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## SOULTZ VSP 2007 CAMPAIGN IN GPK3 AND GPK4: OPERATION REPORT AND PRELIMINARY RESULTS

Nicolas Cuenot<sup>1</sup>, Maria del Mar Mesa Salgado<sup>2</sup>, Charles Naville<sup>2</sup>, André Gérard<sup>1</sup>, Joachim Place<sup>3</sup>

<sup>1</sup>EEIG "Heat Mining", Route de Soultz, BP 38, 67250 Kutzenhausen

<sup>2</sup>Institut Français du Pétrole (IFP), 1 et 4 avenue du Bois-Préau, BP 311, 92852 Rueil-Malmaison Cedex

<sup>3</sup>Ecole et Observatoire des Sciences de la Terre, Institut de Physique du Globe (EOST-IPG),

5 rue René Descartes, 67084 Strasbourg Cedex

e-mail: [cuenot@soultz.net](mailto:cuenot@soultz.net)

### ABSTRACT

Following the encouraging results obtained from the re-processing of the 1988 and 1993 VSP dataset recorded in GPK1 (Place et al., 2007), it was decided to perform a borehole seismic survey in the wells GPK3 and GPK4 at Soultz-sous-Forêts, in order to obtain a better characterization of the faults/fractures network of the granitic massif. The main goal of the experiment is to get a better knowledge of the main permeable fractures which correspond to the major circulation paths of the geothermal water in the reservoir.

The acquisition scheme involved two vibrator trucks and two 4C seismic tools (3C oriented geophone + hydrophone). The operation lasted 4 weeks (20 days of recordings) during which 2 profiles were acquired per day (one in GPK3 and one in GPK4) mainly between 4000 and 5000 m depth. The depth interval between each measurement level was 20 m. The total logged length in both wells reached about 35000 m.

The vibration locations were chosen to ensure a good azimuthal coverage of the region around the logged wells. If possible, for each run a close and a far offset were used and the seismic tools moved in the same time in both wells to be at the same depth for each recording level.

Despite a few operational problems (hydrophones, overheated tools, sweep encoding failures,...) which did not affect the experiment too much, the survey was a great success. Some preliminary results from seismic signal pre-processing already allow observing interesting features in the data.

### INTRODUCTION

One major problem for geothermal project is to obtain the best knowledge of the permeable flowpaths which allow the geothermal water to circulate in the inter-well medium or its surrounding. The structures are generally well-defined at the direct vicinity of the well, but it is difficult to assess their geometry at a certain distance of the well. In that frame VSP survey is a very efficient tool for characterizing the faults/fractures systems.

At Soultz-sous-Forêts, two VSP surveys were performed in 1988 and 1993 in the well GPK1. The datasets were recently re-processed and the results show the ability of the method to characterize the geometry of a major fracture at a distance

up to 150 m far from the well (Place et al., 2007). Other features were observed up to 700 m far from the well. These results demonstrated that the method could be really helpful for the development of geothermal reservoir and it was decided to perform a new VSP survey in the wells GPK3 and GPK4 in order to get a better characterization of the deep fracture network.

### EXPERIMENTAL SETTINGS

#### Acquisition scheme

##### Basic principle

For each run two seismic tools were deployed in GPK3 and GPK4 and had to be at the same depth level for each records. It was planned to log 1 kilometer (4000 m – 5000 m) during each run, with measurement levels every 20 m.

For each run the two vibrator trucks were placed at 2 different locations. 26 vibration locations were then used, corresponding to a multi-offset acquisition scheme, which helps orienting the horizontal components of the VSP tools. We tried as much as possible to use a close and a far offset for each run. As seen in figure 1, we tried to get a good azimuthal coverage around the boreholes, in order to have good chance to illuminate the fractures with various incidence angles.

##### Field equipment and involved personnel

Different organizations in charge of the different parts of the equipment were involved in the operation and contributed to its success (see field disposal in figure 2):

#### EEIG Soultz:

- 2 cranes + operator
- 1 winch unit + operators
- 1 standard 7 conductor cable
- Field support

#### MeSy:

- 1 winch unit + operators

#### Baker-Hugues:

- High temperature VSP tools + 1 field engineer
- Cable heads

#### Landtech

- 2 vibrator trucks Litton LRS 415
- 1 recording unit Bison Jupiter
- Correlator
- Control screen + printer
- Surface monitoring geophones

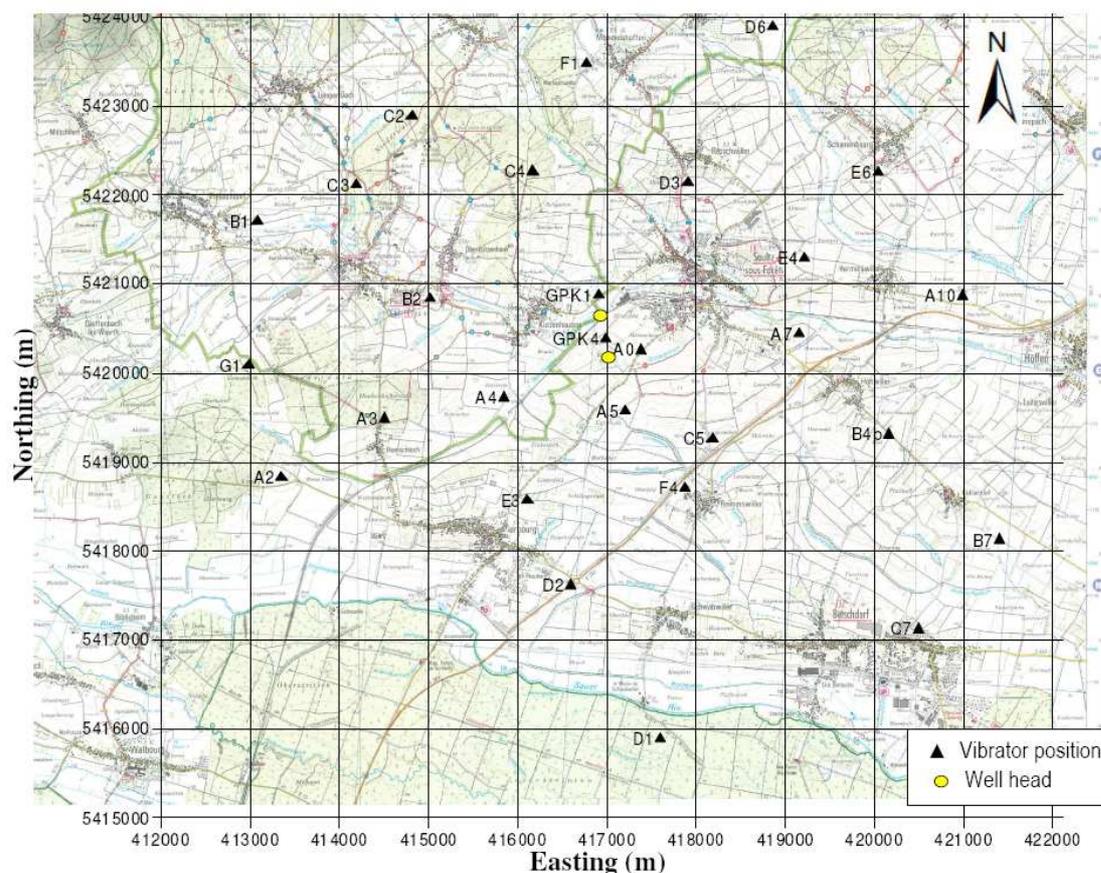


Figure 1: Location map of the vibration positions used for the VSP acquisition

- GPS receiver
  - 2 field engineers
- EOST**
- Field support
- IFP**
- Field coordination

Recording cycles

A sketch of the field disposal is shown on figure 2:

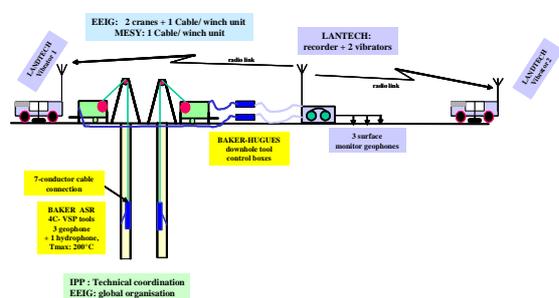


Figure 2: Field disposal

Early in the morning, the tools were pulled into both wells to the beginning depth (see a picture of the installation on GPK2 platform on figure 3). Originally the tools were moved down to 4900 m depth and the profile was made upwards. But because of overheating problems encountered by VSP tools, it was decided to first pull the tools down to 4000 m

depth and to record the profile downwards to 4900 m depth. As soon as the tools were at the required depth, first tests had to be made in order to check the whole acquisition chain:

- Vibrators
- Radio link between recording unit and vibrators
- VSP tools
- Energy received by the tools.



Figure 3: winches, cranes and recording unit on GPK2 platform.

The tools were both clamped in both well GPK3 and GPK4 at the same depth. Vibrators 1 and 2 were activated simultaneously from the recording unit by radio link and the seismic waves recorded. Then the tools had to be unclamped and moved simultaneously by 20 m to the next measurement level. Typically such a cycle took around 3 to 4 minutes if sufficient energy was recorded on the tools, but if more stacks were necessary, a cycle could take up to 10 minutes. Fortunately, the weather was very good during the whole duration of the operation so that the ground was very hard, allowing a good transmission of the generated waves from the vibrators and no high energy loss.

One run was made per day during daytime (to avoid any kind of nuisance for the surrounding population during the evening or night). After the run, the VSP tool maintenance was done and the trucks were moved to their next position to be ready for the following day's run.

26 VSP data sets were acquired in 2 wells simultaneously over 20 days of work. In each run, about 1 to 1.5 km were logged in the deep part of the wells. The total logged length in both boreholes is around 35000 m. Taking into account the simultaneous acquisition, a total of 70500 m were finally logged. Table 1 summarizes the production statistics for the campaign.

Date	Run	dataset	Source Position Number	Vibrator Positions	logged interval (m)		GPK3 length	GPK4 length	Cumulated length	GPK3	GPK4	Observation
					GPK3	GPK4				ASR VSP Tool number		
30/03/2007	0	0		A0-A10*	3200-4500	3200-4500	1300	1300	5200	3192		Test run; move A10 to E4
02/04/2007	1			A0-E4*		1500-3200		1700	3400	3190, Hydro 3	3191, Hydro 2	
03/04/2007	2	1		A0-E4*		800-1500		700	700	3190, Hydro 3	3192, Hydro 2	Water inside tool 3191
04/04/2007	3	1		A0-E4*	3080-3200		120		240		3192, Hydro 2	Failure tool 3190 + hydro 3
05/04/2007	4	1	1-2	A0-E4*	4500-4800		300		600	3192, Hydro 2		GPK4 cable maintenance
10/04/2007	5	2	3-4	A3-C5*	3800-4800	3800-4800	1000	1000	4000	3192	3447	
11-12/04/2007	6+7	3	5-6	A2-A7*	3900-4800	3980-4800	900	820	3440	3192	3447, Hydro 3	
13/04/2007	8	4	7-8	C3-D2*	3540-4800	3540-4800	1260	1260	5040	3192	3446	
16/04/2007	9	5	9-10	B4b-C7*	3900-4900	3900-4900	1000	1000	4000	3192	3446	
17/04/2007	10			A5-B7*	4000-4980	4000-4980	980	980	3920	3192	3446, Hydro 2	
18/04/2007	11	6	11-12	A5-B7*	3000-3980	3000-3980	980	980	3920			
19/04/2007				A4-A10*			0	0	0	3446, Hydro 2	3192	Water inside ASR 3446
19/04/2007	12	7	13-14	A4-A10*	3680-4920	3620-4290	1240	1300	5080	3447	3192	
20/04/2007	13	8	15-16	B2-E6*	3800-4900	3800-4900	1100	1100	4400	3192	3447	
23/04/2007	14	9	17-18	D3-D6*	3500-4900	3500-4900	1400	1400	5600	3447	3192	
24/04/2007	15	10	19-20	F1-C4*	3260-4900	3260-4900	1640	1640	6560	3447	3192	
25/04/2007	16	11	21-22	E3-C2*	3500-4900	3500-4900	1400	1400	5600	3447	3192	
26/04/2007	17	12	23-24	B1-D1*	3800-4900	3800-4900	1100	1100	4400	3447	3192	
27/04/2007	18	13	25-26	G1-F4*	3800-4900	3800-4900	1100	1100	4400	3447	3192	
<b>TOTAL Logged Length (m)</b>					<b>70500</b>							

Table 1: chronological production statistics for the VSP campaign

#### VSP tools used for the operation

The VSP tools were brought by Baker-Hugues (Figure 4).



Figure 4: ASR VSP tool (3C geophone + hydrophone)

They are analogue ASR type (3C geophones) built by Avalon. They are able to withstand up to 200°C. The se tools were slightly modified with an additional High Temperature hydrophone, which was used for the first time. The complete tool allows recording 4C data sets and the combination of 3C geophone and hydrophone represents a powerful mean to efficiently discriminate P and S-waves.

The tools were equipped with a double gimbals setting (Trunnion type) in order to obtain the orientation of the 3C seismic data directly from field measurements (Figure 5). One gimbal is free to rotate around the tool axis (W) and the other is free to rotate around the horizontal axis (YH), orthogonal to the well deviation vertical plane. The axis labeled X-HAZI is oriented toward the borehole azimuth direction.

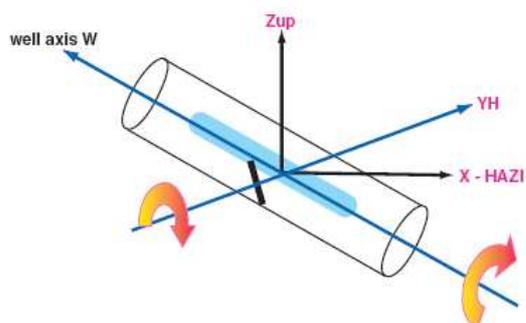


Figure 5: Free rotation axis allowed by the gimbals

As the deviation angle and azimuth of the well are known through trajectory surveys, data can be oriented into geographic coordinates by rotating X and Y components by an angle of  $180^\circ - \text{HAZI}$  (Figure 6).

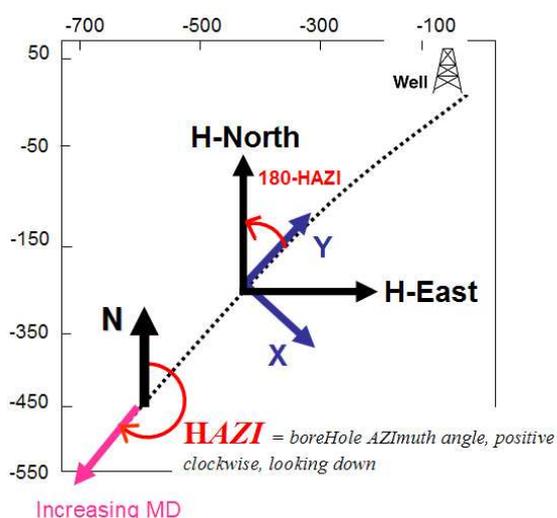


Figure 6: Horizontal plane of borehole trajectory and rotation to be applied for orientation into geographic coordinates

**Simultaneous Vibroseis acquisition**

The seismic source was generated by two vibrator trucks Litton LRS 415 with a peak force of 50000 Lbs (figure 7)

The simultaneous acquisition (developed by CGG in 1982) is a technique which allows reducing the time required for the campaign. For each run, they were placed at different offsets from the wells and activated at the same time. Each trace receives the sum of the signal from the different source location. The signals are then separated by coding/decoding techniques of sweep series. Series of 4 sweeps were used:

Vibro 1: downsweep 88-8 Hz (16 s + 2 s listening)  
Polarity code for simultaneous acquisition: { - + - + }

Vibro 2: upsweep 8-88 Hz (16 s + 2 s listening)  
Polarity code for simultaneous acquisition: { - - + + }

The polarity code is + for  $0^\circ$  phase and - for  $180^\circ$  phase.



Figure 7: Vibrator truck

**DATA PRE-PROCESSING**

All data set have been read successfully. They have been grouped into collections relative to one given source position and one given well. Isotropic displays have been sorted (Figure 8)

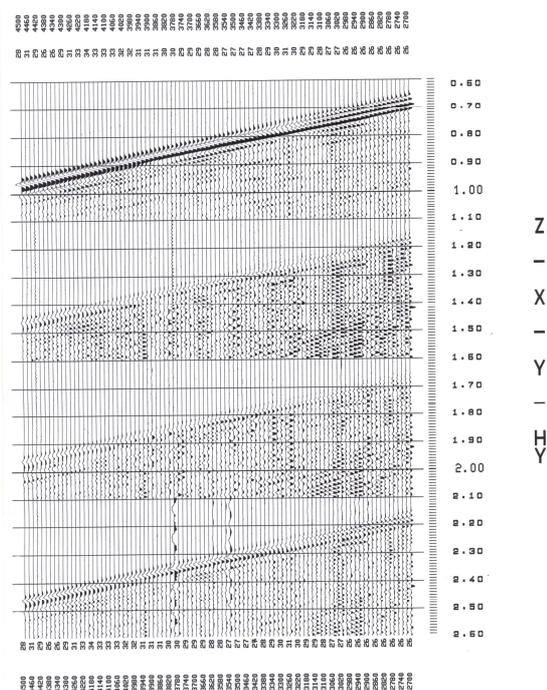


Figure 8: Vibro A0 - 4C isotropic display - GPK4

To illustrate the simultaneous acquisition technique, a short time window around the direct arrivals from both A0 and E4 has been selected, stacked and displayed in true relative amplitude (Figure 9). The direct arrivals appear at different times and amplitudes and no seismic energy residual from the other source can be observed.

Sensitivity of the gimballed geophones to the well deviation angle has been tested and indicates that the gimbals did not rotate for deviation angle lower than  $12^\circ$ .

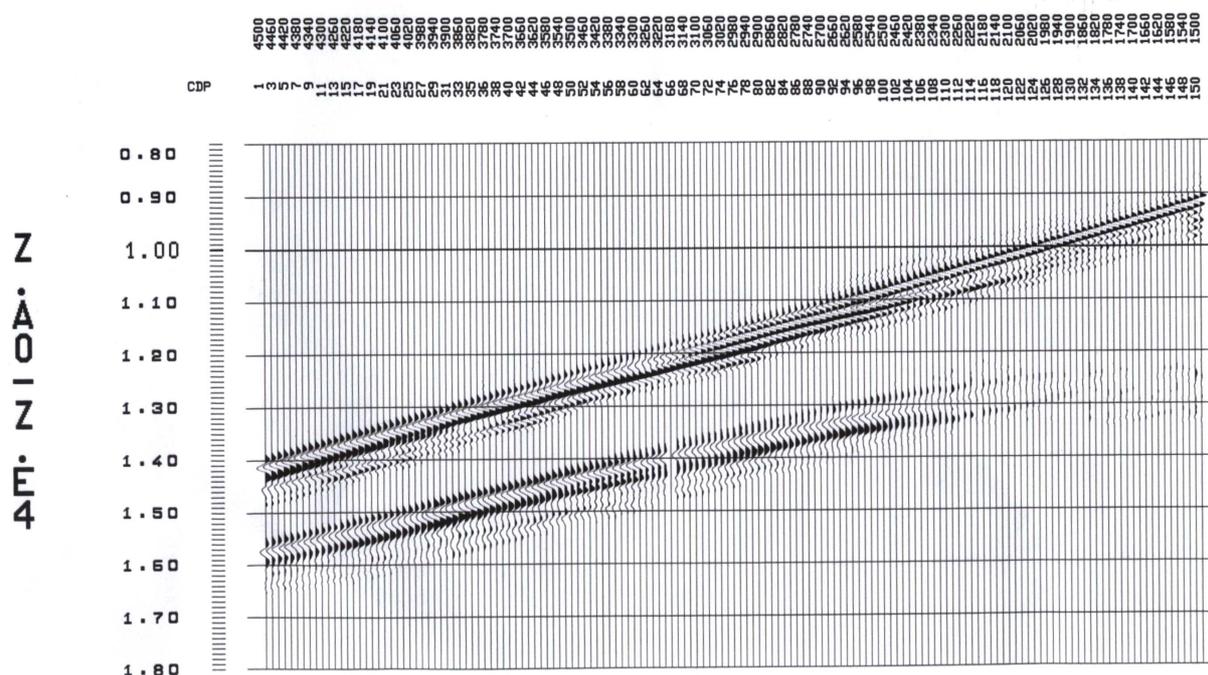


Figure 9: Vibro A0-E4 – Z component – GPK4

#### PROBLEMS OBSERVED

Very few problems affected the operation. The main remaining problem was the ability of the tools to withstand the high temperature. We often observed noise bursts and ringing generated by electronic amplifiers, which led to increase the number of vibration, especially near the well bottom and will increase the pre-processing time. The hydrophone did not work correctly (problems of temperature and water coming inside the tool), only a few profiles could be acquired with hydrophone.

For several runs, some problems of polarity are observed on the ASR tool deployed in GPK4 and will also lead to increased processing time.

Some random malfunction of the downswEEPing vibrator has been observed on the first series of 4 sweeps will complicate the simultaneous pre-processing data recovery, but should not alter the final quality of the data.

#### CONCLUSIONS

The ASR gimbaled geophones despite a few problems at high temperature are very efficient for components orientation procedure, although it seems to work for well deviation angle larger than 12°. Thus, as the logge d interval in GPK4 is always deviated with an angle larger than 12°; no additional technique should be used for the orientation of the components. On the contrary, different orientation techniques should be used for GPK3, as its deviation angle below 4140 m MD is lower than 12°.

The pre-processed data already obtain show unexpected events, such as double arrival typical of refraction arrivals along a major fault, or simply occurring from an additional seismic path generated by the presence of a step-like structure at the top of the crystalline basement.

Observable azimuthal deviations of the direct P-wave arrival polarization relatively to the straight line linking the source position and the downhole position indicate that the velocity field in the crystalline basement is not homogeneous, and possibly varies, even slightly, between fault compartment.

The VSP campaign, from the operational point of view was a great success. A considerable quantity of data could be recorded in a limited time.

Nevertheless, this operation showed that an intense effort has to be made on the high temperature equipment, as working in high temperature results often in failure or malfunction of the tools.

For further geothermal project it should be envisaged to develop these techniques, which could efficiently help assessing the geometry of a fractured reservoir. A combination of 3D seismic survey before drilling, seismic survey while drilling and VSP campaign after drilling could be a powerful mean to get a better knowledge of a reservoir and to define efficiently the trajectories of further boreholes.

#### REFERENCE

Place, J., Cox, M. & Naville, C., 2007. Oriented 3C VSP applied to the delineation of highly dipping faults in a deep granitic basement. *Proceedings of 2007 EHDRA Scientific Meeting*.

#### ACKNOWLEDGEMENTS

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