Acknowledgements

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