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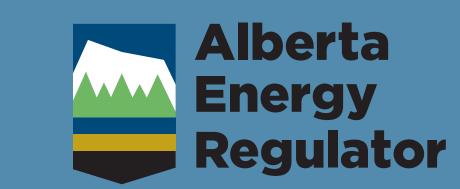Edmonton, AB
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# Using a 3-D Geological Model and Petroleum Data Analyses to Help Mitigate Environmental Impacts of Heavy Oil and Bitumen Production

## Data Collection

A 3-D geological model was created to visualize relationships in the subsurface that otherwise may not be distinguished using 2-D maps (Figure 1). The model was used to assess the spatial stratigraphic and structural extent of the subsurface geological units, to examine possible fluid migration pathways, and to integrate geochemical data identifying relationships between the heavy oils and bitumen within the geological units in the PROS area. Evaluating this information within the model facilitated the design of a petroleum sampling and analysis program necessary to analyze the geochemistry and build the geological plays.

The geological surfaces were modelled using primarily existing data, with the addition of new high-quality data (i.e., formation-top picks, Figure 2) in areas where existing data were found to be erroneous or insufficient. The model is composed of 23 surfaces (Table 1), which together create the tops and bases of the 17 geological units in the model (Figure 3).

A confidence level was assigned qualitatively to each created surface using the following attributes:

- data quantity
- data distribution
- data quality
- the geological complexity of the units

Table 1. Modelled 3-D geological surfaces and their level of confidence.

| Geological Surface | Surface Type | Confidence Level |
|---|---|---|
| Ground surface | digital elevation model | high |
| Upper Mannville Group | unit top | medium |
| Fort St. John Group and equivalents | unit base | high |
| Sub-Cretaceous unconformity | unconformity | high |
| Fernie Formation | unit top | high |
| Gordondale Member | unit top | high |
| Sub-Jurassic unconformity | unconformity | high |
| Montney Formation | unit top | high |
| Sub-Triassic unconformity | unconformity | medium |
| Belloy Formation | unit top | medium |
| Sub-Permian unconformity | unconformity | low |
| Stoddart Group | unit top | low |
| Debolt Formation | unit top | high |
| Shunda Formation | unit top | high |
| Pekisko Formation | unit top | medium |
| Banff Formation | unit top | high |
| Exshaw Formation | unit top | high |
| Wabamun Group | unit top | high |
| Winterburn Group | unit top | medium |
| Woodbend Group | unit base | high |
| Woodbend Group | unit base | high |
| Basement | unit top | low |


Figure 1. The 3-D geological model of the Peace River Oil Sands Area. All model images are at 50× vertical exaggeration.
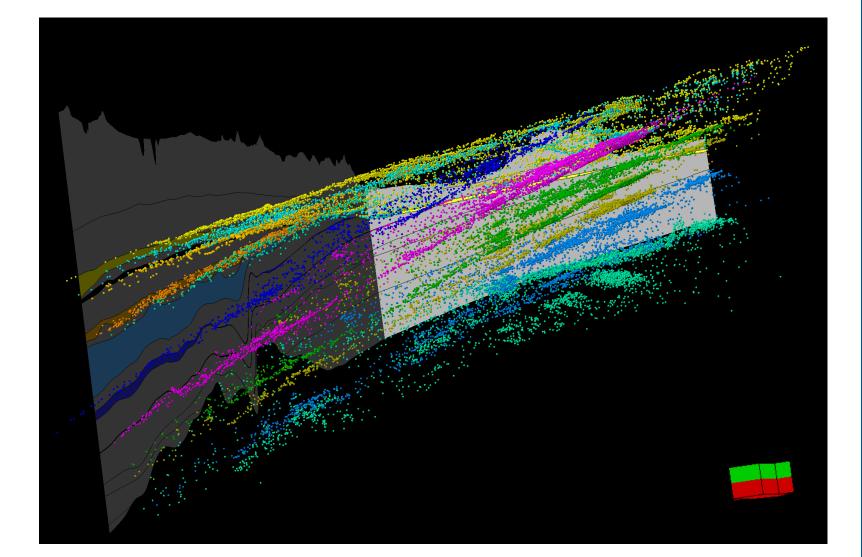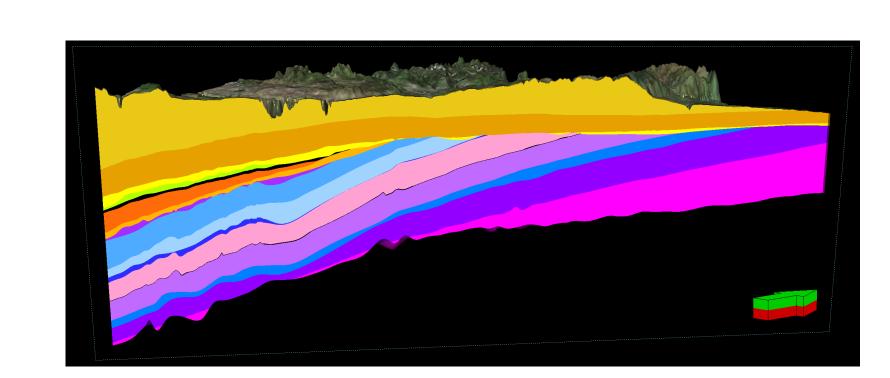

Figure 2. Geological picks used to build the model geological surfaces.


Figure 3. Geological units in the model.

## Integrating Data for Model Evaluation

After completing the 3-D geological model, several datasets were incorporated into the model and used to analyze the extent of the geological plays in the PROS area. The following types of data were incorporated:

- oil and gas well and location data
- oil and gas pool outline and location data (Figure 4)
- approved oil sands in situ recovery scheme outline and location data
- fault location and orientation data
- existing oil and gas routine analytical data

A total of 25 geological plays were identified and created within the model for the initial stratigraphic evaluation and assessment of the relationships between the all heavy oil and bitumen in the PROS area. The main focus of this initial evaluation was to identify the scope of the petroleum sampling and analysis program for geochemical evaluations. The following observations were made:

- The connectivity of the geological units indicates good potential for the oil sands designated heavy oil and bitumen to be quite similar across the PROS area (Figure 5). This means there may be no way to definitively distinguish the oil sands designated heavy oil and bitumen at the scale of the recommendation areas.

- The intense faulting along the Peace River Arch (Figure 6) extends across many geological units in the subsurface, mainly in the southwestern part of the PROS area, providing potential pathways for fluid migration from Devonian geological units all the way up to Cretaceous units. This means there could be ambiguity in determining exactly which heavy oil and bitumen deposits were sourced by the Gordondale and what percentage of Gordondale-sourced oil is present if there is any mixing.

- Examination of oil density and viscosity data for all heavy oil and bitumen in the PROS area indicates that there is a relationship between depth and oil density and viscosity that could be used to separate the oil sands designated deposits from deeper heavy oils (Figure 7). In addition, comparison of PROS area heavy oil and bitumen with heavy oil and bitumen of other OSAs in the province suggests that all the oil sands deposits have similar oil densities and viscosities.
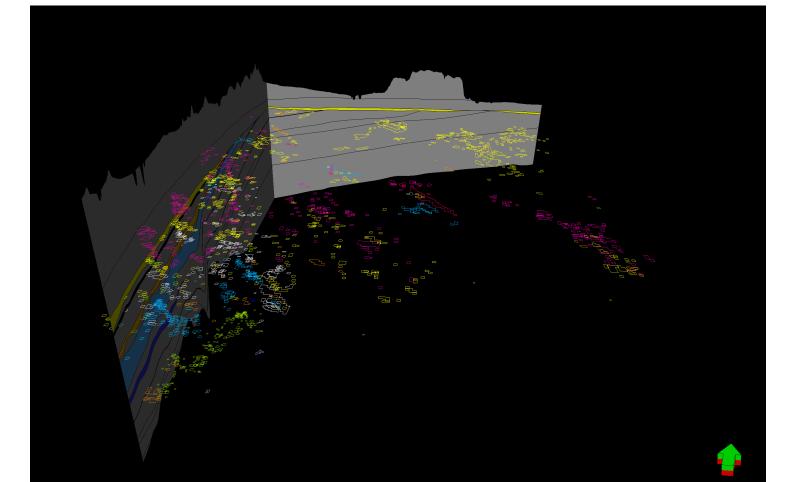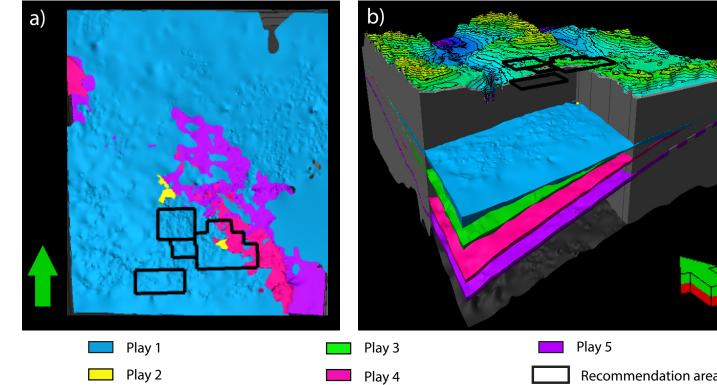

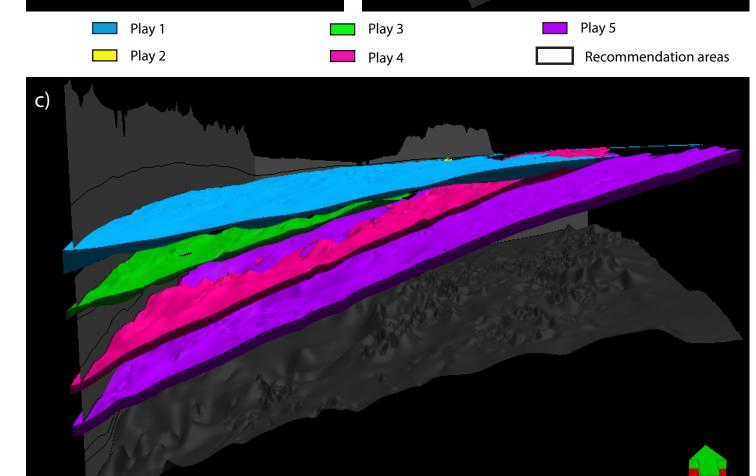Figure 4. Oil and gas pool orders used for model evaluation.


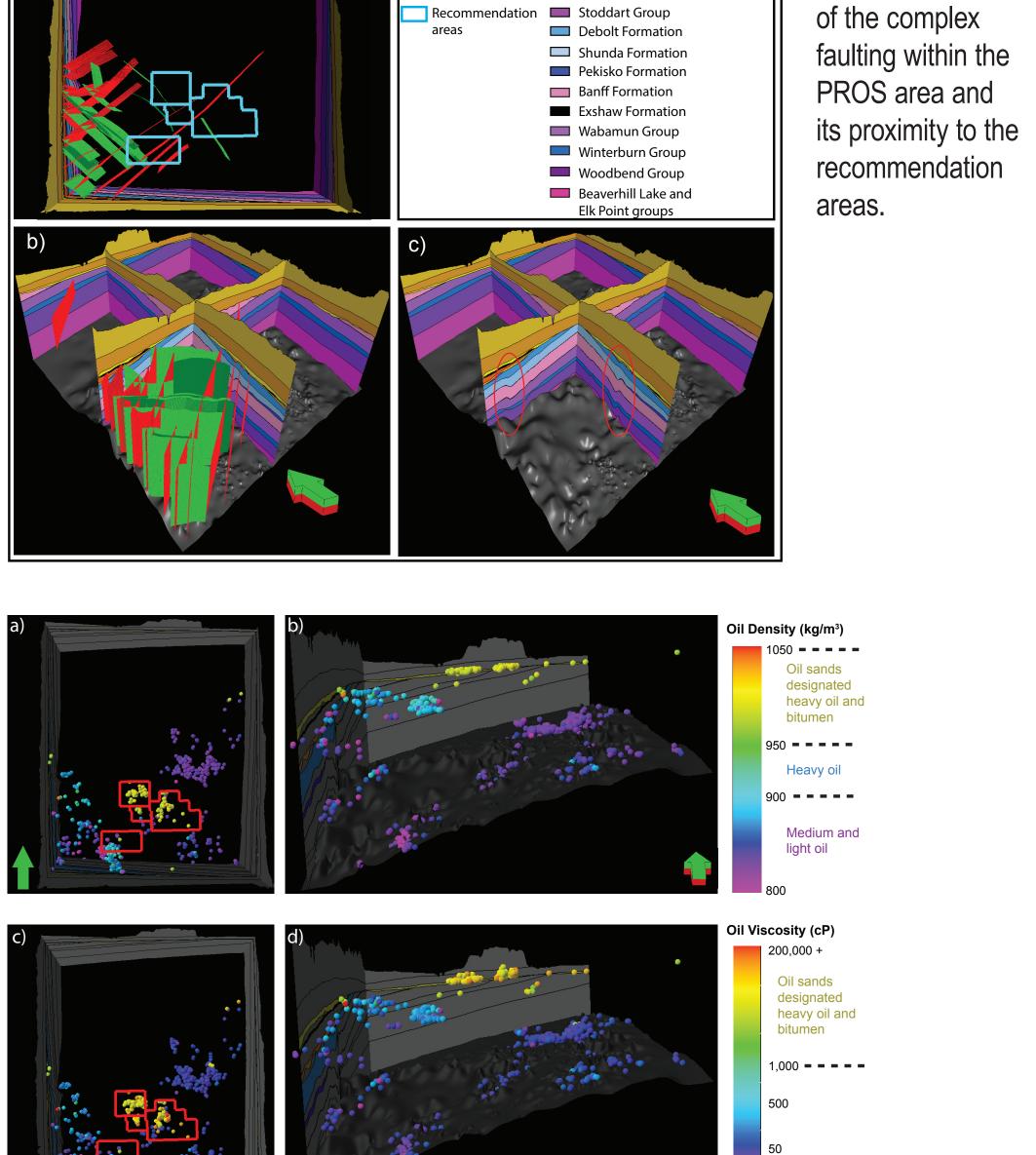Figure 5. Series of images showing the delineation of unrefined plays within the 3-D geological model.


Figure 6. A series of images of the 3-D geological model showing some of the complex faulting within the PROS area and its proximity to the recommendation areas.


Figure 7. A series of images showing oil density and viscosity data within the 3-D geological model area.

## Geological Plays, Heavy Oil and Bitumen Deposits, and Zones

The spatial relationship of the Bluesky, Gething, and older formations subcropping at the Sub-Cretaceous angular unconformity (Sub-K) creates complex reservoirs within the PROS area (Figure 8). Cretaceous strata lie directly in contact with a variety of sub-Cretaceous strata, including porous and nonporous clastic and carbonate units. Log-calculated porosities in formations directly below and above the Sub-K range from zero to greater than 30 per cent. Geological units that have produced or have an approved AER in situ scheme to produce oil sands designated heavy oil and bitumen in this area include the Bluesky-Gething, Debolt, Pekisko, and Belloy formations. These formations were the focus of the work to define geological plays; however, oil sands designated heavy oil and bitumen in the PROS area is not limited to these geological units. The following geological plays were the focus of this project:
In the 3-D geological model, heavy oil and bitumen deposits were identified within

- Bluesky-Gething Play
- Belloy Play
- Debolt Play
- Pekisko Play

each of the four geological plays listed above to aid regulatory response. In the PROS area, the heavy oil and bitumen deposits are identified using different methods based on available data and formation properties:

- The Bluesky-Gething heavy oil and bitumen deposit was defined using a net pay map generated applying a 6% mass bitumen cut-off in the Bluesky-Gething sands (Figure 9).

- The Belloy heavy oil and bitumen deposit is defined anywhere the Belloy is present, due to the lack of currently producing wells to help confine the deposit (Figure 9).

- The Debolt heavy oil and bitumen deposit was limited to the area showing a minimum of three metres of pay (pay defined as having less than 20 API gamma-ray geophysical well log response, an interval transit time of greater than 260 us/m from a sonic geophysical well log, and greater than 20 ohmm from a resistivity geophysical well log) (Figure 9).

- The Pekisko heavy oil and bitumen deposit was estimated where the Pekisko isopach was greater than 7.5 m between the Debolt and Pekisko subcrop areas (because well density was insufficient to conduct log analysis); this area shows increased porosity development in the Pekisko through intense dolomitization (Figure 9).

The spatial relationship of the heavy oil and bitumen deposits and the chemical properties of the oil suggest that, when in contact or near contact with each other, they may act as a single reservoir or a group of related reservoirs (Figure 9).

The 3-D model helped to visualize the complex arrangement of the geological plays, which helped identify the heavy oil and bitumen deposits within each play. Connecting the geobodies representing each deposit and using a defined top and base, we were able to create a geobody representing the cumulative heavy oil and bitumen deposits for the PROS. This geobody is a representation of the area where oil sands designated heavy oil and bitumen is currently most prospective. The top of this geobody is defined as the base of the Fort St. John Group, and the base of the geobody was determined using oil density and oil viscosity data. A surface was created to represent the depth at which the oil density approximates 950 kg/m³ and oil viscosity approximates 1000 cP, called the 'base of PROS surface.' This surface was used to apply a base on the heavy oil and bitumen deposits and the cumulative geobody within the 3-D model. These deposits and surfaces were used for visualization purposes.


Figure 8. A view of the subcrop areas of the geological units on the sub-Cretaceous unconformity, derived from the 3-D geological model.
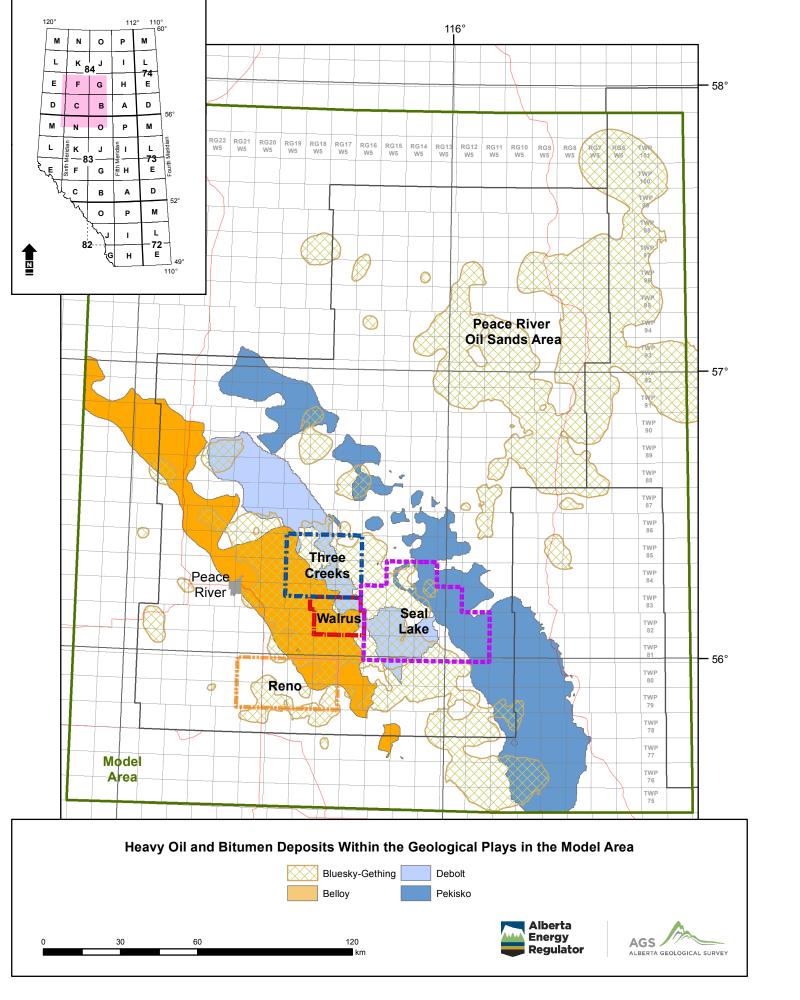

Figure 9. The surface extent of the heavy oil and bitumen deposits identified within each geological play and within the model area.
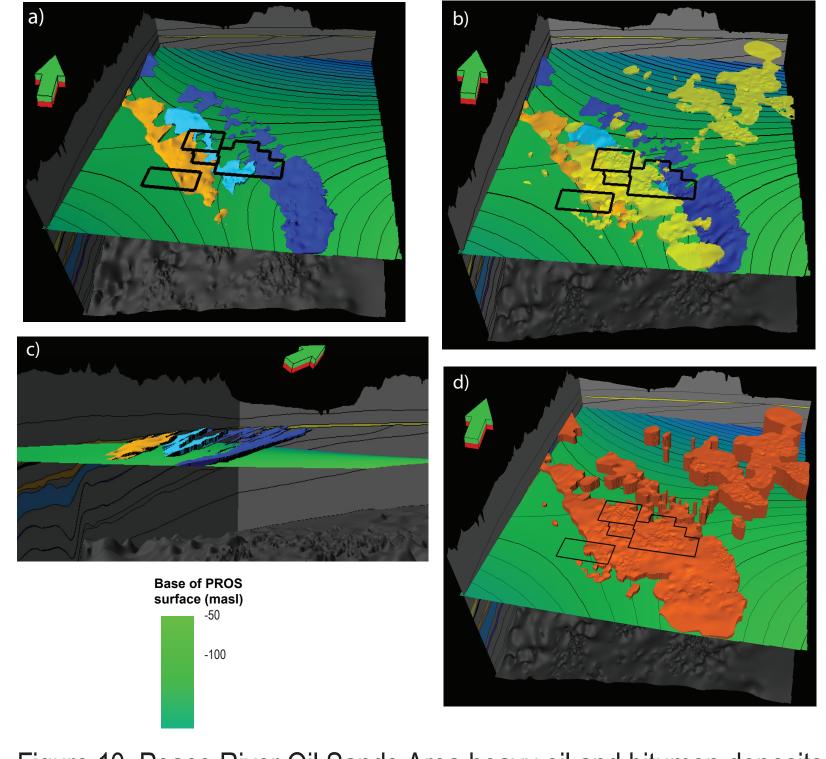

Figure 10. Peace River Oil Sands Area heavy oil and bitumen deposits identified within the four geological plays in the 3-D geological model area.

## Practical Application

A 3-D heavy oil and bitumen odours and emissions assessment profile was created, identifying zones where the probability for releasing odours and emissions from heavy oil and bitumen is high, medium, or low (Figure 11). This assessment is based on the chemical composition and physical properties of oil and reflects the probability that oils will need to be heated by a significant degree during production. The profile is built using five surfaces: the ground surface, the base of the Fort St. John Group, the base of PROS surface, the 'base of heavy oil surface,' and the basement. In order to add the lowest probability zone to the profile, the 'base of heavy oil surface' was generated separating heavy crude oils ≥900 kg/m³ from the lower density light and medium crude oils below (Figure 12). This surface is validated using oil density and viscosity data, confirming that the oils fall into the correct 3-D probability zone (Figure 11).

Any oil found within the red zone on the heavy oil and bitumen odours and emissions assessment profile (Figure 11) would have high probability for odours and emissions due to the high probability that

- the oil will have densities ≥950 kg/m³ and viscosities approximately ≥1000cP (Figure 13), and

- the oil will need to be heated to temperatures significantly higher than initial reservoir temperature (high temperature differential), either in the reservoir or at surface, to allow it to flow.

Oils in the yellow zone (Figure 11) have moderate probability for odours and emissions, and further testing of the oils and how they behave when heated should be considered if the oil has any of the above characteristics. Oils in the green interval (Figure 11) do not show significant probability of having the above characteristics.

The red zone (Figure 11), representing the highest probability of encountering heavy oil and bitumen likely responsible for odours and emissions, has been named the 'PROS Heavy Oil/Bitumen Zone.' The PROS Heavy Oil/Bitumen Zone is currently defined as the volume where the following conditions are found:

- heavy oil and bitumen with density greater than 950 kg/m³ and viscosity greater than 1000 cP that is

- within the model area and

- occurring between the base of the Fort St. John Group and the base of PROS surface.


Figure 12. Base of PROS and base of heavy oil surfaces created within the 3-D geological model using 15°C post-cleaning, absolute density data and 15°C kinematic viscosity data.
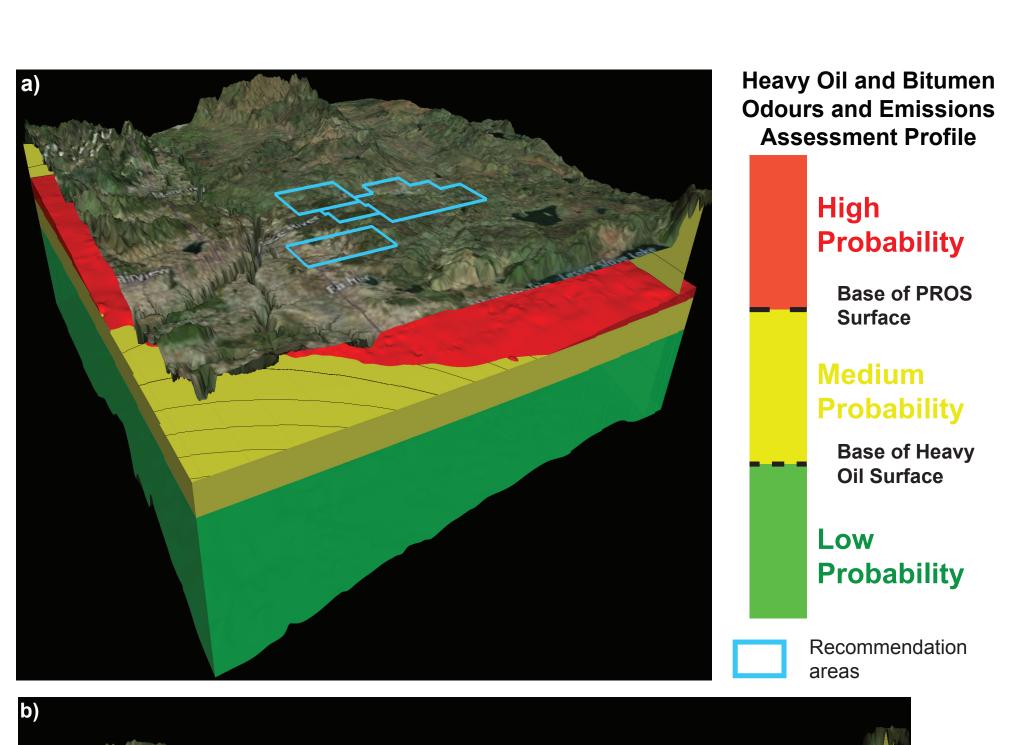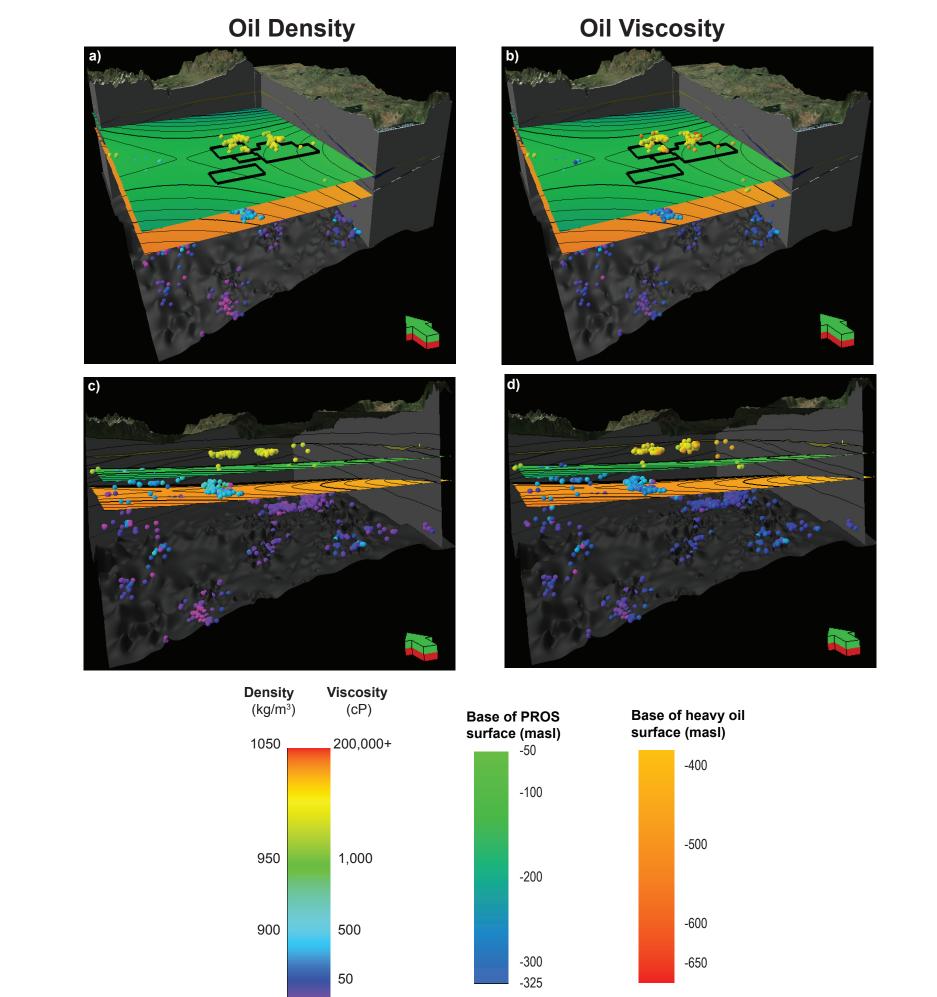

Figure 11. A heavy oil and bitumen odours and emissions assessment profile built within the 3-D geological model identifying the subsurface intervals of high, medium, and low probability for odours and emissions from heavy oil and bitumen in the PROS area.

**Heavy Oil and Bitumen Odours and Emissions Assessment Profile**
- High Probability
- Base of PROS Surface
- Medium Probability
- Base of Heavy Oil Surface
- Low Probability
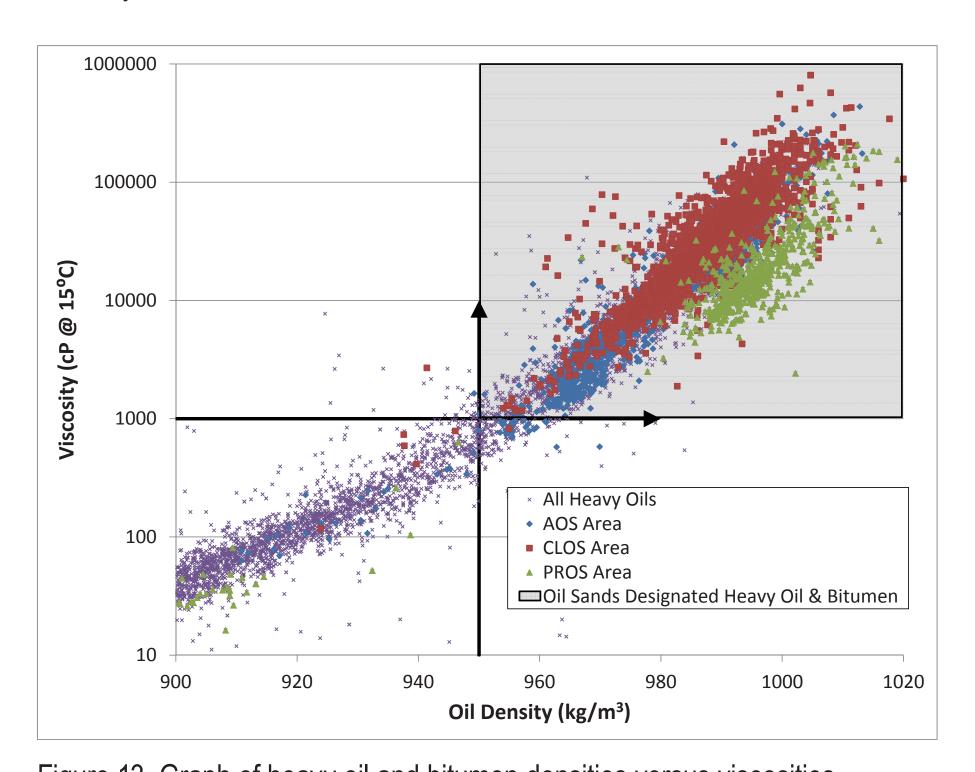- Recommendation areas

Base of PROS surface (masl)


Figure 13. Graph of heavy oil and bitumen densities versus viscosities.