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Through-Tubing Well Seismic: A Mast Campaign Across an Offshore Producing Field, Saudi Arabia-Kuwait Partitioned Neutral Zone

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ABSTRACT

A multi-well VSP Through-Tubing campaign was conducted in order to survey 2 neighboring mature fields in the northern Arabian Gulf. Nine key wells were selected by the reservoir engineers and geophysicists from a total of more than 200 wells. The selection criteria included: (1) spatial distribution; (2) previous well data availability; and (3) completion type. At the planning stage it was estimated that 3 days (excluding night work for safety) would be required per well (one day to rig-up the mast, one day to acquire the seismic data and one day to rig-down). Local experience indicated that a single air gun would be an effective seismic source. A slimhole, monocable, single-axis geophone sonde was selected as the downhole seismic tool. The zero-offset VSP configuration, with 80 foot level-spacing from total depth to surface was adopted. A supply boat was dedicated for the duration of the campaign. The actual operation was completed in 24 days, 3 days earlier than planned. An average of 90% of the VSP levels were found suitable for first break detection, which provided accurate Time-Depth curves for all 9 wells. Geophone coupling quality is dependent on the Tubing-Casing contact. The tube wave is developed at all 9 wells; but, overall 80% of the levels were selected for VSP processing. In 5 wells, where sonic logs had been acquired, synthetic seismograms were generated which confirmed the validity of VSP reflections. The data is now integrated in a 3-D velocity model.

INTRODUCTION

In 1958, a 2-D seismic survey helped discover two offshore fields in the Partitioned Neutral Zone (PNZ) between Saudi Arabia and Kuwait (Figure 1). However, since then, seismic was only rarely used to support development and production drilling. After having drilled more than 200 wells, the Arabian Oil Company (AOC) has increasingly realized that a complex fault network is affecting reservoirs production. A better understanding of the fault system and its influence improves ultimate recovery in mature reservoirs.

In recent years 3-D seismic has been widely used in the Arabian Gulf region for the purpose of fault delineation. Therefore a 3-D seismic survey will shortly be acquired to improve reservoir characterization. The integration of the 3-D seismic survey with other reservoir data requires Vertical Seismic Profiles (VSP) or Check Shot surveys in key wells. The conversion of time maps derived from the 3-D seismic survey into depth maps will also require VSPs and Check Shot surveys.

Unfortunately very few surveys have been collected in the two fields. Furthermore with the single rig currently active in the area, mainly assigned to drilling horizontal wells, it was not possible to survey enough new wells or take advantage of workover operations for gathering velocity control in the right time frame. A campaign approach involving Through-Tubing Well Seismic was therefore adopted. This paper will describe the campaign approach and seismic results.

THROUGH-TUBING WELL SEISMIC SURVEY

Logging through-tubing in an alive well differs in two ways from open-hole or cased-hole logging: (1) well head pressure, and (2) tubing. Pressure-control equipment is considered routine technology for production logging; grease is pumped around the cable to balance well head pressure and safely prevent

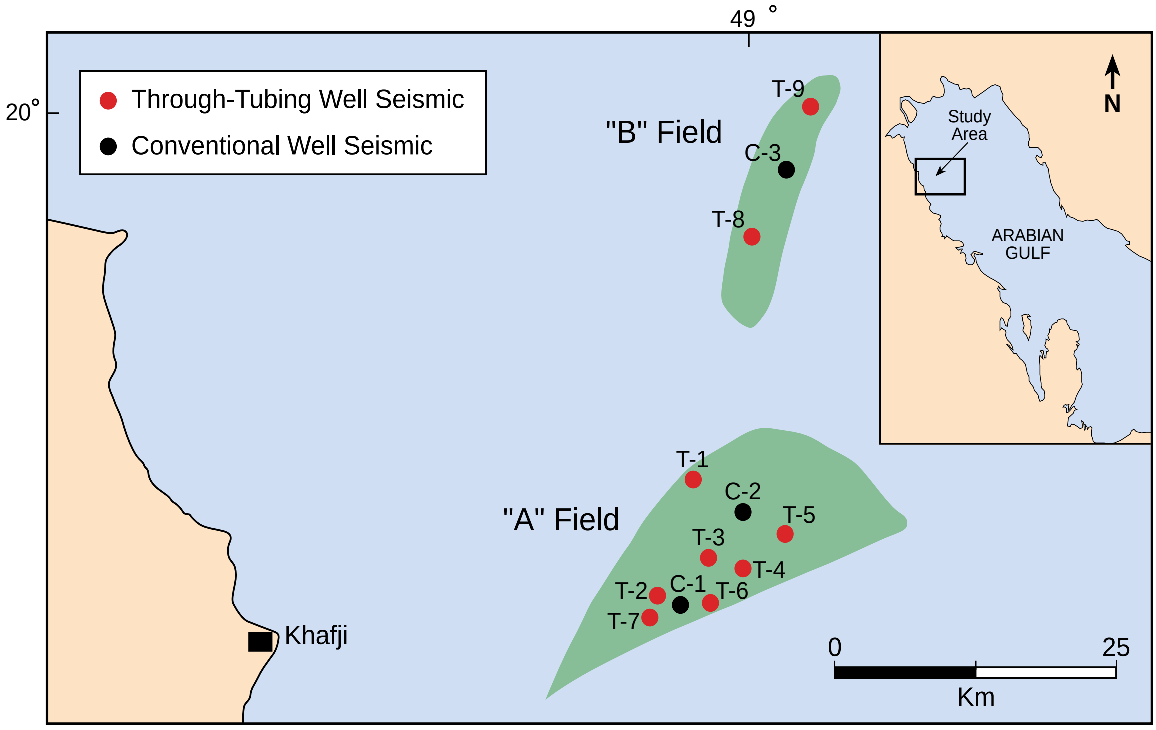

Figure 1: Position map.

any borehole fluid to escape. Both logging monocable and heptacable can be used. Standard production logging tools (e.g. production logging tool or thermal decay tool) are designed for monocable, and can stand well head pressures as high as 15,000 pounds per square inch (psi). Pressure-control is more challenging with heptacable tools and not recommended above 3,000 psi.

Conventional Well Seismic tools cannot be operated through tubing because of the required minimum 4-inch Internal Diameter (ID) holes. The Slimhole Well Seismic tool (SWST) was designed to operate down to $2^{3/8}$ inch ID holes with an heptacable. A modified version, the Monocable Well Seismic Tool (MWST), shown in Figure 2, was developed for Through-Tubing operations at high well head pressures.

Several Through-Tubing surveys have been acquired in the Arabian Gulf area during the last decade with both SWST and MWST. For each of these surveys, the objective was to acquire VSP or velocity data for a single well, but not a campaign. Coupling quality and noise problems were the main concerns, in addition to the traditional cased-hole VSP pitfalls (lack of cement, etc.).

SWST and MWST are efficiently anchored to the tubing. But the tubing-casing mechanical coupling is beyond control. Two completion types are used by AOC: either (1) tubing hanging from surface, or (2) anchored by packer above the reservoir. Experience shows that packer-anchored tubing provides an improved coupling quality over hanging tubing. In any case, Through-Tubing geophone coupling is not expected to match conventional cased-hole, and some tube wave is expected to affect the recorded seismic signal.

Noise is another potential problem associated with Through-Tubing seismic. Any fluid displacement in the vicinity of the wellbore generates significant background noise. Injection or production has to be stopped atleast one day prior to Through-Tubing seismic operation. If several wells have been drilled from a single platform, it is also recommended to shut them down. Finally, pressure-control equipment also generates noise which may propagate along the wireline cable.

PLANNING

In order to establish the operation's feasibility and plan the campaign, close communication was established with the production department. Well files are compiled to compare maximum reachable depths, current status, available logging data, tubing and completion type.

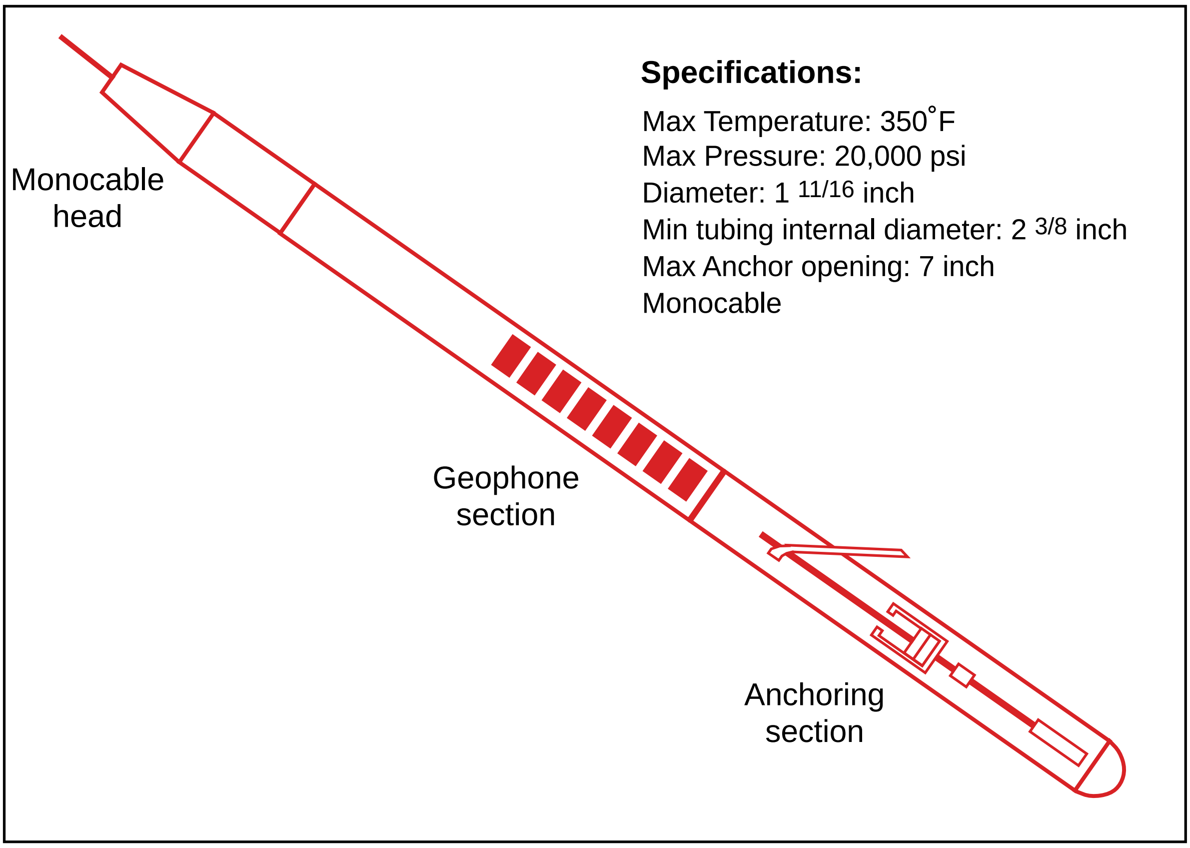

Figure 2: Monocable Well Seismic Tool (MWST).

Candidate wells were selected on the following criteria:

(1) equal sampling in the field and deep total depths,
(2) availability of sonic and density logs, and
(3) completion type; production well or observatory well; completed with packer-anchored tubing.

Some candidate wells were canceled and changed with others due to the obtrusive conditions of the jacket and / or facilities.

Potential well candidates would complement existing wells (C-1, C-3 in Figure 1) and planned (C-2) conventional well seismic surveys. Nine wells (T-1 to T-9) were selected for the campaign; 4 observers and 5 producers. Eight wells were completed with anchored tubing, and only one well (T-6) had a hanging tubing. Figure 1 displays these well locations on a map.

Examination of existing VSPs in wells C-1 and C-3 showed a single gun was powerful enough to generate a good-quality signal down to 13,000 feet (ft). Level depth increment was set to 80 ft from total depth (TD) to surface, as for conventional VSPs in the area.

Maximum well head pressure (approximately 1,000 psi) allowed the option to use either heptacable SWST or monocable MWST without the pressure-control problem. Both tools were mobilized. A boat for rigless well testing operations at fields "A" and "B" was dedicated to the operation for a one-month period. The vessel's crane was necessary to move equipment to the platform and hang the air gun during the seismic operation.

Local safety rules prevent night work. Based on local experience in multi-well production logging campaigns, it was estimated that each well seismic survey would require three days: one day for the operation setup (shutting-down the well, installing the offshore mast, recording and pressure-control equipment); a second day for shooting the survey; and a the third day to pack equipment and restore the platform to its initial state.

ACQUISITION CAMPAIGN

The campaign took place in August, 1994. The first well (T-1) was surveyed with the heptacable SWST. Figure 3 shows a typical Through-Tubing seismic acquisition setup. A higher-than-expected noise slowed the acquisition, which required more than a day. The high baseline noise was attributed to pressure-control and all following wells (T-2 to T-9) were surveyed with the monocable MWST, which resulted into lower baseline noise. A couple of days were also lost because of bad weather.

Start-up delays were more than compensated by increased crew efficiency in the second and third weeks. The campaign was completed in 24 days, or 3 days less than initially planned. The total volume of delayed production was less than 20,000 barrels.

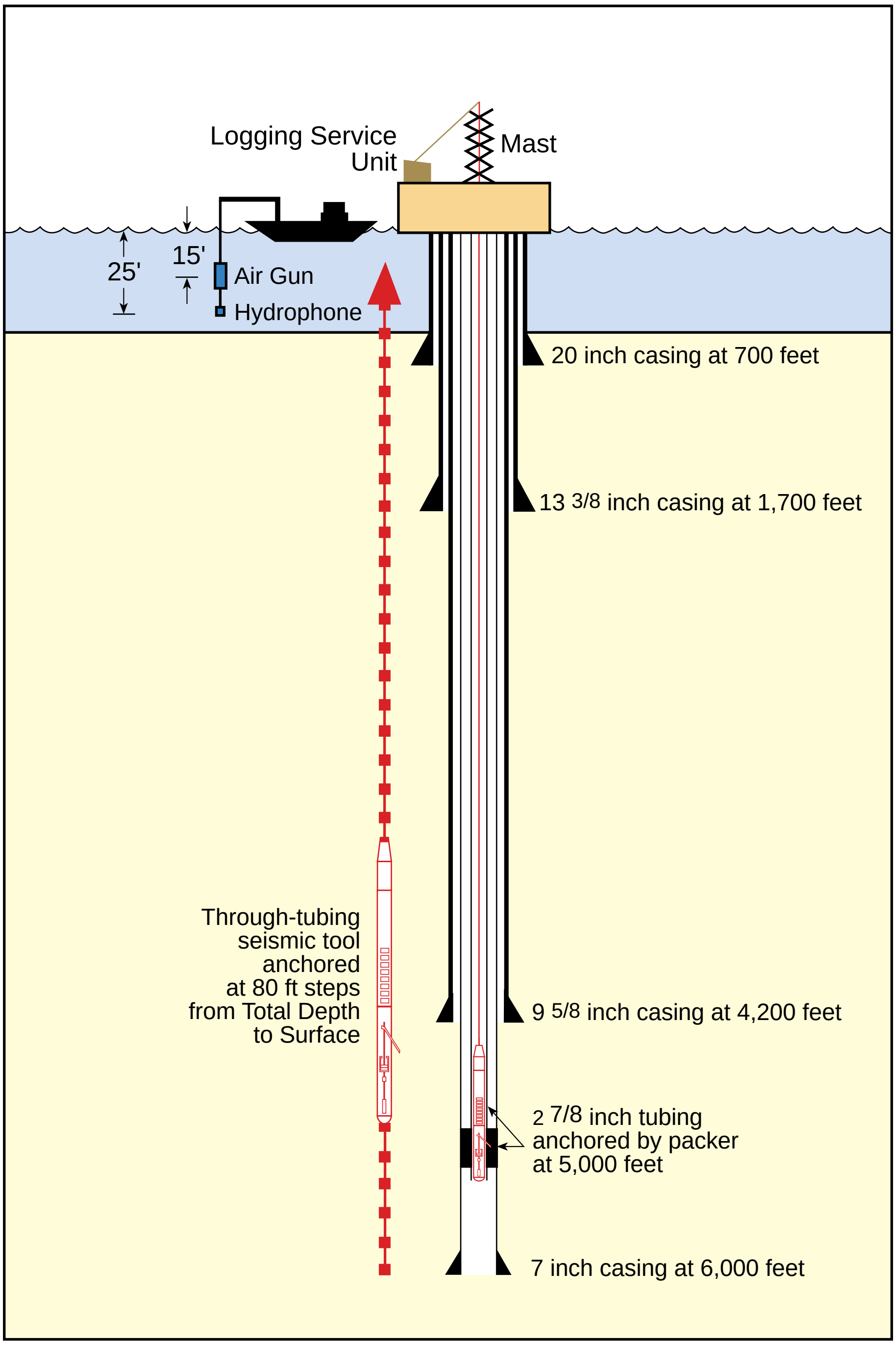

Figure 3: Typical through-tubing seismic tool VSP acquisition setup.

RESULTS

Seismic first breaks can be accurately picked at most levels in all 9 wells. Figure 4 shows unfiltered data from 3 wells. The records from Well T-1 display higher noise, linked to the heptacable pressure control, but first arrival are still clear. Baseline noise is lower at wells T-2 and T-6 surveyed with monocable pressure control. Figure 4 also illustrates coupling degrading quality with depth at well T-6, the single well surveyed with hanging tubing completion. Signal quality is restored for the bottom 4 levels, located below tubing and with MWST directly anchored into casing.

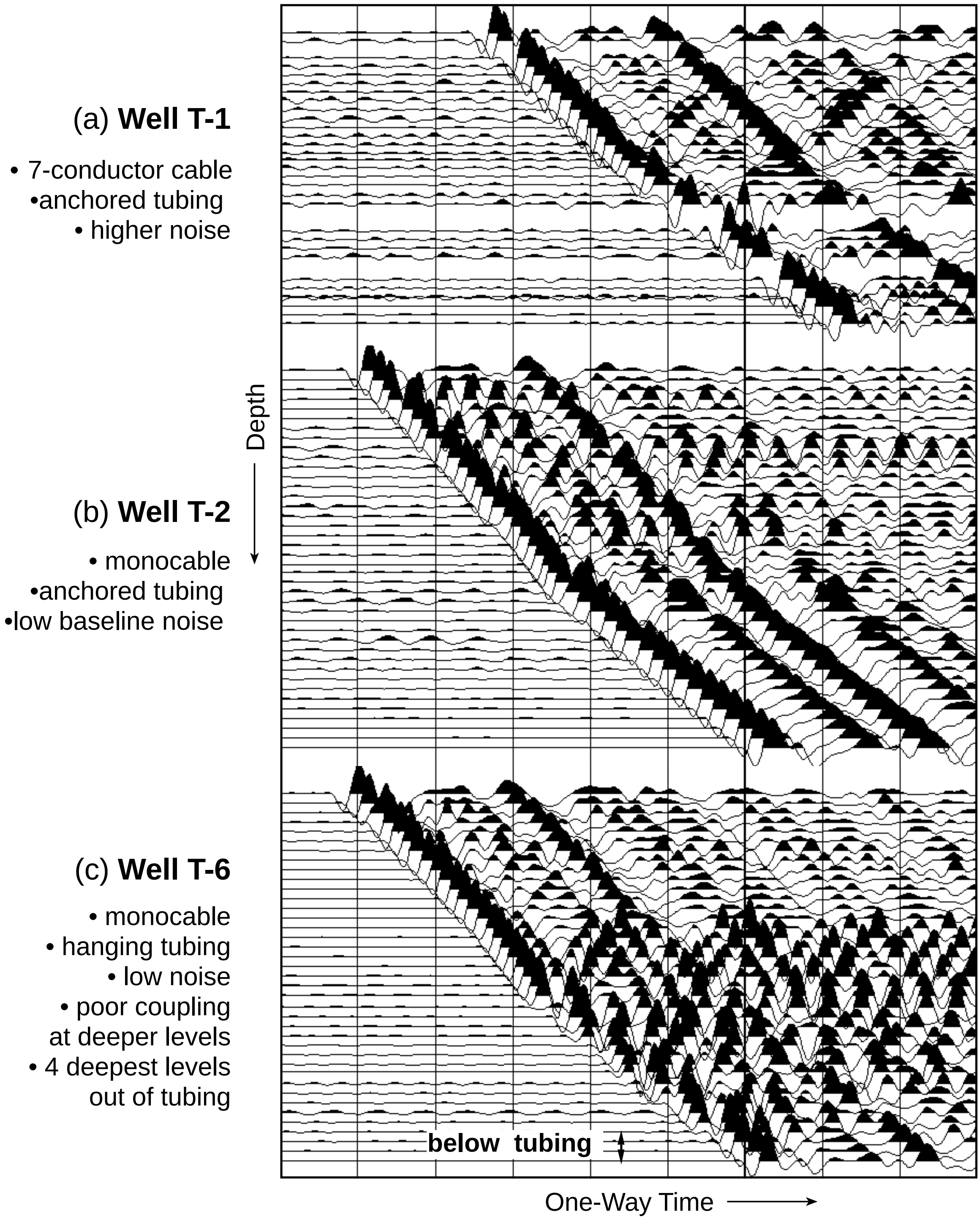

Figure 4: Example of unfiltered well seismic data acquired through tubing.

After rejection of noisy or poorly-coupled levels (overall less than 10%), the vertical Time-Depth relation was derived at the nine wells. A selection from field "A" wells is displayed in Figure 5: it points to significant velocity variations. Figure 6 is a simplified cross-section along the five wells, broken into three geologic intervals. Table 1 lists interval velocities at each well. Significant high-velocity anomalies are found in the intermediate (well T-2), and deep intervals (flank well T-1).

The 80-foot level spacing was primarily designed to provide velocity data redundancy. Tube wave noise was present at all wells, but not worse than with some early VSPs recorded in the late 1970s or early 1980s. It appears that most levels have sufficiently low baseline noise to apply VSP processing. Figure 7 includes VSP results at wells T-3 and T-4. Consistent reflectors are identified at the Gudair, Zubair and Ratawi formation tops. The VSP shows a reasonable match at the five wells with sonic-derived synthetics. In shallow well T-4, good reflections are detected below TD, in particular the Zubair and Ratawi tops by correlation with deeper well T-3.

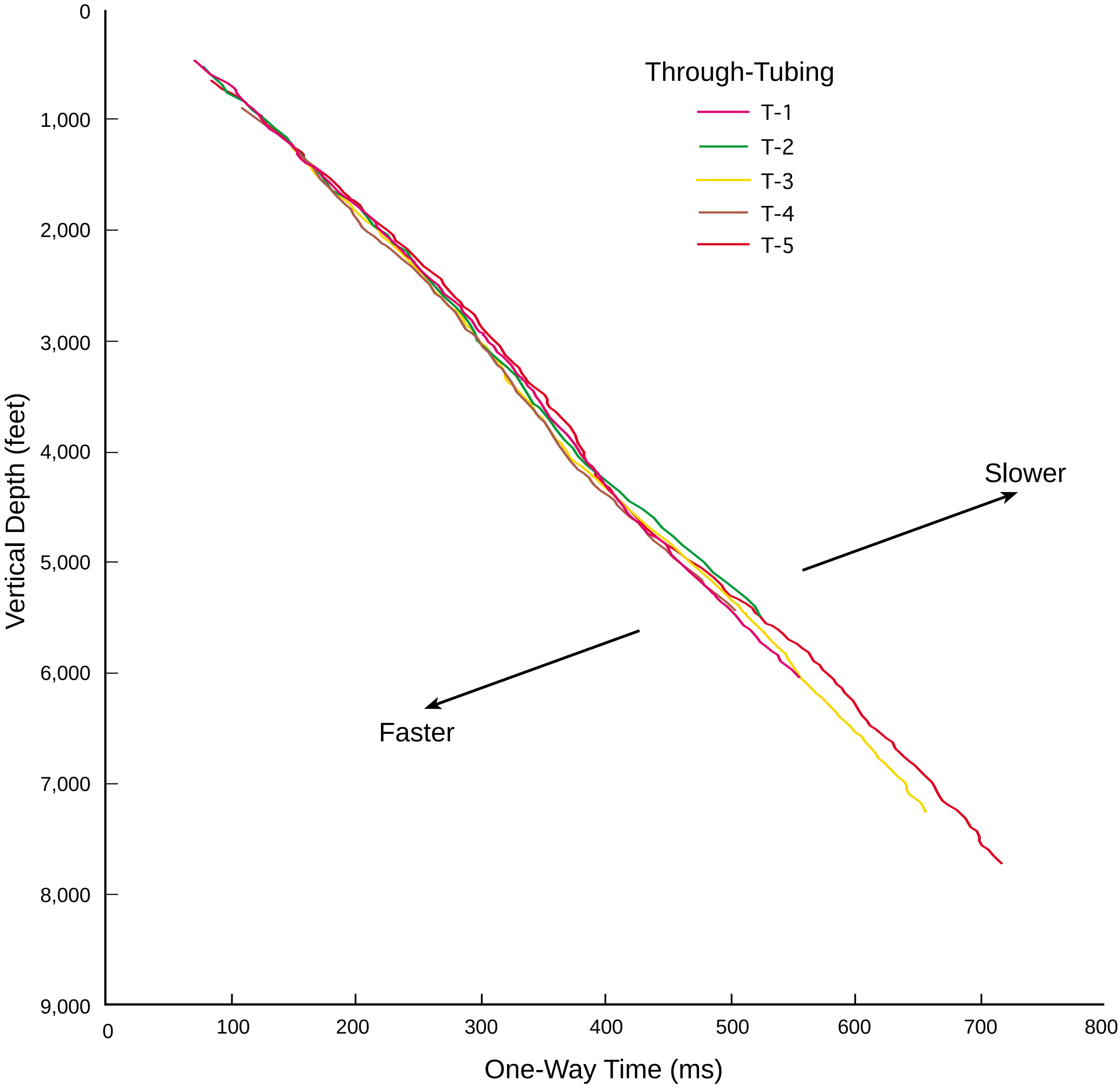

Figure 5: Time-Depth comparison at 5 well seismic surveys with slimhole tool.

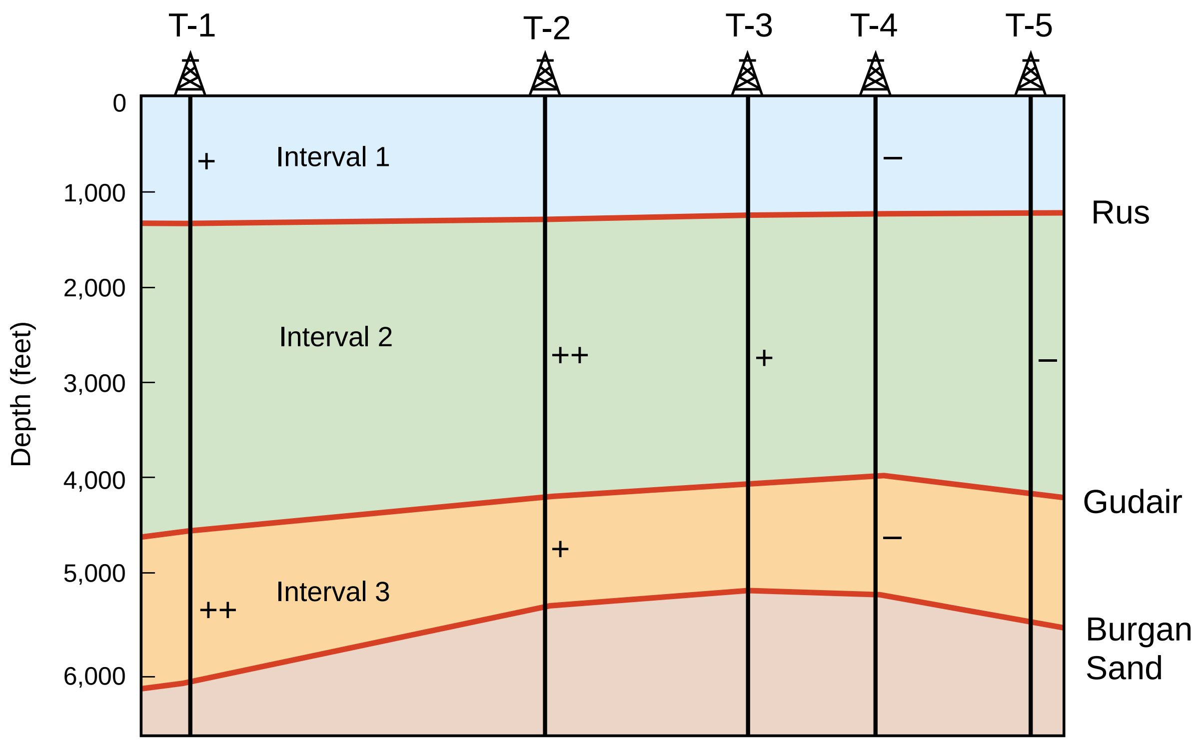

Figure 6: Cross-section illustrating lateral velocity variations. Relative Interval Velocities are shown as faster (++), fast (+) or slow (-).

Table 1

Interval Velocity (Ft/Sec)

Interval Velocity	T-1	T-2	T-3	T-4	T-5
1	8,490 (+)	8,365	8,365	8,175 (-)	8,265
2	12,320	12,770 (++)	12,570 (+)	12,330	12,150 (-)
3	10,885 (++)	10,195 (+)	10,020	9,760 (-)	10,080

THROUGH-TUBING VERSUS CONVENTIONAL WELL SEISMIC

Before the campaign, two conventional VSPs had been acquired in well C-1 at field "A" and well C-3 at field "B". A third conventional VSP was acquired when C-2 was later drilled. Figure 8 shows the Time-Depth curves at wells C-1 and C-2 fall within the trend defined by Through-Tubing well seismic (wells T-1 to T-5). The slower C-2 well is close to well T-5 time-depth curve, while the faster C-1 well overlays the T-1 well below 6,000 ft. Both Conventional and Through-Tubing well seismic detect similar significant lateral velocity variations.

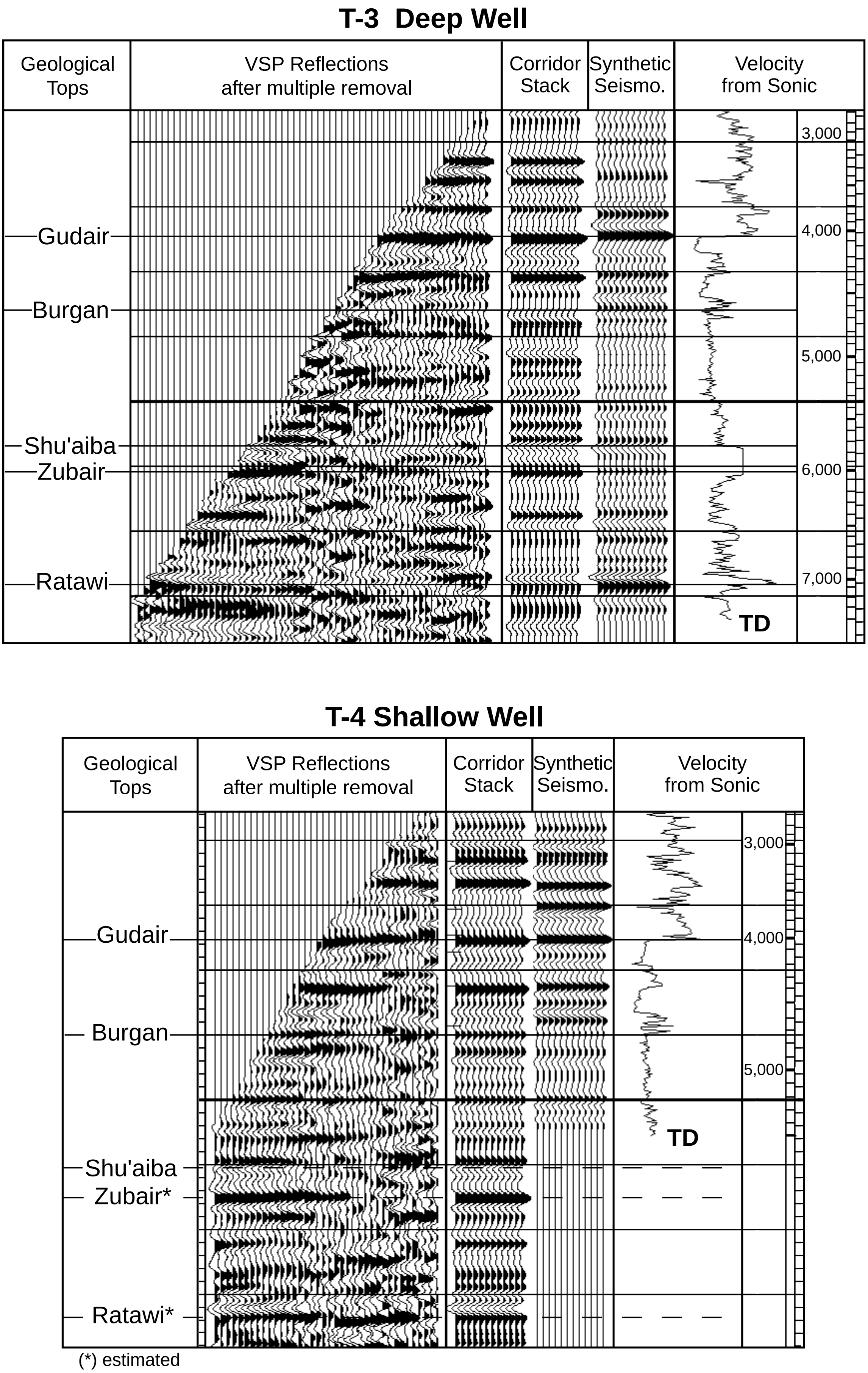

Figure 7: VSP-Log composite display at two wells.

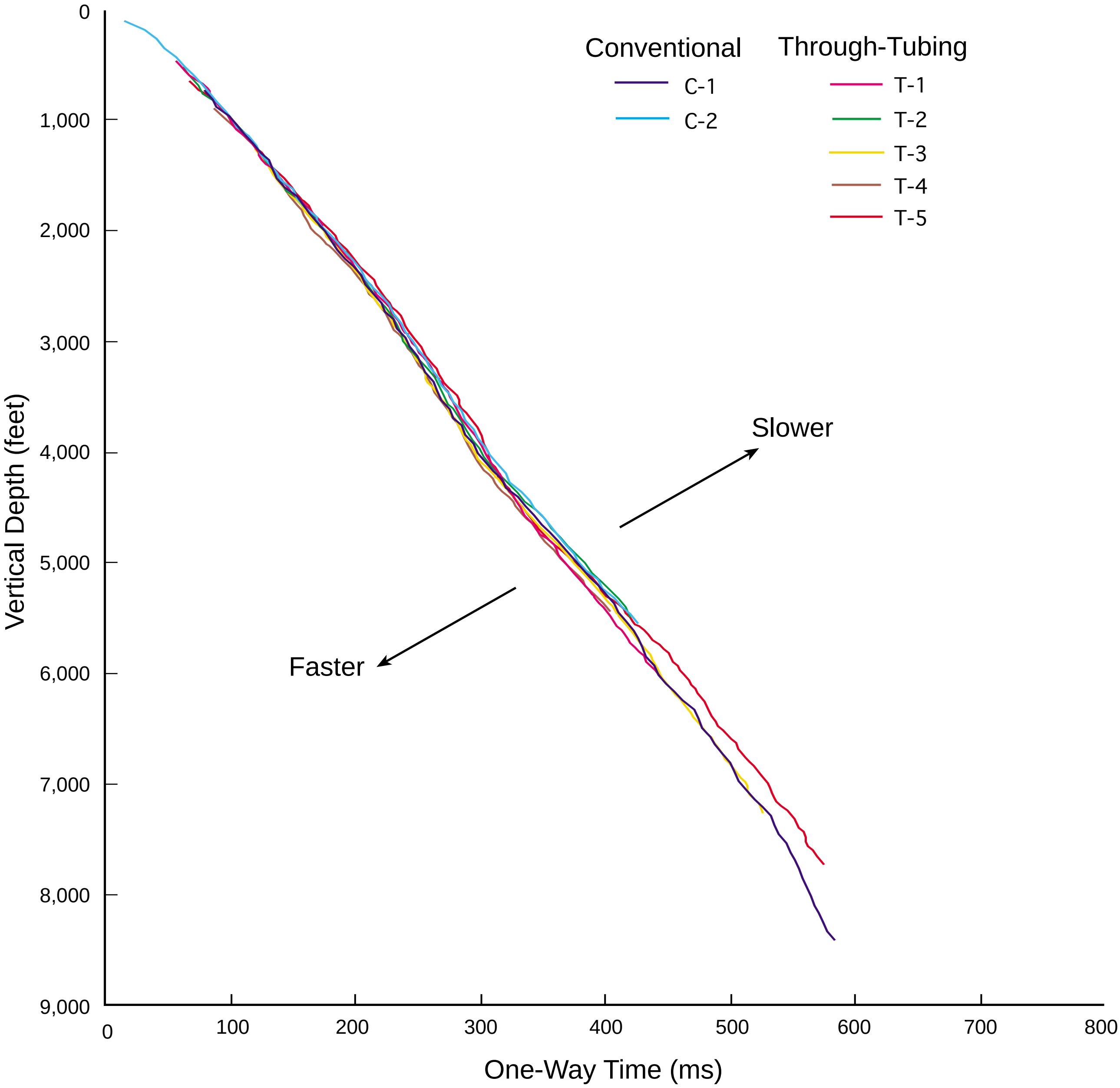

Figure 8: Slimhole versus Conventional Seismic Time-Depth.

Figure 9 compares Conventional and Through-Tubing raw data at wells C-2 and T-4. Notice the tube wave at well T-4. The same air gun was used at both wells, but the higher frequency content observed at T-4 is mainly caused by the different geophone types (14 Hertz versus 10 Hertz natural frequencies). When comparing the VSP results (Figure 10), a reasonable match between the VSP and Synthetics is observed. The Zubair reflection can be seen below total depth in both wells.

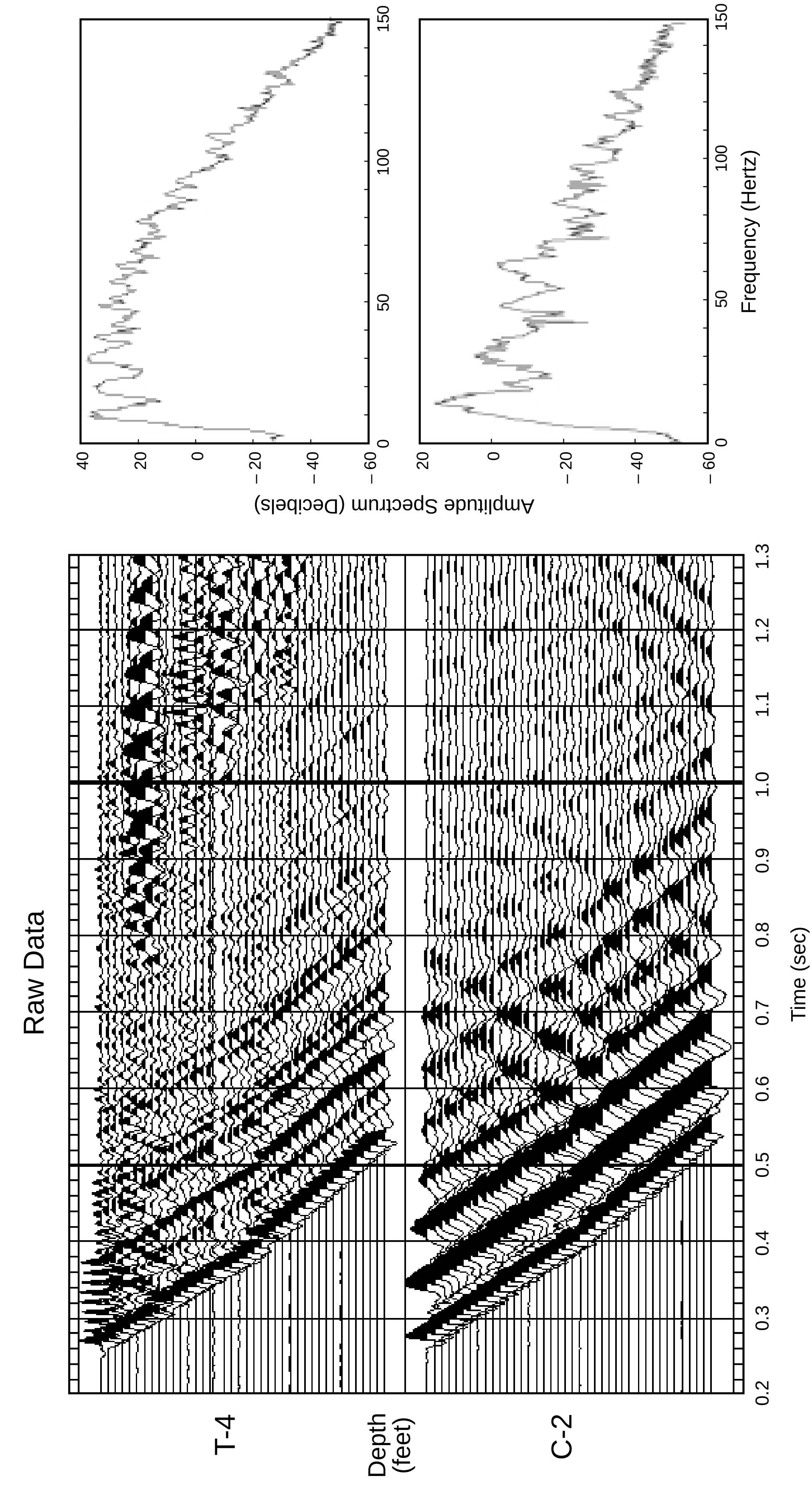

Figure 9: Through-Tubing versus Conventional VSP raw data in two nearby wells.

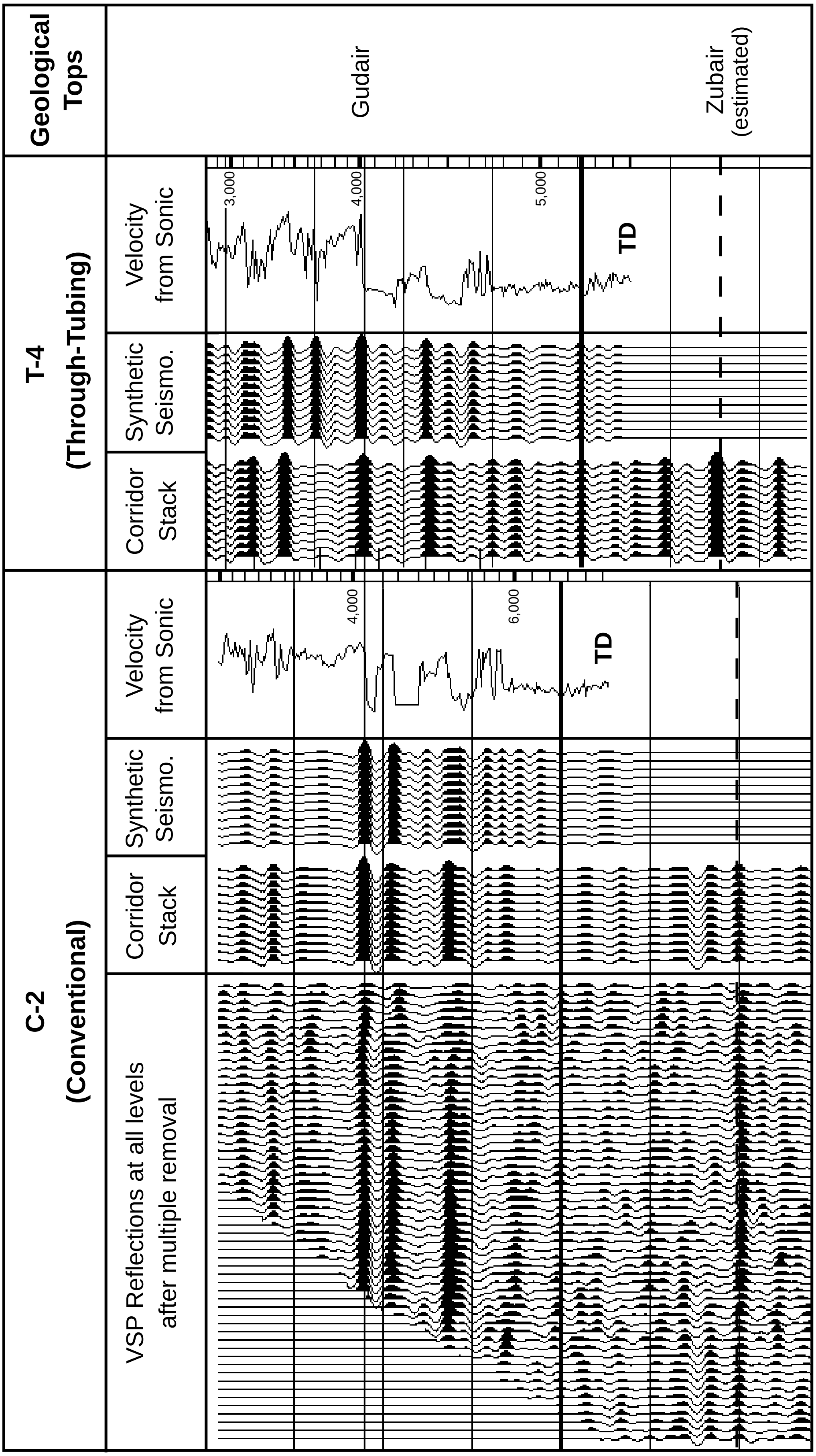

Figure 10: Through-Tubing versus Conventional VSP results in two nearby wells.

CONCLUSION

Careful campaign planning and coordination with the production department was essential to collect valid well seismic data in a cost-effective operation. The 9-well Through-Tubing campaign was completed in 24 days, and resulted in less than 20,000 barrels of delayed production.

Less coupling and noise problems were encountered than anticipated. The selection of packer-anchored tubing completions minimized mechanical coupling problems. A monocable downhole seismic tool limited the background noise generated by surface pressure-control equipment. Although the through-tubing data quality exceeded expectation, the tube wave was still present for all 9 wells. In general, open-hole or cased-hole well seismic surveys are preferred over Through-Tubing.

Comparison of Through-Tubing and Conventional well seismic demonstrates a compatible range of velocities and confirms potential 3-D depthing problems in the area. The data is now integrated into a 3-D velocity model for future 3-D Seismic / Well Tie.

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