# An Application of LOTEM around Salt Dome near Houston, Texas


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**Abstract.** A salt dome is an important large geologic structure for hydrocarbon exploration. It may seal a porous reservoir of rocks that form petroleum reservoirs. Several techniques such as seismic, gravity, and electromagnetic including magnetotelluric have successfully yielded salt dome interpretation. Seismic has difficulties seeing through the salt because the seismic energy gets trapped by the salt due to it high velocity. Gravity and electromagnetics are more ideal methods. Long Offset Transient Electromagnetic (LOTEM) and Focused Source Electromagnetic (FSEM) were tested over a salt dome near Houston, Texas. LOTEM data were recorded at several stations with varying offset, and the FSEM tests were also made at some receiver locations near a suspected salt overhang. The data were processed using KMS's processing software: First, for assurance, including calibration and header checking; then transmitter and receiver data are merged and microseismic data is separated; Finally, data analysis and processing follows. LOTEM processing leads to inversion or in the FSEM case 3D modeling. Various 3D models verify the sensitivity under the salt dome. In addition, the processing was conducted pre-stack, stack, and post-stack. After pre-stacking, the noise was reduced, but showed the ringing effect due to a low-pass filter. Stacking and post-stacking with applying recursive average could reduce the Gibbs effect and produce smooth data.


## BACKGROUND

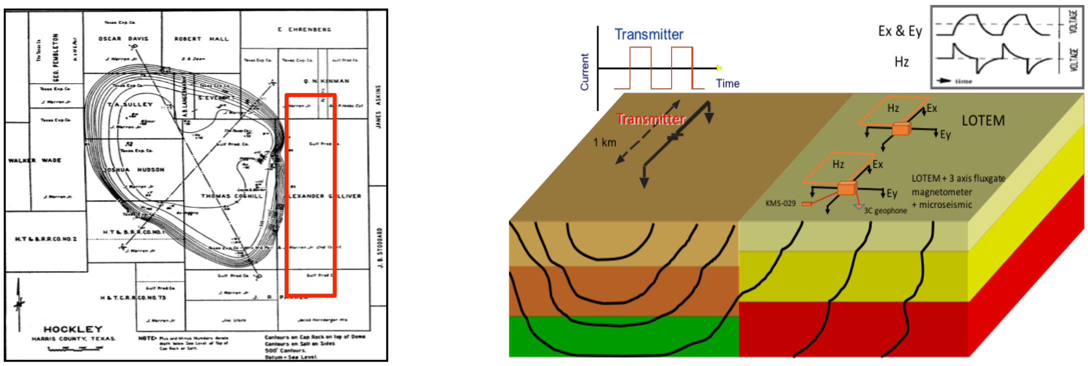
A salt dome is an important large geologic structure in hydrocarbon exploration, which may seal a porous reservoir of rocks and can lead to the formation of petroleum reservoirs. Oil and gas are trapped and accumulated due to excellent sealing capabilities of the salt dome. Its shape often reminds a cylinder buried at the depth of several kilometers, and then it sometimes moves upward until it shatters through the surface [1].

The seismic technique has been widely used to study the structure of salt dome. This technique was used to study salt dome such as in the Gulf Coastal Plain [2] demonstrating a good accuracy in the data analysis and developed interpretation [3, 4]. In the area under the salt dome overhang or salt dome flank, seismic result has low-resolution image due to that salt absorbs seismic energy due to its high velocity in rock salt [5]. Therefore, gravity and electromagnetics such as Control Source Electromagnetic (CSEM) [6], and Magnetotellurics (MT) [7] are more suitable methods to get a satisfactory interpretation. Several studies have been published using LOTEM, for petroleum exploration [8, 9, 10] and to monitor fluid injection during enhanced oil recovery (EOR) operation to observe oil and injected water contacts [11]. The LOTEM was also successful to image subsurface in the rugged area where seismic method has difficulties [12]. The confidence of using LOTEM can be applied to the area with high electromagnetic noise where other methods have difficulties to produce the satisfactory interpretation.

## GEOLOGIC SETTING

The study area is located in the Texas Gulf Coast and consists of two main formations, the Lissie and Willis. The Lissie is part of the Houston Group [13]. Its thickness is approximately 61 m, and both the upper and the lower part consist of clay, silt, sand and the minor amounts of gravel. Gravel is slightly coarser in the lower part than in the upper part. Iron oxide concretion is also more abundant in the lower part [14]. The lower part of the Lissie is directly adjacent to the upper part of the Willis. Willis formation comprises clay, silt, sand, and minor siliceous gravel in granule to pebble sizes. It also includes some petrified wood. It is deeply weathered and lateritic, indurated by clay and cemented by iron oxide locally [14]. Its maximum thickness is approximately 23 m [13]. There exist fault zones surrounding the Hockley salt dome with the main direction from Northeast to Southwest [15,16].

## MATERIAL AND METHODOLOGY




(a) (b)

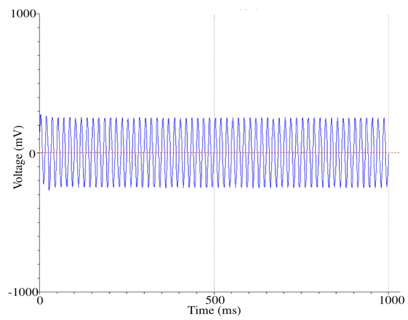
**FIGURE 1** (a) Subsurface contour of Hockley Salt Dome with the study area [17], (b) Typical LOTEM transmitter and receiver setup. In the left, sowing transmitter configuration and transmitted current wave form. In the right, showing 2 typical receiver configurations and signal response in the magnetic and electric field.

The LOTEM system consists of a grounded transmitter and receivers consisting of an induction loop or a magnetometer for the magnetic field and non-polarized electrodes for the electric field. Receiver can be moved to several stations while transmitter is fixed for the part of the survey [18]. The grounded wire transmitter is used to inject a square-wave current into the subsurface. Induced currents propagate outwards and downwards in the subsurface as time after switch-off increases causing a step response in the electric field and transients in the magnetic field at the receivers as depicted in Fig. 1b. Further, the information of the subsurface structure is obtained by interpreting the amplitude and shape of both the electric and the magnetic field signals [10]. A new technology of Focused-Source Electromagnetic (FSEM) is an improvement of the conventional CSEM method which has significantly higher spatial resolution and provides deeper resistivity data. FSEM technique [19, 20] uses the vertical focusing of the EM field, the idea inspired by the resistivity well logging.

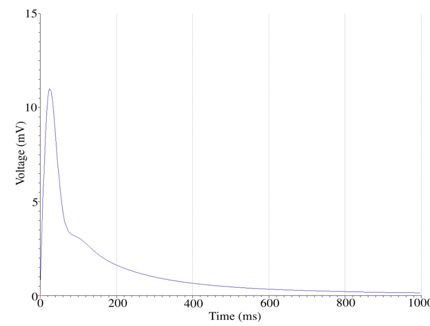
As shown in Fig. 1a, LOTEM and FSEM data were measured over the Salt Dome near Houston, Texas. Three receivers (R1, R2, and R3) simultaneously measured electric field (Ex and Ey), vertical magnetic field (Hz), microseismic, and fluxgate magnetometer and three additional receivers (Rx0a, Rx0b, and Rx0c), were connected to the electric field receiving electrodes (Ex and Ey). The receivers, R1, R2 and R3 were placed at the offset of 900 m,100 m and 1,300 m respectively from southern transmitter electrode. Additional receivers, Rx0a, Rx0c are placed at 25 m and 400 m, respectively from the south transmitter electrode and Rx0b was located between the northern and the southern transmitter electrodes. The transmitter operated in two directions: 1.) Inline transmitter in the North to South direction 2.) Broadside transmitter in the East to West direction. The distance between the transmitter electrodes was designed to be 400 m for N-S and 340 m for E-W directions. Two measuring systems were modified in order to control the transmitter for the data acquisition, and measuring the system response. The receiver and the transmitter systems were connected using either the normal digital cable or the differential cable.

## RESULTS AND DISCUSSIONS

The pre-processing and processing which consists of pre-stacking, stacking, and post-staking, was done using KMS Pro software, developed by KMS Technologies Company. Before the processing, each raw data recorded from the field must be checked for assurance to prevent or avoid problems in data processing. The calibration and header checking aim to correct the amplitude of the signal recorded in the receiver which sometimes has incorrect arrangements and definitions of receiver coordinate and current. The transmitter and receiver data were merged later for normalization, and microseismic data were separated.



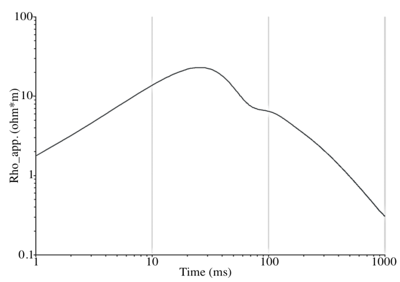

**(a)**



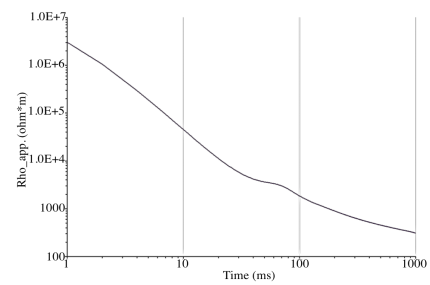

**(b)**

**FIGURE 2.** The magnetic field (Hz) data processing. a) The raw data, b) the data after filtering stacking and smoothing.

The low-pass filter was selected to reduce influence of the harmonic noise (Fig 2a), mainly from power line, for each data set. The main frequency of the noises was 60 Hz, with and its several center harmonics (60, 80, 120, 180, 300, etc.). They were filtered out using automatic harmonics detection with threshold levels 3.00 and with width 10 for each center. The minimal ringing effect appears after filtering due to the impulse respond of a perfect low-pass filter. The filtered transient is almost perfectly cleaned out from the harmonic noise and amplitude distortion. To compensate the unrecognized sporadic noise that could not be eliminated by pre-stacked, and a strong distortion still exists, the selective stacking algorithm with adding T/2 additional stacking (mostly for 50% bipolar pulses) was performed. The pulse should be processed in the half of period for the bipolar signal of 100% duty cycle and in a quarter of a period for 50% bipolar pulses. Under post-stacking, the recursive average was mainly applied to smooth the data, which also reduce the ringing due to Gibb's phenomenon (Fig.2b)



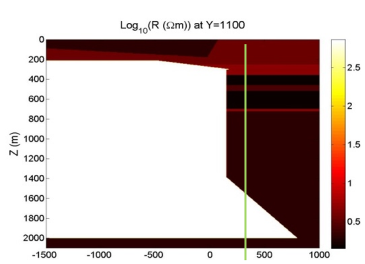

(a)



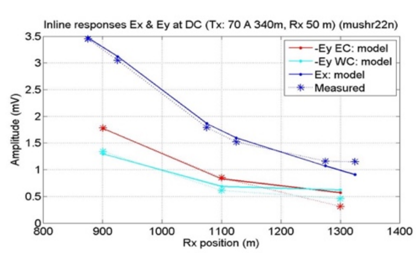

(b)

**FIGURE 3** (a) Early time apparent resistivity and (b) late time apparent resistivity of magnetic field.

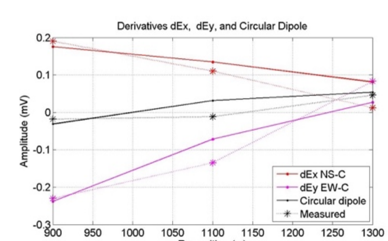
The signal-to-noise (S/N) ratio at early times is good, but signal becomes very weak at late times after 3 s. It is due to instrument sensitivity and low injected current (only 70 A). To improve the S/N ratio at these late times, we performed recursive average of 0.50. Although, the average can be increased to 0.90, but the noise appears at average of 0.60. Based on transient currents diffusion theory, we have derived the early (Fig. 3a) and late time (Fig. 3b) apparent resistivities.




(a)




(b)




(c)

**FIGURE 4** (a) Vertical (East-West) cross-section of 3D model of the Salt dome and the FSEM results acquired in Rx1 (900 m offset from transmitter South), Rx2 (1100 m offset) and Rx3 (1300 m offset), (b) measured and modeled data of Ex and Ey, (c) derived formation model of Ex, Ey, and circular dipole.

Figure 4. shows the processed measurements in Rx1, Rx2 and Rx3 (asterisks) and 3D modeling results (solid lines) calculated from a 3D model depicted on Fig. 4a. The model was initially derived from the known geological information and then further refined using the acquired data. Rx1 and Rx2 demonstrate excellent agreement between the modeling and the measurement. The model needs to be further refined and verified to get better agreement with the data in Rx3.

## CONCLUSION

The preliminary results of our study on Hockley salt dome area near Houston, Texas, indicate that the LOTEM method is an effective exploration method even in areas plagued by very high level of cultural noise, and FSEM method allows increasing the sensitivity to the area under the salt dome. The LOTEM processing, conducted pre-stack, stack, and post-stack, yields confidence to the data quality and will allow us performing inversion of the data into a resistivity image section. The results will be compared with 3D EM modeling and geologic information from an existing well. The combination of those techniques will contribute to the excellent interpretation.

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