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Downhole seismic sources for Reverse 3D-VSP surveys

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SUMMARY

Acquisition of Reverse 3D-VSP with Downhole seismic sources and large amount of surface seismic sensors is desirable in many instances. A non exhaustive overview of existing powerful prototype downhole seismic source devices is presented, as well as the main results obtained in a recent past, as well as the emerging technology which can contribute to industrialise the Reverse 3D-VSP method. Discussion with industry is welcome

Introduction

Drilling still occurs in places where surface seismic results are poor to null. 3D-VSP surveys using multilevel downhole receivers depth arrays are well suited for marine environments. For land surveys, where the terrain conditions are rough, such as foothills or the transition zones for instance, the deployment of seismic sources and the increased rig time necessary to shoot a 3D patch around the well may render the conventional 3D-VSP survey cumbersome and uneconomical.

In hot geothermal wells, recording borehole seismic may not be possible due to the temperature limitations of the existing downhole receiver technology; this situation is not going to change soon.

Alternative techniques consist in using powerful downhole seismic sources, and large surface land or seabed receiver arrays, so as to record Reverse-3DVSP surveys during a short period on the field, in order to yield some structural seismic information to the geologists and drillers in charge of the difficult prospects above mentioned, for a reasonable cost.

Prototype techniques and experiments with powerful downhole seismic sources are in very limited number: explosives, drillbit noise, mainly with roller cone rock bit drilling sufficiently hard rock, and near bit enhanced vibrating device. Existing and emerging technology contributing to potentially feasible downhole seismic source techniques are presented, in a informative and non exhaustive way.
Unfortunately, at present, none of these techniques are implemented industrially.

A concerted effort to overcome the technological challenges and to adjust the appropriate field practice is suggested to the industry. In prolific hydrocarbon onshore regions where deeper targets are looked for, Reverse and Direct 3D-VSP techniques would need to be concurrently tested.

1) The point of view of a geothermal driller: well safety and Drilling dynamics issues

Geothermal areas are often located in heterogeneous hard rock formations, either sedimentary, basal or igneous, and the hot geothermal fluids are preferably produced from faults and fractures. Consequently roller cone bits are mostly used to drill this kind of rocks.
Premature fatigue of all the drillstring elements can be induced by the abrasive rock, combined with high levels of downhole vibrations during drilling.

Considerable decrease of downhole temperature while drilling is observed relatively to the natural temperature of the formation under drilling, which allows for using MWD systems, as long as the drilling fluid flow which cools down the MWD electronics is not interrupted for long time periods, even if partial or total loss of drilling fluid while drilling occur.
Therefore, in order to use any sort of MWD technology economically and safely, it is desirable to make progress in mitigating the harsh downhole drillstring vibrations and the risks of drilling problems such as twist-off, drillstring failures, which could result in burning the downhole electronic systems, even when the elements lost in the well are recovered.
In turn, using downhole MWD technology could help improve the drillstring dynamics, mitigating the drilling problems and drilling faster to the target depth.

Alternatively, as the borehole wall stability of hard geothermal rocks is generally good, limited charges could be exploded in the open hole with limited risk of borehole collapse, especially if the borehole is cleaned and a casing is set right after the explosions.
Services companies acquainted with perforation jobs would seem to be suited to design explosive settings and operate them in the open hole for seismic emissions, with minimal damage to the well.
LANDVIRKUN Power is currently proposing a medium hot, non productive well with a large open hole interval, to test the effect of explosives in the open hole, and their seismic suitability for reverse 3D-VSP surveys, in complement to the current international IDDP project : http://www.lvpower.is/en/projects/iddp/ , http://iddp.is/)

2) Explosives as R-3DVSP downhole source :

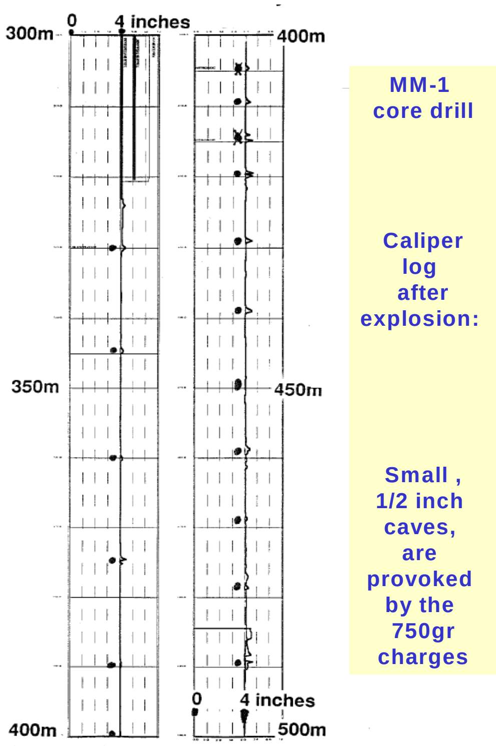

***Figure 1** Illustration of recovered plastic pipe holding the 750gr explosive charge, MM-1 well(left). Small caves , 0.5inch, are provoked by the explosions; NO hole collapse (right).*

In the scientific well BA-1, South France, IFP and CGG successfully shot 16 dynamite charges of 1kg lowered one by one in a 8"½ open hole vertical well, 15m apart, in the 815-1030m depth interval. No well damage has been noticed on a caliper log repeated after shooting the charges in a hard calcarenite rock formation (Vp 5km/s). No metallic debris were left in the hole, only plastic elements.
The shape of source signal is exceptionally repeatable shot to shot, so that one can apply the same seismic processing procedures currently used for standard 3D-VSP data recorded with surface source and downhole array of receivers. Detailed results in *SEG Abstracts, 1991, BG3.7,vol1, P94-97*.
In 1992, a second Reverse-VSP operation using 750gr explosive charges was carried out in the neighbouring well MM-1, a 4" diameter core-drill down to 1000m, located 1.5km west of BA-1, in conglomerate and carbonate rocks, about 4km/s velocity (Vp). The seismic data were equally as excellent as in BA-1. A few details about the field operation are presented in the following. Plastic pipe debris were left in the well after explosion, one per charge, some of them being recovered (**Fig.1 left**), as they unexpectedly remained stuck to the iron sink bar used to add weight to the charge, in order to speed-up the wireline manoeuvres. Small ½ inch caves have been built, as testified by the post-explosion caliper log (**Fig.1 right**). This log was run after all the plastic debris have been successfully pushed to the bottom of the well by the small truck mounted work-over drilling machine. Liquid explosive charges have been used as well, which released insoluble gases in the fluid column and drastically attenuated tube waves provoked by the subsequent explosions.

Remark: minor incidents occurred while pulling out the sink bar after the explosion, as some chunks of conglomerate rock detached from the borehole wall, above the sink bar. Fortunately, the size of this rock chunks did not lock the sink bar while pulling out, although unexpected tension spurts occurred on the weak cable winch. The sink bar was screwed not too tightly on the cable, so as to slide beyond a moderate tension threshold, in the case the sink bar would get stuck (CGG - Yves Ollivier's design)

For future operations, it would be recommended to improve the charge design and the field practice of exploding elongated cylinder shaped charges in the well, in order to leave behind only drillable debris, minimise the cave diameter, thus allowing for cleaning the well with the drillstring after the explosions and resume drilling operations. Preferably, shooting a reverse 3DVSP with explosives should be planned BEFORE setting a casing, an additional borehole cleaning trip being performed right after shooting the charges in the bottom interval of the open hole.

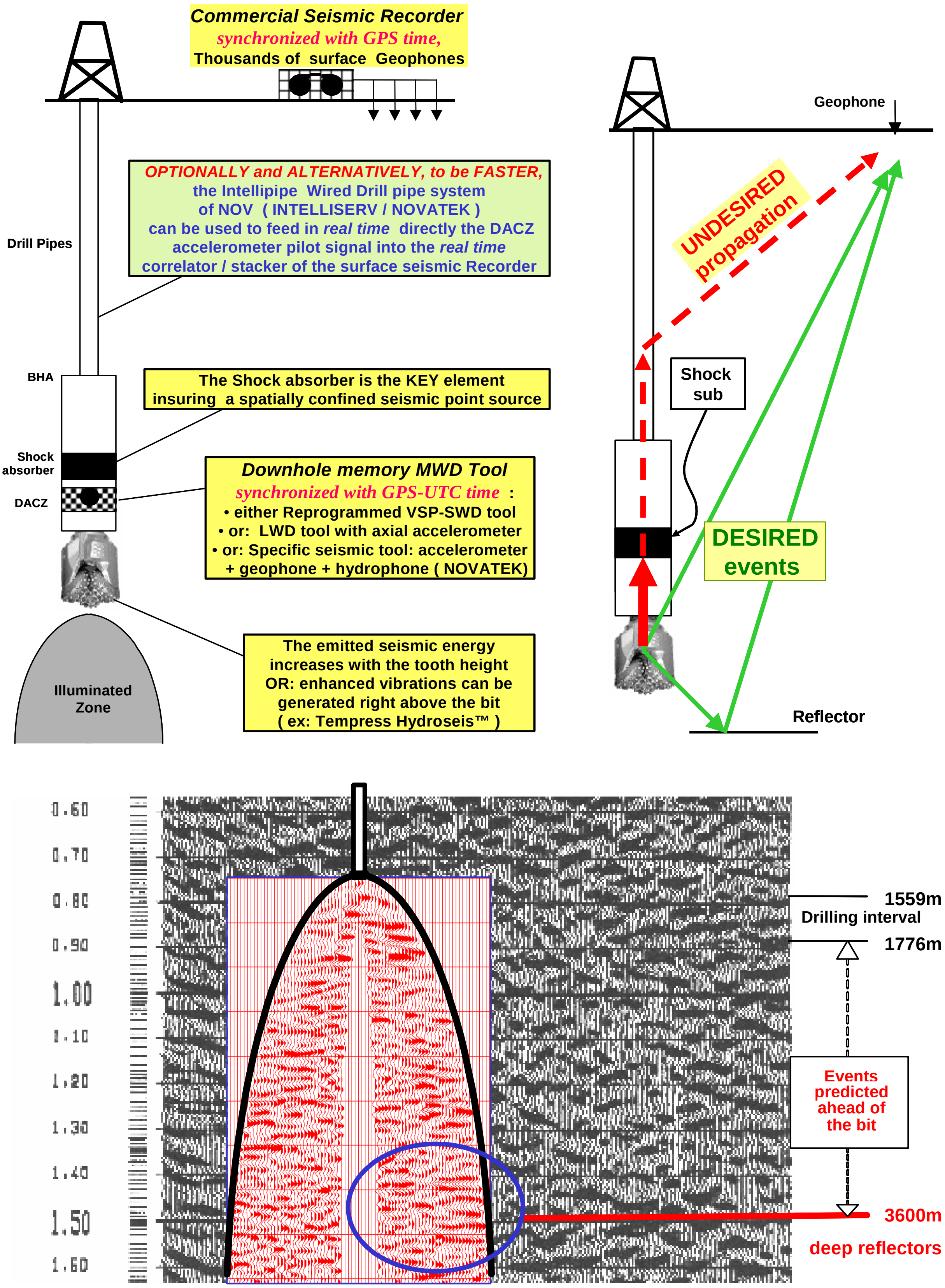

Figure 2: *Reverse 3D-VSP-WDsection using drillbit noise: method and results*

- *Feasible recording chain with existing and emerging technologies(top left) ,*
- *Key role of Shock absorber to **KILL** undesirable seismic re-emissions (top right),*
- *Example of seismic image, 2km ahead of the bit (bottom), courtesy of ENEL.*

The successful drillbit SWD technology, method and results outlined in above **Fig.2** have been obtained using a downhole memory tool developed by Geoservices. Detailed results at: http://ogst.ifp.fr/index.php?option=article&access=standard&Itemid=129&url=/articles/ogst/pdf/2004/04/naville_vol59n4.pdf , or in SPE65115.
At present, the industrial Intellipipe WDP system (http://www.nov.com/IntelliServ/ or SPE92477), represents an invaluable tool to speed up SWD field operations as well the simultaneous technical evaluation of the newly built pieces of drilling equipment aimed at enhancing the seismic emission.

3) Enhanced downhole seismic emission "AT the BIT" while Drilling.

Tempress, has focused on the development of technology to overcome critical issues with deepwater offshore field development, with DOE support, in particular the **HydroSeis™** downhole pulsing system.
The HydroSeis™ seismic-while-drilling tool provides a way to generate seismic noise at the bit. The tool incorporates a self-piloted valve that periodically stops the flow of drilling fluid through the bit. The valve closes for 50 milliseconds (**Fig.1**), and cycles at 1 to 2 Hz.. Closing the valve creates a pressure impulse upstream and a impulsive force on the bit. The impulsive force from a 6.5-inch diameter tool operating at 1500 lpm on 9.5 ppg mud is equivalent to a magnitude *M*=-1.5 seismic event. A 200 second stack increases the effective amplitude to *M*=-1.0.
Microseismic monitoring is envisaged in order to track the tool location and well trajectory on the seismic record for geothermal MWD. The signal can be used for vertical seismic profiling while drilling and look-ahead pore-pressure prediction.
This device contains no electronics, is capable of operation at geothermal temperatures >230°C. Additional details are described at : http://www.tempresstech.com/
A smaller version of this tool is used commercially to enhance weight transfer for coiled tubing milling in extended reach horizontal wells. Milling rates increase by a factor of 5 to 20 indicating good mechanical coupling of the pulse to the bit.

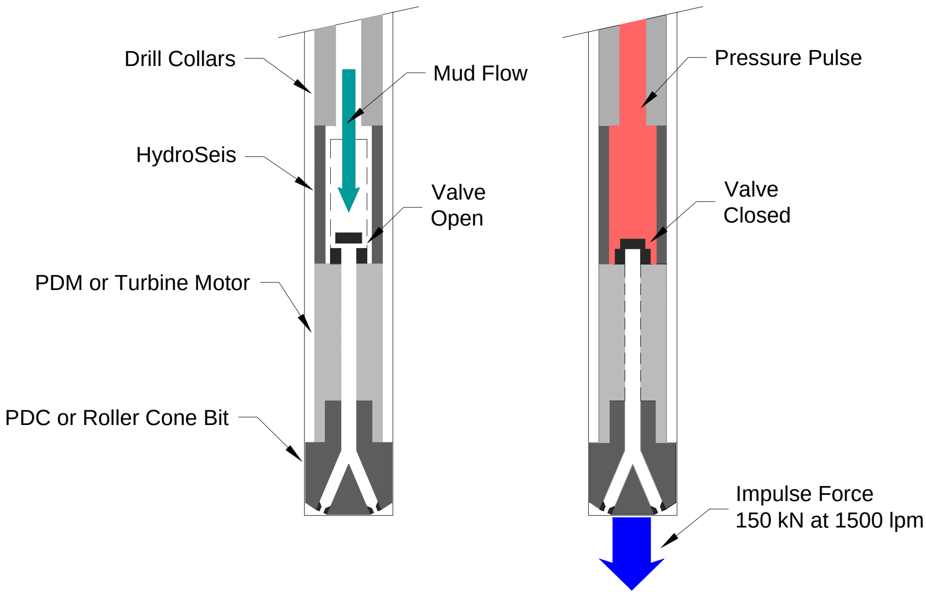

Figure 3 *Illustration of the HydroSeis system and operating sketch.*

Conclusion:
The emerging technologies presented above awaits for a moderate effort and field testing to be fully operational industrially. Downhole sources constitute an attractive technological and economical alternative to 3D-VSP operations in specific terrain and geologic conditions, yet to be discovered. Therefore, a consortium of Oil& Gas and Geothermal operators would be appropriate to investigate the downhole source avenue, with cooperation of MWD, Logging and Seismic service companies. Questions can be addressed to Charles.Naville@ifp.fr , or Ragnar.Asmundsson@isor.is