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Hydrocarbon Charge Analysis of the SECC Block, Columbus Basin, Trinidad and Tobago

STEVE HERTIG[1] AND MARK VER HOEVE[2]

[1]*Steve Hertig, EOG Resources International, Inc., 333 Clay Street, Houston, Texas, USA*
[2]*Mark Ver Hoeve, EOG Resources International, Inc., 333 Clay Street, Houston, Texas, USA*

ABSTRACT. **Rocks of the Cretaceous age Naparima Hill and Gautier formations are well established as the principal source rocks for the gas/condensate fields of the Columbus Basin. Critical components to understanding hydrocarbon charge in any basin are 1) source rock distribution, 2) source rock maturation and 3) hydrocarbon migration paths. In the Columbus Basin, the hydrocarbon charge story is somewhat unique in that much of this very deep basin up to 12,000 m (40,000 ft) formed rapidly during Pliocene – Pleistocene time. The main driver of maturation occurred less than 5 Ma and was related to progradation of an ancestral Orinoco delta across the area. Maturation analysis suggests the source rocks pasted rapidly through the oil window during the early Pliocene and entered into the gas window in the late parts of the Pliocene - Recent to produce the mainly gas-prone hydrocarbon province seen today. Migration paths and trapping style are affected by structure and stratigraphy of post-Cretaceous rocks. The goal of this paper is to understand the hydrocarbon charge history for the 1.5 trillion cubic feet (TCF) so far discovered on the SECC Block.**

1. INTRODUCTION

The hydrocarbon charge of the SECC block (Fig. 1) is significantly controlled by the structural and stratigraphic history of the Columbus basin. The Columbus basin, part of the easternmost Venezuela basin (Leonard, 1983), is located within the convergent boundary between of the Caribbean and South American plates (Babb and Mann, 1999; Pindell and Erikson, 1993). The Venezuelan basin accumulated more than 12,000 m (40,000 ft) of sediment from the Orinoco River since the mid-Miocene (Wood, 2000). In the Columbus basin, SECC Block post-Cenozoic sedimentary thickness can reach as much as 9000 m (30,000 ft) it comprises a succession of fluvial, deltaic and marine deposits (Fig. 2) cut by numerous and mainly northwest-trending, normal faults.

Columbus basin hydrocarbons account for an estimated 3 billion barrels of oil in place and 20 TCF of gas in place (Fletcher, 2002). These hydrocarbons are postulated to originate from source rocks of the Cretaceous (Persad *et al.*, 1993) Naparima Hill and Gautier formations. A significant biogenic contribution to the estimated gas in place can not be excluded, but is not a topic of this paper.

Within the SECC Block, as much as 1.5 TCF of gas and minor quantities of oil have been discovered. As exploration in the Columbus basin matures, it is necessary to better understand the risks associated with hydrocarbon charge and potential controls on

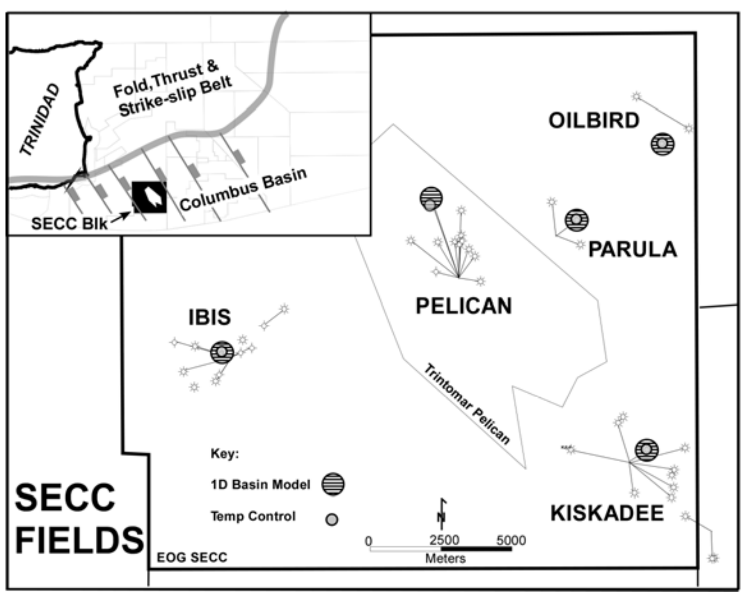


Figure 1. Location of SECC Block, Trinidad and Tobago. Temperature data points and 1D-basin models are also shown.

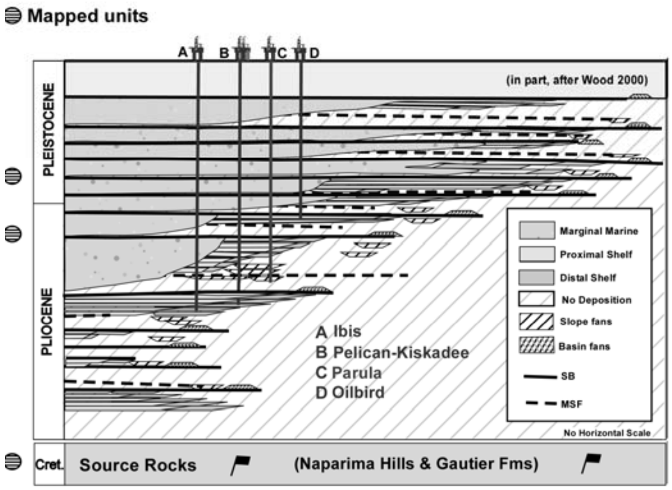


Figure 2. Stratigraphy and key hydrocarbon system components of the SECC Block and surrounding Columbus Basin (after Wood, 2000).

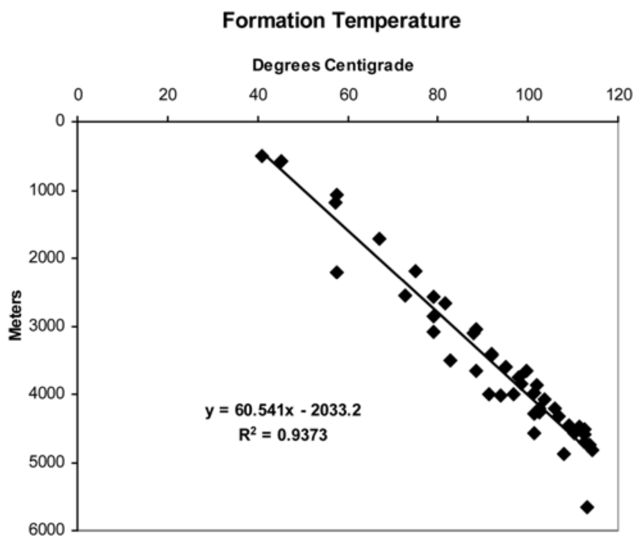
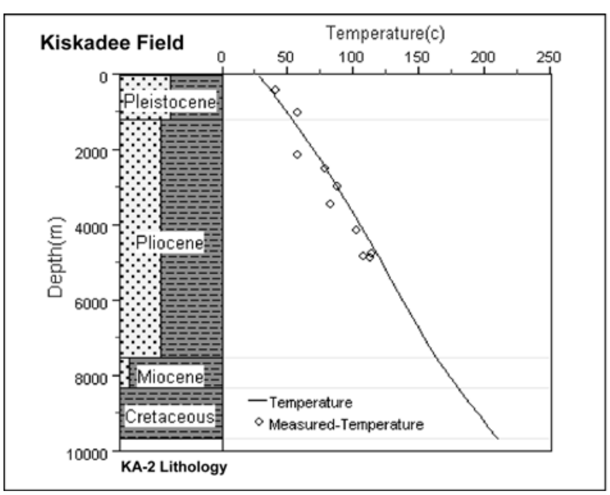


Figure 3. Temperature data, including temperature logs, DSTs, and BHTs, from multiple wells within SECC Block. Location of wells for this figure and following figures are shown in Figure 1.



the distribution of both oil and gas. Hence, the goals of this paper are to

1. Determine the Recent thermal regime from analyses of available temperature data;

2. Model the maturation of the Cretaceous source rocks; and

3. Explore possible primary influences on hydrocarbon migration and compare these influences to the location of known hydrocarbon accumulations.

2. THERMAL MODEL

Temperature data from wells from 5 fields within the SECC Block display a consistent and depth-dependent thermal regime (Fig. 3). The average gradient of the block is approximately 1.6 degrees C/100 m (0.9 degrees F/100 ft).

Key optimized heat flow assumptions are

1. Transient model with temperature boundary at the base of lithosphere;

2. Base of lithosphere temperature is 1330º C;

3. Radioactive heat production from the crust; and

4. Constant heat flow during the post mid-Miocene.

With the temperature data, heat flow assumptions are optimized using GENESIS software and the resultant thermal model corresponds to area temperature data (Fig. 4).

3. MATURATION MODEL

Maturation of the Naparima Hill and Gautier formations is modeled using GENESIS software for 5 wells in the SECC Block (Fig. 1).

Key inputs to the model are

1. Stratigraphic framework established from paleontology studies from the SECC block;

2. Stratigraphic thicknesses from wells and seismic data to extrapolate below well control; and

3. Source rock kinetics of a typical marine

Figure 4. Kiskadee field measured temperatures illustrating the thermal calibration with modeled heat flow and lithosphere temperature assumptions. Location of field is shown in Figure 1.

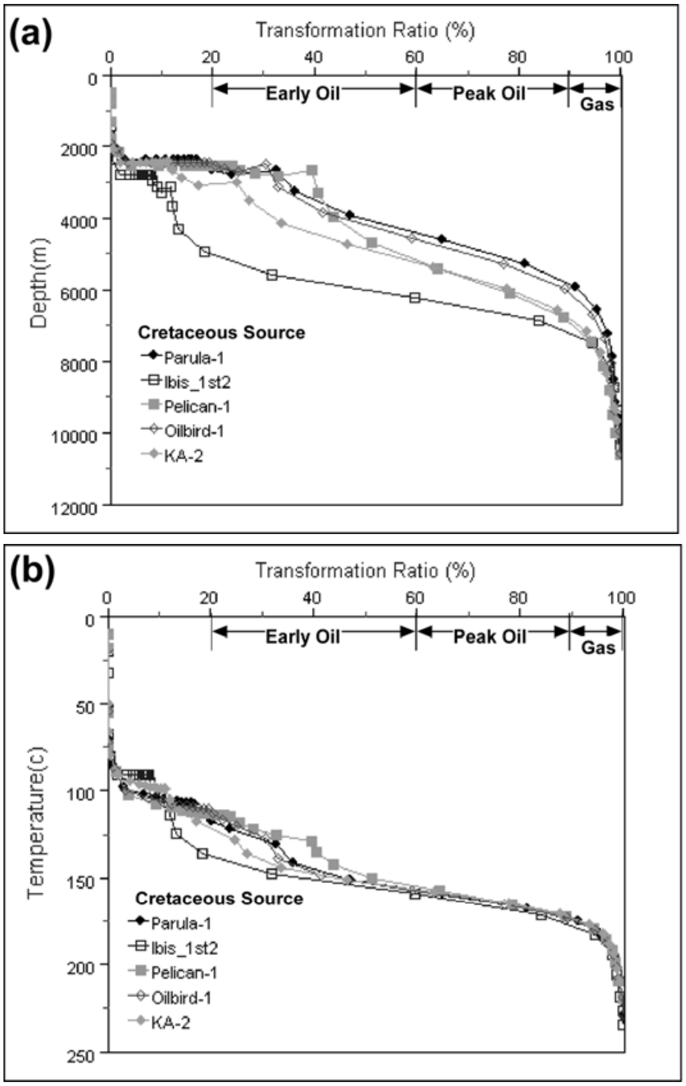


Figure 5. a, modelled trans-formation ratio verses depth. b, Modelled trans-formation ratio verses temperature.

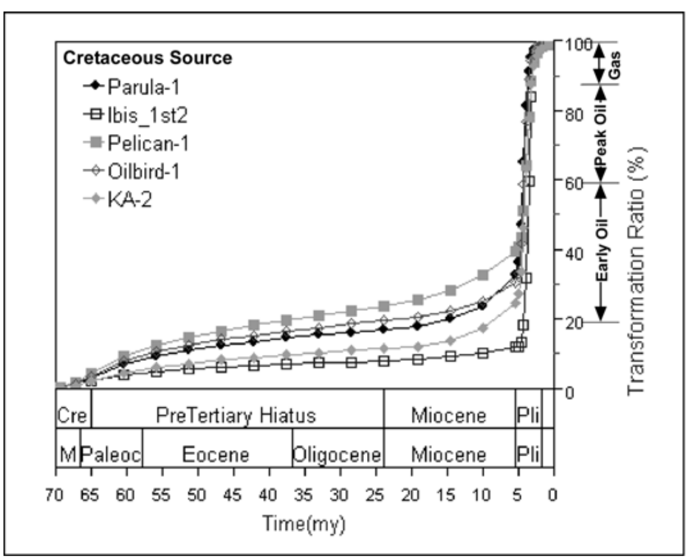


Figure 6. Modelled transformation ratio verses geologic time. Note most kerogen transformation occurs < 5 Ma.

shale/mudstone – 60% low Sulfur 40% high Sulfur. (The input alternative (Persad, 1993) of mixed a Type I/II kerogen is not presented.)

Model results included

1. Depth and temperature verses kerogen transformation (Fig. 5);

2. Timing of kerogen transformation (Fig. 6);

3. Rates of oil and gas generation (Fig. 7); and

4. Burial history verses transformation relations (Fig. 8).

Peak generation and associated inferred expulsion of hydrocarbons from the source rocks of the Naparima Hill and Gautier formations occurred between 4 and 3 Ma for oil and approximately 2 Ma for gas over most of the SECC Block. Rapid source-rock burial, as fast as 1500 m (5000 ft) per 1 Ma, by Pliocene and Pleistocene-Recent sediments controlled this timing. Because of rapid transformation, differentiation of independent maturation stages of hydrocarbon phase may be beyond the error ranges of the model's input assumptions. However, the change form immature to gas-expulsion is considered to have occurred between 5 Ma and Present Day.

Transformation verses depth relations and paleo-surface mapping using EXODUS software provides maturity extrapolation from well control to areas within and surrounding the SECC Block at different critical times. Maps important to source-rock burial history as well as potential stratal-migration pathways are 1) Cretaceous (approximately the top of Naparima Hill and Gautier formations), 2) intra-Pliocene and 3) top Pliocene (Fig. 9).

These structure maps are back stripped and decompacted to build paleo-transformation maps for the top Cretaceous at key times (Figure 10). These maps illustrate much of the thermogenic portion of the hydrocarbon maturation history of the Cretaceous source rocks in this area.

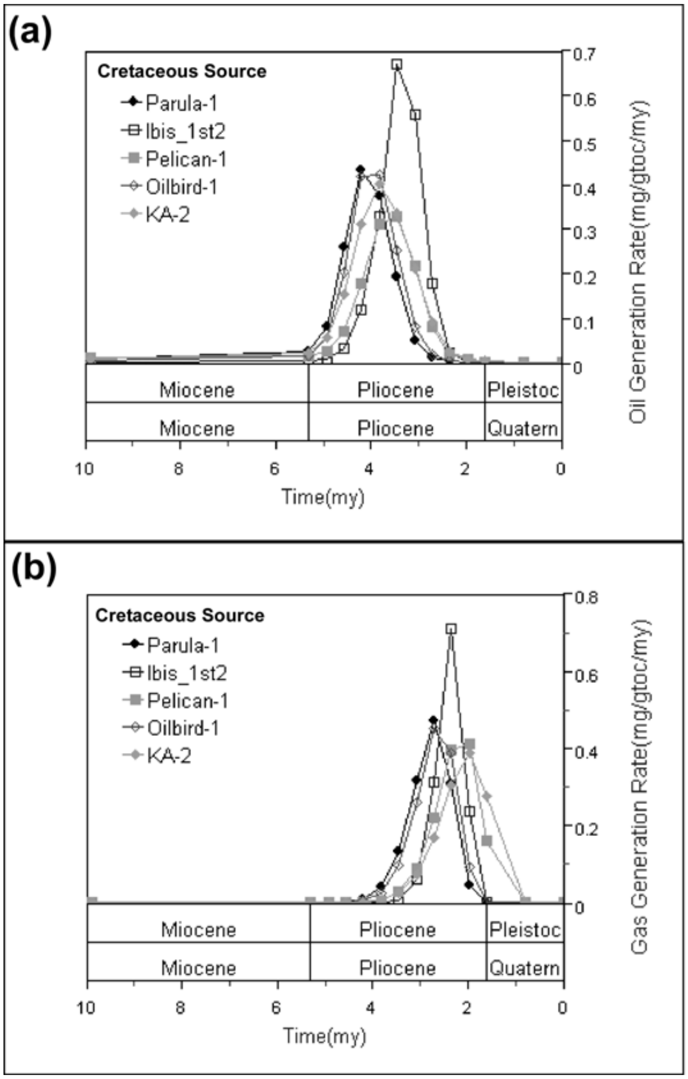


Figure 7. Modelled rates of hydrocarbon generation, a) oil and b) gas.

4. MIGRATION MODEL

The complex interplay of structure and sedimentation during the evolution of the Columbus basin (Wood, 2000) makes detailed analyses of migration paths and hydrocarbon phase difficult (Talukdar *et al*., 1990) on a field scale. However, simplifications on a basin scale can be insightful. EXODUS software provides the means to quickly evaluate the various migration stratal-paths and foci from areas of different transformation levels as well as from different times during the basins history (Cross-stratal pathways, such as faults, are also possible to interrogate using EXODUS software, but are not within the scope of this paper.).

First, a sequence of maps (Figs. 11a-d.) illustrates potential migration foci on the paleo-Cretaceous surface from 4 Ma to 1 Ma. Second, Present Day maps (Figs. 12a-c) illustrate potential migration stratal-paths at important stratigraphic levels- Top Cretaceous, intra-Pliocene, top Pliocene. In both map series, many of the known gas fields in the Columbus basin occur along migration foci south of the basin's northeast-trending axis, inferring a possible primary stratal control on hydrocarbon accumulations in this part of the Columbus basin.

5. SUMMARY AND CONCLUSIONS

Controls on the timing of maturation as well as the degree of transformation of the Naparima Hill and Gautier kerogens is influenced by:

1. Present Day thermal regime, approximately 1.6 degrees C/100 m (0.9 degrees F/100 ft and assumed the same since the mid-Miocene);
2. Depth and rate of burial of the source rocks of the Naparima Hill and Gautier formations controlled by the high sedimentation rates of the Orinico delta; and

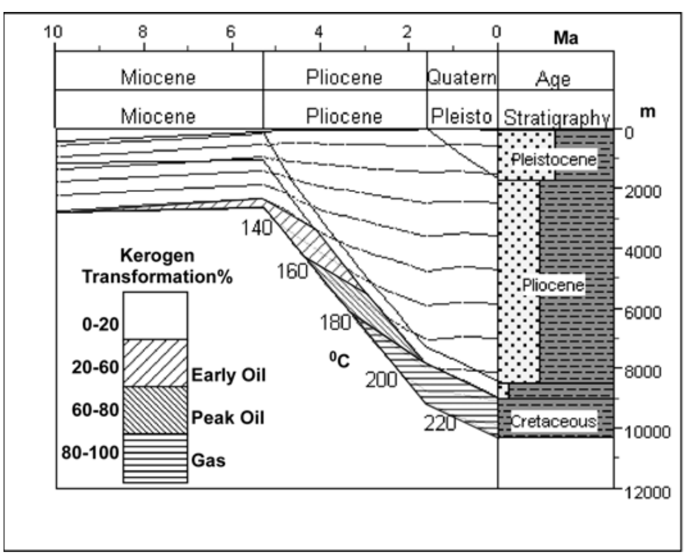


Figure 8. Burial history of Kiskadee field well (KA-2) illustrates the relationship between depth, geologic time and transformation ratio.

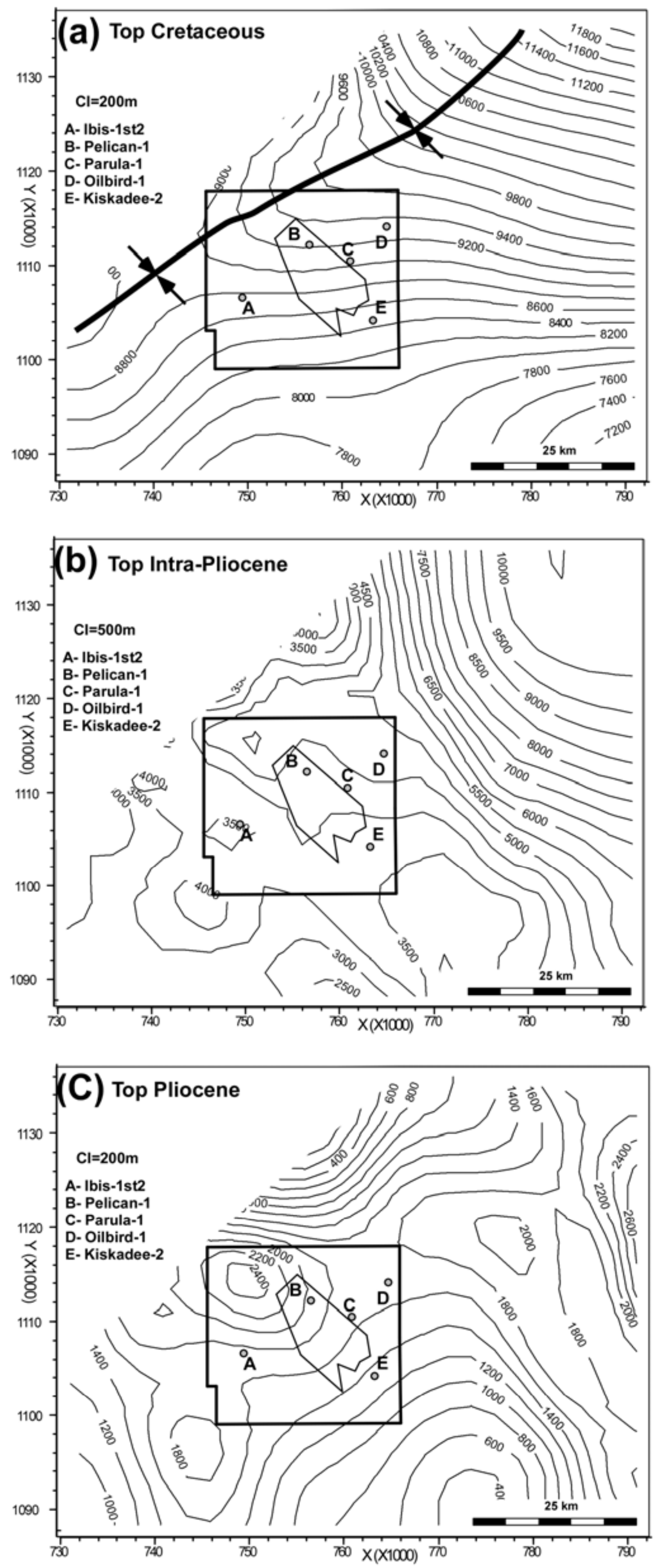


Figure 9. Regional Structure maps, (a) top Cretaceous, (b) intra-Pliocene and (c) top Pliocene. SECC Block is outlined in this figure and on the following figures.

3. Kinetics of the source rocks (assumed typical marine shales/mudstones, type II kerogen)

Naparima Hill and Gautier kerogen transformation from immature, oil and then gas occurred mainly from 4 Ma to Present Day in and adjacent to the SECC Block. The primary driver of transformation is rapid deposition of the post mid-Miocene Orinoco sediments in the Columbus basin.

Migration paths from known Columbus basin fields in SECC Block and others south of the basins axis correlate with foci of stratal paths (also possible biogenic paths) and paleo-stratal paths (<4 Ma old). However, charge of these fields was in all likelihood assisted by fault-related, cross-stratal paths, also.

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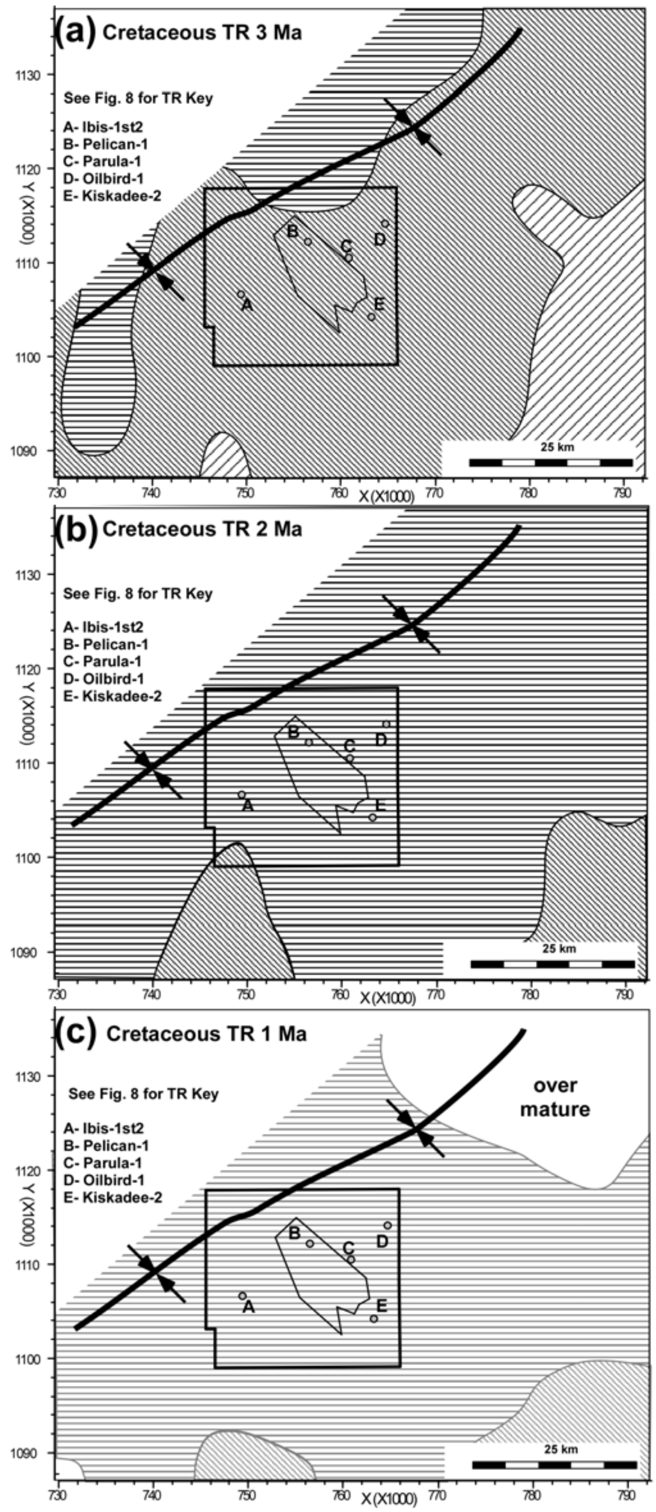

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Figure 10. Transformation ratio maps on Top Cretaceous at (a) 3 Ma (b) 2 Ma (c) 1 Ma. Refer to Figure 8 for key to transformation.

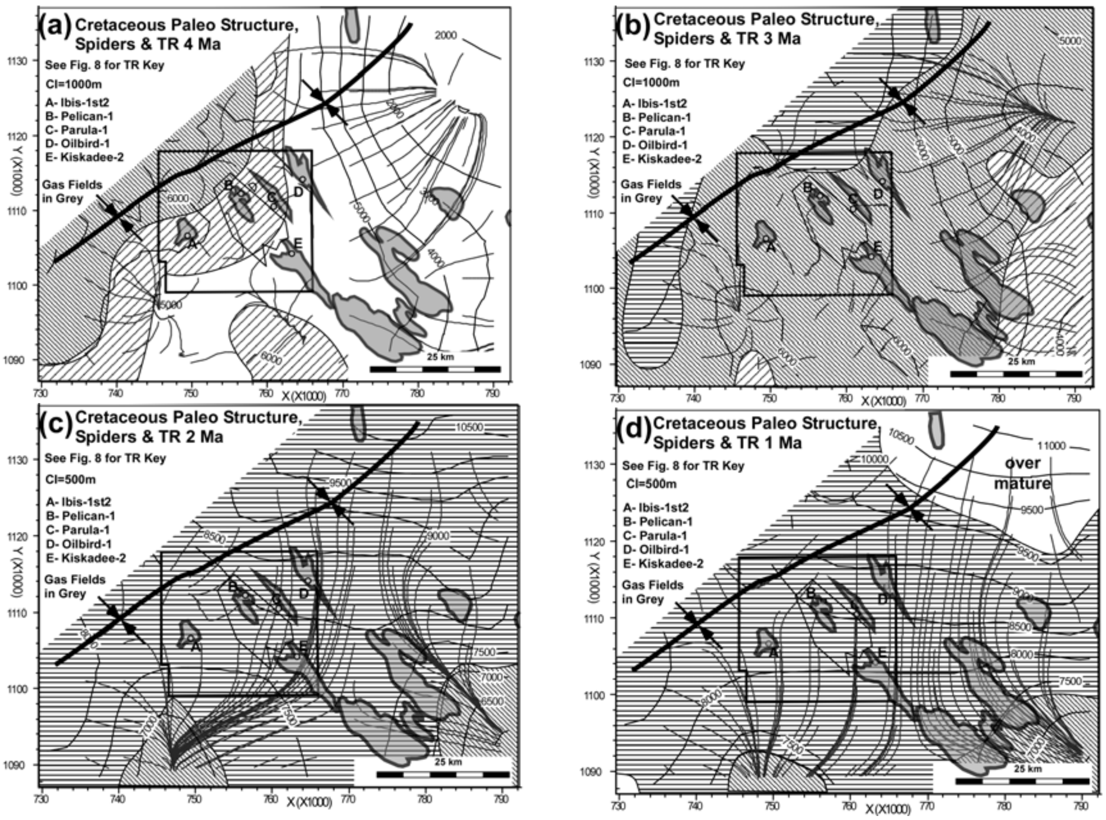
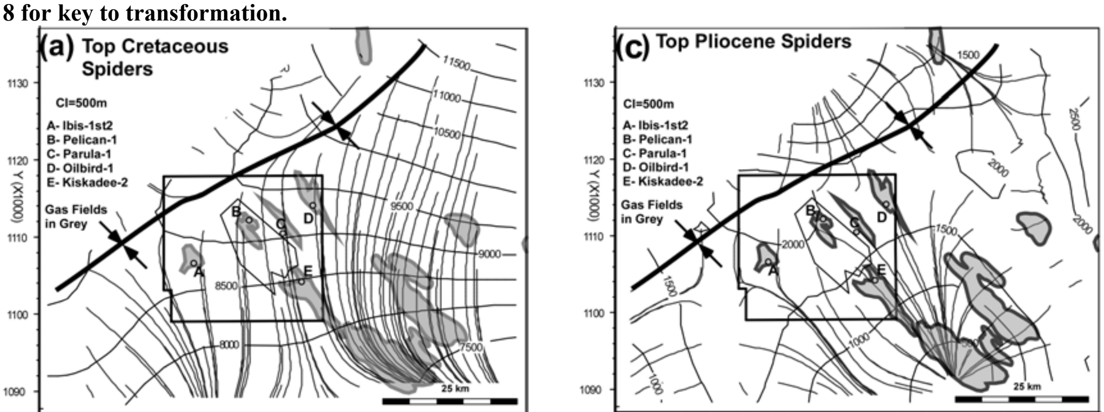


Figure 11. Top Cretaceous paleo-structure maps with migration paths (Spiders) are overlaying age-corresponding transformation ratio maps at (a) 4 Ma, (b) 3 Ma, (c) 2 Ma and (d) 1 Ma. Refer to Figure 8 for key to transformation.



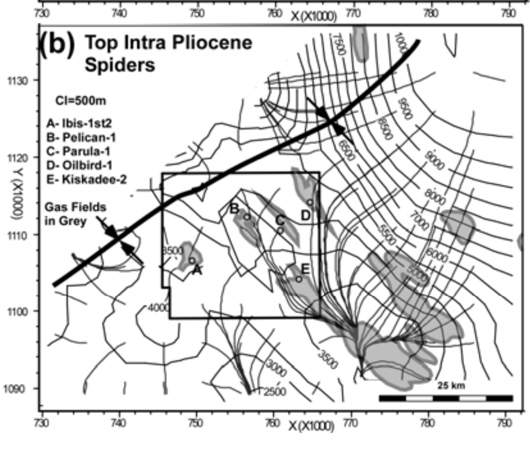


Figure 12. Regional structure maps: (a) top Cretaceous, (b) Intra-Pliocene, (c) top Pliocene with migration paths (Spiders). Note the coincidence of migration path foci and discovered gas fields south of the axis of the Columbus basin in SECC Block and adjacent areas.

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