

**Reactivation of an Idle Lease to Increase Heavy Oil  
Recovery Through Application of Conventional Steam Drive  
Technology in a Low Dip Slope and Basin Reservoir in the  
Midway-Sunset Field, San Joaquin Basin, California**

**Quarterly Report  
April 1 - June 30, 1998**

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TITLE: REACTIVATION OF AN IDLE LEASE TO INCREASE HEAVY OIL RECOVERY THROUGH APPLICATION OF CONVENTIONAL STEAM DRIVE TECHNOLOGY IN A LOW DIP SLOPE AND BASIN RESERVOIR IN THE MIDWAY-SUNSET FIELD, SAN JAOQUIN BASIN, CALIFORNIA

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### **Objective**

A previously idle portion of the Midway-Sunset field, the ARCO Western Energy Pru Fee property, is being brought back into commercial production through tight integration of geologic characterization, geostatistical modeling, reservoir simulation, and petroleum engineering. This property, shut-in over a decade ago as economically marginal using conventional cyclic steaming methods, has a 200-300 foot thick oil column in the Monarch Sand. However, the sand lacks effective steam barriers and has a thick water-saturation zone above the oil-water contact. These factors require an innovative approach to steam flood production design that will balance optimal total oil production against economically viable steam-oil ratios and production rates. The methods used in the Class III demonstration are accessible to most operators in the Midway-Sunset field and could be used to revitalize properties with declining production of heavy oils throughout the region.

The 40 ac Pru Fee property is located in the super-giant Midway-Sunset field and produces from the late Miocene Monarch Sand, part of the Monterey Formation. The Midway-Sunset field was discovered prior to 1890. Cumulative production from the field through 1995 was 2.3 billion barrels of oil and 563 billion cubic feet of gas, with remaining reserves estimated to exceed 450 MMBO. The average daily field production in 1995 was 163,400 barrels of oil. In the Pru Fee property, now held by ARCO Western Energy, cyclic steaming was used to produce 13° API oil. However, the previous

operator was unable to develop profitably this marginal portion of the Midway-Sunset field using standard enhanced oil recovery technologies, at that time cyclic steaming, and chose rather to leave more than 3.0 MMBO of oil in the ground that otherwise might have been produced from the 40 ac property. The objective of the demonstration project is to encourage a significant incremental increase in production in this and all other marginal properties in the Midway-Sunset and adjacent fields in the southern San Joaquin Basin.

In January 1997 the project entered its second and main phase with the purpose of demonstrating whether steamflood can be a more effective mode of production of the heavy, viscous oils from the Monarch Sand reservoir than the more conventional cyclic steaming. The objective is not just to produce the pilot site within the Pru Fee property south of Taft, but to test which production parameters optimize total oil recovery at economically acceptable rates of production and production costs.

### **Geostatistical Modeling Using Heresim3D™**

In an early stage of demonstration phase (BP-2) of the Midway-Sunset project 18 new wells were drilled and logged (Fig. 1). The new wells complete the pattern of injector, producer and thermal observation wells required for an 8 ac pilot steam flood at the Pru Lease. Modern geophysical logs run in each hole provide a sound foundation for improving the geological and petrophysical models needed as input for reservoir simulation.

In the characterization phase (BP-1) of the project, it was necessary to rely on a set of geophysical logs obtained from wells completed during many decades of exploration and development within and near the Pru Lease. Only three modern, reliable log suites were available for the Pru Lease. These were the logs for a cored well, Pru-533, and the two new project wells, Pru-101 and TO-1. Thus, geological and petrophysical models developed during BP-1 were based primarily on data obtained outside the Pru, particularly from the adjacent AWE Kendon lease which is under active development. Drilling and logging of the 18 new wells within the Pru Lease enabled us to increase our confidence in the geological and petrophysical models developed within the relatively small reservoir volume involved in the 8 ac pilot.

The sequence of steps involved in building new geological and petrophysical models (Table 1) is essentially the same as that followed during the characterization phase. The reader is referred to 1996 annual report for this project. The 20 new suites of geophysical logs were used to redefine the geometry of the primary *lithofacies* and their bounding surfaces. Once defined, the lithofacies and bounding surfaces were imported into Heresim3D™. This software was used, in turn, to develop stochastic geological models within the area shown in Fig. 1. Combining a series of geological realizations with petrophysical measurements obtained from Pru 101 core analyses yields a series of petrophysical models needed as input to a new round of reservoir simulation. One realization has been constructed and a preliminary set of reservoir simulations are

underway. A full set of geological and petrophysical models will be developed to test the possible impact of geological variability within the 8 ac Pru pilot site once the results of the ongoing simulations are fully analyzed.

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*Table 1: Modeling Procedure*

- **Set up reservoir modeling domain** by establishing grid and model limits;
  - **Define lithotype characteristics** discernible in well logs; lithotypes are pebbly sand, sand, and diatomaceous mudstone;
  - **Compute distribution of lithotypes** conditioned by variogram models, vertical proportion curves, and lithotypes at each well;
  - **Develop detailed stochastic petrophysical models** for statistical distribution of porosity and permeability;
  - **Upscale the petrophysical models** and transfer to reservoir simulator.
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Each lithofacies incorporated in the geological model is defined through qualitative assessment of the new geophysical logs combined with the logs Pru 101 and Pru TO-1 obtained during the initial phase. Four lithofacies (pebbly sand, coarse to medium sand, fine sand, mudstone) were modeled in the initial phase. However, the petrophysical properties of the medium and fine sand lithofacies were determined to be very similar. Therefore, for the current geostatistical modeling we elected to define only three lithofacies - pebbly sand, coarse to fine sand, mudstone. The "mudstone" class is actually a silty diatomite. A statistical description of the permeability and porosity values assigned to each lithofacies is given in Table 2.

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*Table 2 - Lithofacies Permeability and Porosity*

<u>Facies</u>	<u>Description</u>	<u>Permeability (md)</u>				<u>Porosity (%)</u>			
		Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
1	Pebbly Sand	748	4133	2277	1038	24.9	32.9	28.6	2.2
2	Coarse-Fine Sand	185	6000	2841	2356	26.2	43.6	31.9	2.4
3	Mudstone	10	200	35	10	32.0	38.0	35.0	1.0

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An important difference between the initial (BP-1) and the current (BP-2) geological model is reflected in the number of *lithotypes* or stratigraphic modeling elements incorporated in the geological model. Whereas just two lithotypes, an upper and a lower, were defined in the earlier modeling, three lithotypes are defined in the current modeling

(Fig. 2). The new lithotype (middle lithotype) represents a discontinuous, lower permeability layer between the upper and lower lithotypes (Fig. 2). We anticipate that incorporating the middle lithotype will help improve our ability to mimic the progress of the pilot flood.

A recent enhancement to the Heresim3D™ software provides an opportunity to mimic non-stationarity within the 3-D geostatistical model of lithofacies. In the initial phase only one *vertical proportion curve* could be constructed. It was applied across the entire model domain. In the current modeling a different vertical proportion curve is constructed at each well as a basis for developing an interpolated variation in proportion curve properties throughout the model domain (Fig. 3). Several different matrices of curves were constructed using a variety of interpolation rules until the most geologically plausible result was obtained. A 10 x 10 matrix of vertical proportion curves was developed for each of the three lithotypes. Fig. 3 shows the result obtained for the upper lithotype.

The vertical proportion curves and corresponding *variograms* are used in Heresim3D™ to construct a realization of plausible geological variability at the Pru Lease. Figs. 5, 6 and 7 show lithofacies distributions typical of each lithotype. The X and Y dimensions of the gridblocks shown in Figs. 5, 6 and 7 are both equal to 4 meters. Subtle, but possibly important, differences in the variogram models derived for each lithofacies (Fig. 4) lead to characteristic differences in the lithofacies patterns.

A NW-SE cross-section (Fig. 8) shows the vertical distribution of lithofacies computed using Heresim3D™. The Z dimension of the gridblocks is, on average, about 0.5 m throughout the model domain. As in the bedding-parallel sections of Figs. 5, 6 and 7, the vertical section shows clear differences in the facies architecture associated with each lithotype.

Values for the petrophysical properties associated with each facies type (Table 2) are distributed statistically within each facies applying *log normal* distributions for permeability and *normal* distributions for porosity. Heresim3D™ does not provide an option for including spatially correlated petrophysical properties within each facies type, but such a refinement is not justified by the data constraint of a single core. Figs. 9 through 13 illustrate the stochastic permeability and porosity distributions obtained in one realization of the geological model.

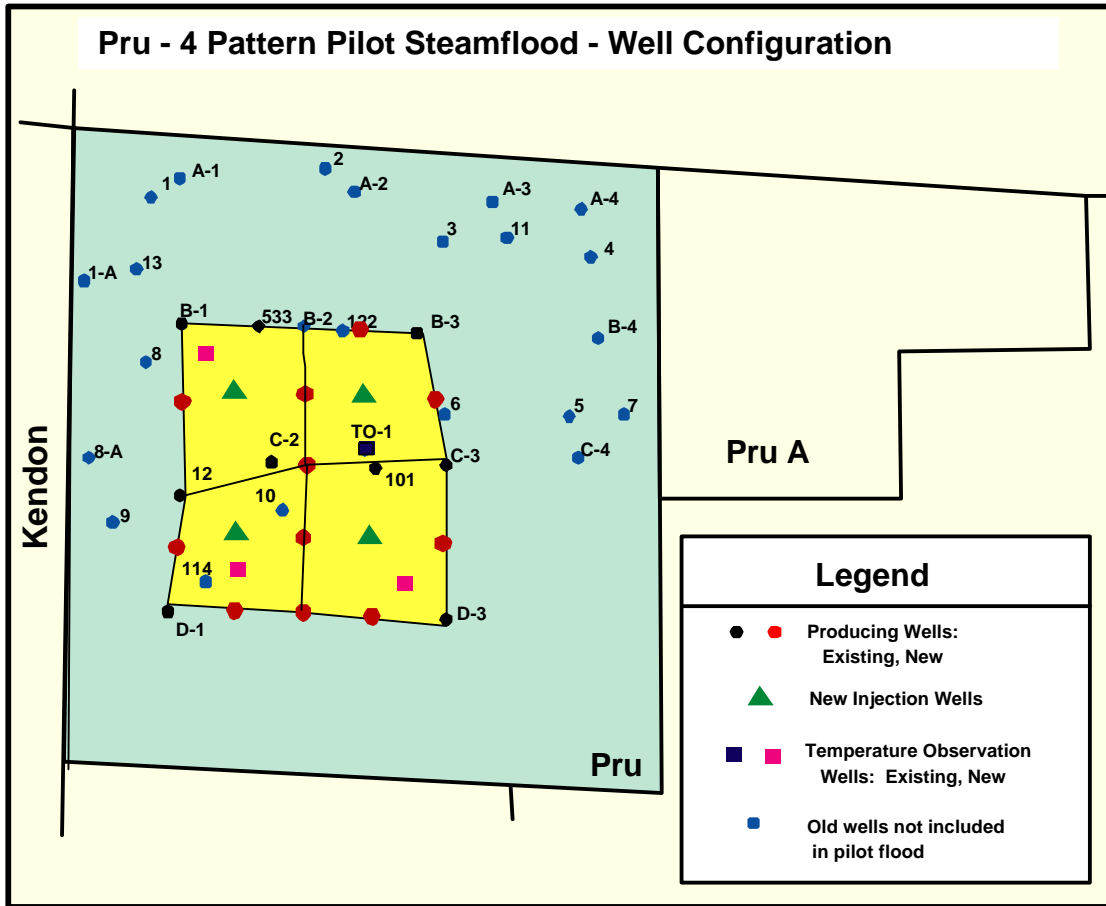
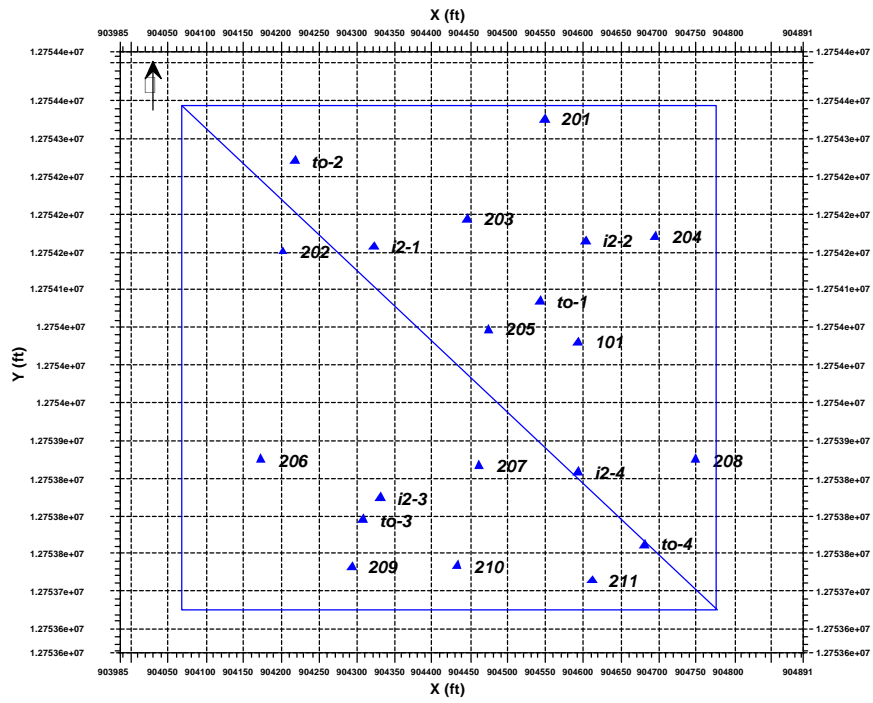


Figure 1. Location map showing existing and new wells at the Pru Lease.

Location Map



Location Map

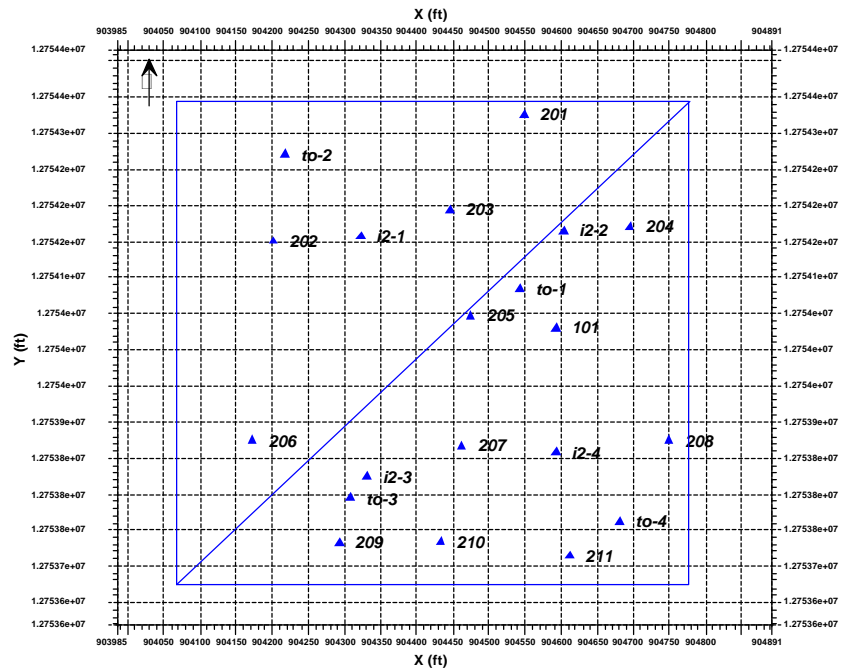


Figure 2 . Vertical sections showing the three lithotypes incorporated in the geological model: a) northwest-southeast section, and b) southwest-northeast section. Cross-section locations are shown in Figure 1.

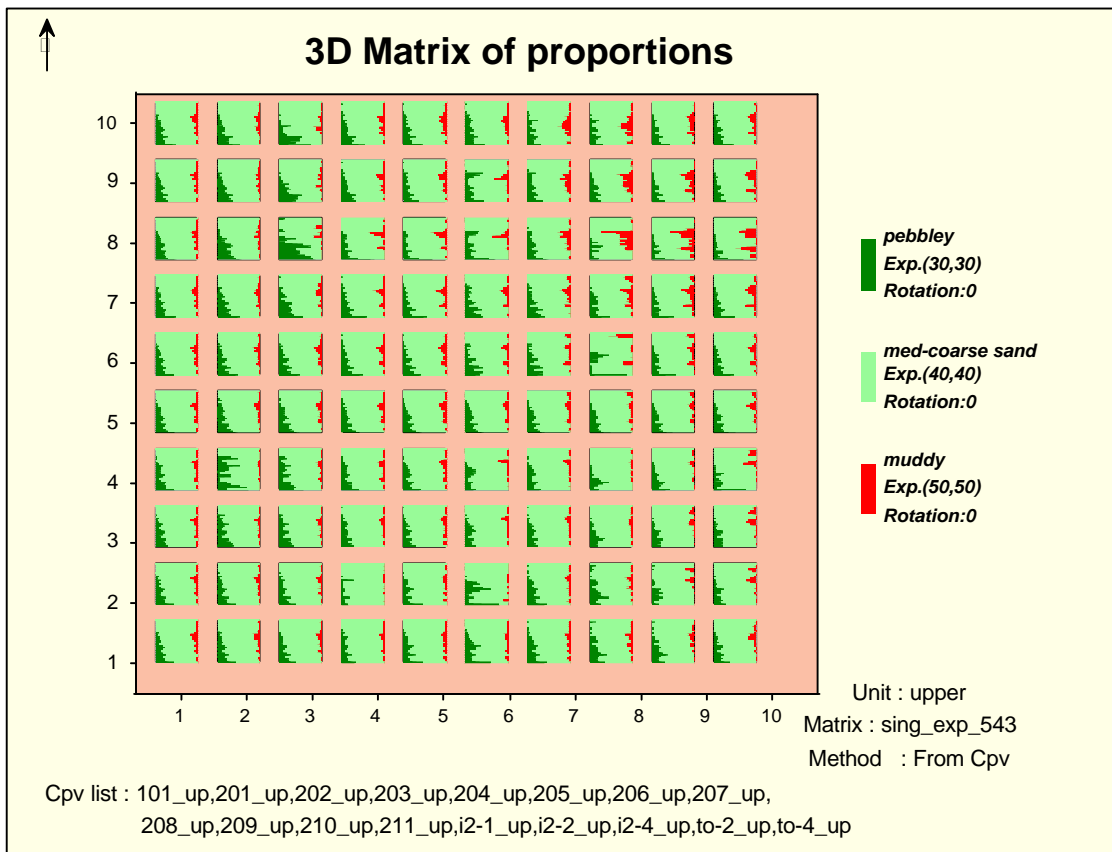


Figure 3. Matrix of vertical proportion curves used to represent non-stationarity in lithofacies distributions within the model domain for the upper lithotype.

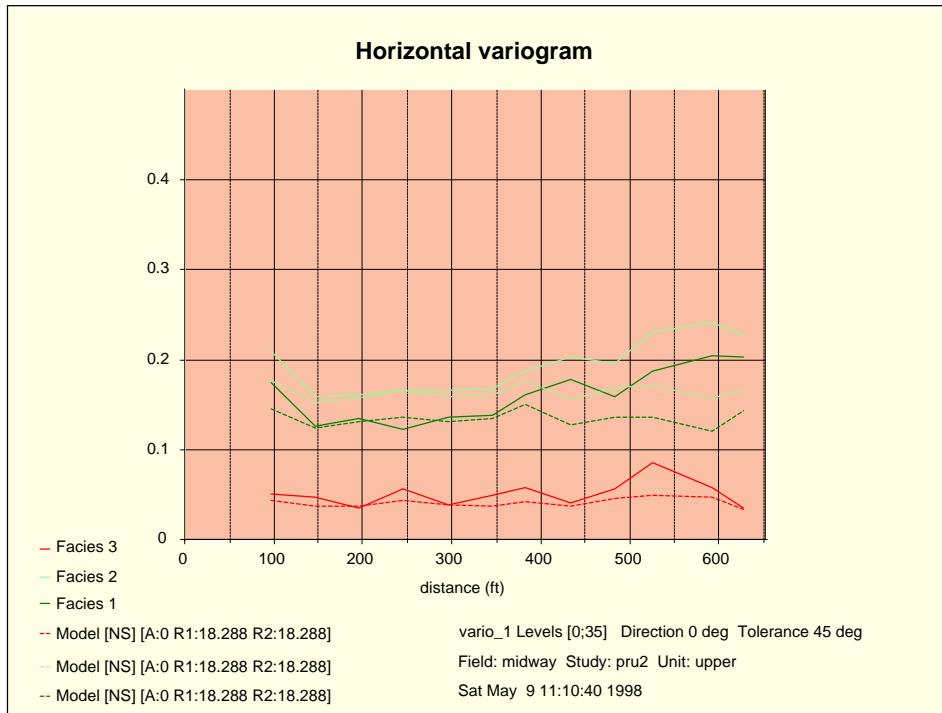
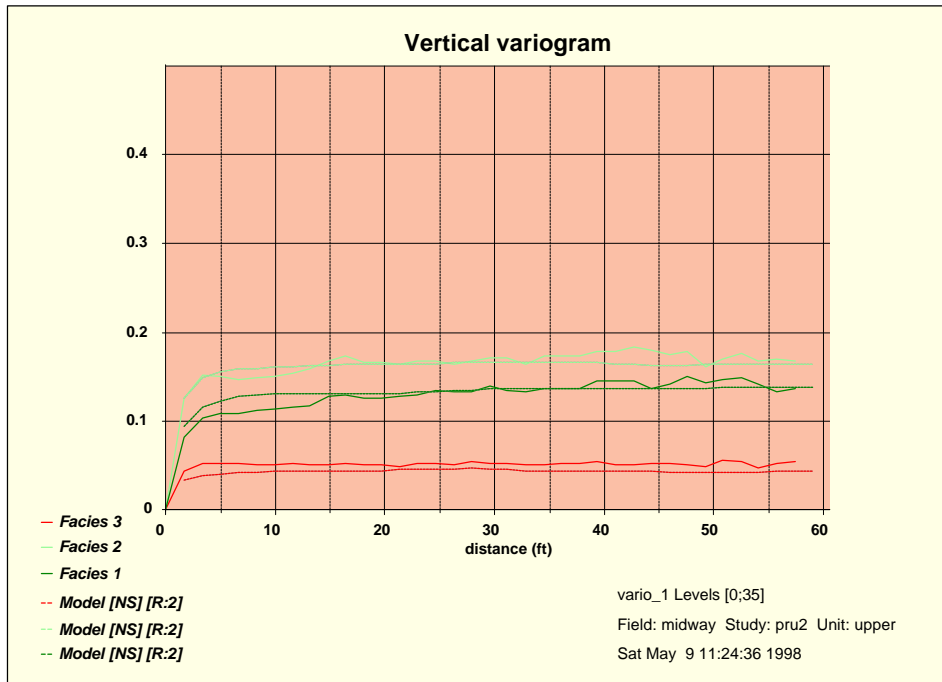


Figure 4. Vertical and horizontal variograms computed for the three lithofacies contained within two lithotypes shown in Figure 2: a) upper lithotype, and b) middle lithotype

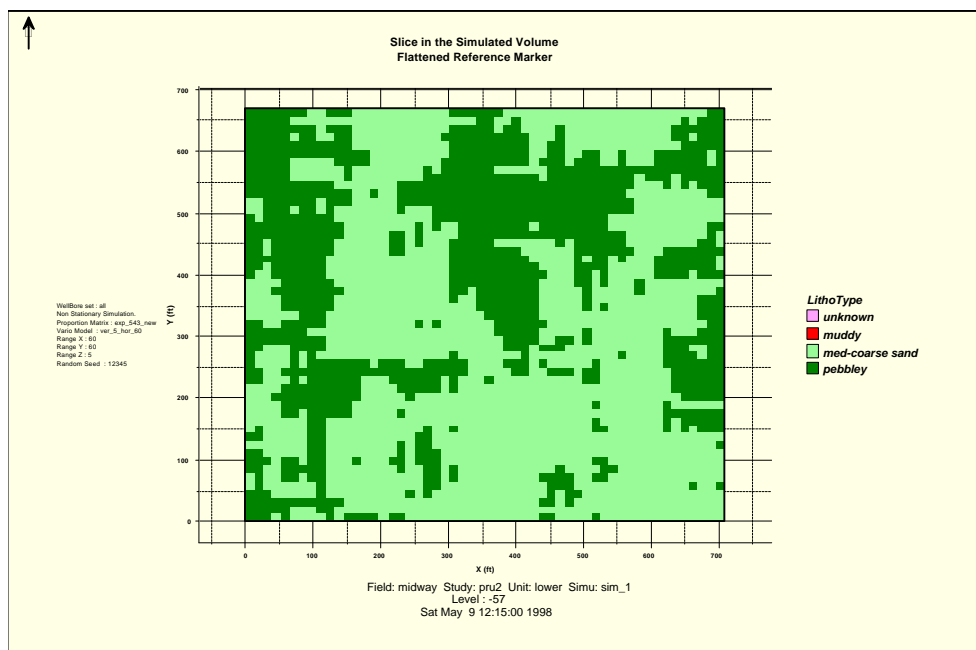


Figure 5. Bedding-plane parallel section of lithofacies cut from within the upper lithotype.

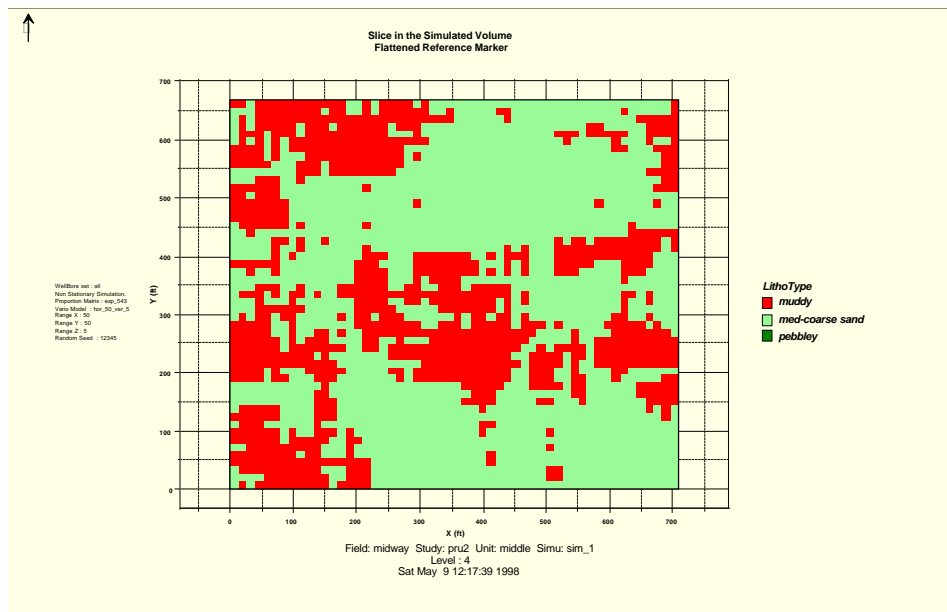
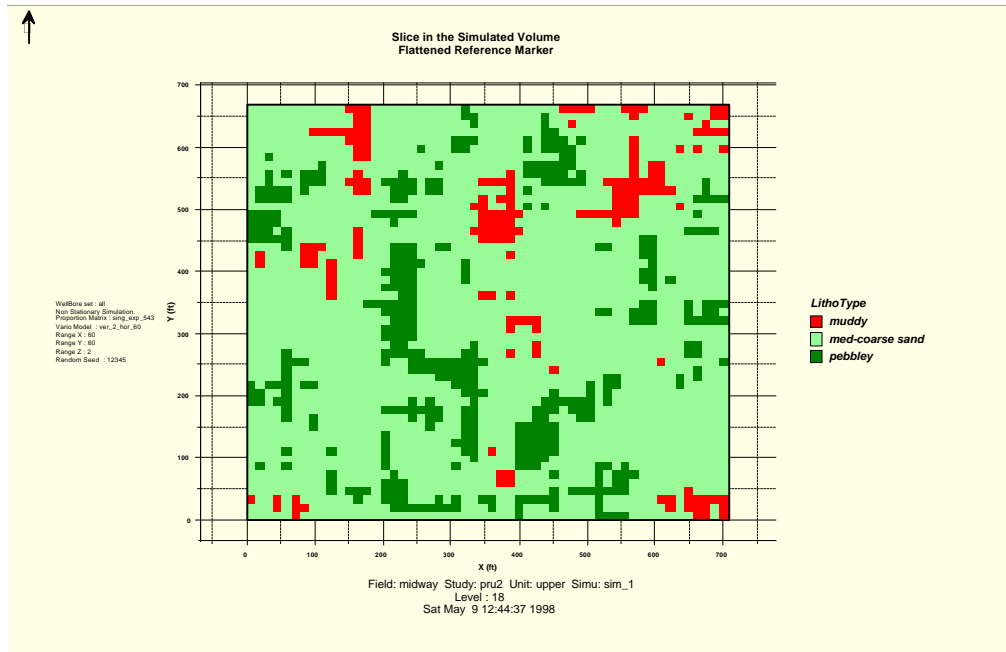


Figure 6. Bedding-plane parallel section of lithofacies cut from within the middle lithotype.



*Figure 7. Bedding-plane parallel section of lithofacies cut from within the lower lithotype.*

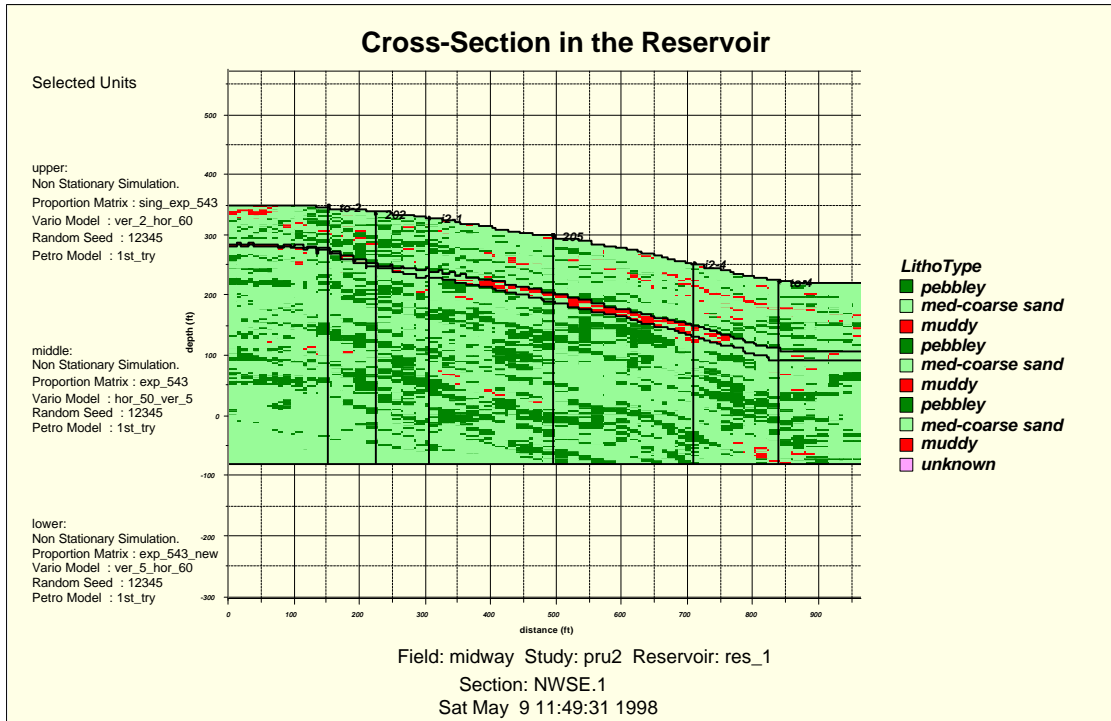


Figure 8. Vertical cross-section showing lithofacies within a northwest-southeast section. Cross-section location is shown in Figure 1.

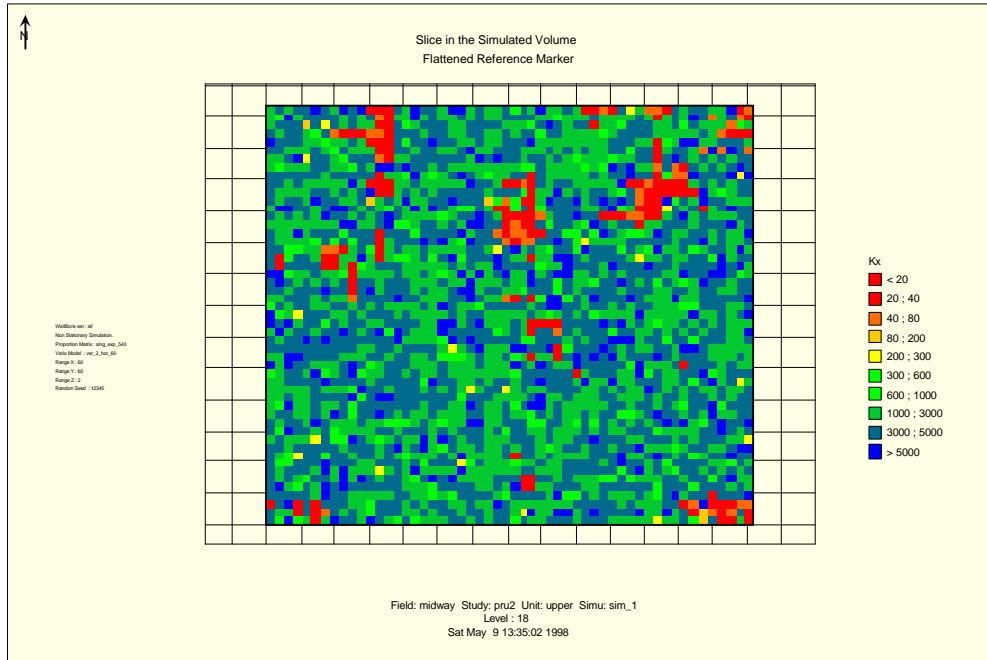


Figure 9. Bedding-plane parallel section of permeability cut from the upper lithotype.

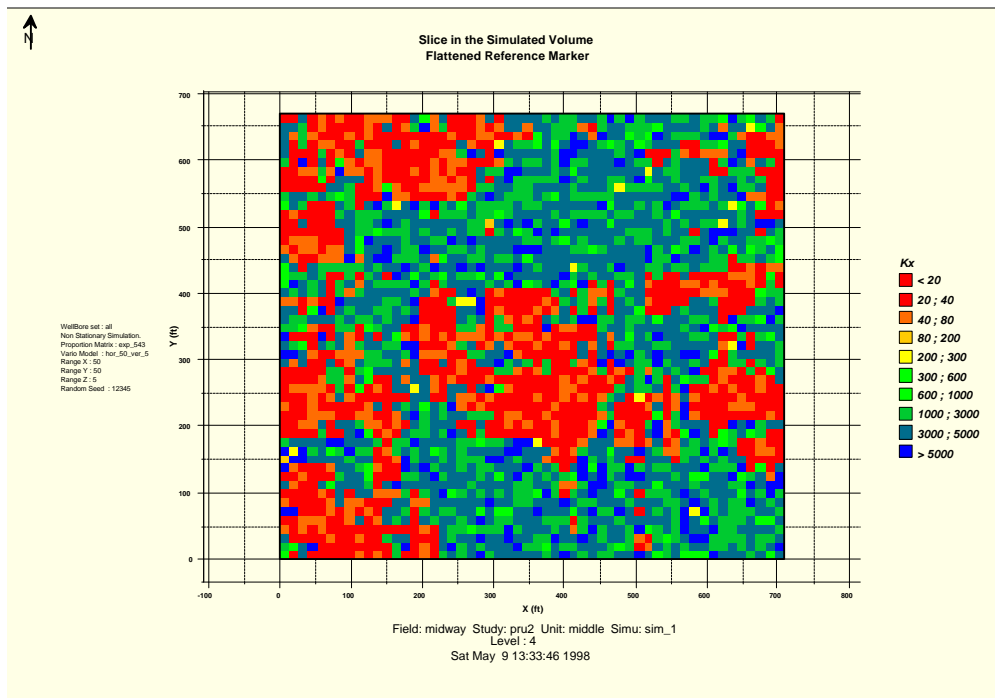


Figure 10. Bedding-plane parallel section of permeability cut from the middle lithotype

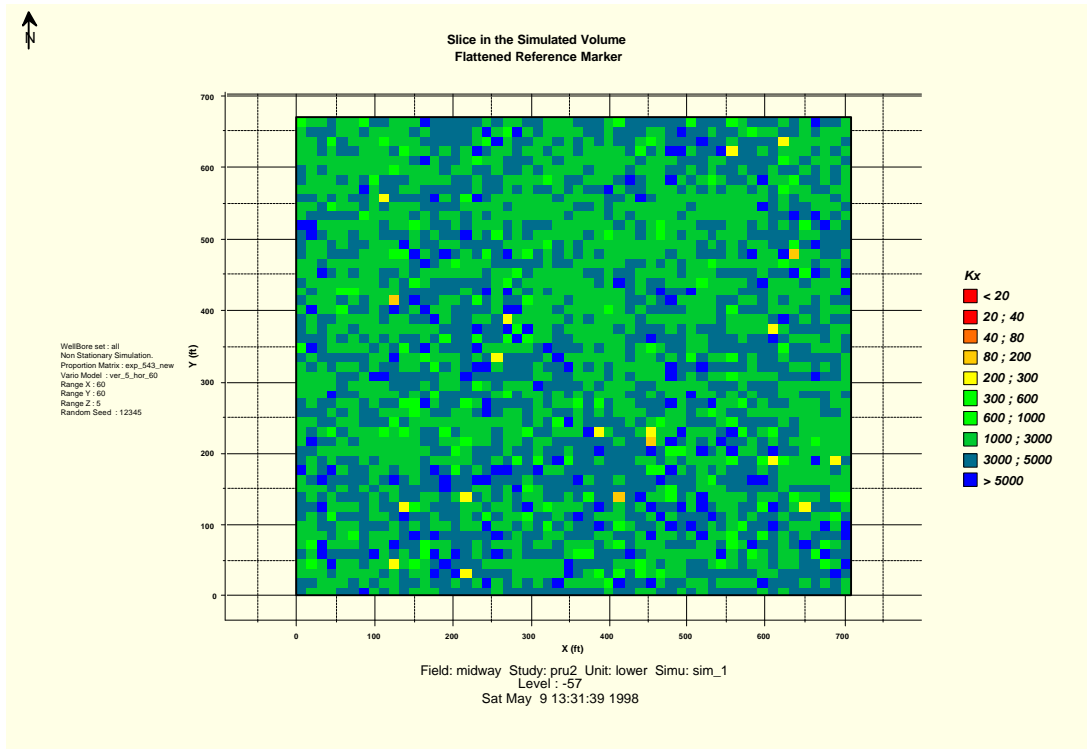
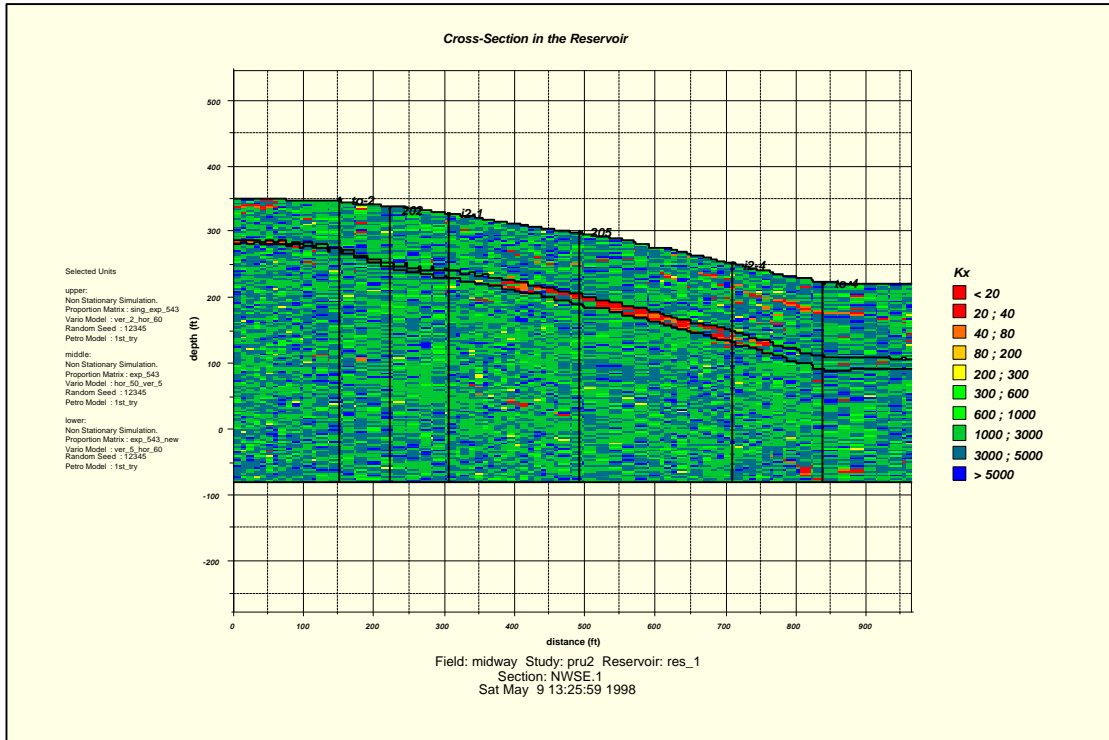
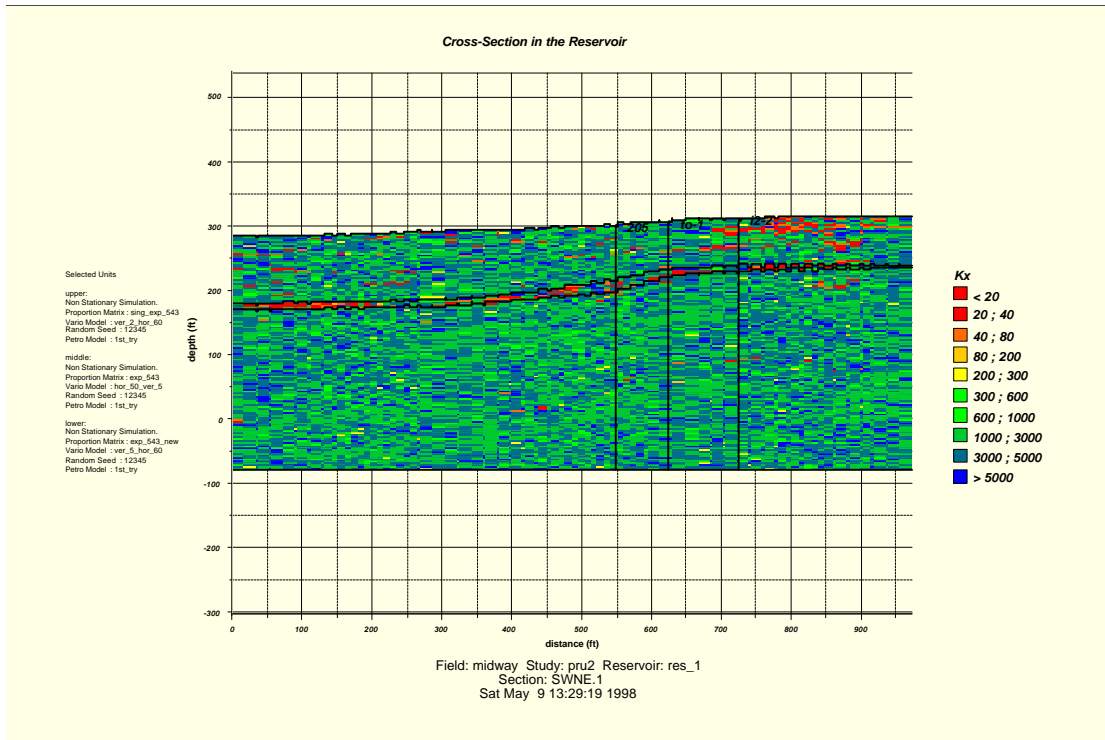


Figure 11. Bedding-plane parallel section of permeability cut from the lower lithotype.



*Figure 12a. Vertical cross-sections showing computed permeability within a northwest-southeast section. Cross-section locations are shown in Figure 1.*



*Figure 12b. Vertical cross-sections showing computed permeability within a southwest-northeast section.*

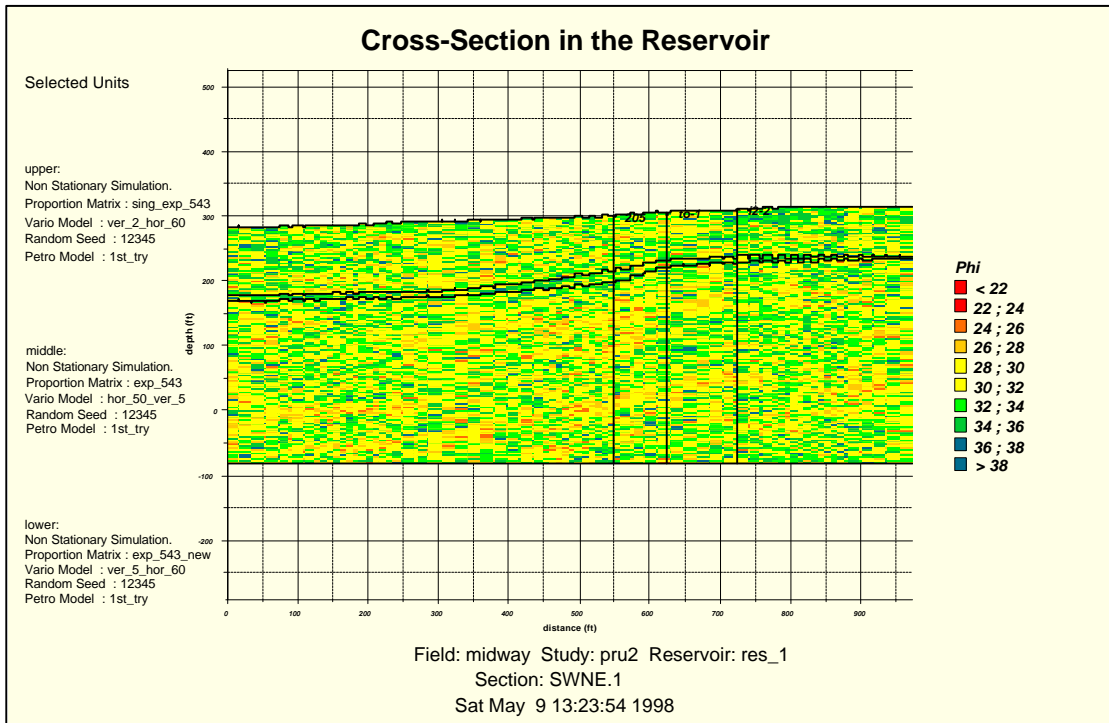
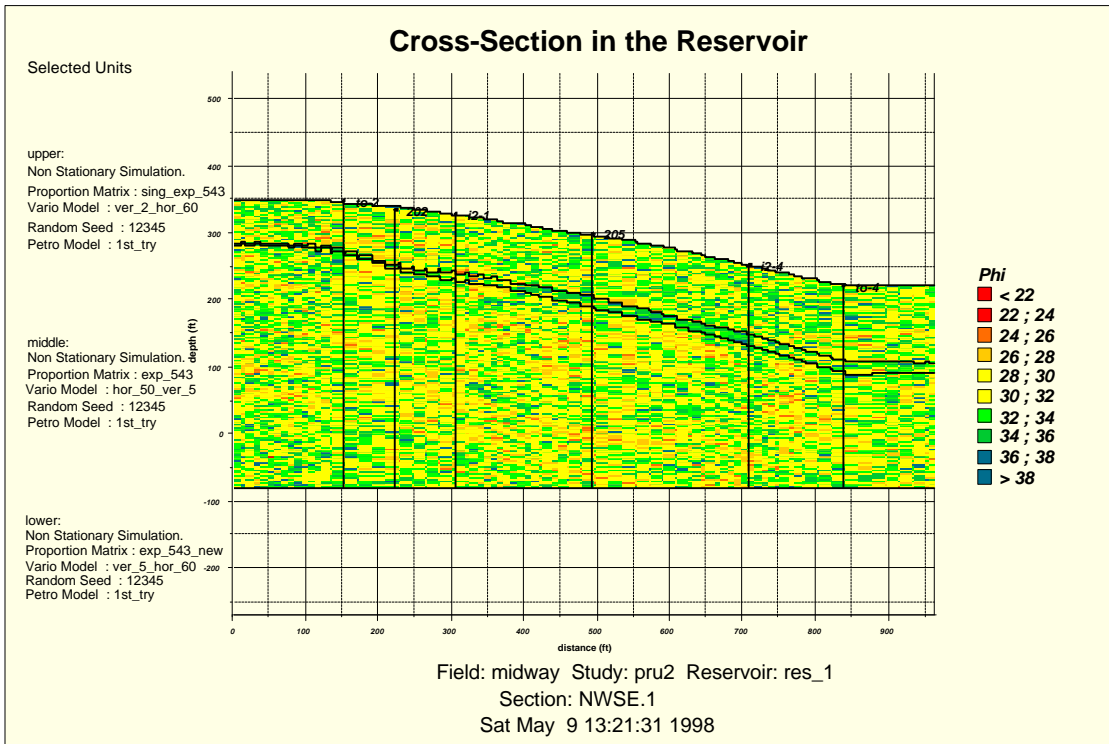


Figure 13. Vertical cross-sections showing computed porosity within a) northwest-southeast section, and b) southwest-northeast section. Cross-section locations are shown in Figure 1.