VSP tool orientation using Magnetometer and Inclinometer sensors

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Introduction

Onshore wireline borehole seismic in rough, mountainous foothill terrains is very often restricted to rig-source vertical seismic profiling (VSP) and offset VSP using a single fixed surface source, one run per source position, for economic reasons. This technique also applies to common offshore rig-source VSP surveys. Complex subsurface tectonics complicate surface seismic imaging, and borehole seismic imaging is equally difficult. Solving structural features in the borehole vicinity can benefit from three-component (3C) VSP processing techniques, but such processing requires orientating the 3C data at the pre-processing stage. The orientation of the three-component VSP signals recorded in a near-vertical well section, mostly cased, was successfully obtained by combining in the field a magnetometer–inclinometer orientation tool, the GPIT* General Purpose Inclinometry Tool, to a single-level VSP tool with fixed setting of three-component seismic sensors, available at the time.

The present paper illustrates how the current VSP tools and the common logging orientation hardware, namely the GPIT tool, associated with the borehole geometry, can be used without need for a third-party gyroscope to be combined with a single or multilevel VSP tool .

The geologist end-user needs additional accuracy in the VSP processing results that cannot be reliably obtained from the non-oriented rig-source VSP datasets currently recorded in the industry to complement the structural information from the borehole wall imaging techniques.

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Method

Rig-source VSPs are usually shot at the end of the wireline logging program, partly in the **open hole (OH)** deep part of the well, partly in cased hole, deviated or not. VSP recording in borehole depth sections with double or triple casings is generally avoided. The 3C VSPs orientation is achieved by:

Orientation in OH is obtained using the three angles measured by the GPIT tool.

Orientation in deviated cased hole is obtained using the relative bearing (RB) and the hole inclination angle (DEV or SDEV) measured by the GPIT-inclinometer connected to the VSP tool. RB angle is meaningless in a cased hole if SDEV<1.5°. The borehole azimuth (HAZI) angles in the cased interval are provided by the borehole survey. (The GPIT tool runs in the open hole prior to casing installation, or gyroscope.) Figures 1 and 2 illustrate the process.

Orientation of the few VSP stations in near-vertical cased hole, where the GPIT tool cannot yield reliable RB angles, is achieved during pre-processing. The process uses the stable particle motion property of the seismic body waves versus depth to solve the remaining RB rotation jitter of the off-borehole axis components into the same system as the adjacent VSP levels reliably orientated using the angles measured independently by hardware orientation devices, as outlined in Kazemi (2009, chapter 6). Then, processing 3C VSP data can start.

Results

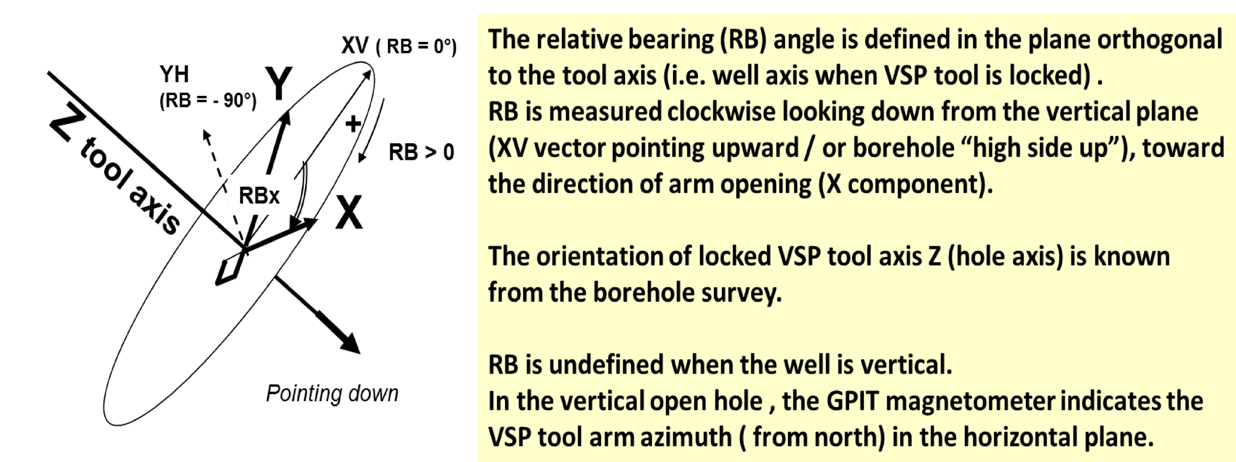

Figure 1: *RB angle definition. RB variations indicate that the VSP tool rotates randomly level to level, although the tool arm remains open while moving between VSP stations.*

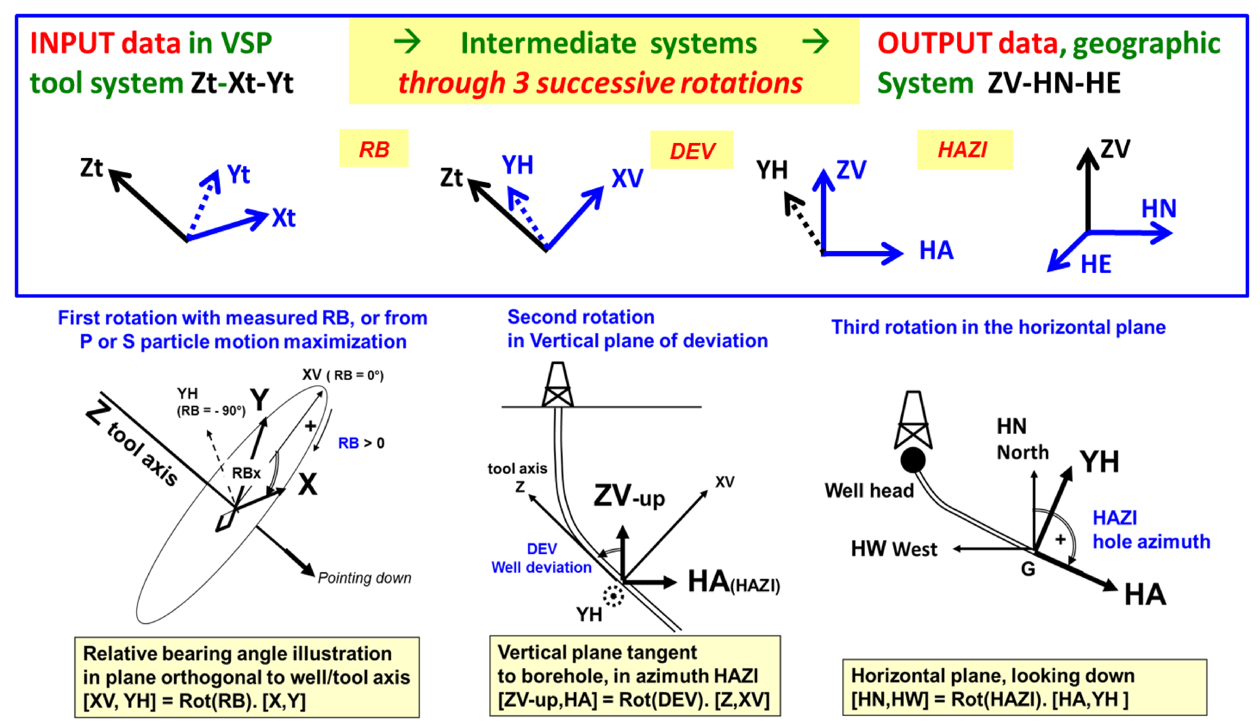

Figure 2: *Three successive rotations illustrate the orientation process of 3C VSP signals.*

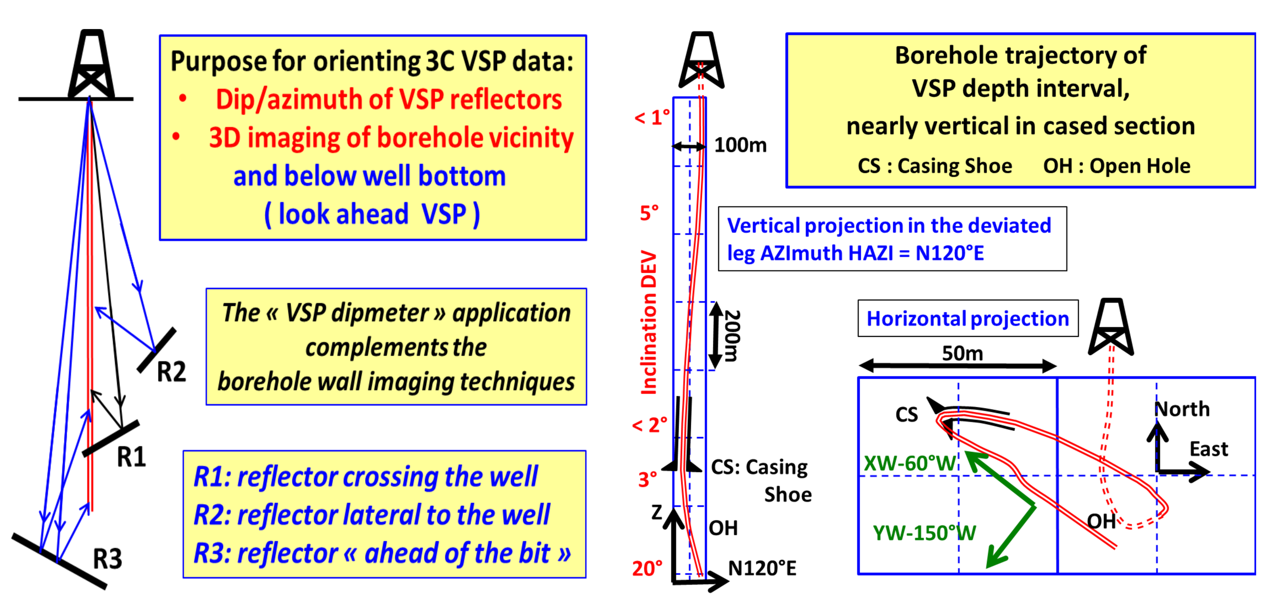

Figure 3 ***Left:*** *Reason for orienting the 3C VSP tools and data (Naville et al., 2015).* ***Right:*** *Geometry of the VSP depth interval. The HAZI changes by nearly 180° right above the casing shoe.*

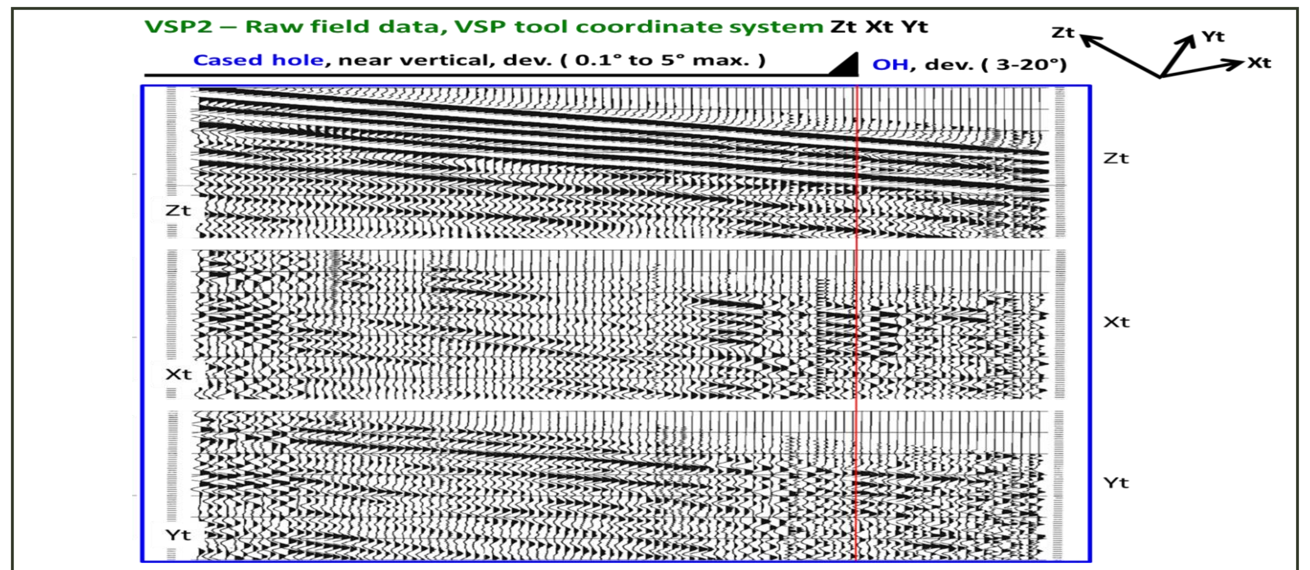

Figure 4: *Raw 3C data. The VSP tool can rotate randomly level to level, mainly in the open hole.*

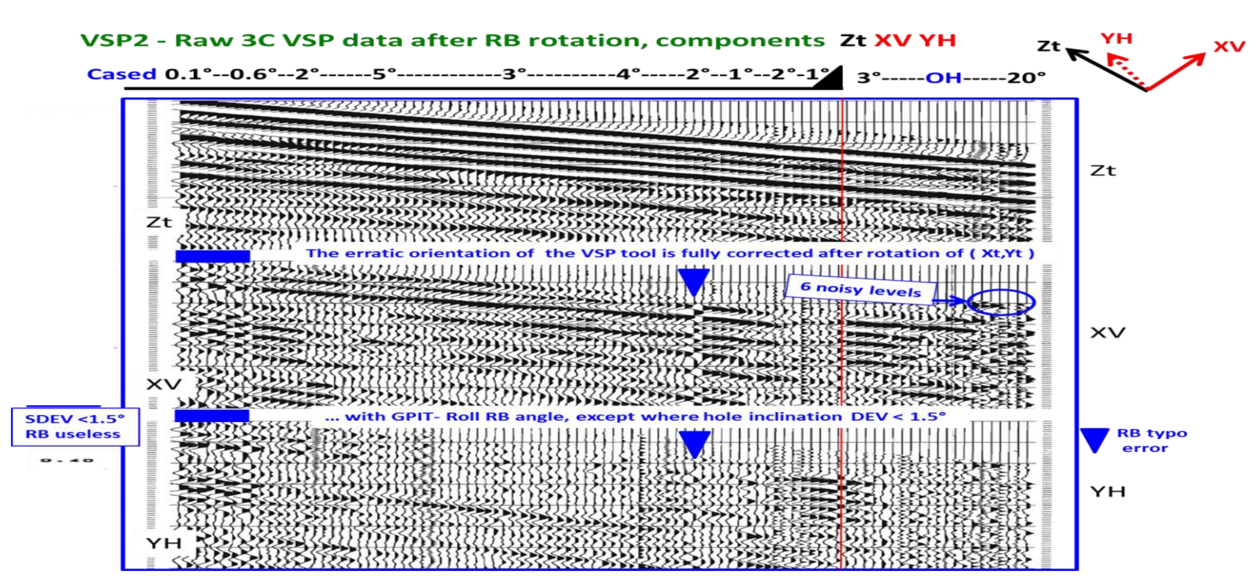

Figure 5: *Raw 3C data after RB angle rotation: it fails where the hole inclination DEV <1.5°*

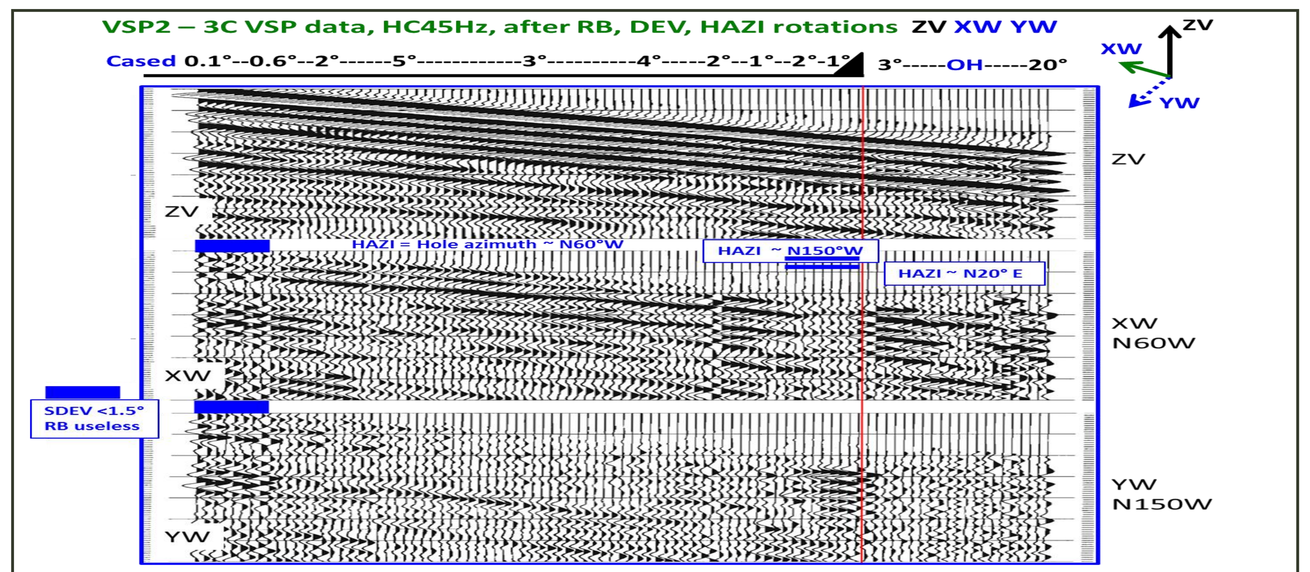

Figure 6: *3C VSP data after all three successive rotations: RB/azimuth jitter in near-vertical borehole sections remains to be corrected.*

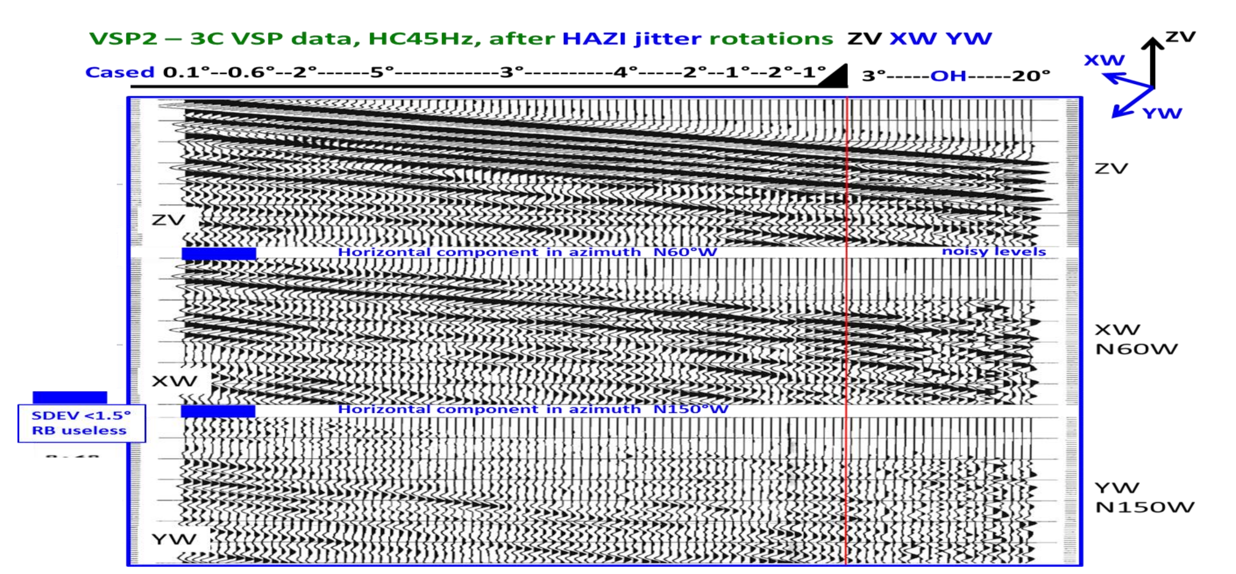

Figure 7: *3C VSP data fully oriented in geographic system after jitter corrections based on coherency of seismic data versus depth. 3C seismic data processing can start from this point.*

Field Examples

The vibroseis raw 3C VSP data (isotropic display, Figure 4) is of excellent quality, exempt of undesired tube waves; random noise attenuation was applied during the vertical stack of repeated records **before** correlation. Continuous noise remains on a few levels in the open hole near total depth (TD), which would compromise orientating the horizontal components without GPIT measurements. The borehole geometry of the VSP depth interval (Figure 3) shows near-vertical intervals where the GPIT inclinometer tool cannot expectedly yield a correct RB angle, at the top and right above casing shoe, as observed on 3C data after rotations (Figures 5 and 6). Rush conditions and retyping the rotation angles led to a few errors in the input rotation angles. The final orientation shown in Figure 7 was obtained by correcting the RB values of VSP levels located in the near-vertical cased section, down to 20 m below casing shoe, using the coherency criterion of seismic body waves within a few wavelength of propagation (Kazemi, 2009). The excellent quality of the oriented 3C data (Figure 7) illustrates the high vector fidelity of the 3C seismic data delivered by modern VSP tools (de Montmollin, 1988). Thus, orientation of 3C VSP data is an added value.

Conclusions

Orientation is necessary prior to advanced 3C seismic processing, and must be fast in order to be generalised in the industry, even in the challenging near-vertical cased hole intervals. The method for orienting the 3C- three component VSP signals of rig source VSP data illustrated by the present example is robust and reliable. The few VSP levels located in the near-vertical cased hole can be properly oriented without needing a third-party gyroscope, and with a reasonable extra effort during pre-processing. The next step will be to test orienting the current multilevel VSI* versatile seismic imager VSP data with a GPIT / magnetometer and inclinometer / tool combined to one of the shuttles, with no cumbersome stiff bridles. As a result, added geological information can be extracted from the common rig-source VSP surveys.

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