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SEISMIC WHILE DRILLING MEASUREMENTS IN ITALIAN DEEP GEOTHERMAL WELLS

Fausto Batini(1), I. Dini(1), Mario Certo (2), Tiziano Cola(2),
Fabio Cecconi(3), Louis Soulier(3), Charles Naville(4), Sylvain Serbutoviez(4)

(1) ERGA, ENEL Group, *Pisa (Italy).*, (2) ENEL/SRI, *Milano(Italy)*

(3) GEOSERVICES, 7, rue Newton, 93151, *Le Blanc Mesnil (France*)

(4) IFP, 1-4, ave. de Bois-Preau, 92852,*Rueil Malmaison (France)*

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ABSTRACT

The development of energy production from the main Italian geothermal fields (Larderello and Mt. Amiata) is closely correlated with the exploration of high enthalpy reservoirs in a very complex geological structure. Usually a cluster of geothermal wells is drilled from the same site in order to reach high temperature (>350 °C) reservoirs in metamorphic rocks (some 3500 m below surface).

Well Seismic Profiling (WSP) plays a very important role in the interpretation of the data supplied by reflection seismics when exploring such deep geothermal reservoirs, since the thermal conditions and seismic noise in geothermal wells drastically limit any conventional well seismic measurement. A multidisciplinary project (partially supported by the European Union) is currently in progress. The project combines the application of the following innovative techniques:

- EMWD®, Electro-Magnetic While Drilling – transmission of information between bottom hole and surface, and
- SWD, Seismic While Drilling - a survey technique using the drill bit as a seismic source, several multiradial surface geophones lines and a downhole reference sensor, placed in the Bottom Hole Assembly (BHA) including a shock absorber and a roller cone bit.

The main objectives of this multidisciplinary approach, which should lead to the improvement of drilling techniques and a reduction of the mining risk and the direct costs of drilling operations, are:

- better control of directional wells during the kick-off phase, by real time transmission of drill-bit orientation parameters from bottom hole to surface;
- a detailed seismic image of the geological structure around the vertical well, useful for better definition of the drilling targets of the following directional wells;
- real time drill-bit localisation by means of a SWD integrated automatic monitoring system permanently installed at the well site. This should complement or avoid the conventional orientation measurements in the hot deep part of the wells.

This paper relates the results obtained so far concerning the two first objectives, through a successful directional EMWD field test in the Larderello area, and a pre-operational EM-SWD field test in a low temperature well using the new downhole recording BHA element built by GEOSERVICES, synchronised and interfaced with a commercial SERCEL SN388 surface seismic recorder. The new equipment behaved successfully on the field. The processing results are encouraging, thus allowing for the preparation of large-scale SWD operations on geothermal wells under drilling.

1. INTRODUCTION

The innovative technological feature underlying the present project is the introduction of downhole MWD equipment using the EM-electromagnetic two way downhole to surface transmission technique pioneered by GEOSERVICES. This choice was guided by the unique capability of the wireless EM technique to finely synchronise the clock of a surface seismic recorder with the clock of an independent downhole recorder and memory storing the drill-bit vibration signal, with a precision compatible with seismic requirements.

In July 1997, the EMWD directional technology, (Soulier and Lemaitre, 1993), was successfully operated during the kick-off phase of a geothermal well. The purpose of this test was to ensure that the EM technique could be applied efficiently in the moderate to high resistive formations present in the area, and that the operating temperature while drilling could be monitored and sustained by the downhole equipment, so as to evaluate the technical and economic benefits of the directional EMWD method for geothermal drilling.

In October 1998, a pre-operational SWD acquisition was carried out in a low temperature Gaz de France (GDF) well near Paris, with the objective to validate, by a field test, the new Down-hole Recorder Unit (DRU) developed by GEOSERVICES and the whole EM-SWD acquisition chain including the interfaced surface equipment.

2. EMWD DIRECTIONAL TEST IN KICK-OFF PHASE.

In July 1997, a commercial EM directional tool was run during the kick-off phase of a geothermal well near Larderello. The EMWD tool worked properly, which saved some operational time in comparison with the steering tool / single shot directional drilling technique commonly used on geothermal wells, thus contributing to the drilling efficiency and to the reduction of drilling risks.

Additionally, the EMWD yielded the downhole pressure and temperature parameters in real time, which showed that the downhole temperature at the bit while drilling was lower than expected. The temperature rise could also be measured when the drilling fluid circulation was interrupted for several hours. Moreover, the EMWD directional measurements could still be obtained even if there was total circulation loss and no fluid return, which constitutes an advantage over the Mud pulse transmission technique.

3. PRE-OPERATIONAL EM-SWD FIELD TEST

3.1 Description and layout of the field equipment

A SERCEL SN388 recorder from CGG recorded a short surface line of 12 geophone group receivers, 50m apart. The GEOSERVICES Surface Command Unit (SCU on Fig.1) generates a periodic Time Break (TB) to start the seismic recorder automatically. The Downhole Recorder Unit (DRU) records and stores the drill-bit pilot signals during an entire drilling run, in synchronisation with and under command of the SCU.

After the drill-string is pulled out of the well, the downhole signal is segmented according to the instants of the TB orders sent every 54 seconds by the SCU to the seismic recorder during the effective drilling periods. The synchronised segments are then converted into the standard SEG-Y format, before correlating with the surface records and processing with commercial seismic software. Two vertical accelerometers have been placed at the top of the drill string and connected to the seismic recorder.

The acquisition has been run during the drilling of a deviated Gaz de France (GDF) well, up to 25° incidence (12''1/4 diameter, 620m to 880m depth), and has been completed without any major incident or inconvenience.

The downhole EM-SWD recording sub is illustrated in Fig.2; it is placed above the directional mud pulse MWD system in the BHA. The mud pulse transmission was not altered by the presence of the EM-SWD sub.

Although the presence of a shock absorber in the BHA is recommended to attenuate undesired drill string head waves, as from Rector and Hardage (1992), Naville et al. (1994), and U.S. Pat. N° 5,372,207, GDF drilling operators did not wish to have any shock absorber in the deviated well part.

The GEOSERVICES SCU was located inside the CGG seismic recording truck mounted cabin, which simplified the connections between the SCU and recorder and facilitated the dialog between field operators. During the operation, the EM orders were sent downhole during the drill pipe connection manoeuvre, while the drill string is on slips. Thus, the EM signal is optimal and no rig downtime is necessary for transmission.

All the recorded data have been correctly recovered. 2400 surface seismic records of 50s with 16 channels have been stored by the SN388 on IBM 3490 cartridges in SEG-D format. Out of the downhole memory, 1000 time segments of 54s have been extracted with 8 bits per 4ms sample, and 1300 time segments in sign bit (1 bit per sample), all converted into SEG-Y formats. Downhole and surface channels were almost continuously recorded while drilling. The depth was hand picked at each drill pipe.

3.2 Pre-processing.

The pre-processing phase addresses the questions of merging control of the downhole and surface data, synchronisation control and correction of the clock drift between the downhole and surface recorders.

The TB pulse number labelling of surface and downhole records has been extremely useful to facilitate merging surface records and corresponding downhole reference time segments.

First, the top drill string accelerometer SACZ signal is correlated by the downhole reference accelerometer DACZ corresponding to the same time segment and TB number, in order to ensure the following quality control actions:

- Check of the exactitude of the downhole and surface TB pulse number correspondence, by correlation.
- Editing of the single surface (downhole response) seismic records without correspondence with downhole (surface response) record, and during the drilling interruptions.

With all compensations and corrections applied, the pre-processing output is a vertical stack after shaping deconvolution of the surface records by the downhole pilot signal, illustrated on source collection, Fig. 3, and geophone collection, Fig. 4, where the signal is stacked over 20 minutes of drilling time for each drill pipe.

The final correlated data is excellent even with the absence of the shock absorber in the BHA, due to the partial attenuation of drill string guided waves within the deviated section of the well where the drill-string drags against the borehole wall. In contrast, experience shows that, in vertical wells in the same area, SWD surveys run without a shock absorber in the BHA yield very noisy stacked records.

3.2 VSP processing.

As the well was deviated, the correlated data do not show a very high level of undesired drill string head waves or rig noises. The pre-processed data look good (low noise level before direct arrival, compressed wavelet) so that conventional Vertical Seismic Profile (VSP) and WalkAway (WA) produced encouraging results from the 8 bit DRU data. The frequency content reaches 70Hz on the direct arrivals.

Fig. 5 shows the time-depth curve obtained by SWD, with a good precision on interval velocities. Fig. 6 shows the reflected VSP wavefield results from a near offset geophone collection, 150m from the well. Refining the alignment of the two ways time reflections by a standard trim static routine allows compensating for potentially remaining residual synchronisation uncertainties (up to +/-1ms).

3.3 Walkaway processing (WA).

In order to process the set of 12 geophones, residual geophone static has been computed from a hyperbolic regression on the deepest source collection, then applied.

For each geophone collection the direct arrival wavelet for shaping deconvolution is obtained by median stack of the direct arrivals. The signature length (250ms) is chosen short enough to avoid the drill string reemission arrivals.

NMO velocities are estimated from the VSP interval velocities, then adjusted so as to have a good direct arrival horizontalization after NMO correction. After NMO correction and before stack, an FX white noise rejection filter is applied, followed by an FK filter rejecting the undesirable drill string seismic re-emissions. Final geophone residual static is computed by a trim static procedure on deconvolved geophone stacks.

Fig. 7 shows a final time image within and below the depth interval logged by EM-SWD, far ahead of the bit. Reflections are visible down to 1450 m, far below the deepest SWD measurement level (880m).

For comparison with conventional direct well seismics, a vibrator walkaway image is displayed on the right of Fig. 7: it was obtained using a geophone array located in a nearby well. The maximum frequency reaches around 65 Hz on the present on the drillbit reverse walkaway versus 85 Hz for the vibrator direct walkaway image

4. CONCLUSION

The first EM-SWD field test was successful thanks to an appropriate design and preparation. Some technological imperfections of the acquisition chain evidenced by this test have been corrected for the next field operations.

Although the sign-bit safety procedure did not yield the best results, they would be satisfactory in case of any transmission malfunction. So, the whole acquisition chain is now ready for industrial applications.

The authors are confident about the future tests of the newly developed technique in the Larderello area, which suffers from a poor surface seismic response, and where it is difficult to obtain good well seismic results with usual methods.

ACKNOWLEDGEMENTS

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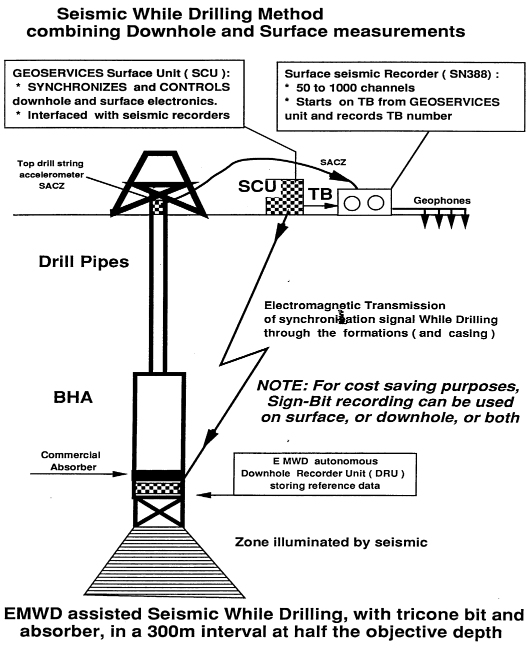

Fig. 1SKETCH of new Recording Device

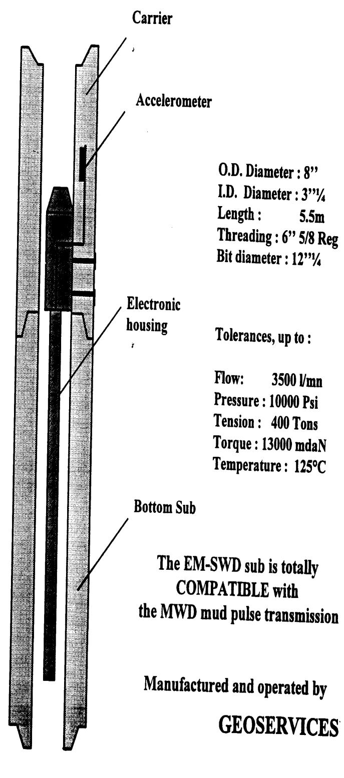

Fig. 2 EM SWD Recording Sub

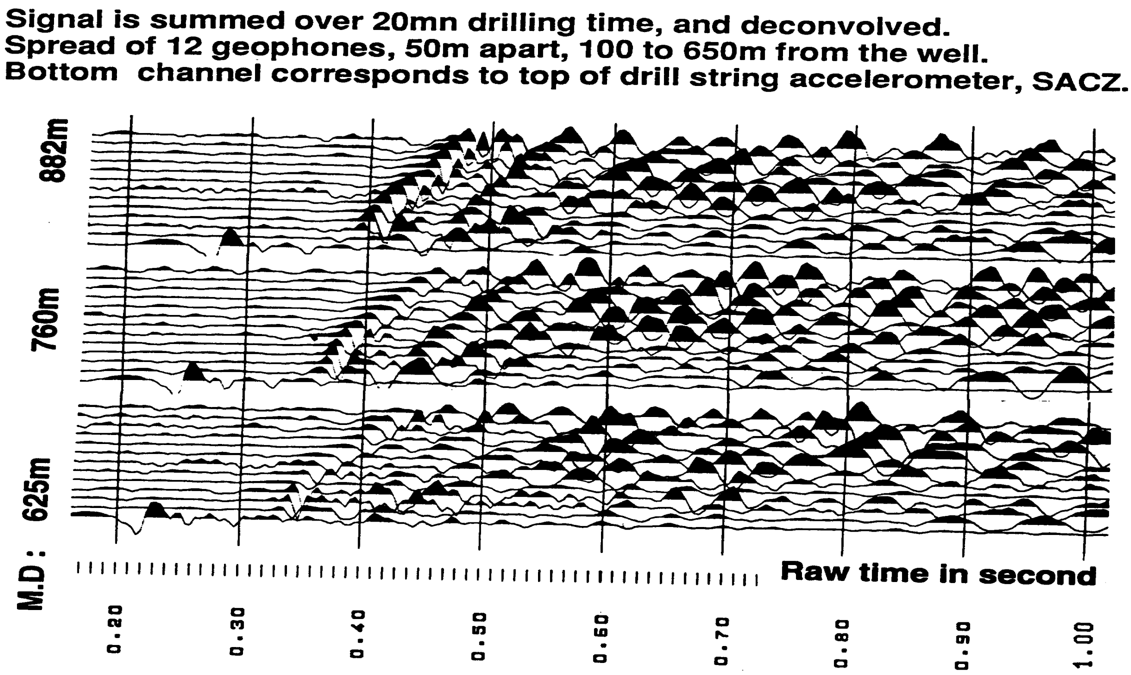

Fig. 3 EM-SWD: Source Collections

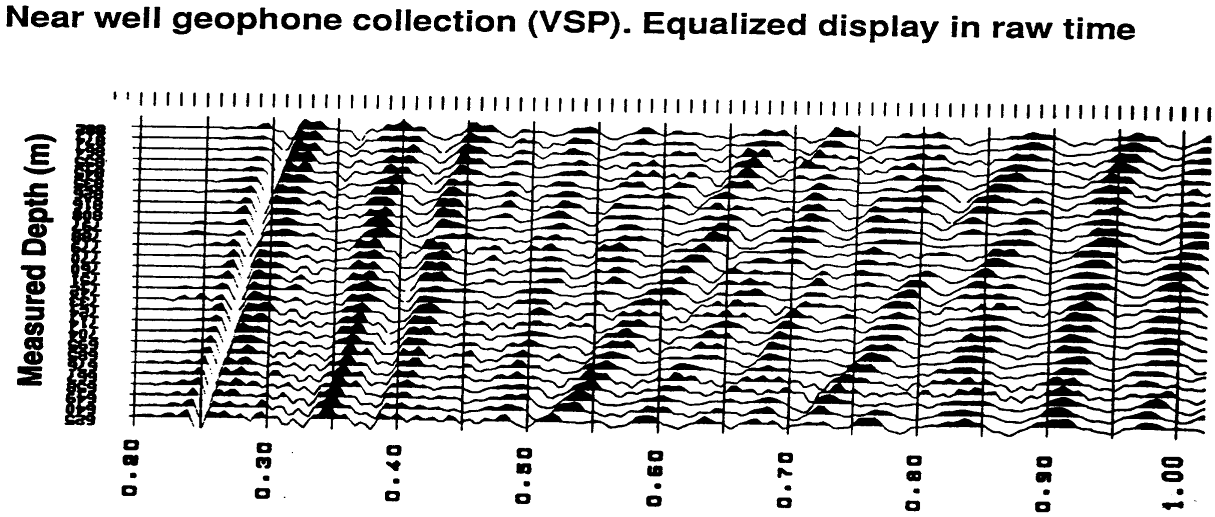

Fig. 4 EM-SWD: Geophone Collection

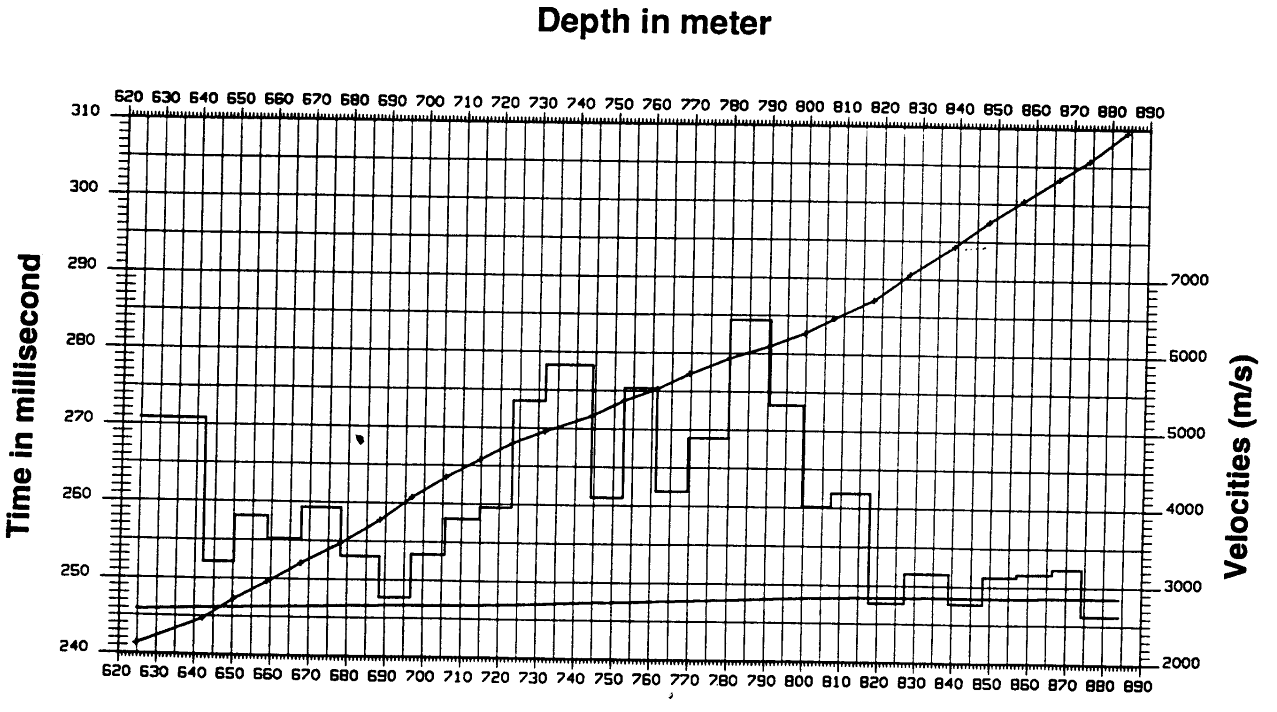

Fig. 5 EM-SWD: Time-Depth & Velocity curves

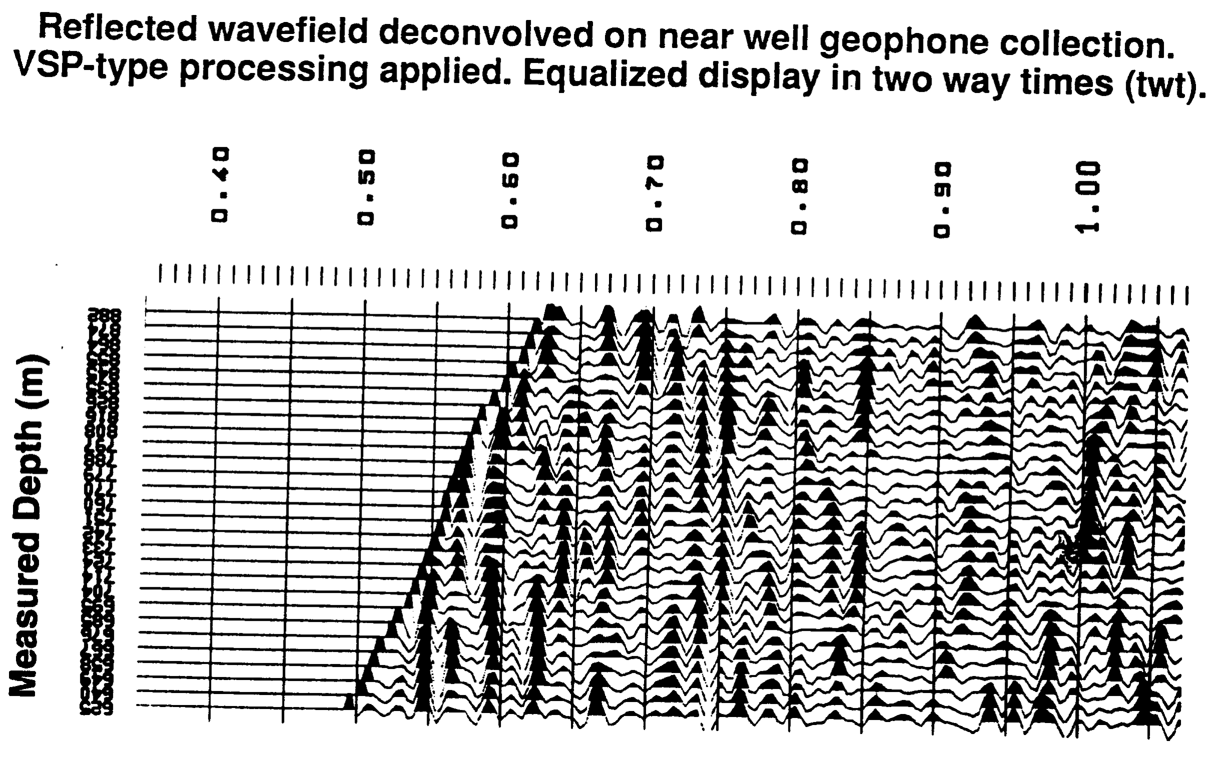

Fig. 6 EM-SWD: Geophone Collection

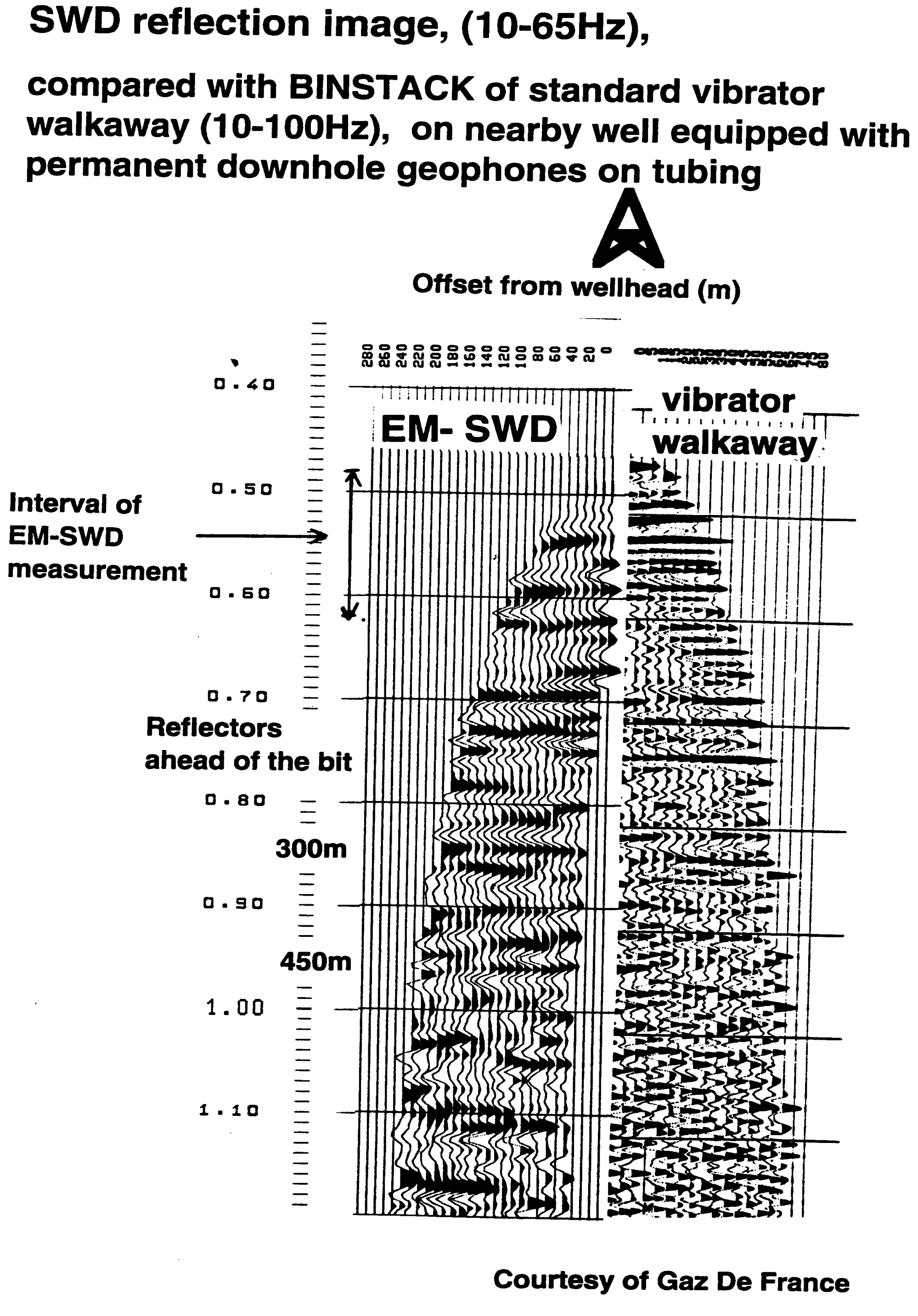

Fig. 7 EM-SWD: Binstack Image