PPZG – IFPEN : Orientation Method for onshore 3-Component VSP's recorded with a Relative Bearing sensor in partially low deviated holes.

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Summary: A hybrid technique is proposed for orienting RELIABLY the 3 component seismic signals of rig-source VSP's, in two steps:

a) integrating affordable orientation hardware device(s) into the VSP tools , such as cost effective fluxgate magnetometers and inclinometers combined with the VSP tool or VSP toolstring, without altering the vector fidelity characteristics of the VSP tool response and field data.

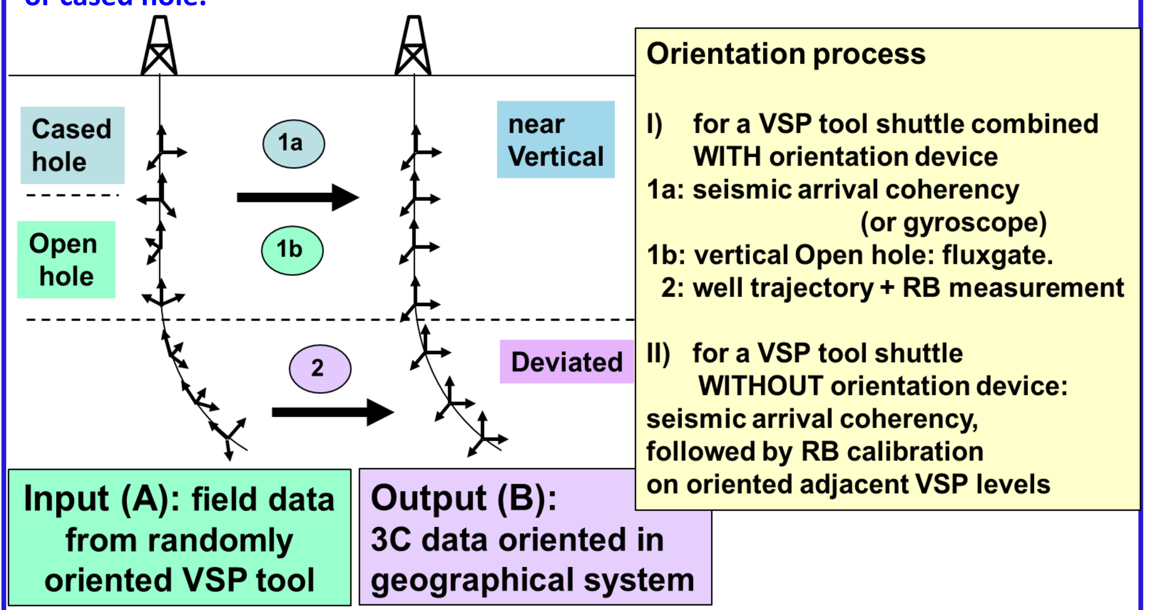
b) a pre-processing seismic technique to render the X-Y component signals coherent versus depth in respect with rotation around the VSP tool axis/ borehole axis, to be applied in low deviated sections of the borehole where the orientation readings become useless or irrelevant.

The orientation step is mandatory prior to full 3 component VSP processing, yielding additional and more reliable structural information in the borehole vicinity for the geologist; and/or information about the azimuth of eventual flow noise at the depths of permeable formations.

ORIENTING the 3-component signals from a modern multilevel VSP tool.

The sketch below illustrates the FIX geophone setting of 3C trihedrons within most of the present day multilevel VSP tool. At the time of VSP acquisition, the deep reservoir interval generally includes a cased hole section (1a), and an open hole section (1b and 2); the borehole may be sufficiently deviated (section 2) for the inclinometers to yield valid Relative Bearing angle (RB) measurements from gravity detection. The cased hole section (1a) might be locally deviated beyond the inclination threshold of the inclinometers… The problem to solve is to orient the trihedron 3C signals from field recorded positions (A) into geographical position (B), prior to processing. *One assumes the vector fidelity of the 3C tool response.*

The depth interval of application of the different orientation devices is indicated: fluxgate in near vertical open hole to indicate the magnetic North direction (1b), and inclinometers to indicate the Relative Bearing angle (RB), from gravity, in open or cased hole.



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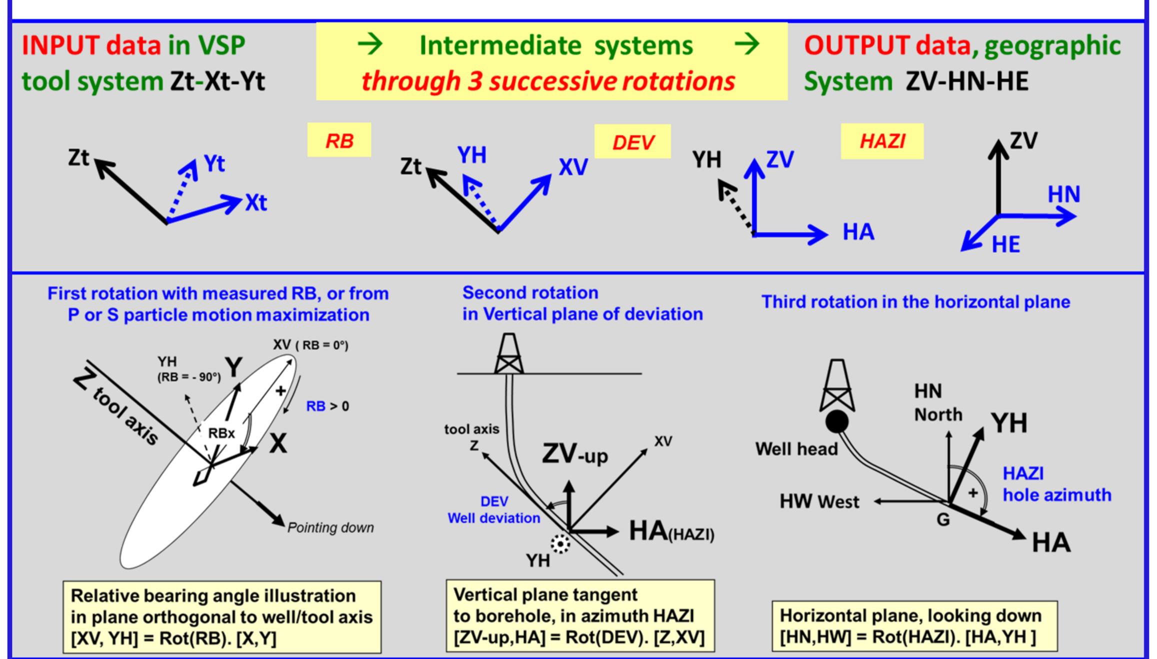
The orientation process from VSP field measurements consists in three successive rotations, sketched below, starting with the RB angle from the inclinometers:



The borehole inclination (DEV) and Azimuth (HAZI) angles are known over the entire well as they are derived from the borehole survey commonly executed during the logging operations. The VSP tool axis Z can be assumed as aligned with the hole axis. A high precision Relative Bearing sensor or inclinometer is assumed to be mounted on at least ONE of the VSP tool shuttles, or on all shuttles; additionally, a magnetic sensor is assumed to be mounted on at least ONE of the VSP tool shuttles. By design, a magnetometer cannot detect the earth magnetic field inside steel casing, and inclinometers cannot measure the Relative Bearing angle (RB) from gravity on small inclination positions from vertical.

Problem to solve:

One observe that the first rotation, by angle RB around tool axis, exhibits the largest jitter variations level to level, since the VSP tool(s) can rotate easily around the well axis, since the cable connecting the tool shuttles can easily twist. In contrast, the two following rotations, by hole inclination DEV and hole azimuth HAZI angles depend on the Hole trajectory, which is spatially smooth and show slow angular variations versus measured depth (MD).

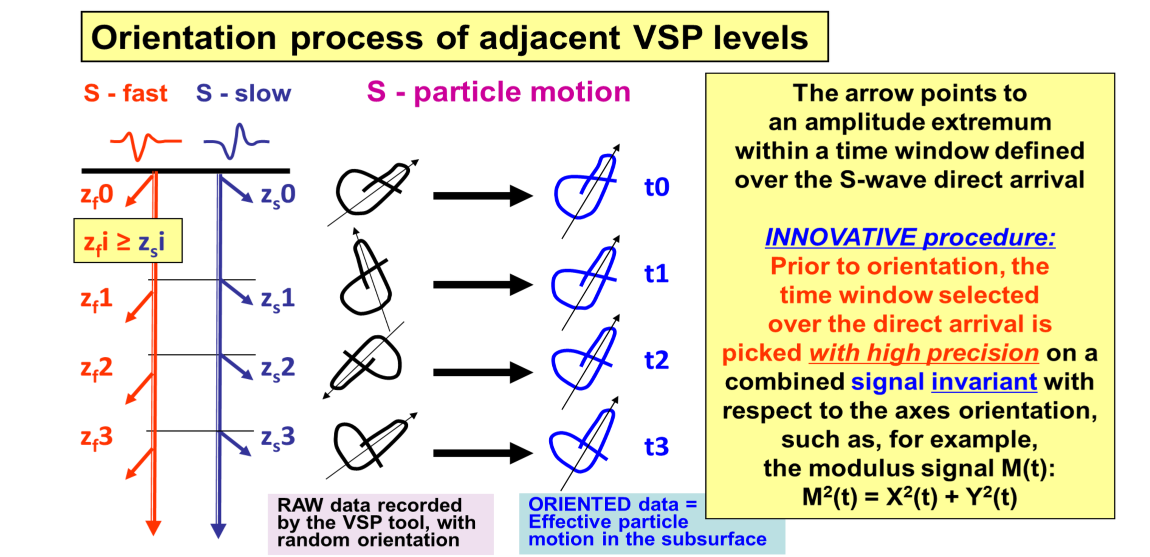
Actually, the technological limitations of the orientation devices considered are that the most accurate inclinometers cannot yield correct RB angles for very small hole inclinations (below 1.5°), and that all the VSP tool shuttles cannot be economically equipped with a magnetometer and a highly accurate inclinometers.

A pre-processing seismic signal solution is proposed to overcome the above hardware limitation: it consists in orienting adjacent 3C VSP signals into a common system, then calibrating the computed RB rotation on the single VSP tool shuttle usually combined with a high precision inclinometer.

In an open hole vertical section, the tool azimuth (instead of RB) is measured by a magnetometer (instead of inclinometers) mounted on one of the VSP tool shuttles.

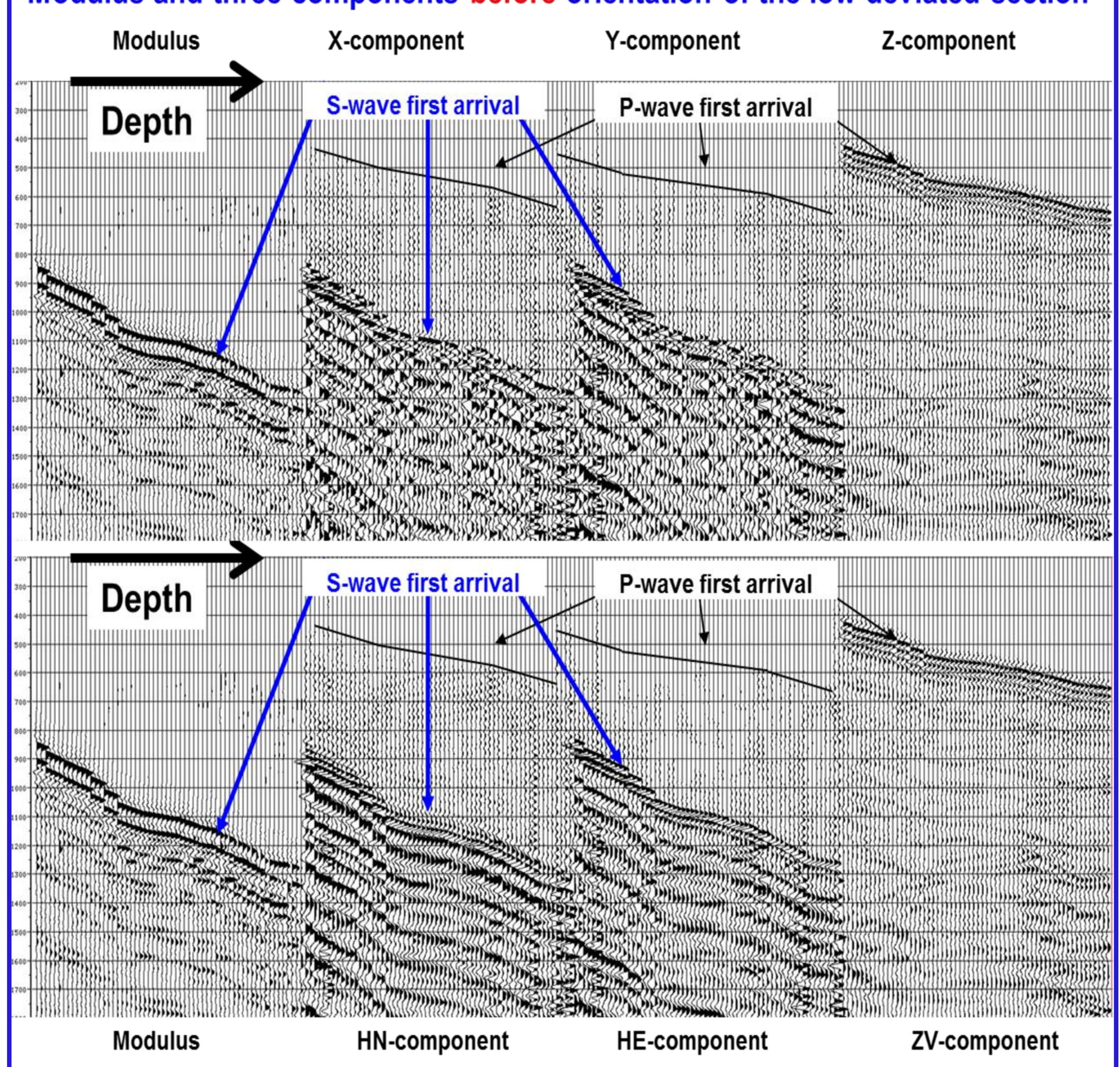
Preprocessing Method for orienting 3C VSP signals on adjacent depth levels.

Physics suggests that the particle motion of major seismic body waves keep a similar shape over many adjacent VSP levels, even in presence of weak anisotropy. Thus the field particle motion of a single body wave differs mainly by a rotation on adjacent VSP levels, and a high coherence of signal shape versus depth is sought for after orientation. As we are looking at orienting mainly the components X,Y of the 3C signals, orthogonal to the tool axis Z, the following reasoning has been applied to the downgoing Shear wave train, or any P or P-S downgoing arrivals, showing dominant amplitudes on components X,Y of rig source VSP's in vertical to deviated boreholes.



A modulus signal trace M(t), INVARIANT from rotation, is computed from the two component signals X(t) and Y(t). On M(t), it is easy to time pick the maximal amplitude peak (arrow direction above) after application of a bandpass filter or a noise rejector improving the coherency versus depth (example below). The peak time is then used to define a narrow time window for polarization maximization from components X(t) and Y(t), compute the RB angle, and rotate the data accordingly: this procedure is similar to the one commonly applied on direct P arrival for offset VSP data orientation. The computed RB values are then calibrated by the reliable RB measurements in the deviated sections before applying the two remaining rotations (DEV and HAZI).

Modulus and three components before orientation of the low deviated section



Modulus and three components after orientation of the low deviated section

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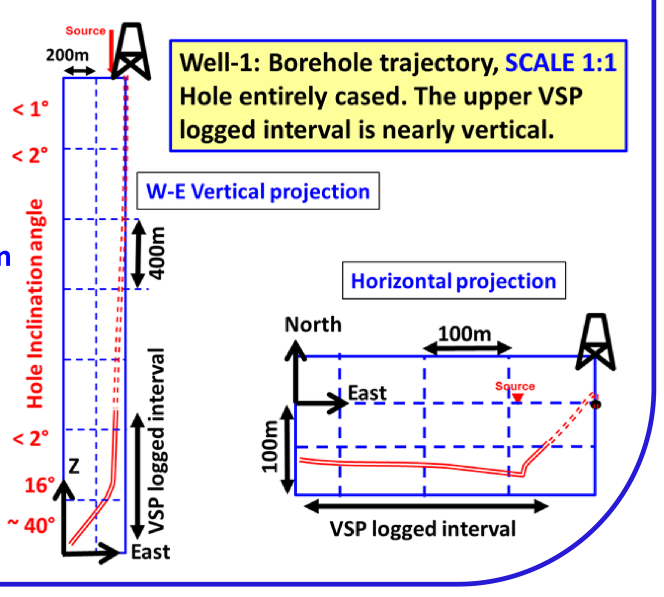
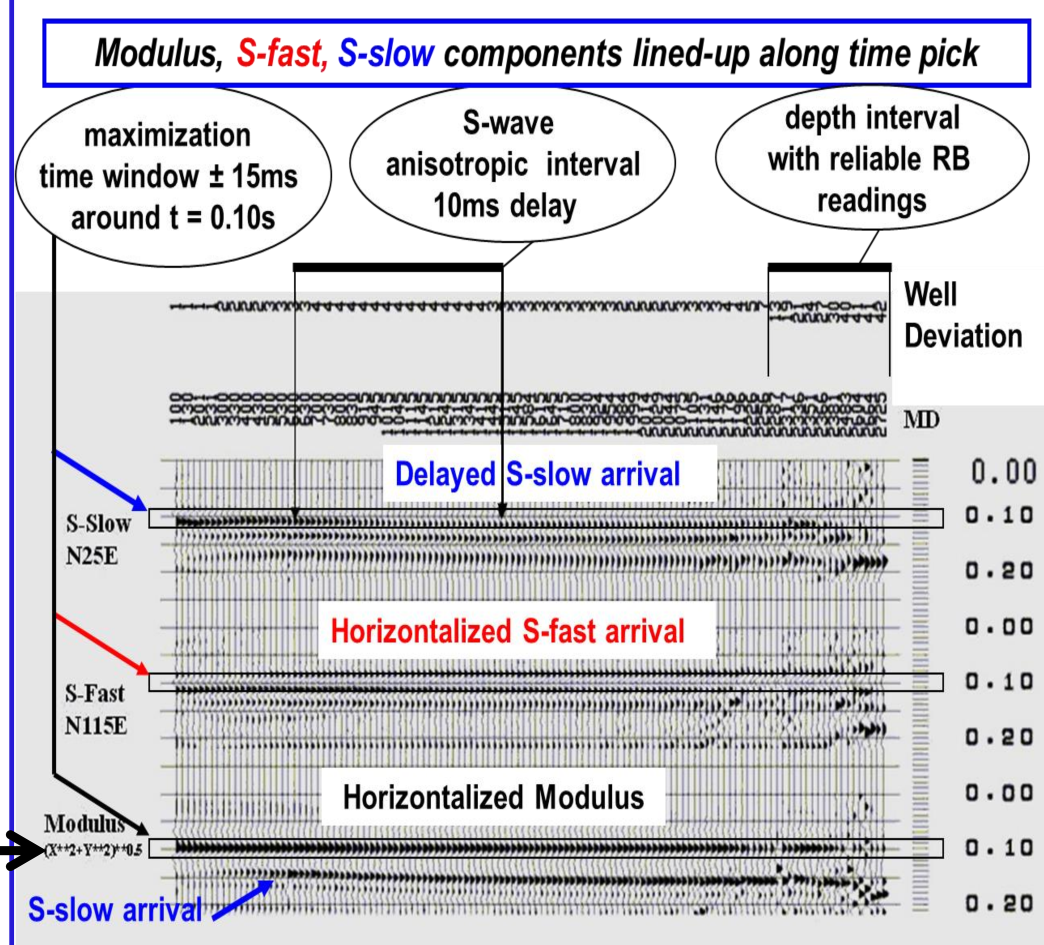
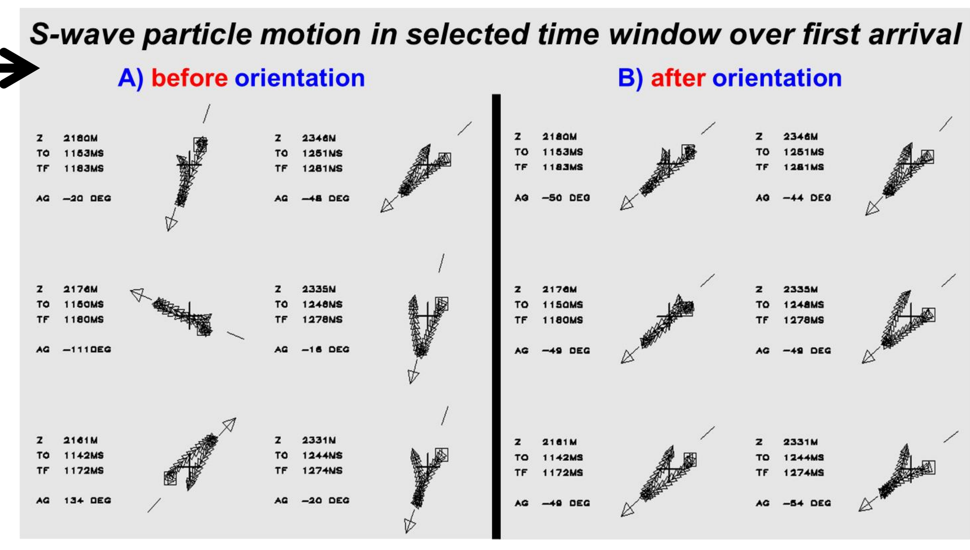
The *borehole trajectory* inclination the upper part does not exceed 4°. The deep part of this old well is side-tracked, with low to medium inclination angles up to 40°. As the RB sensor readings in the present case study are reliable above 8° inclination, the deep VSP levels were used to calibrate the RB angles computed over the entire near vertical VSP upper section.



Peculiar observation on the invariant modulus signal M(t).



The filtered computed modulus trace M(t) has been horizontalized on its first peak (above figure), which corresponds to a Fast S-wave phase signal. A 10ms delay clearly appears on the modulus trace between 630-1450m MD, evidencing a Slow S-wave phase, confirmed after rotation by the RB jitter angle computed on the fast S-wave first arrival. The presence of S-wave azimuthal velocity anisotropy does not alter notably the described orientation process; however, the S-attenuation anisotropy may alter the RB jitter estimation over large depth intervals; RB orientation will of course be more accurate when a high precision inclinometer is combined on one of the multilevel VSP shuttle tool. S-wave particle motions in the selected orientation time window are displayed below (using CGG software).



Conclusion, discussion and suggestions :

The method for orienting the 3C signals of adjacent VSP levels demonstrated in the present example is quite robust, as long as the vector fidelity of the VSP tool is good. The orientation process based on a parameter invariant with rotation is aimed to enhance the signal coherency level to level characterizing the oriented 3C VSP data, by correcting the field RB rotation jitter. A modest extra orientation effort at the pre-processing stage is necessary, but the procedure can be accelerated. A progressive azimuthal orientation drift (+/- 15°) may appear in large near vertical hole intervals in absence of regularly distributed RB calibration depth levels .

The exposed method does not call for cumbersome stiff bridles, or a gyroscope, and it applies for orienting most of rig-source VSP's. The RB sensor readings of the present VSP are meaningless where the hole inclination angle DEV is smaller than 8°. Combining a high precision inclinometer on ONE of the VSP tool shuttles would definitely improve the RB accuracy of pre-processing orientation procedures.

Therefore the authors encourage the VSP tool manufacturers to combine inclinometers and magnetometers with their VSP toolstrings, and to label the trace headers of the output SEG-Y VSP data with the orientation angles.

In places where oriented rig-source VSP acquisition is desired, such as foothills, deep offshore environment, or in presence of complex overburden, operational geophysicists may ask their VSP service contractor for oriented VSP tools with advanced notice, to make sure that appropriate orientation devices are combined with the VSP tool or VSP tool string.

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Oriented 3C-VSP Potential:

- Dip/AZimuth of seismic reflectors in reservoir interval, around and below the borehole.
- Fault dectection in borehole vicinity.
- Improved structural geological understanding.
- Reflected P-P & P- S imaging updip from borehole.

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