

# IFPEN – APS – PPZG: Orientation of 3 component Rig-source VSPs



Borehole seismic acquisition, processing and interpretation.

APS: Applied Physics Systems, Mountain View, CA, USA  
Russ Tavernetti, Mark Sweeny, Electronic engineers & designers

PPZG: Pars Petro Zagros Geophysics Engineering & Services Co.  
Kazem Kazemi, Head of Geophysics

[charles.naville@ifpen.fr](mailto:charles.naville@ifpen.fr)

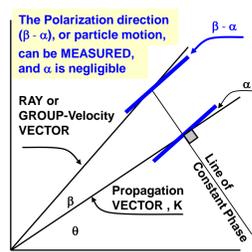
[russ@appliedphysics.com](mailto:russ@appliedphysics.com)  
[mark@appliedphysics.com](mailto:mark@appliedphysics.com)

[kkazemi@parspetro.com](mailto:kkazemi@parspetro.com)

**Summary:** About 75% of commercial borehole seismic operations are zero-offset VSPs, or “Rig-source VSPs”. VSPs are recorded before final completion in low deviated holes, with a deep open hole interval, a single casing interval, then multiple casing depth intervals above. Three components of geophones are recorded, with excellent mechanical tool coupling to the borehole wall, but usually the VSP tool cannot be oriented into geographical coordinates. Therefore only the Z-axis component is processed, or a near vertical component computed from the 3 recorded components (3C), resulting in a SEVERE reduction of the geological information derived from rig-VSPs. The authors suggest to implement current and future generations of VSP tools with cost effective fluxgates and inclinometers to improve the present situation.

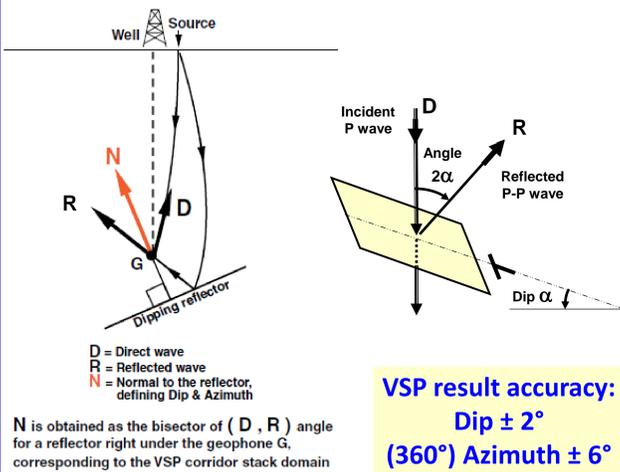
## PRINCIPLES of METHOD:

In fairly homogeneous medium, even anisotropic, P-wave polarizations of direct and reflected P-wave events are linear, nearly in line with the group velocity, thus can be measured. (ref. Crampin, 1982)



\* \* \*

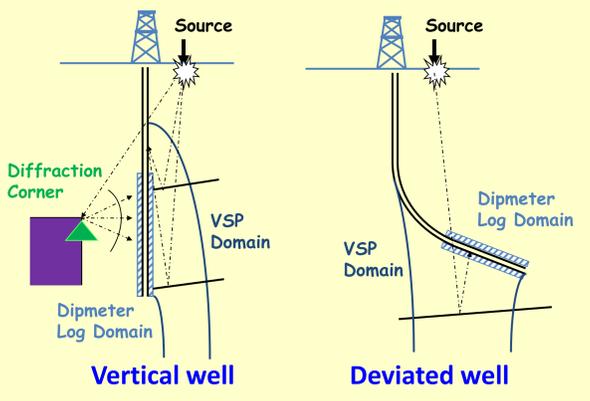
Snell-Descartes law applies as illustrated below.



VSP result accuracy:  
Dip  $\pm 2^\circ$   
(360°) Azimuth  $\pm 6^\circ$

\* \* \*

Respective domains of investigation at target depth  
Rig Source / walkabove VSP versus Borehole wall image Logs



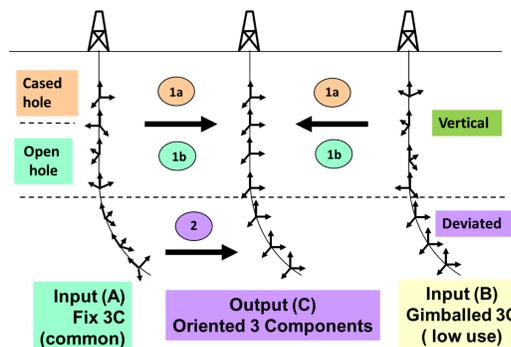
Although imaging accuracy decreases away from the well, laterally or at depth, relevant 3D structural information can be derived in the borehole vicinity (up to 500m) even with complex overburden.

## ORIENTING the 3-component signals from a VSP tool, single or multilevel.

3C seismic signals of VSP's need to be oriented in the SAME coordinate system prior to processing.

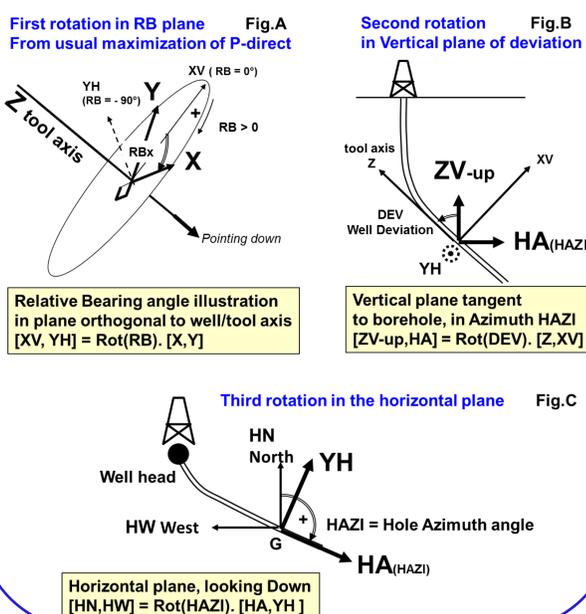
The sketch below illustrates the 3C trihedrons with two well-known geophone settings, Fix of Gimbaled, and the depth interval of application of different orientation devices: fluxgate in open hole to indicate the magnetic North, and inclinometers to indicate the Relative Bearing angle (RB), from gravity, open or cased hole. At the time of VSP acquisition, the deep reservoir interval generally includes an open hole section, and the borehole may be sufficiently deviated in another section for the inclinometers to yield valid RB measurements. The coherency of the 3C seismic signals versus depth on adjacent VSP levels should be improved after orientation; this property can be used for orienting the VSP levels left un-oriented by hardware devices, mainly in the near vertical cased hole section located above reservoir interval. 3C seismic signal coherency is usually obtained in the industry by maximization of Direct P; direct S arrivals or P-S downgoing arrivals may be used in favorable VSP cases when P-wave energy is too small on components orthogonal to well axis (Ref: Patents on 3C VSP orientation).

Orientation process 1a: gyro or seismic arrival coherency  
Orientation process 1b: vertical Open hole: fluxgate.  
Orientation process 2: well trajectory + RB measurement



\* \* \*

Orientation process 2, in a deviated well, using the borehole survey angles Inclination & Hole Azimuth available prior to VSP survey, and Relative Bearing RB angles measured on each probe of the VSP toolstring. The sketches below illustrates the 3 successive rotations applied; the angle names (DEV, HAZI, RB) have been chosen because they are widely used by logging and drilling professionals.

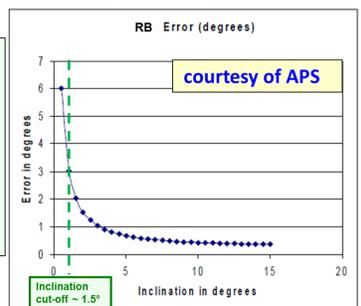


## PROPOSED cost efficient technology: to overcome present orientation limitations.

Currently, the borehole vertical Inclination must be  $> 8^\circ$  on commercial VSP toolstring shuttle implemented with RB measurement devices. The sensitivity plot below illustrates that this limit could be reduced to less than 2 degrees, using existing accelerometer-based inclinometers. Implementing such device in each shuttle of VSP toolstring would certainly enlarge the depth domain where the 3 Component of rig-source VSP's could be reliably oriented, and allow for extracting more information from Rig-source VSP's from 3C processing.

Accuracy of the Relative Bearing versus vertical Inclination angle, for existing small solid state inclinometers.

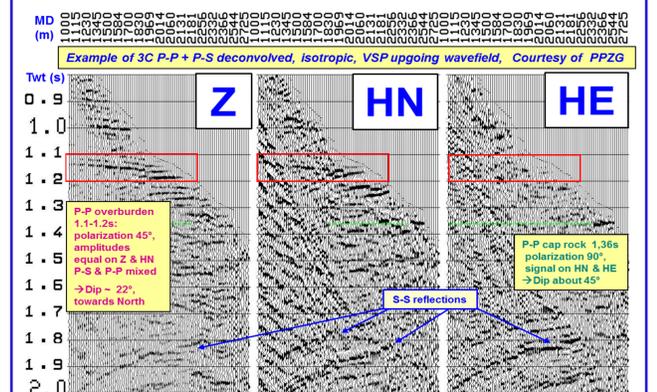
The Relative Bearing angle well known by loggers is also called Tool Face angle by drillers, or Gravity Roll angle by others (ex. aviation)



VSP recording occurs when the tool is clamped to the borehole wall, in still position, thus it is not necessary to record orientation parameters continuously. Miniature, modern and high precision solid state inclinometers could be implemented on each shuttle of commercial VSP toolstrings, with minimal additional volume and mass, while at least one fluxgate located in an a-magnetic housing could be mounted on one of the shuttles, in order to have one geographic orientation tie-point for each VSP toolstring position in the open hole. Many drilling BHA, and wireline logging tools are currently implemented by APS hardware orientation elements, or equivalent systems, designed to resist shocks and temperature. Last, it is easier to take in account the implementation of orientation elements at design stage of future generations of wireline VSP tools and toolstrings, as the questions of electronic management and transmission of ancillary data must be addressed simultaneously.

EXAMPLE of 3C isotropic VSP upgoing wavefield, quickly obtained after orientation into geographical system.

Presently, VSP's are recorded in 3C, but often, only the vertical, or tool axis component is processed, so that much of 3D information is LOST.



**CONCLUSION:** In places where oriented rig-source VSP acquisition is desired, such as foothills, or deep offshore environment, or in presence of complex overburden, the authors recommend that operational geophysicists ask their VSP service contractor for oriented VSP tools with advanced notice, (months rather than days) so that the hardware engineers can address this question in time. VSP tool manufacturers will eventually fulfill the need of professional borehole seismic geoscientist users for more information at target depth. Last, questions about oriented 3C VSP techniques unanswered by the industry still need to be examined, and the authors suggest that VSP tool manufacturers, service companies and operating companies keep improving the whole chain of oriented 3C VSP: tool design, acquisition procedures, processing and interpretation.

## Oriented 3C-VSP Potential:

- Dip/AZimuth of seismic reflectors in reservoir interval, around and below the borehole.
- Detection of certain Faults in borehole vicinity.
- Better geological understanding at target depth.
- Reflected P-P & P-S images updip from borehole.
- Downgoing converted P-S images downdip from borehole.

## References:

- Crampin, Geophys.J.R. astr.Soc. 1982, 68, 477- 485;
- Patents on 3C VSP orientation: US2012046871A1;FR2942045; FR2942547
- Patents on 3C VSP processing: US6,076,045;US20030086335A1;
- AAPG2001-Naville (Google), EAGE2002-PO18, EAGE2014-TuG102\_12
- KAZEMI thesis, online ( google link: Cergy univ, kazemi) : [https://hal.inria.fr/file/index/docid/414628/filename/Thesis\\_kazemi.pdf](https://hal.inria.fr/file/index/docid/414628/filename/Thesis_kazemi.pdf)