# High Resolution Monitoring and Modeling of Steam Injection in the Athabasca Oil Sands at UTF: A Case Study

Evan Bianco*
University of Alberta, Edmonton, AB
evan.m.bianco@gmail.com

and

Douglas Schmitt
University of Alberta, Edmonton, AB, Canada

## Summary

This case study explores rock physical properties of heavy oil reservoirs subject to the Steam Assisted Gravity Drainage (SAGD) thermal enhanced recovery process. Previously published measurements [e.g. Wang et. al, 1990, and Eastwood, 1993] of the temperature dependant properties of heavy oil saturated sands are extended by fluid substitutional modeling and wireline data in order to assess the effects of pore fluid composition, pressure and temperature changes on the seismic velocities of unconsolidated sands. Rock physics modeling is applied to the shallow McMurray reservoir (135-160m depth) encountered by the Underground Test Facility (UTF) within the bituminous Athabasca oil sands deposit in order to construct a petrophysical velocity model of the SAGD process. Although the injected steam pressure and temperature controls the fluid bulk moduli within the pore space, the stress dependant elastic frame modulus is the most poorly known yet most important factor governing the changes of seismic properties during this recovery operation. The results of the fluid substitution are used to construct a 2-D synthetic seismic section in order to establish seismic attributes for analysis and interpretation of the physical SAGD process. The findings of this modeling promote a more complete description of 11 high resolution time lapse 2-D seismic profiles collected at the UTF. This work presented is intended to provide an overview of the U of A's geophysical involvement with the UTF project.

## Introduction

The SAGD process has been adopted as the recovery method of choice for producing bitumen from the Athabasca tar sands and it has changed relatively little since the first test installation and experiment at the UTF back in the mid 1980's (Birrel, 2003). Engineering models (e.g. Chow and Butler, 1996) assume that steam chamber growth is symmetric about the well pairs, but due to lithologic hetereogeneities and steam baffles, this is most certainly not the case (figure 1). Before seismic can be optimized as a tool for reservoir surveillence, it is important to understand the behaviour of oil sands material when subjected to elevated temperatures, pore pressure and fluid saturation conditions inflicted by SAGD.

The suggestion that the seismic monitoring of thermal recovery processes is possible was initially based on laboratory observations of a significant decrease in the compressional velocity with temperatures in heavy oil saturated materials. Unfortunately, for the SAGD case, the situation is substantially more complicated than simply increasing the temperature of the material. After steam injection, the ‘effective’ pore fluid will surely be an immiscible mixture of residual hydrocarbons and water in both liquid and gas phases, which are distributed in a complex fashion within the pore space of the material.

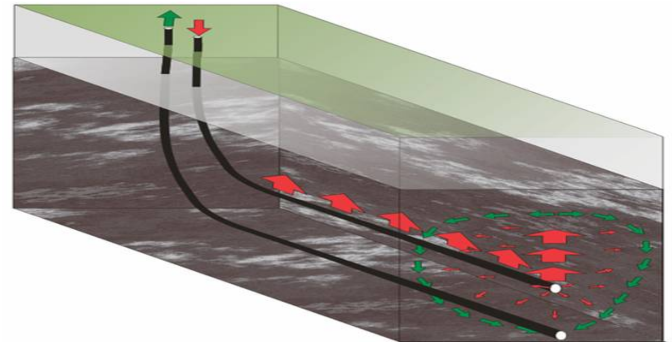

Figure 1: Schematic of the SAGD operation in the midst of widespread and unpredictable lithologically-defined permeability heterogeneities.

## Rock Physics of Steam Injection

Effective rock properties (namely, effective P-velocity, $V_p$, effective S-Velocity $V_s$, and effective density, $\rho$) are extracted from wireline data in order to establish reasonable elastic parameters ($\kappa_{eff}$, $\mu_{eff}$, $\rho$) for input to Gassmann’s equation for fluid substitution (figure 2). We constrain the steam-saturated moduli for unconsolidated sands using Hertz-Mindlin type contact formulations. Ternary diagrams aid in studying the effective response of a three component fluid ensemble (oil, water, steam) for a variety of temperature and pore-pressure scenarios. The result is a more accurate description of the in-situ elastic parameters within an idealized steam chamber.

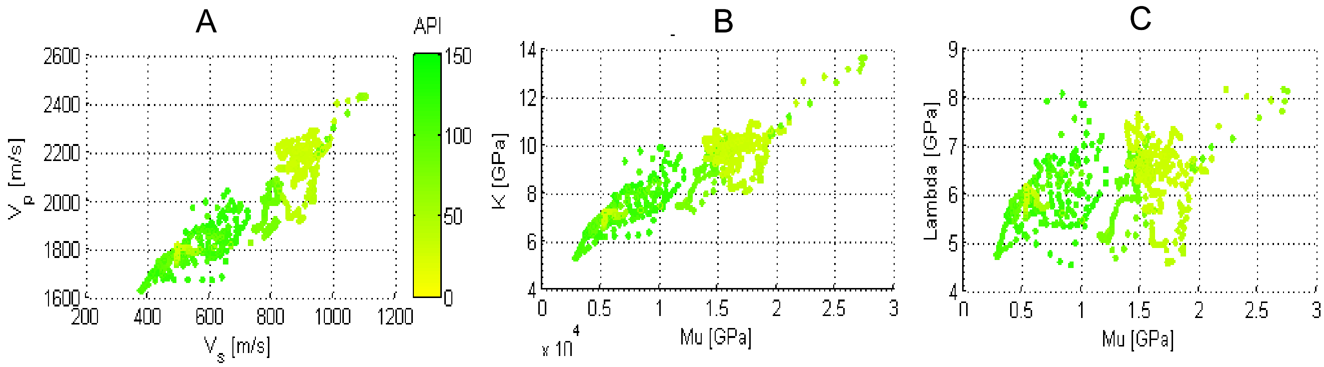

Figure 2: Scatter-plot of A) $V_p$ vs. $V_s$ and B) *Lambda (λ)* vs. *Mu (μ)* determined from a dipole-sonic log through the McMurray formation and the overlying mudstones of the Clearwater formation. The colorscale is cast to the Gamma-ray count (API) for each depth measurement.

## Wave Propagation Modeling

To explain the propagation of seismic energy through an oil-depleted steam chamber surrounded by cold, untouched, virgin reservoir, a finite-difference algorithm was employed to calculate the wavefield generated through an acoustic velocity model. The anomaly produced by the steam zone yields a large increase in amplitude and small time delay as anticipated, but this example also shows that steam substitution also presents scattering symptoms; diffraction hyperbolae, complicated reverberations and multiple reflections from within the steam zone (figure 3C). The perturbation in the wavefield is very localized about the steam zone it appears that internal multiples persist beneath the thickest part of the steam zone (~108 to ~118m along the profile in figure 3C).

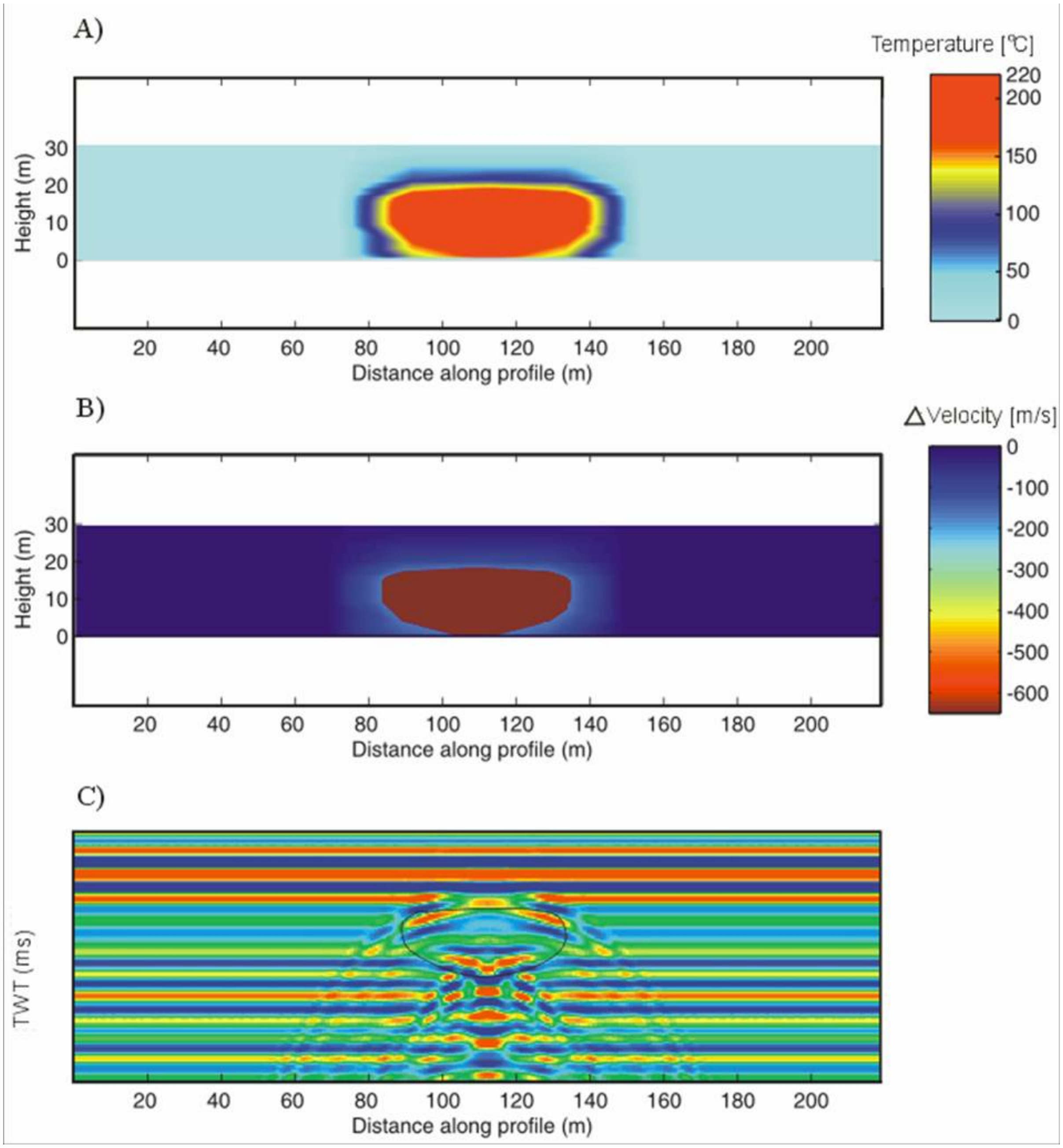

Figure 3: A) Hypothetical temperature profile of a typical steam chamber in Athabasca reservoir B) Computed P-wave velocity anomaly result from rock physics and fluid substitution analysis. C) Un-migrated synthetic seismic profile generated using an acoustic finite difference algorithm. The steam anomaly in B) is superimposed on the background reflectivity determined by closely spaced well logs at the UTF. The offset range used in this stacked section is 48 -142m.

## High Resolution Seismic Data and 2-D Time-Lapse Imaging

The 11 2-D lines collected by the University of Alberta between 1995 and 2000 over the UTF Phase B site were sampled with 1m CMP spacing and offsets ranging from 48m – 142m (48 channels were available and spaced 2m apart). The product is an unusually highly sampled data set exhibiting very good repeatability. Figure 4 shows a volume visualization of this time-lapse data, where the 'brightest' amplitudes have be highlighted as green 'iso-surfaces'. This image shows three very interesting results; 1) The amplitude increase caused by the steam is very large and detectable, 2) the steam anomalies are similar to the reverberation and scattering symptoms as modeled in figure 3C, and 3) the steam anomalies are not symmetric about the well pairs, (in particular the leftmost steam chamber is entirely asymmetric) and they appear to swing 'to and fro' in response to the inconstant production conditions that were varied during the piloting of this experiment.

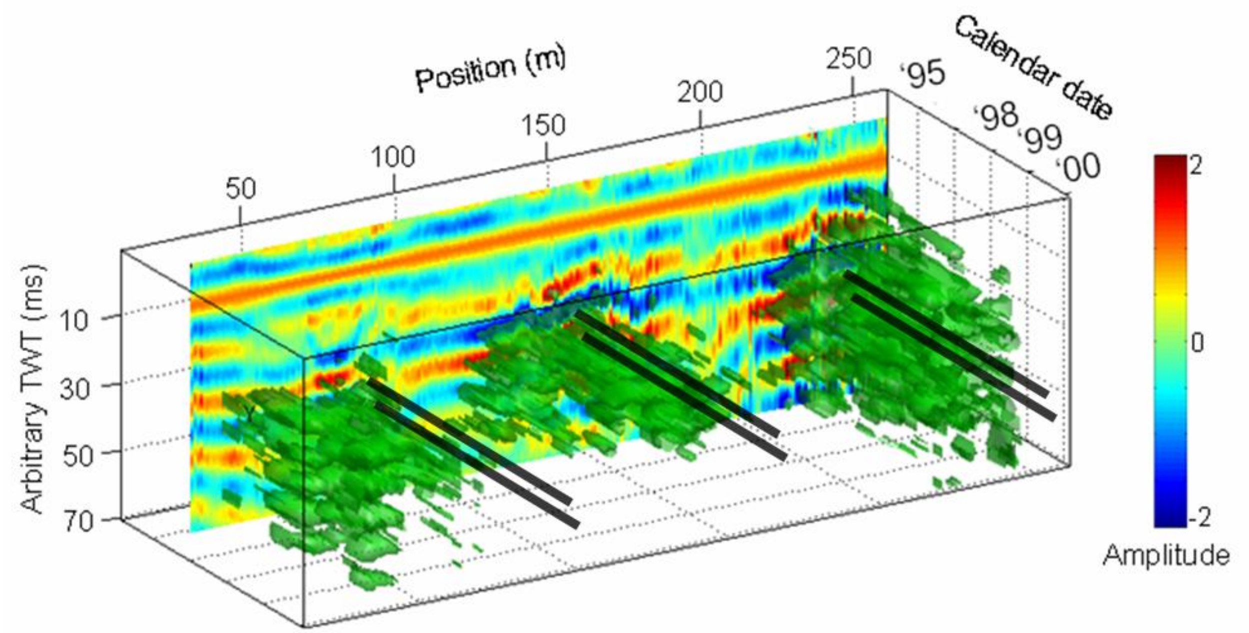

Figure 4: 3-dimensional representation of repeated 2-D seismic (time-lapse) data collected over 3 steaming horizontal well pairs at UTF. Position and two-way-travel time are on plotted the x and y axes respectively, and the volume of data is given a 'depth' perspective by stacking the repeated sections along the z-axis (in ascending calendar date). The 'brightest' amplitudes (both positive and negative) have been rendered as semi-transparent '*iso-surfaces*'. These *iso-surfaces* are thought to be indicators of the lateral extent of the steam chambers. The reverberations are proportional to the magnitude of steam in the reservoir and coincides with the modeled reverberations in FIG 3.C. The approximate location of the well pairs are indicated by the black lines, however their size and vertical separation are not to scale.

## Conclusions and Future Work

The results from this analysis suggest that the feasibility of seismic monitoring does not only depend on the thermal and mechanical related changes associated with fluid substitution, but also on the scale of the steam anomaly itself. Thorough rock physics modeling can aid in the long term survey design for monitoring reservoir depletion. Parameters such as spatial sampling, optimal fold, repeat time intervals, source type, etc., can all be evaluated prior to first steam. Future work is required to correlate these seismic measurements to the thermocouple profiles from observation wells, after which time the full extent and utility of such highly sampled data can be ascertained.

## Acknowledgements

Research funded via NSERC and earlier contracts from AOSTRA and COURSE.

### References

Birrel, G., 2003, Heat transfer ahead of a SAGD steam chamber: A study of thermocouple data from Phase B of the UTF (Dover Project), March, **42(3)**, 40-47

Chow, L., and Butler, R., Numerical Simulation of the Steam-assisted Gravity Drainage Process (SAGD), JCPT, June, **V35 N6**, 55-61, 1996

Eastwood, J., 1993, Temperature-dependant propagation of P- and S- waves in Cold Lake oil sands: Comparison of theory and experiment: Geophysics, **58**, 863-872.

Wang, Z., and Nur, A., 1990, Effect of temperature on wave velocities in sands and sandstones with heavy hydrocarbons: S.P.E. Res. Eng., **3**, 158-164