V018 RESERVOIR MONITORING – THE TOOLS AND THE LOOPS

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EXPANDED ABSTRACT:
Reservoir characterization and reservoir monitoring is a scientific and mathematical discipline which defines input data needed to **predict** (by simulation) and **confirm** (by measurement **flow through permeable media**. This implies that **cross-disciplinary integration** has to be established.
The **reservoir simulator** in principle gives **pressure changes** and **saturation changes** in the spaces between the history-matched wells, based on a **block model of the reservoir**.
Fig.1 gives a summary of the **tools** and the **loops** envisioned for a successful implementation of reservoir monitoring.
In terms of measurements we restrict the following discussion to **surface seismics** and **VSP/MSP - data**, either vertical component only or up to three components. The conventional view today here is that **repeated measurements** (in terms of P-wave data!) are required to map changes in the pore-space of the reservoir resulting from ongoing production of Hydrocarbons. The initial data set is called the **BASE-LINE-SURVEY** (which of course could be and should be linked to already existing seismic data sets from previous 2 D-surveys), which then is followed by **REPEATED SURVEYS** (which will cover only a subset of the initial area for obvious reasons). The acquisition-geometry of the surveys to be compared should be identical for reasons of multiples, S/N-ratio etc , which implies that the acquisition geometry of the repeated survey has to contain that of the base-line-survey. This means that we can modify the new acquisition geometry relative to the old one, provided that one can **simulate by decimation** the old geometry from the extended new one.
From the base-line-survey normally the **structural model** in terms of velocity distribution and reflector geometry is derived by using the first two phases (out of three in total) of processing, i.e. **TIME DOMAIN AND POST STACK DEPTH DOMAIN**-processing.
Depending on the **validity of the ZERO-OFFSET-(ZO)-CONDITION** (i.e. does the DMO-stack represent a Zero-Offset data volume) „locally" the third phase in data processing , i.e. **PRE STACK DEPTH DOMAIN** may have to be applied in order to achieve the optimum, i.e. correct image of the data-volume. This final result (in terms of eg fault definitions) could be of utmost importance for **local block refinement** in the simulator-model.
The next step is the **SEQUENCE-STRATIGRAPHIC INTERPRETATION** of the reservoir-interval (carbonates or siliciclastics) in question, resulting in e.g. SHELF TRENDS, CHANNEL DISTRIBUTIONS, etc and finally in the **LITHO MODEL** of the reservoir. The litho units are described by their **acoustic impedances (AI)** , and well-data are used here for that purpose. In addition normally **INVERSION FOR AI** of the migrated data-volume (i.e. usually only a sub-volume containing the reservoir-interval is used) is carried out as well and subsequently used by the interpreter.
In parallel **„engineering equations"** for the P- and (if available) the S-wave velocities are established, which typically have the following form:
$V_{p,s} = V_o + (\partial V/\partial \phi).\phi + (\partial V/\partial p).p$, where ϕ=porosity, p=calcite content for carbonates or clay content for sandstones
The established Litho Model then is confirmed/corrected by **FORWARD MODELLING** (acoustic/elastic),, i.e. the seismic response of the Litho Model is checked against the actual measurement. This type of checking is called the **VERIFICATION LOOP**.
The next steo is to **quantify** the effects of the different pore-fills within the reservoir (See **Fig.2**) using the engineering equations in conjunction with the **BIOT-GASSMANN-THEORY**.
For this part one needs to know if the reservoir is **above the bubble point line** (i.e. fluids only) **or not** (fluids and gas). Clearly in the case of gas being present **SHEAR WAVES (S/S)** are needed in order to be able to **quantify for gas saturation,** i.e. the acoustic impedance for the S/S-wavefield is needed here.
The **P/S-WAVEFIELD** in the **presence of gas** is just an **anomaly indicator** like P/P-AVO.
An interesting additional aspect here is in case of **FRACTURED RESERVOIRS** , that the S/S-reflection coefficient (and the P/S-reflection coefficient as well) is sensitive to **FRACTURE INTENSITY**.
The final result of this exercise is a data-base containing velocities/densities/impedances along with the individual moduli/elastic constants for a range of lithologies/porosities/saturations, allowing to **quantify** for the effect of variing pore-fill , based on **impedance changes due to pore fill-changes.**

It is worthwile to note that **shear wave data** (S/S), since they allow a **DIRECT QUANTIFICATION via the corresponding DENSITY CHANGE**, in principle **do not require repeated measurements!**
This is important e.g. in terms of **SECONDARY RECOVERY**, if one changes from water injection to **WAG (= water-alternating-gas).**
For P-data in principle for the fluid-case (i.e. above bubble point) we may think of quantification in terms of the **fluid modulus** K_F as well by a single measurement, but have the problem of wetting/non wetting phases and drainage/imbibition. Therefore a repetition of surveys using P-waves at present seems to be unavoidable.
In addition the combination of P and S allows to map the Vp/Vs-ratio as well, which is a convenient lithology/fracture/etc-indicator, i.e. in case of sandstones the ratio gives a Gamma Ray log and in case of carbonates the ratio gives a density log.
The **splitting phenomenon** for S-waves on the other hand at least is „very difficult" to be used in conjunction with surface-seismic data, but is very effective and stable, if we measure it at **two different depth-levels** (VSP-aspect).
The last step then is to go for **INVERSION FOR AI** (usually L1-Norm spike deconvolution, followed by Born-inversion) of the base-line-survey and the repeated survey , and to map the **IMPEDANCE CHANGES** within the reservoir. These impedance-changes have to be compared with the result of the parallel reservoir-simulation, i.e. **PRESSURE- AND SATURATION CHANGES** (See Fig.1).
A local mismatch between these two sets then should result in a **local correction of the simulator model** and a **rerun of the simulation.**
A sensitivity analysis should preceed above loop in order to define the range of values, within which the **QUANTIFICATION** (i.e. the **impedance change-to-saturation change transform**) is reliable and applicable.
At this stage a **local zoom into the reservoir** by using e.g. additional data acquisition (shear waves,VSP/MSP) is envisioned as a possible complementary optional step.
Finally the improved HC-recovery in terms of additional production should be quantified as well.

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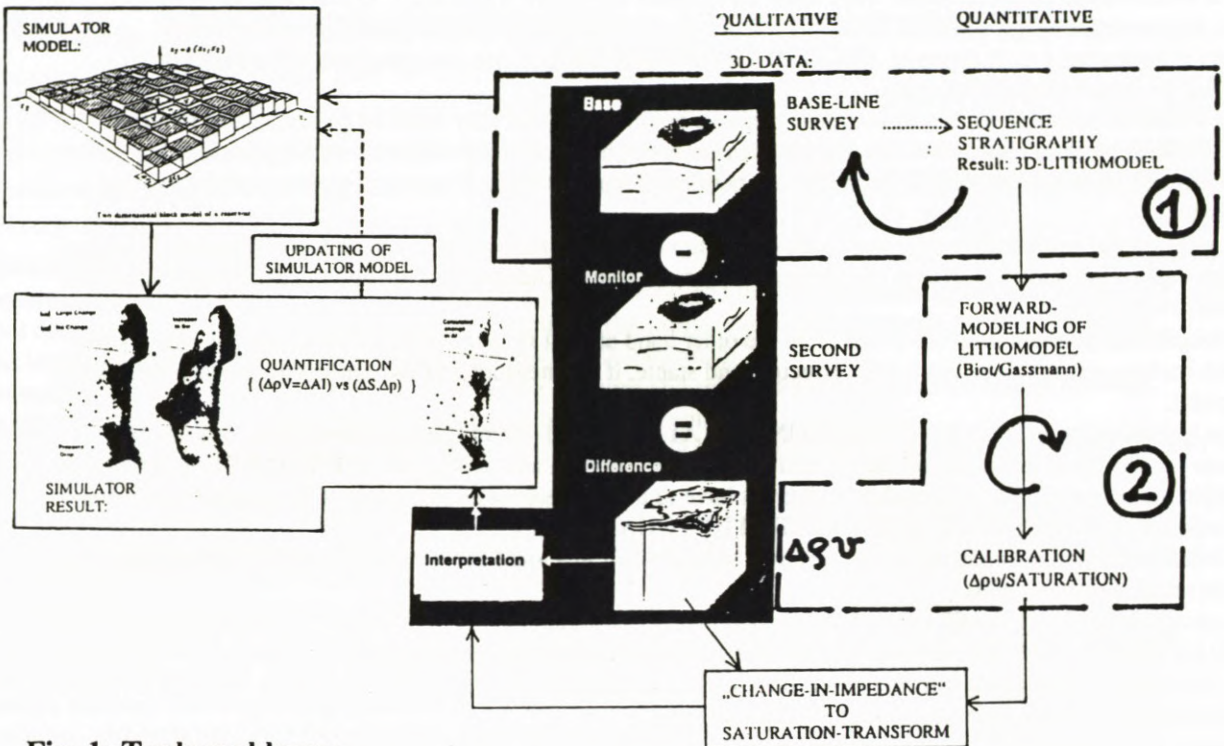

Fig. 1: Tools and loops

SO WE MAY EXPECT THE FOLLOWING
„REGIONS OF USEFULNESS" FOR P- AND S-WAVES:

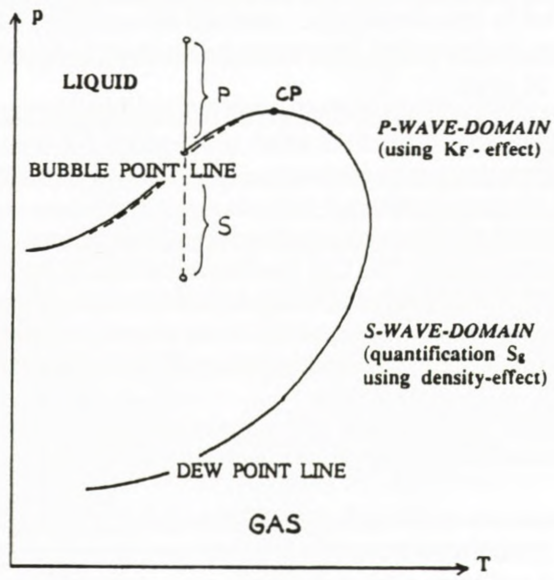

Fig.2: Reservoir above/below Bubble Point