TIME-LAPSE SEISMIC IN SABIRIYAH OILFIELD - KUWAIT

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OUTLINE

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- WATERFLOOD PILOT
- THE MAUDDUD RESERVOIR
- 4D SEISMIC STUDIES
- MINI 3D PILOTS
- EVALUATION METHODOLOGY
- RESULTS
- CONCLUSIONS

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TIME-LAPSE SEISMIC IN SABIRIYAH OILFIELD - KUWAIT

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A fieldwide waterflood development plan is under consideration for the Sabiriyah Oilfield.

Extensive preparation studies for this plan include:

- **A waterflood pilot, and**
- **3D Time-Lapse Seismic Surveys (4D).**

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Sabiriyah Oilfield

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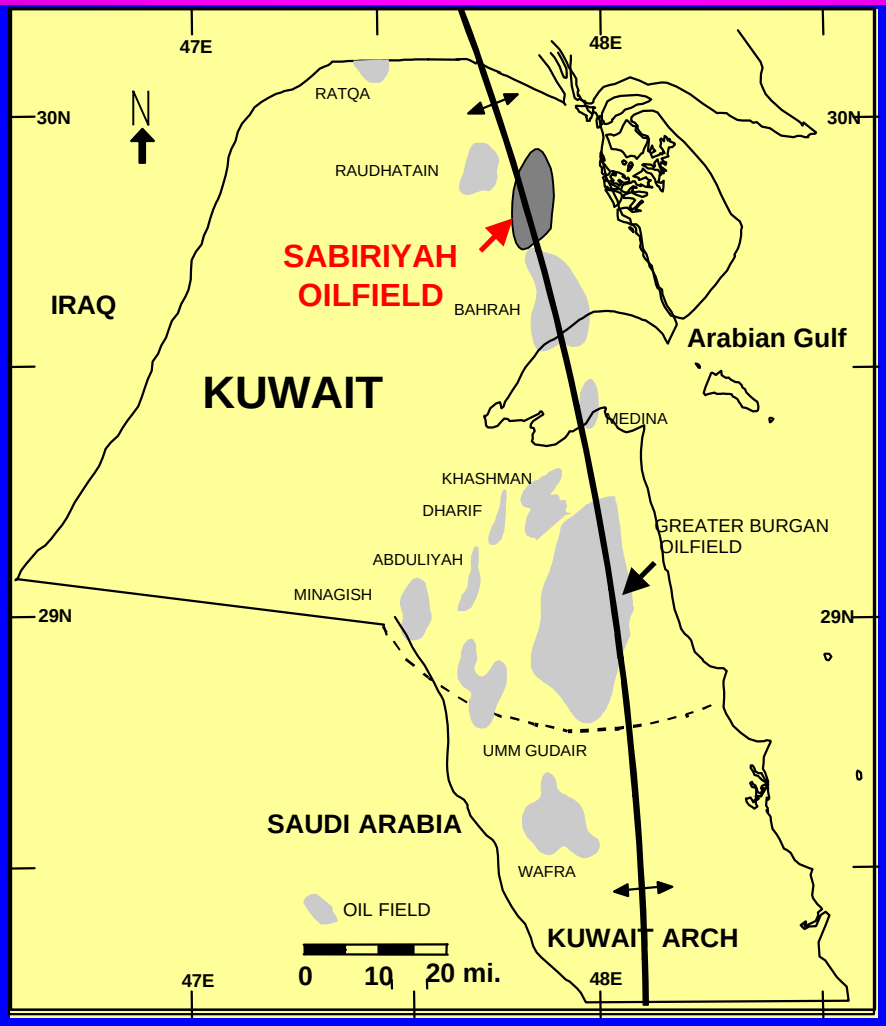

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Waterflood Pilot

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- A long term 5-spot pattern waterflood pilot production test with a central injector was initiated in May 1997 on the **Mauddud carbonate reservoir**.
- The geometry of the 5-spot pattern is a "skewed" square with side length of approximately 600 meters.
- Water injection is approximately 7,000 to 10,000 bpd with production wells flowing naturally at between 1,000 and 1,500 bpd.

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Mini 3D Base Map and Waterflood Pilot

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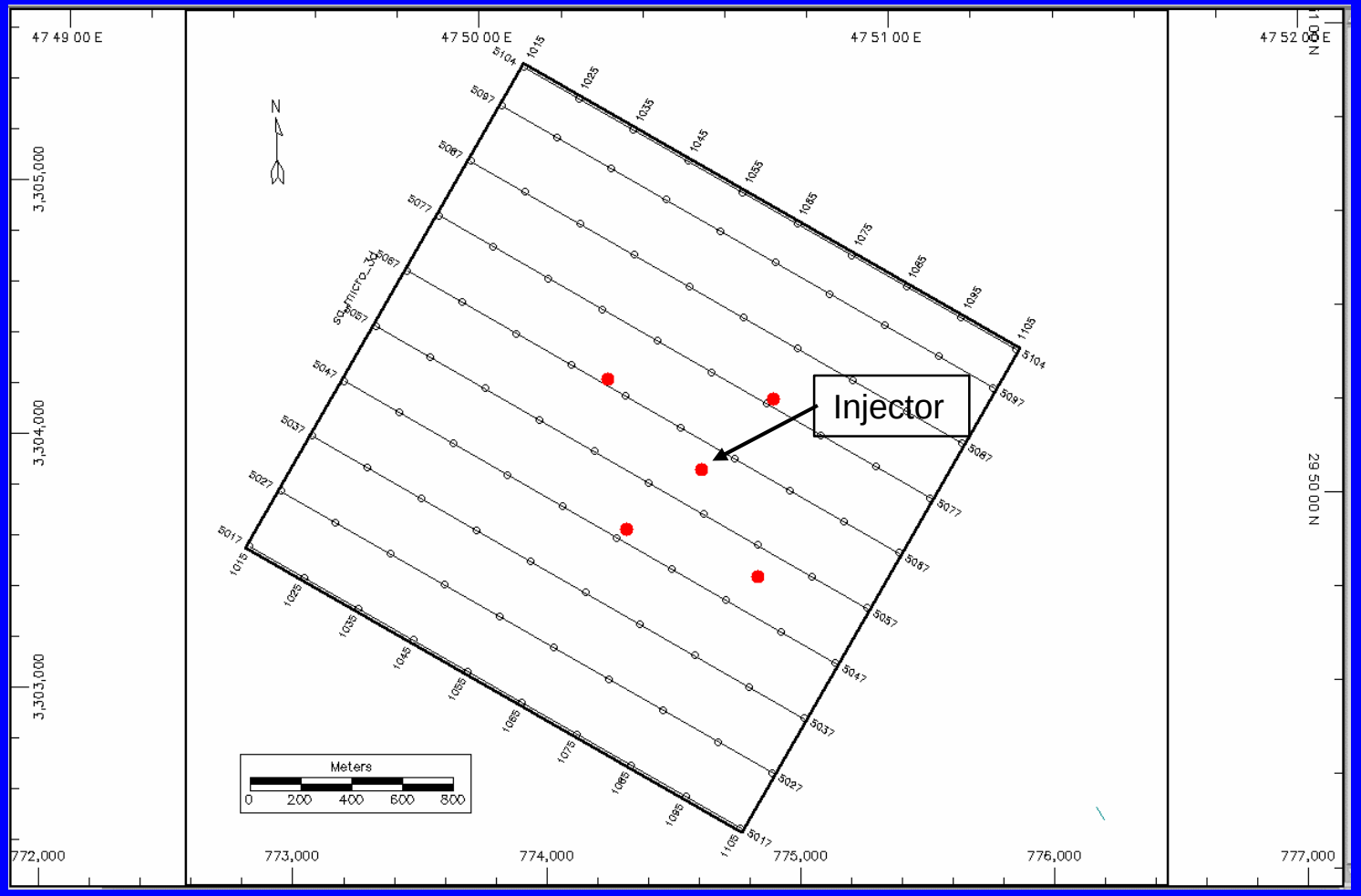

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The Mauddud Reservoir

Sabiriyah Oilfield

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- The top of the Mauddud carbonate reservoir is at a depth of 7,000 feet (2,100 meters).
- The reservoir average porosity is 21%, its average permeability is 31 millidarcies and its thickness is 300 feet (90 meters).

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4D Seismic Studies
(1)

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4D seismic studies and pilots to find out whether **4D** could result in economically optimizing well positions instead of geometric drilling for the planed fieldwide water development plan.

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4D Seismic Studies
(2)

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Petrophysical modeling studies predicted for the Mauddud carbonate reservoir :

An increase in P-wave acoustic impedance (AI) of 4.6% resulting from water injection, assuming oil saturation changes from 75% to 25% during injection/flooding.

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4D STUDIES
(3)

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The success of 4D in the Mauddud carbonate reservoir, which has lower porosity and higher impedance than in sandstone reservoirs is more challenging.

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Mini 3D pilots (1)

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- Two mini 3D pilots surveys were conducted, in May 1997, at the initiation of the waterflood pilot and again in November 1997, a time step of 6 months, with the same stationary patches and acquisition parameters.
- The objective of these two 3D pilot surveys was to monitor saturation changes in the Mauddud carbonate reservoir over the six month period.

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Mini 3D pilots
ACQUISITION PARAMETERS

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- 8 receiver lines, 200 meters apart, 60 live stations each.
- 8 orthogonal shot lines, 200 meters apart, 60 shots per line.
- 50 meters shot and receiver station intervals were.
- 36 linearly spaced geophones per station.
- 8 linear sweeps of 8 seconds duration.
- 8 – 70 Hertz frequency range.
- 4 ms sample interval.

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Mini 3D pilots
Processing (1)

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- The identical processing sequences of the two data sets are fairly standard time domain sequences, giving at the end time migrated stack.

- The time migrated stack is then input to a L1-norm deconvolution, followed by BORN-inversion for the HF-part of the acoustic impedance (AI).

- No attempt was undertaken to recover the base trend (AI-baseline) as the **key monitoring quantity is the difference-in-AI** derived from both surveys.

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Mini 3D pilots
Processing (4)

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The data were converted into AI differences by taking into account the time shift of the second survey.

In addition, a median filter of 5 points was applied to the resulting delta-AI-cube in order to achieve the required noise-suppression in a controlled manner.

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Mini 3D pilots
Evaluation

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The first result of the evaluation is the quantified saturation map for the Mauddud carbonate reservoir which shows a clear definition of the resulting saturation distribution after 6 months of injection.

The Resulting Saturation Map
s-approach

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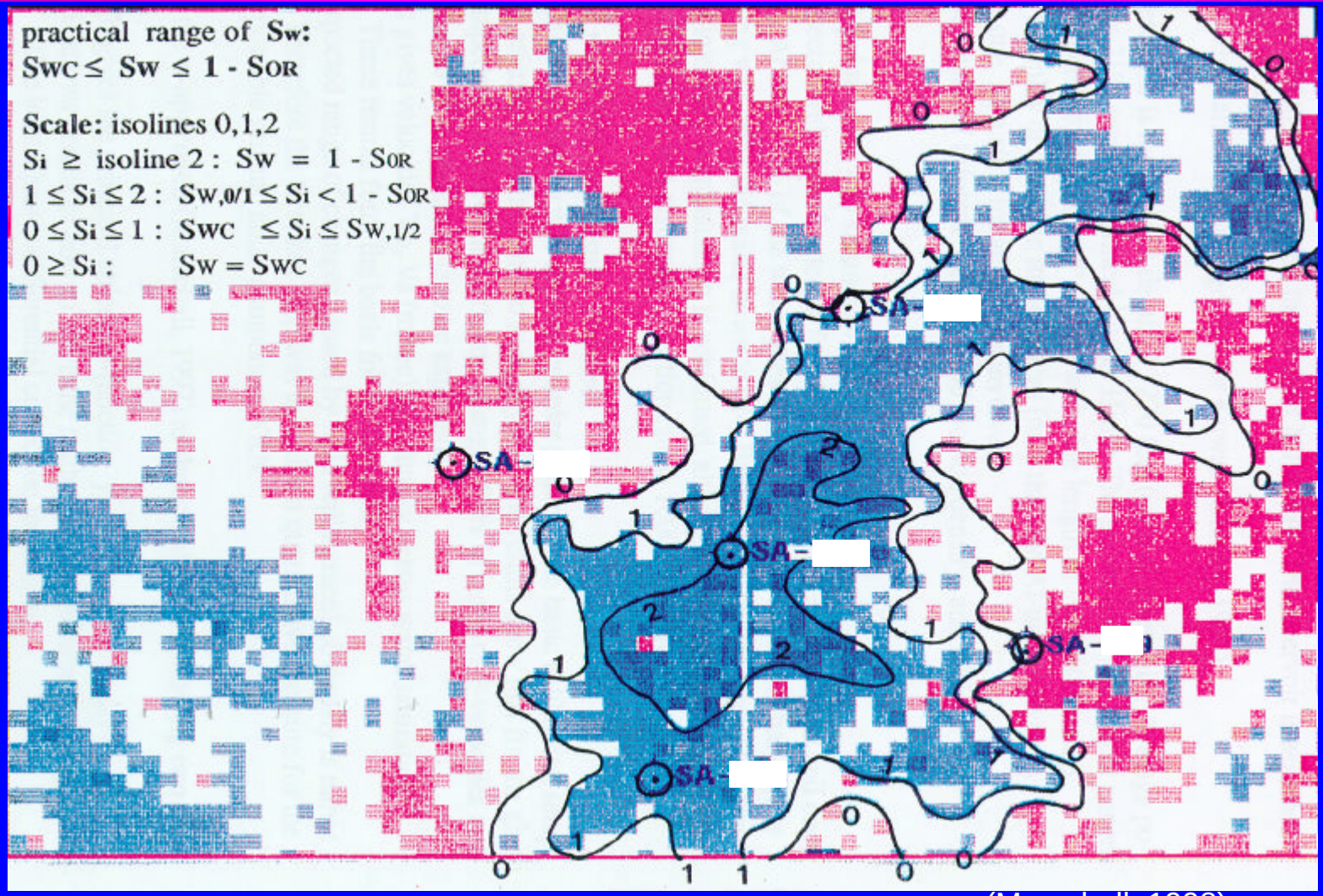

Contour interval=90kPa.s/m

(Marschall, 1998)

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Mini 3D pilots
Evaluation Methodology (1)

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- Biot-Gassmann theory was applied in order to derive the basic calibration setup linking seismic measurements to rock physics.

- The results show that for this high impedance reservoir a **maximum change of 3% in terms of P-velocities and 5% in terms of acoustic impedance are to be expected over the six months period.**

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Mini 3D pilots
Evaluation Methodology (2)

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- For Sw change from 0.158 to 0.542, the change in acoustic impedance is only **2.46%.**

- These results in conjunction with the proper definition of the acoustic impedance baseline (AI-baseline) derived from logs form the basis for calibration.

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Mini 3D pilots
Evaluation Methodology (3)

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A key step for evaluation was to derive a quantitative measure for the **non-repeatable seismic noise** component **(NRN)** using the s-approach (Marschall, 1997a, 1997b and 1998).

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Mini 3D pilots
Evaluation Methodology (4)

Kuwait Oil Company

The **NRN-level** within the target travel time was determined to be approximately **2%.** This is a critical number, since the maximum calculated impedance change between the cases of:

a) irreducible water saturation, i.e. full oil saturation: Sw = Swc , and

b) irreducible oil saturation, i.e. maximum water saturation: Sw = 1 - Sor

is 5% and the change over the 6 months period is only 2.46%.

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Evaluation Methodology (5)

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- The resulting saturation map was obtained from the **difference-in-AI-cube** in the form of an average saturation in the vertical direction, that is **average over time (AOT),** over the whole **reservoir interval**, i.e. approx., 50 ms.

- The length of the averaging vector in time determines the type of the grid obtained along with its mean error.

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Mini 3D pilots
Evaluation Methodology (6)

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- Interpretation was done based on three isolines labeled as 0,1,2, with the contour interval equal to 90 kPa.s/m
- The region of validity of these saturation lines was checked using the s-approach.

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Mini 3D pilots
Evaluation Methodology (7)

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- The level of expected background noise **(NRN-component)** is defined for the target-travel time and gives the **"area of no change"**, i.e. the domain of constant NRN (minimum constant background noise energy).

- Within the **area of no change**, the original saturation distribution remains unchanged, i.e. it represents the status of the reservoir prior to flooding.

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Evaluation Methodology (8)

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Mapping of saturation changes is only valid outside the area of no change, i.e., in, the valid area of mapping changes: “Area of Confidence”.

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Mini 3D pilots
Evaluation Methodology (9)

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Isoline 2 encircles the injector-well, and therefore for this part of the saturation map (i.e. inside isoline 2), the value Sw = (1-Sor) defines the maximum value of the actual water saturation.

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Mini 3D pilots
Evaluation Methodology (10)

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The area outside isoline 0 marks the area of no change where the water saturation is assumed as the irreducible water saturation, i.e., Sw = Swc. This defines the area of maximum oil saturation or equivalently the area of minimum water saturation.

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Evaluation Methodology (11)

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The actual end saturations points, Sw=Swc and Sw = (1-Sor) should be defined by the reservoir engineers.

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Mini 3D pilots Results

WATER SATURATION MAP

(AOT WITH GATE = RESERVOIR THICKNESS

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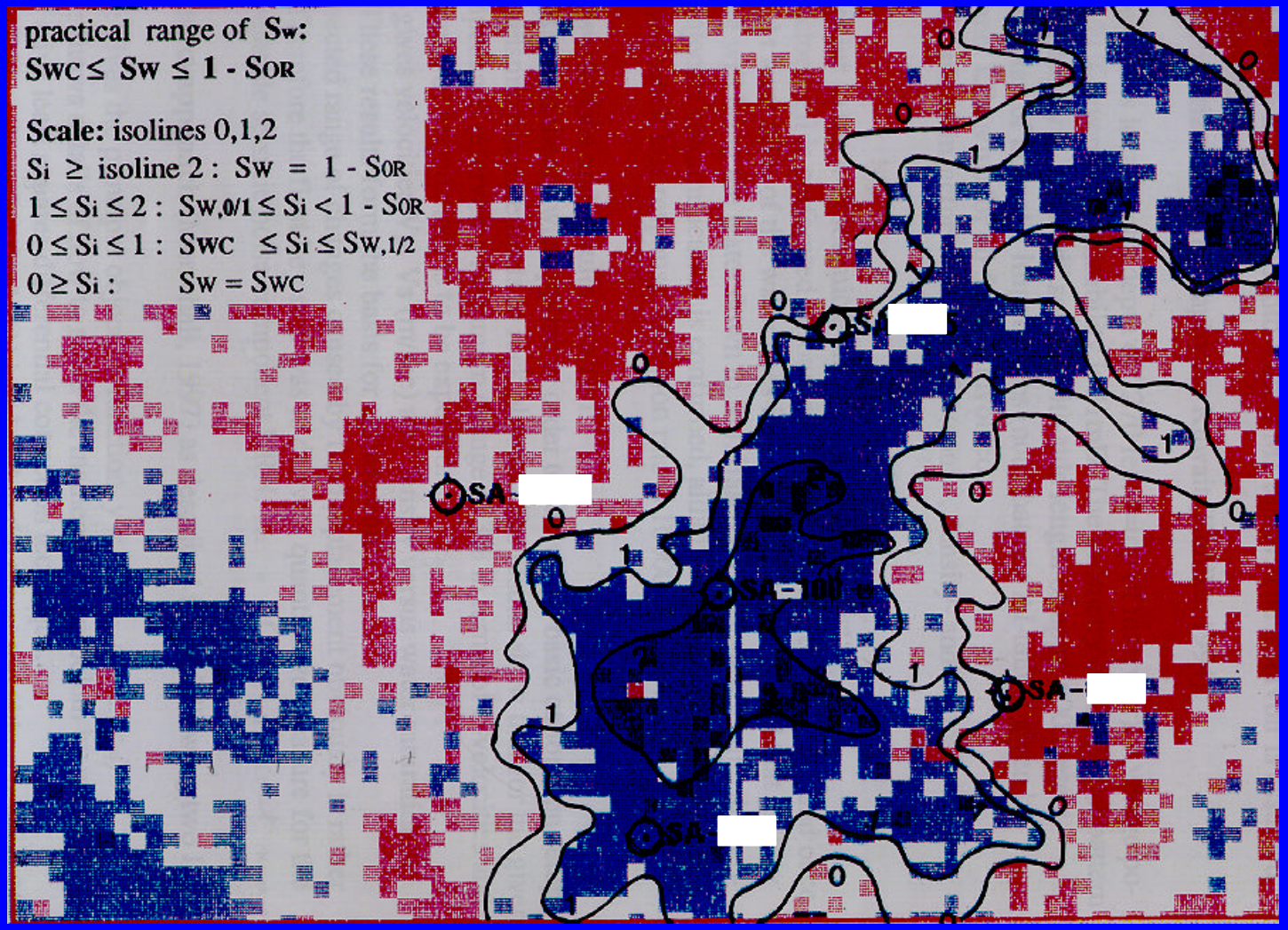

Contour interval=90kPa.s/m

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Mini 3D pilots
Results (1)

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This saturation map gives:

- The **saturation distribution** due to injection **(first objective of 4-D, i.e., quantification).**
- An indication of the **degree of inhomogeneity** of the reservoir which could be used to stabilize the results of the pilot and extrapolated to large scale flooding **(the second objective of 4-D).**

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Mini 3D pilots
Results (2)

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The quantified saturation map for the Mauddud carbonate reservoir showed a similar correlation to the water cuts observed in the producing wells.

Mini 3D pilots Results (3)

WATER SATURATION MAP

(AOT WITH GATE = RESERVOIR THICKNESS

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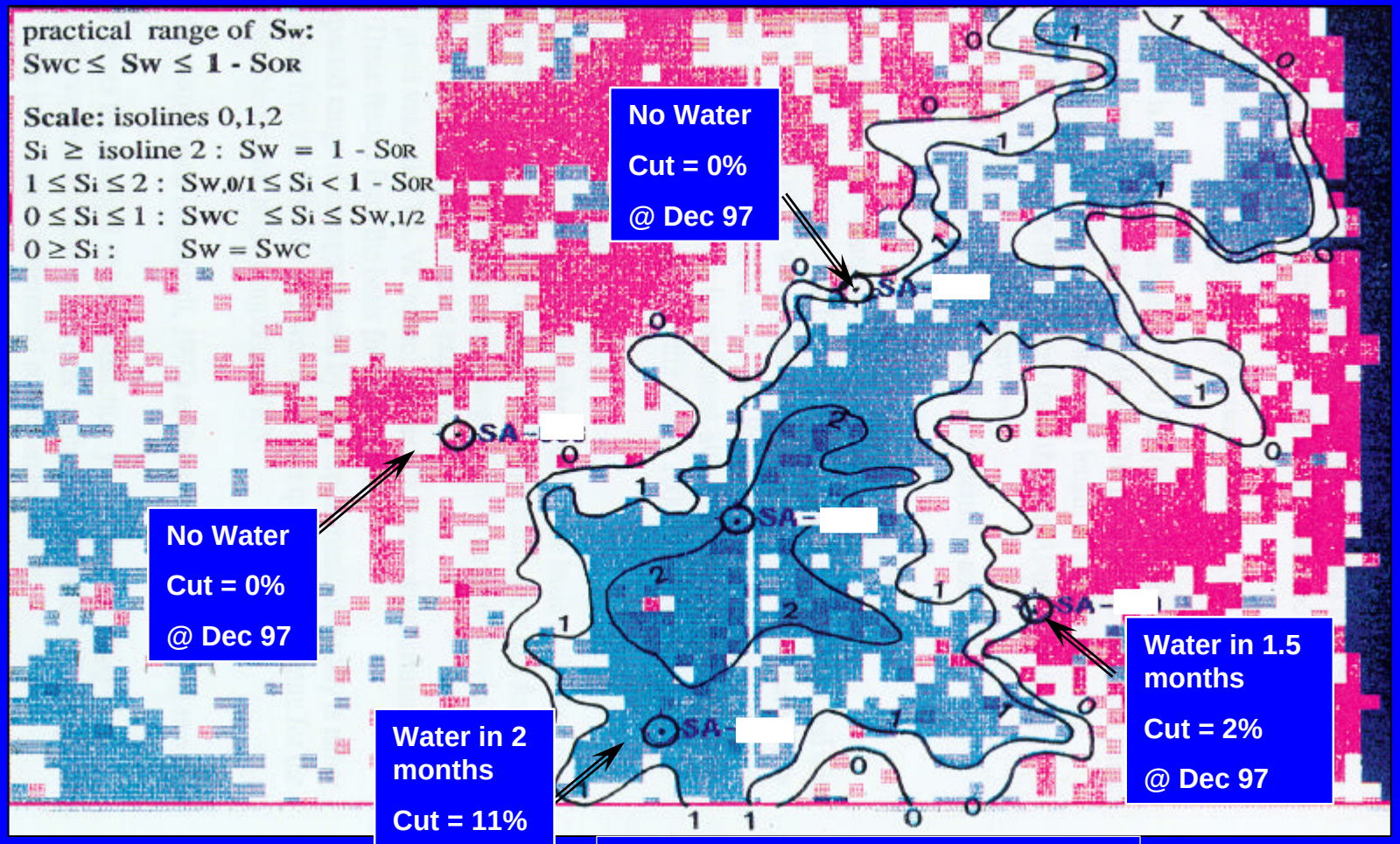
Kuwait Oil Company



Contour interval=90kPa.s/m

Water cuts after 1 mmb water injection later added by Dave Foster

(Marschall, 1998)

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Zooming into the Reservoir (1)

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The procedure was further refined:

- By subdividing the reservoir into vertical sub-units of **4 ms (approximately 25 feet=7.5m)**, using the top-of-reservoir as the starting value of the time gate.
- By keeping the vector constant in the time direction (i.e., keeping the length of the now moving gate constant), a sequence of grids is obtained.
- The length chosen for this procedure is called the **tN-comb**, where N stands for the number of samples used for averaging.

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Zooming into the Reservoir (2)

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The results of **“zooming into the reservoir”** by the **s-process** are given in the next slide which indicates that most of the changes due to water injection occurred in the top part of the Mauddud reservoir.

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Zooming into the Reservoir (3)

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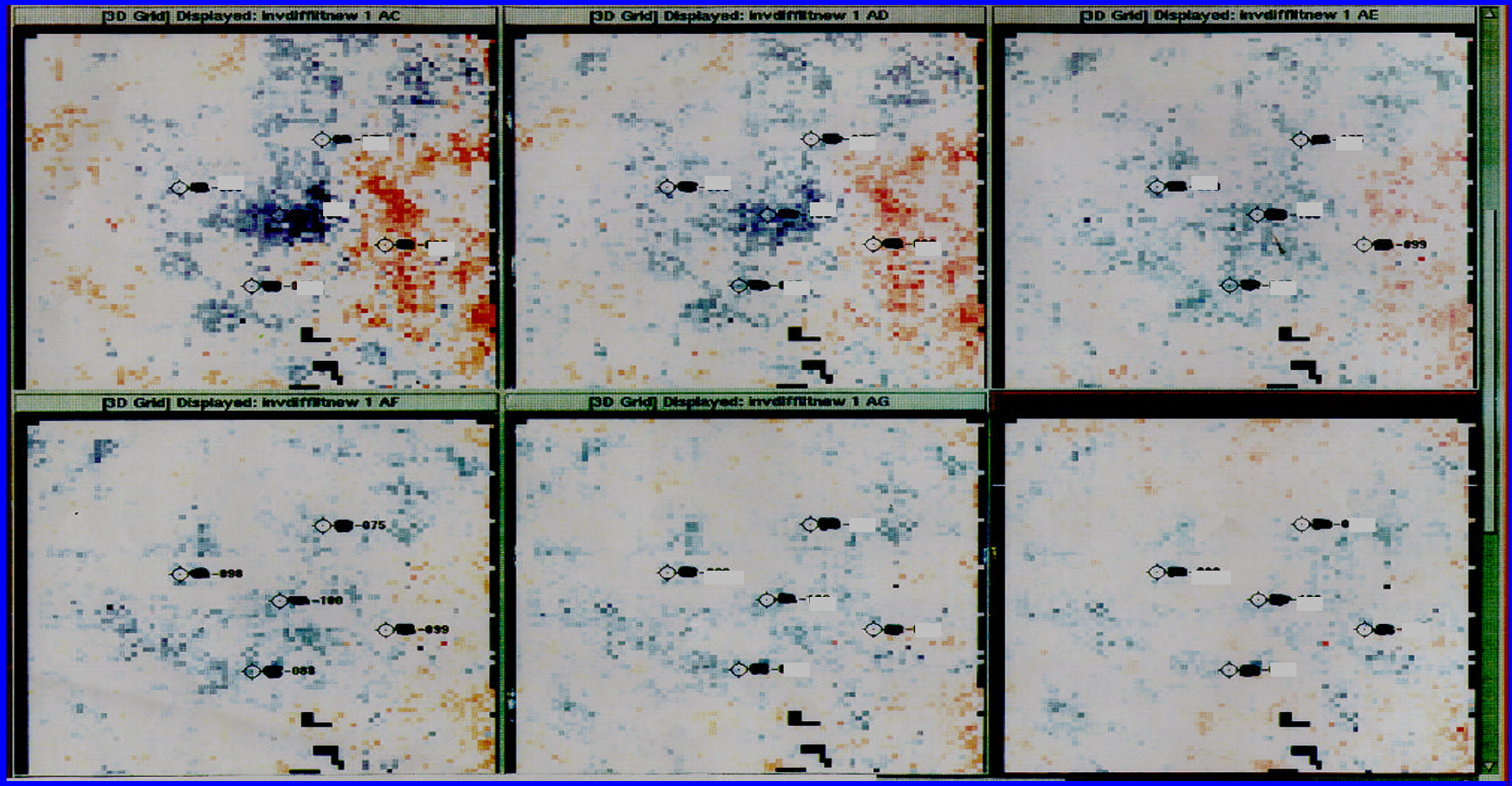

6 ZOOMS (t5-COMB): TOP RESERVOIR, TOP +4/+8/+12/+16/+20MSEC

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CONCLUSIONS

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- This 4D study, over a waterflood pilot project in a **CARBONATE RESERVOIR**, proved the tremendous power of 4D measurements in giving the actual fluid saturation changes.

- The key process is the use of the s**-approach** to quantify the **non-repeatable noise (NRN)**, since the **change in the monitoring quantity, acoustic impedance,** is very small (in this case **2.46%**) and the level of **NRN-noise** is not negligible (in this case **2%**).