Borehole seismic acquisition, processing and interpretation.

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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 method 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-waves 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.

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 inclusions with two well-known geophysics settings, fix of Gimbaled, and the depth interval of application of different orientation devices. Figure is 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 ray component 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 coherence of the 3C seismic signals versus depth an 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 coherence is usually obtained in the industry by maximization of Direct P; Direct S arrivals or P-S downgoing arrivals may be used for this with VSP source when P-wave energy in the drill on components orthogonal to well axis (Ref: Patents on 3C VSP orientation).

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

Respective domains of investigation at target depth

3C Vibroseis VSP vs 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.

PROPOSED cost efficient technology:

Currently, the borehole vertical inclination must be > 8° on commercial VSP tooling utilized with VSP 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 tooling would certainly enlarge the depth domain where the 3 Component of rigsource VSP’s could be reliably oriented, and allow for extracting more information from Rig-source VSP’s from 3C processing.

VSP recording occurs when the tool is clamped to the borehole wall, in still-position, then it is not necessary to record orientation parameters continuously. However, 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 figure located in an e-magnetic housing could be mounted on one of the shuttles, in order to have one geographic orientation tool for each VSP toolstring position in the open hole. Many drilling rigs, while and wireline logging tools are currently implemented by APS hardware orientation elements, or equivalent systems, designed to resist shocks and temperatures. Last, it is easier to take into account the implementation of orientation elements in design stage of future generations of wireline VSP tools and toolstrings, as the questions of electronic management and transmission of anisotropy 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 recommended 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 specialists 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:
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