Enhancing SAGD Bitumen Production through Conductive, Convective and Radiant Heating*

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Abstract

The majority of the production from steam-assisted gravity drainage (SAGD) projects is sourced from the steam-swept portion of the reservoir; however, conductively, convectively and radiantly heated bitumen intervals can also provide a significant contribution to total reservoir recovery. Recovery of conductively heated bitumen appears to result from a combination of gravity flow providing downward movement; and injection of non-condensable gas or methane - providing gas push. Mud-dominated inclined heterolithic stratification (IHS), which commonly acts as a barrier for steam, may not act as a barrier for solution gas or co-injected gas introduced into the reservoir during SAGD operations. Thinking in three dimensions, as the steam chambers of a series of well pairs coalesce, conductively heated bitumen within sand-dominated IHS can flow down-slope to the producer at the base of the well pair, or be produced from an adjacent well pair, depending on the geometry and dip direction of the IHS. Further studies are recommended to verify potential recovery factor increases and optimize production during all stages of SAGD operations

Introduction

Steam-assisted gravity drainage (SAGD) works on the principle of a continuously expanding steam chamber and associated bitumen/emulsion production. Steam reduces bitumen viscosity from a semi-solid to a mobile liquid state and provides critical drive energy for sustaining this injection/bitumen displacement cycle. The steam chamber grows at a similar rate as bitumen is displaced, feeding and sustaining this continuous production loop. Reserves and recovery factor are therefore attributed to maximum steam-chamber height and width. This is controlled largely by vertical permeability and associated reservoir heterogeneity, assuming efficient sand control and sub-cool conditions are maintained. If these assumptions are valid, the cumulative bitumen production would be limited to the growth of the steam chamber, and bitumen-rich intervals of the reservoir located above the steam chamber would remain isolated and unproduced. This paper proposes that although most production is derived from the steam-swept portion of the reservoir; conductively heated bitumen (isolated from steam), can contribute an additional 5 to 10% to ultimate reservoir recovery. Production data, post-steam core analyses, temperature observation data, RST interpretations and time-lapse seismic results provide evidence that conductively heated bitumen located above the steam chamber can be mobilized in later stages of the production cycle (including wind-down).

Theory and/or Method

Inclined heterolithic stratification (IHS) contributes most of the heterogeneity and associated challenges for SAGD production, as indicated from sedimentology and point-bar depositional models for the McMurray Formation. Interbedded successions of mud-dominated IHS and sand-dominated IHS commonly dip at angles of 5 to 12 degrees, with lateral continuity on the order of 160 m x 300 m (perpendicular and parallel to flow direction, respectively) creating a series of barriers limiting vertical steam-chamber growth for an individual well pair. On a well pad scale of 600m x 800m, conductively heated bitumen within sand-dominated IHS can flow down-slope to the producer well located within the well pair or a producer located in an adjacent well pair (Figure 1).

Data from an adjacent temperature observation well (BC5) with complementary RST logs within the UTF (Underground Test Facility) Phase B reservoir provide strong evidence for recovery of bitumen from a 12 m interval located above the steam chamber, where mud-dominated IHS prevents steam rise. Based on temperature observations, conductively heated oil as low as 50 degrees Celsius (Ito and Chen, 2012, and Figure 2, this paper) can be recovered.

An excellent producing analogue illustrating the important contribution of conductive and radiant heating to cumulative SAGD production is offered by the C11 well pair in the Cenovus Foster Creek “C” pad (Figure 3). The temperature observation well B6-22 illustrates steam chamber rise to the base of IHS beds, and conductively heated bitumen interval extending 6 m higher than the steam chamber (Figure 4).

Time-lapse seismic (Figure 5) provides evidence for recovery from the intermediate casing point to the high quality bitumen pay located in the heal area of the injector well; heat losses from the injector combined with radiant heating from the adjacent steam chamber; appear to increase recovery factor significantly. Multiple lines of evidence for production provided by conductive heating are offered in Figure 5, Figure 6, and Figure 7.

Enhanced production was achieved in the C11 well pair. The increase in production from 75 E3M3 to 100 E3M3 and reduction of the SOR can be attributed to methane co-injection (green circle) and recovery of conductively heated bitumen (Figure 7).

Conclusions

Conductive heating and associated recovery of bitumen that is not in contact with the steam chamber, can provide significant contributions to the cumulative bitumen production from SAGD well pairs. Understanding the 3D geometry of the reservoir is critical for predicting the potential for this additional production, since connection to the producer well is achieved in the third dimension. Conductively heated oil is mobilized down-slope along IHS beds, under the combined influence of gravity and gas push to production wells underlying the steam chamber or produced from an adjacent well pair. A further benefit is observed with mature well pairs as instantaneous SOR’s that are expected to increase significantly due to heat losses to the roof and changes in slope of the steam chamber can stabilize due to injection of methane, displacing conductively heated bitumen as part of the latter stages of the SAGD recovery process.

Acknowledgements

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References Cited

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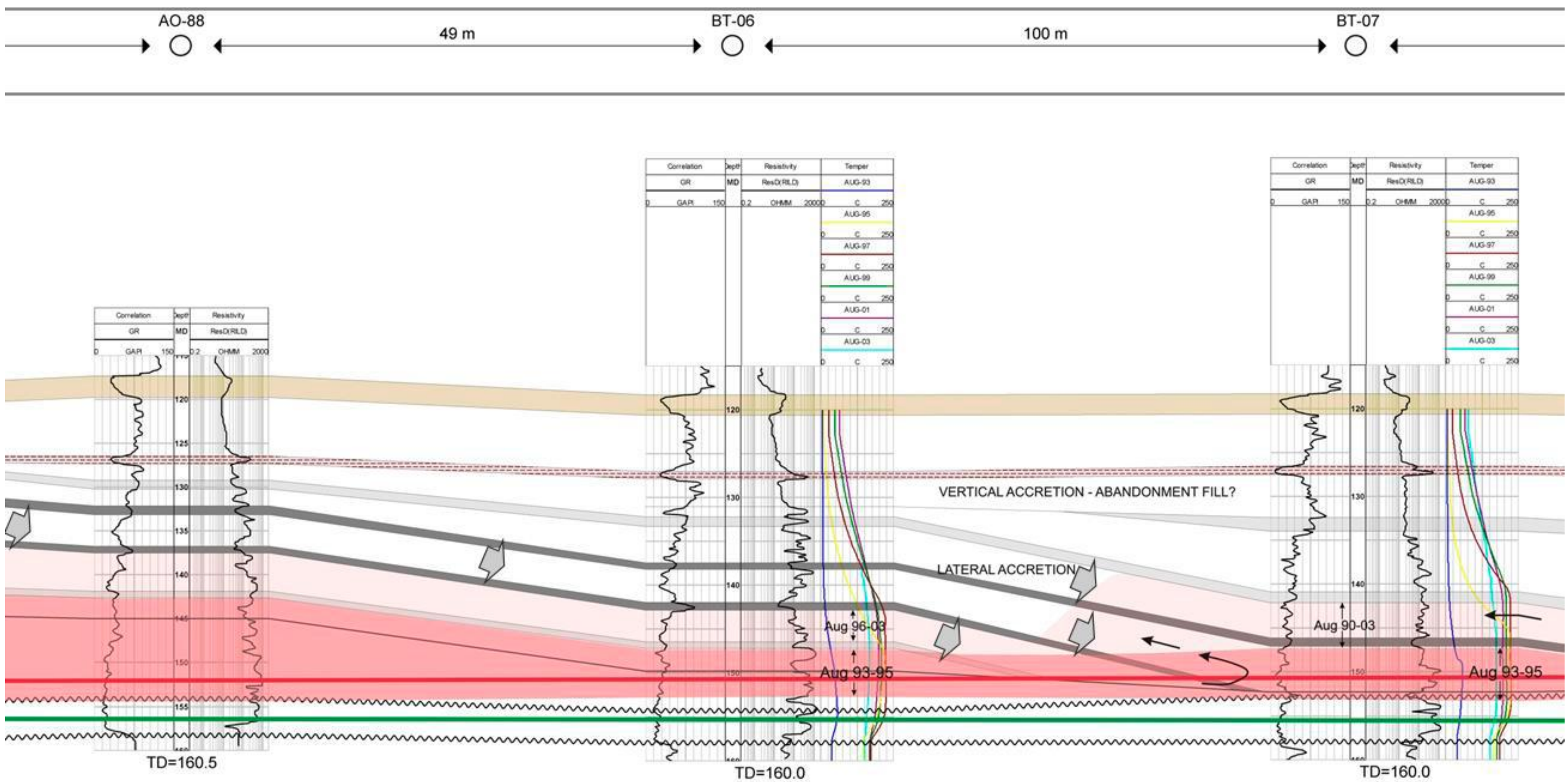

Figure 1. UTF Phase B steam temperature data for the middle portion of the B2 SAGD well pair, illustrating the limited steam-chamber growth due to mud-dominated IHS beds 75 cm thick, but with a lateral extent of 160 m x 300 m. Note the proposed down-slope displacement of conductively heated bitumen (large, grey arrows) along sand-dominated IHS beds and subsequent production. Source: Strobl, 2012.

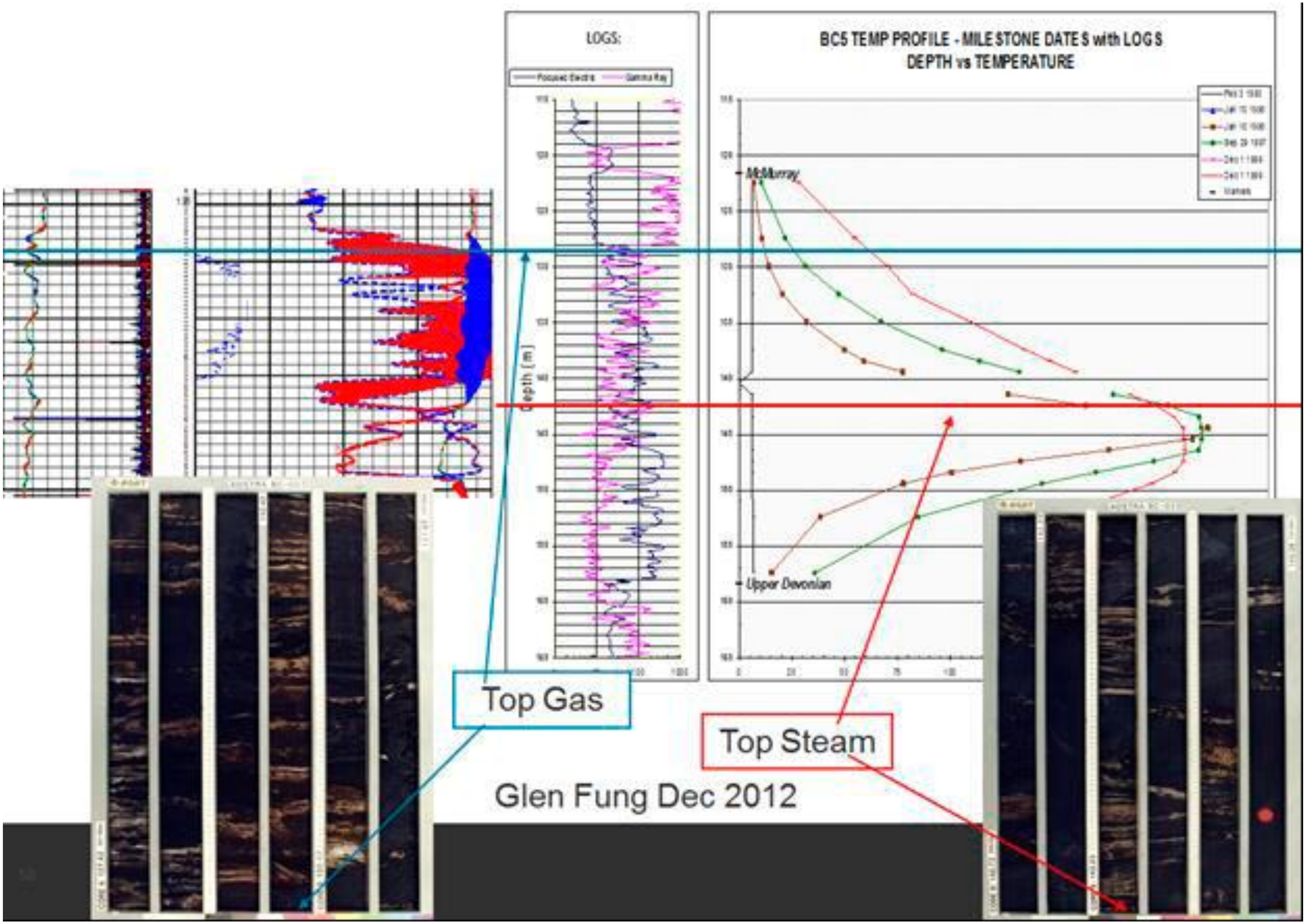

Figure 2. UTF Phase B steam temperature data and RST data, with core images for the observation well BC5. Source: Glen Fung (pers. corr.)

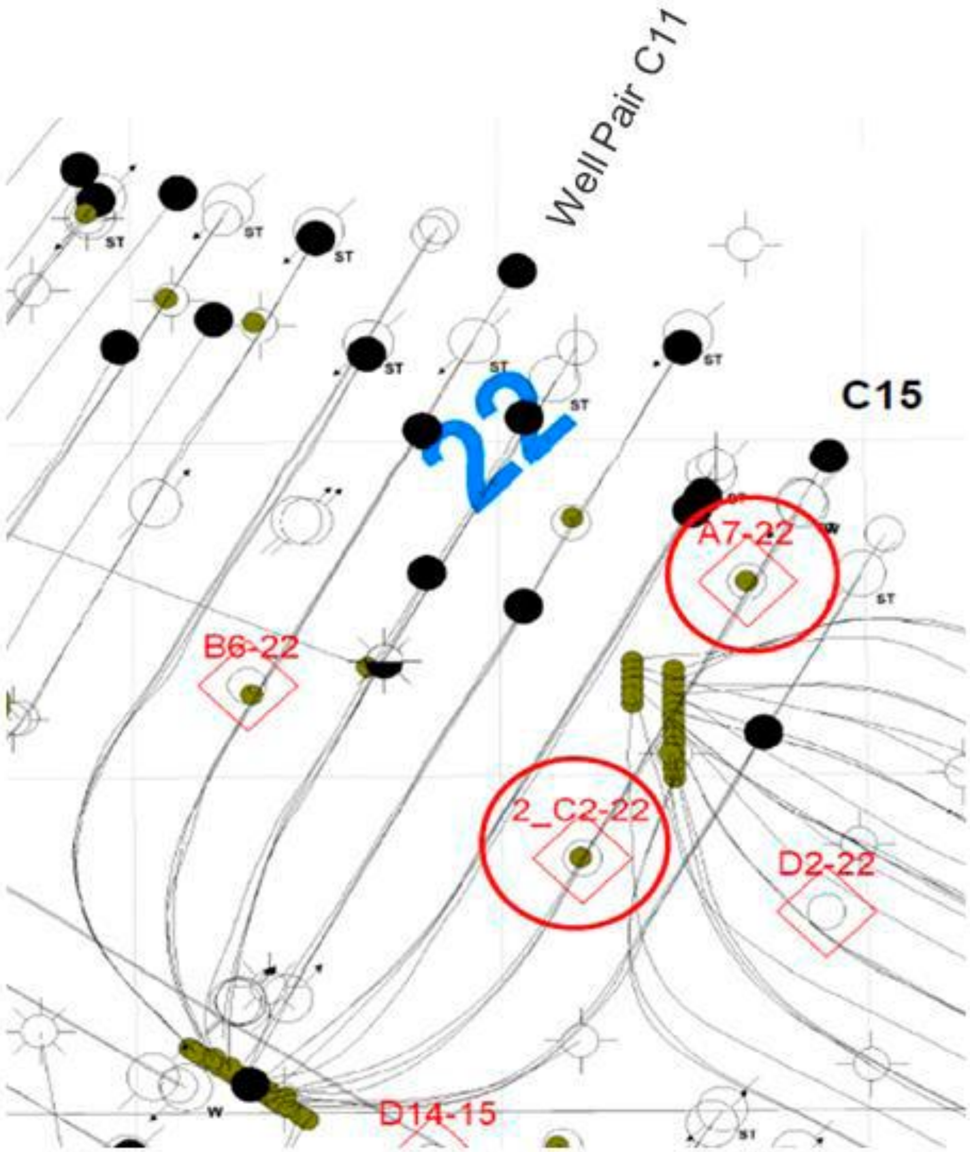

Figure 3. Location of well pair C11 and associated observation well B6-22 at the Cenovus Foster Creek "C" pad. Source: Cenovus 2012 annual report to the ERCB.

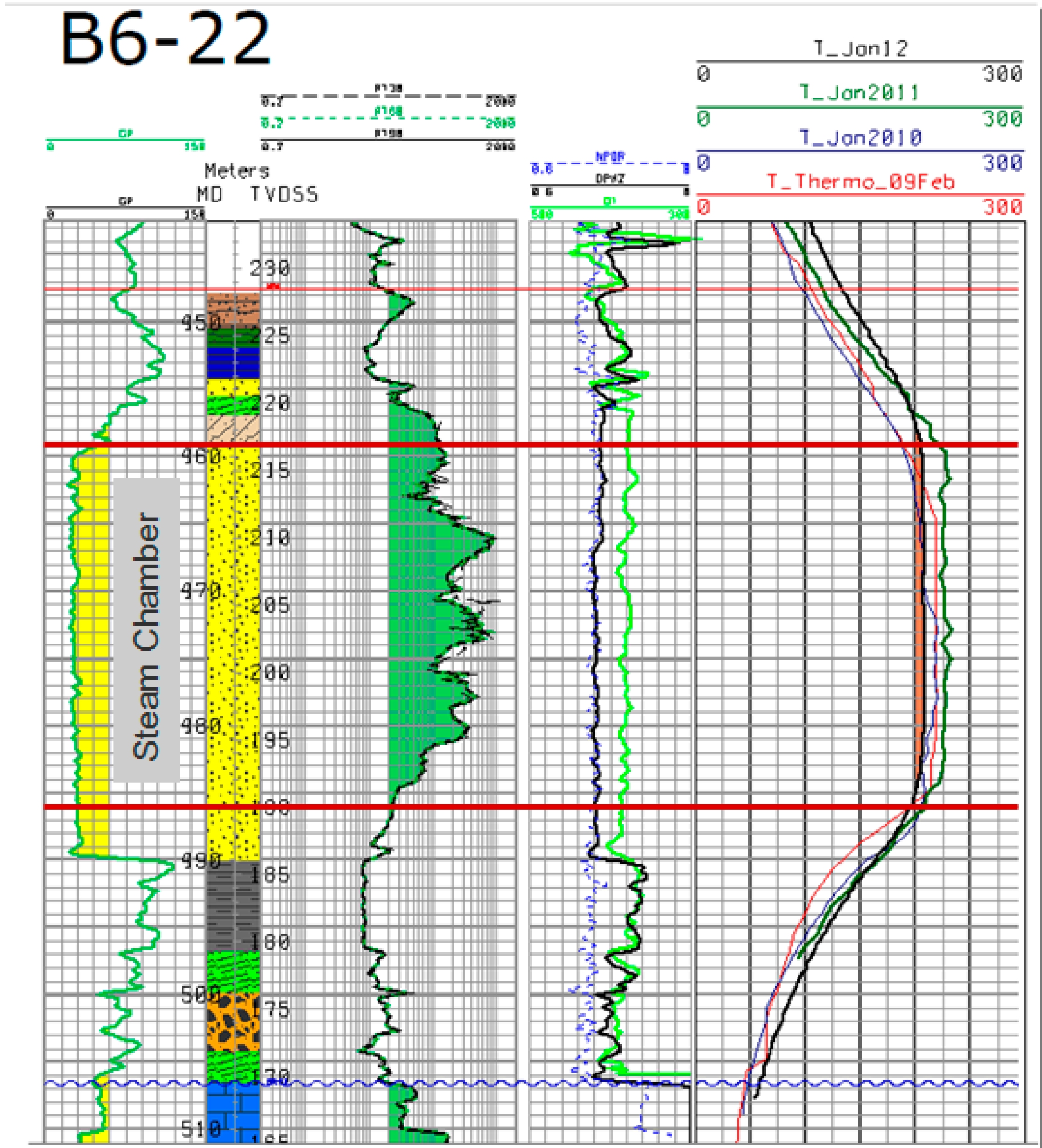

Figure 4. Temperature observation well B6-22, Well Pair C11, illustrating steam chamber rise (far right) and associated reservoir quality (far left). Source: Cenovus 2012 annual report to the ERCB.

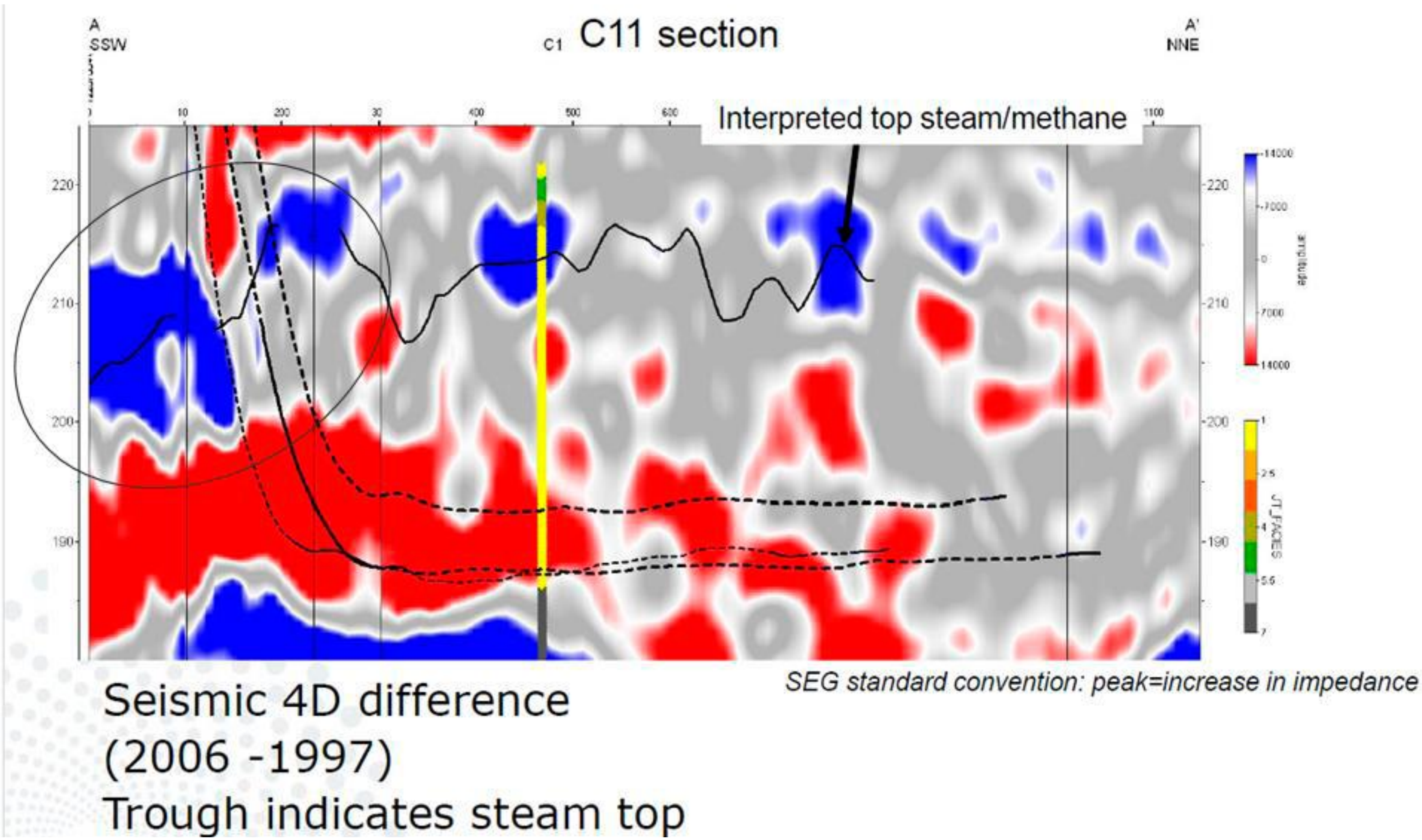

Figure 5. Time lapse seismic for the C11 well pair indicating steam chamber conformance over the entire well pair to the heal portion of the well pair. Source: Cenovus 2012 annual report to the ERCB.

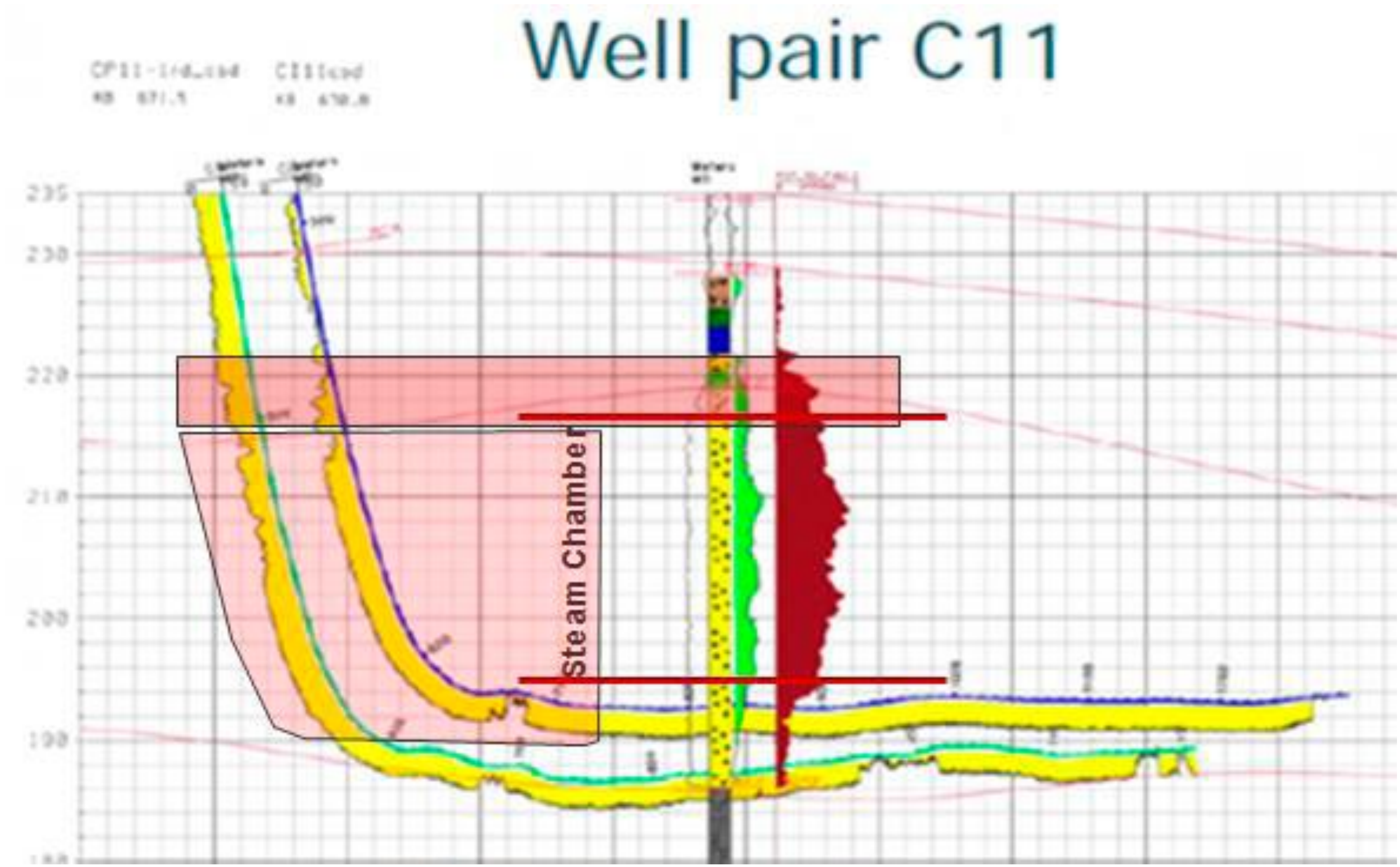

Figure 6. Observation well B6-22, Well Pair C11, illustrating production due to conductive and radiant heating. Additional recovery from the heal area of this well is verified by time-lapse seismic. Modified after the Cenovus 2011 annual report to the ERCB.

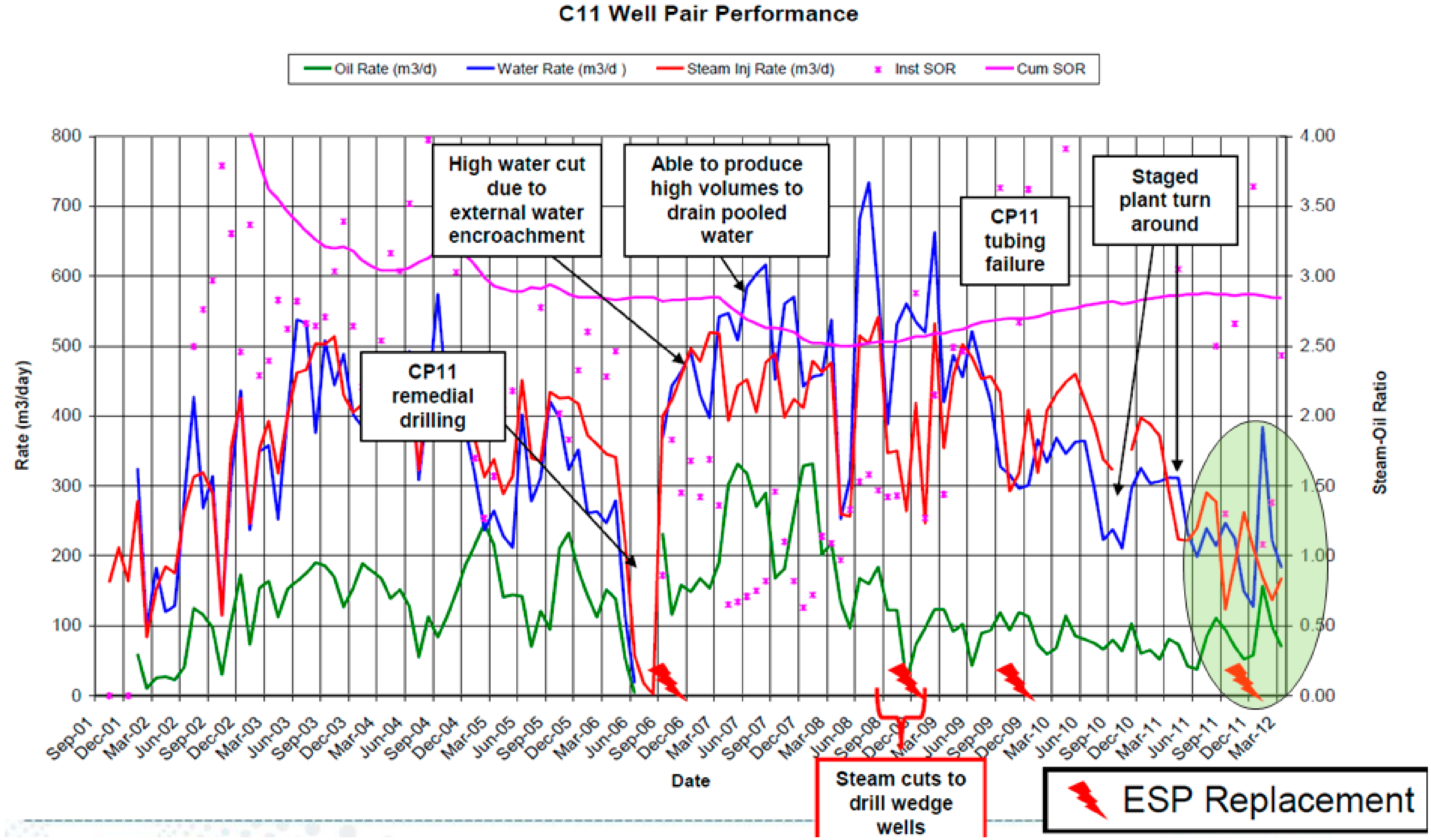

Figure 7. C11 production chart for the 2002 - 2012 periods. Source: Cenovus 2012 annual report to the ERCB.