The Viola Group as a Petroleum System: Implications for Horizontal-Drilling Prospects

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ABSTRACT.—The petroleum-system concept is advanced on the premise that the essential elements required for commercial accumulation of hydrocarbons must be considered as interrelated items that are interpreted collectively. A key element is the accurate correlation between the oil and source rock. The oil fields assigned to the Viola Petroleum System are charged from source facies described as diluted kurokites; this designation emphasizes the diversity of the biogenic input. An element of the source facies is derived from the organism Gloeocapsomorpha pruica, but this contribution varies between minor and moderate. A fairway of reduced risk is defined where positive trends in the source-rock volume, organic richness, thermal stress, and tectonic evolution overlap. The critical moment for this petroleum system follows the Arbuckle deformation event (approximately 290 Ma, Virgilian). This event is responsible for a fault network that limited the source-rock drainage volume but contributed to the trap and reservoir configuration. The fairway can be exploited with a minimum number of horizontal wells.

INTRODUCTION

The basic elements required for the accumulation of commercial hydrocarbon reserves have been documented in numerous studies: source rock, reservoir, and seals. The petroleum-system concept is advanced on the premise that these essential elements are interrelated and should be interpreted collectively. As defined (Magoon, 1992), "a petroleum system encompasses a mature hydrocarbon source rock and all generated oil and gas accumulations and includes all the geologic elements and processes that are essential if the oil and gas deposit is to exist." The geologic elements include the petroleum source rock, reservoir rock, sealing units, and overburden rock. In this usage, the reservoir rock is considered to be synonymous with a migration conduit that is not filled with hydrocarbons because of the lack of a trapping mechanism. The geologic processes include the mechanism responsible for trap formation and those factors that drive the generation, migration, and accumulation of hydrocarbons. It is important that the essential elements and processes be correctly coordinated in time and space for the generated hydrocarbons to be trapped as commercial reserves (Wavrek and Barker, 1988).

The petroleum system is designated by the name of the source rock, followed by the major reservoir unit and the confidence indicator (Magoon, 1992). Three confidence indicators are recognized: (!) for known, ( ) for hypothetical, and (?) for speculative. Where the source rock coincides with the reservoir unit, the name is simplified to a single element. With this premise, the Viola (!) Petroleum System in this study is restricted to the confines of the Ardmore and Marietta basins (Fig. 1).

This paper expands the petroleum system concept by including a discussion of the application to horizontal drilling prospects.

Geologic Setting

The Ardmore and Marietta basins (Fig. 1) were the part of the Oklahoma basin that coincided with the eastern part of the source-rock area (Fig. 2). The uppermost structural feature is the arcuate fold axes, suggesting a fault sheet (Hoffman and others, 1976; Thompson, 1976; and others). The column is almost completely overlain by units containing all the major source-rich organic units by clastics. This resulted from the filling of the basin by an important contribution from clastics (Fig. 2).

The Viola Group, which includes the marine-limestone sequences, consists of the Cochran Limestone (Glaser, 1965; Gabriner, 1985; Finney, 1989). The Cochran Limestone is known from the Oklahoma basin and is part of the Cincinnatian Stage. It is divided into two formations, the upper Fernvale Limestone and the lower Malott Limestone unit (Fig. 3). These units are compared to the Viola Group, occurring in the upper Fernvale Limestone unit (Fig. 3). The Viola Group is interpreted to result from...
Implications for horizontal drilling in the Meso-Cenozoic of the Midcontinent, 1994.

Figure 1. Geographic location of the Ardmore and Marietta basins. The two framed views represent the outlines for map figures in the text.

Tem part of the southern Oklahoma aulacogen (Johnson and others, 1988), which is a west-northwest-trending structural feature that has been the subject of numerous studies (Hoffmann and others, 1974; Pruett, 1975; Thompson, 1976; Wickham, 1978). The sedimentary column is almost entirely Paleozoic (Fig. 2), with the lower units dominated by carbonates and the higher units by clastics. The current structural configuration is the result of late Paleozoic deformation events.

The Viola Group (Fig. 2) is an Upper Ordovician marine-limestone sequence (Decker, 1933; Ham, 1955; Glaser, 1965; Galvin, 1983; Grammer, 1983; Teague, 1985; Finney, 1988) that was deposited throughout the Oklahoma basin during the mid-Mohawkian to early Cincinnati Stages. The group is routinely subdivided into two formations: a lower Viola Limestone and an upper Fernvale Limestone. Lithofacies in the Viola Limestone include subunits 1L and 1C, and a middle unit, 2; subunits 3CM and 3C are part of the Fernvale Limestone (Fig. 3). The lithologic and paleontologic differences between the subunits are gradual and are interpreted to result from a systematic variation in the depositional energy and water depth in a carbonate-ramp setting. This study focuses on subunit 1L, which is described as siliceous laminated mudstones that were deposited in a deep-water anaerobic environment. It is proposed that the anoxic condition that existed during deposition of this subunit was enhanced by the aulacogen setting, which provided physical isolation from open-water circulation.

Materials and Methods

The oils (Table 1; Fig. 4) represent a subset of the samples interpreted by Wavrek (1992) as Type D, whereas the rock samples (Fig. 5) are the focus of a study by Garcia (in preparation). The rock samples were collected in the context of previous studies of subunit 1L depositional facies, and sources include outcrop, core, and cuttings. The cuttings were hand-picked to provide samples that conform to lithologic variation observed at outcrops, and they represent a channel sample through the basal chert facies. Positive picking is not usually advocated as a geochemical-sampling technique, but it is valid in this study because the focus is on a subunit...
with a unique lithology and special care was paid to evaluate the potential for contributions from caving (e.g., casing points, examination of overlying sample lithologies). The tectonic and stratigraphic analyses used in this study are based on the examination of over 500 well logs (Ferebee, 1991). Calculations for the individual burial-history reconstructions (Fig. 6) were accomplished with the program BasinMOD (v. 4.02; I-D for Windows; Plate River Associates).

The geochemical analysis of the rock samples includes total organic carbon (TOC) (Leco Instruments), Rock-Eval pyrolysis (Delsi Instruments), and Soxhlet extraction. The oil samples were analyzed for density (Parr Instruments), total sulfur (Leco Instruments), and metals (Inductive Coupled Plasma). Both sample sets were analyzed by gas chromatography–flame ionization detection (GC–FID) prior to separation into fractions by column chromatography and analysis by gas chromatography–mass spectrometry (GC–MS). Several samples were selected for stable-carbon-isotope analysis.

RESULTS AND DISCUSSION
Geologic Elements and Processes

As a petroleum system encompasses a mature hydrocarbon source rock and all generated oil and gas accumulations, an accurate correlation between the oil and source rock is an essential element. This correlation is established with a combination of analytical techniques: GC–FID for the general components and GC–MS for the biomarker fraction. Oils indigenous to the Viola (1) Petroleum System are characterized by a moderate odd-carbon preference in the \( nC_{11}-nC_{19} \) range, moderate amounts of acyclic isoprenoids, pristane to phytane ratios near 1.1, and moderate \( nC_{35} \) n-alkanes (Fig. 7). They tend to have a relatively high concentration of sulfur compounds, organic metal complexes, and moderate API gravities (Table 1). The carbon-isotope values measured for two of these oils provided average values of -31.1\%, -31.3\%, and -30.9\% for the whole oil, saturate, and aromatic fractions, respectively (Wavrek, 1992). The biomarker analyses indicate that the steranes have dominant \( C_{29} \) members, with the \( \alpha\beta \) form preferred over the \( \alpha\alpha \) configuration, plus a moderate amount of rearranged steranes (Fig. 8). The tarpane fraction contains relatively abundant extended hopanes, minor amounts of gammacerane, a moderate abundance of 28,30-bisorhopane, and a \( C_{34} \) tetracyclic that is greater than the \( C_{36} \) tricyclic terpanes (Fig. 9). The methyl hopanes are quantitatively significant, with 2\( \alpha \) and 3\( \beta \) varieties in near-equal abundance. Distinctive peaks that are apparent on the GC–FID traces (Fig. 7) are identified by GC–MS SCAN analysis to be \( n \)-alkylcyclohexanes and \( n \)-alkylbenzenes with anomalous \( C_{31} \) and \( C_{32} \) members (Fig. 10). Wells that produce from this petroleum system are prone to paraffin precipitation during production and pipeline transport owing to the presence of quantitatively significant high-molecular-weight compounds (Wavrek and Dabah, 1995).

The molecular composition of Viola Group rock extracts and correlative crude oils suggests that a diverse assemblage of organisms contributed to the source facies. An element of these source facies is derived from the organism *Gloeocapsomorpha prisca*, which is reported to be responsible for the distinctive Ordovician signature of oils and source rocks on a global scale (see Fowler, 1992, for review). This signature is readily apparent in the associated marls of subunit 1L (Fig. 11), whereas the chert facies provides the remainder of the Viola Group molecular signature. It is emphasized that the kukersite facies of *G. prisca* have not been observed in extracts from the Viola Group and that an oil composition represents the collective components of the individual source facies within the source rock. The kukersite facies of *G. prisca* appear to be restricted to the Simpson Group (Middle Ordovician, Champlainian), a conclusion that is reinforced by documentation that oils with the kukersite chemistry (Type E of Wavrek, 1992) are generally restricted to Simpson and Arbuckle Group reservoirs.

![Diagrammatic section of the Viola Group (modified from Glaser, 1965; Grammer, 1983).](image-url)
isotane to phytane ($i$-alkanes (Fig. 7)). Concentration of sul-
phur, and moderate stable isotope values measured as average value of whole oil, saturate, n-alkanes (Wavrek, 1992). 
- the steroids have an $\beta$-form preferred over $\alpha$-form, and intermediate amount of C30 and C31 hopanes, minor abundance of cyclic that is greater than 9%. The methyl content, with 2$\alpha$ and 3$\beta$-stanol peaks that (7) are identified by $C_{29}$ and $C_{30}$-alkylcyclohexanes from this petroleum fraction during processing of the source rock composition.

Viola Group rock unit is diverse facies. Is derived from which is reported to have a unique signature of the chert (see Fowler, 1992). In the association Ptahle, whereas the chert of the Viola Group molecular kerogen facies of the principal kerogen extracts from the source rock represents the individual source facies of $G$. priscus. This paired portion of the Viola Group (Middle Devonian to Pennsylvanian) is rich with the klerikerite (2) are generally referred to as the Viola Group reservoirs.

![Viola Petroleum System](image)

**Table 1.** OIL WELLS THAT PRODUCE FROM THE VIOLA (1) PETROLEUM SYSTEM

<table>
<thead>
<tr>
<th>Field</th>
<th>Operator</th>
<th>Well</th>
<th>Location</th>
<th>API well number</th>
<th>Reservoir formation</th>
<th>Permeability (mD)</th>
<th>API gravity</th>
<th>Total sulfur (ppm)</th>
<th>Nickel (ppm)</th>
<th>Vanadium (ppm)</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Marion NE</td>
<td>L. E. Jones</td>
<td>No. 1 Dadeh Sutton</td>
<td>27-55-2W</td>
<td>35-085-20559</td>
<td>Viola</td>
<td>3580-3640</td>
<td>37.3</td>
<td>0.45%</td>
<td>11</td>
<td>15</td>
<td>Mixed?</td>
</tr>
<tr>
<td>Simon NW</td>
<td>Unocal</td>
<td>No. 1 Loving</td>
<td>16-55-2W</td>
<td>35-085-20222</td>
<td>Viola</td>
<td>9300-12000</td>
<td>42.2</td>
<td>0.21%</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ot SE</td>
<td>Unocal</td>
<td>No. 1 Rosseth</td>
<td>4-65-3W</td>
<td>35-085-20657</td>
<td>Viola</td>
<td>917-10512</td>
<td>37.3</td>
<td>0.24%</td>
<td>8</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Aloe</td>
<td>L. E. Jones</td>
<td>No. 1 Lamoth</td>
<td>29-55-4W</td>
<td>35-085-20684</td>
<td>Viola</td>
<td>616-7143</td>
<td>35.6</td>
<td>1.40%</td>
<td>28</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Aloe</td>
<td>L. E. Jones</td>
<td>No. 1 Porter</td>
<td>21-55-4W</td>
<td>35-085-20659</td>
<td>Viola</td>
<td>7844-8002</td>
<td>36.1</td>
<td>1.38%</td>
<td>28</td>
<td>64</td>
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<tr>
<td>Aloe</td>
<td>L. E. Jones</td>
<td>No. 1 Allen</td>
<td>21-55-4W</td>
<td>35-085-20657</td>
<td>Viola</td>
<td>7229-7802</td>
<td>36.6</td>
<td>1.46%</td>
<td>26</td>
<td>73</td>
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<tr>
<td>Ringing West</td>
<td>Kaiser-Francis</td>
<td>No. 1-5 Zachary</td>
<td>5-55-4W</td>
<td>35-085-20688</td>
<td>Viola</td>
<td>6695-7085</td>
<td>28.1</td>
<td>1.56%</td>
<td>36</td>
<td>94</td>
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<td>Simon North</td>
<td>Bogen</td>
<td>No. 35-3 Mason</td>
<td>35-55-2W</td>
<td>35-085-20118</td>
<td>Viola</td>
<td>7427-8249</td>
<td>38.0</td>
<td>0.55%</td>
<td>7</td>
<td>8</td>
<td></td>
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<td>Rock East</td>
<td>Sanoraton</td>
<td>No. 1-15 Howard</td>
<td>15-55-2W</td>
<td>35-085-21892</td>
<td>Viola</td>
<td>6251-7718</td>
<td>38.3</td>
<td>1.69%</td>
<td>27</td>
<td>44</td>
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<tr>
<td>Junker City SE</td>
<td>Chevron</td>
<td>No. 1 Bates</td>
<td>32-55-2W</td>
<td>35-085-20735</td>
<td>Viola</td>
<td>10,126-10,360</td>
<td>38.9</td>
<td>0.41%</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Junker City SE</td>
<td>Holten</td>
<td>No. 1 Anderson</td>
<td>32-55-2W</td>
<td>35-085-22831</td>
<td>Viola</td>
<td>10,083-10,095</td>
<td>35.4</td>
<td>0.47%</td>
<td>7</td>
<td>15</td>
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<tr>
<td>Wilson SE</td>
<td>Walker</td>
<td>No. 1 North</td>
<td>9-55-2W</td>
<td>35-085-22647</td>
<td>Viola</td>
<td>5565-7521</td>
<td>36.6</td>
<td>0.61%</td>
<td>11</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Junker City SE</td>
<td>Unocal</td>
<td>No. 1-18 Simmons</td>
<td>18-55-2W</td>
<td>35-085-22398</td>
<td>Viola</td>
<td>7085-7140</td>
<td>40.3</td>
<td>0.52%</td>
<td>6</td>
<td>15</td>
<td></td>
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<tr>
<td>Ot North</td>
<td>Jones</td>
<td>No. 1 Jones-Kallman</td>
<td>31-55-2W</td>
<td>35-085-22621</td>
<td>Viola</td>
<td>9152-9240</td>
<td>34.1</td>
<td>0.66%</td>
<td>6</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Simon NE</td>
<td>L. E. Jones</td>
<td>No. 1 Rockland</td>
<td>7-55-2W</td>
<td>35-085-22883</td>
<td>Viola</td>
<td>7950-9118</td>
<td>35.1</td>
<td>0.57%</td>
<td>9</td>
<td>19</td>
<td></td>
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<tr>
<td>Hewitt</td>
<td>Exxon</td>
<td>No. 1-16 Mullen</td>
<td>16-45-2W</td>
<td>35-085-21893</td>
<td>Viola</td>
<td>3444-3828</td>
<td>26.6</td>
<td>1.27%</td>
<td>35</td>
<td>75</td>
<td>Mixed?</td>
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<td>Sho-Val-Turn</td>
<td>K. Walker</td>
<td>No. 1 Lima-Boggs</td>
<td>19-35-2W</td>
<td>35-085-22936</td>
<td>Viola</td>
<td>7304-4127</td>
<td>41.7</td>
<td>0.25%</td>
<td>5</td>
<td>2</td>
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<tr>
<td>Headlon</td>
<td>Kingery Drilling</td>
<td>No. 1 Inbello</td>
<td>34-35-2W</td>
<td>35-085-21747</td>
<td>Viola</td>
<td>6576-6720</td>
<td>30.2</td>
<td>1.08%</td>
<td>15</td>
<td>47</td>
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<td>Caddo</td>
<td>O'Sullivan Drilling</td>
<td>No. 7 Smith</td>
<td>22-35-1E</td>
<td>35-085-23368</td>
<td>Viola</td>
<td>6100-6472</td>
<td>28.5</td>
<td>0.47%</td>
<td>12</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Sho-Val-Turn</td>
<td>Holden Energy</td>
<td>No. 9-1 Lamb</td>
<td>0-25-4W</td>
<td>35-137-23077</td>
<td>Viola</td>
<td>5680-6610</td>
<td>30.3</td>
<td>0.47%</td>
<td>15</td>
<td>14</td>
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<tr>
<td>Pate SW</td>
<td>K. Walker</td>
<td>No. 1 Redmond</td>
<td>23-75-2W</td>
<td>35-085-20255</td>
<td>Doraich Hills</td>
<td>9006-9177</td>
<td>23.5</td>
<td>1.41%</td>
<td>27</td>
<td>22</td>
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<tr>
<td>Velma West</td>
<td>TGO</td>
<td>No. 1 Brown-Batt</td>
<td>13-15-5W</td>
<td>35-137-24090</td>
<td>Viola</td>
<td>7464-8550</td>
<td>38.9</td>
<td>0.42%</td>
<td>3</td>
<td>2</td>
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</table>

**Note:** Sample suite from Wavrek (1992).

![Viola Petroleum System](image)

**Figure 4.** Geographic distribution of oil wells that produce from the Viola (1) Petroleum System (from Wavrek, 1992, sample suite).

![Viola Petroleum System](image)

**Figure 5.** Geographic distribution of rock samples analyzed from Viola Group, subunit 1L (from Garcia, in preparation).
After the relationship between the Viola Group source facies and crude oils has been established, positive trends in source-rock volume, richness, and maturity can be addressed. A regional isopach map of Viola Group units 1L/1C (Fig. 12) shows that the thickness ranges from less than 100 to over 300 ft. The unit thickens toward the southwest, whereas thinning about the perimeter of the anacogen and toward the Arbuckle Mountains is generally observed. The Viola Group contains effective petroleum source rocks within the lami-

Figure 6. Geographic distribution of sites selected for individual burial-history reconstructions.

Figure 7. GC–FID of a typical oil from the Viola (1) Petroleum System.

Figure 8. Sterane trace (m/z 217) from GC–MS analysis of saturate fractions.

Figure 9. Terpane trace (m/z 191) from GC–MS analysis of saturate fractions.

Figure 10. n-alkyloctane (m/z 82) and n-alkylbenzenes (m/z 92) from GC–MS analysis of whole extract and crude oil.

Figure 11. GC–FID of whole extract from Viola Group marns (TOC average = 2.4%; n = 7) and a basal chert (TOC average = 1.3%; n = 30). The geographic distribution of source-rock potential (Fig. 13) is distinctive, with poor source potential near the basin margins, particularly on the south flank of the Arbuckle uplift, but with progressive increases to good and excellent values
in the vicinity of the Marietta basin. Rock-Eval pyrolysis of these samples indicates oil-prone Type IIa and II kerogen with hydrogen indices up to 720 and 760 mg HC/g TOC for the chert and marl facies, respectively. Interestingly, the increase in source potential coincides with the direction of progressively deeper water setting in the depositional model for Viola Group unit II. Optical analysis indicates that the kerogen is dominantly derived from algal sources, with both structured and amorphous varieties present. The degradation of the kerogen to amorphous varieties is promoted by the reworking of the primary organic matter by bacterial populations. The thermal maturity of the source rock is also addressed, as adequate thermal stress is required for the transformation of the kerogen into a free hydrocarbon phase. As Figure 14 shows, the areas that have not reached the oil window coincide with the Criner uplift and the northwest extension of the Marietta basin.

The reservoirs that produce within the Viola Petroleum System may include primary and secondary porosity, although the zones that produce from the siliceous laminates rely on a fracture network, since the matrix porosity and permeability are quite low (Evans, 1984; Northcutt and Johnson, 1997; Gonzalez, 1997; Candelaria and Roux, 1997). The fracture systems are developed as a function of the brittle nature displayed by the siliceous laminates, particularly in areas subjected to multiple episodes of tectonic deformation. The reports that these reservoirs generally produce water-free (Evans, 1984; Candelaria and Roux, 1997) may be related to the reservoirs being charged in-situ, as the expulsion event would only be into the fracture system of the source rock instead of into a water-wet carrier bed. This aspect of the expulsion-migration event would account for the water phase being undersaturated with respect to hydrocarbons and the water-free production. Noteworthy is the report of a similar phenomenon in the Williston basin (Price and Le Fever, 1991). The Viola Group reservoirs that rely on fractures are self-sealed by the limits of propagation, although the Sylvan Shale serves as an auxiliary regional seal. The Sylvan Shale (Fig. 2) is described as a widespread green to greenish-gray shale in
the Oklahoma basin that ranges in thickness from 300-400 ft in the aulacogen to 200-200 feet in the shelf areas (Johnson and Cardot, 1992). The locally abundant graptolites and chitinozoans, and well-developed lamina-
tions, have been used to infer a depositional environment in a deep-water setting (Ham, 1969). The potential for this unit to have acted as a source rock is generally con-
sidered poor to marginal (Burress and Hatch, 1989), although the unit has not been extensively studied.

Although a complete discussion of the structural evolu-
tion is beyond the scope of this paper, the aim of this study is to establish the relationship between deformation and the generation-expulsion event. Time-slice analysis (Wavrek and Barker, 1988) of the basin model indicates that the critical moment of the Viola (!) Petroleum System occurred near the end of the Arbuckle deformation event (Fig. 15). The critical moment (Magoon and Dow, 1994) represents the geologic moment during which the bulk of the hydrocarbons in the petroleum system experienced generation—migration—accumulation. Thus, it is important to recognize that the region had experienced significant tectonic deformation (Fig. 16) prior to the critical moment. The fault sys-
tems had the negative effect of limiting the source-rock drainage volume, but they contributed to the trapping mechanism of associated folds and faults and propagated the fractures within the reservoir units. Collectively, these events account for the relatively small fields that have been developed in the Viola (!) Petroleum System. By identifying the region in which the positive elements of the petroleum system overlap, a fairway is defined (Fig. 17) that will be associated with reduced risk. The lower risk is attributed to the combined factors of increased source rock volume (Fig. 12), organic richness (Fig. 13), adequate thermal stress (Figs. 14, 15), and tec-
tonic activity to promote the development of traps with fractured reservoirs (Fig. 16). The hydrocarbon resources in this fairway appear to be excellent candidates for exploitation with a minimal number of horizontal wells oriented perpendicular to the dominant fracture pattern.

CONCLUSIONS

The Viola (!) Petroleum System can be developed with a minimal number of horizontal wells within a defined fairway. The exploitation model encompasses source-rock volume, organic richness, thermal stress, and tectonic activity to reduce exploration risk. The critical moment is defined to be 290 Ma; this period followed regional tectonic deformation. The fault network limited the source-rock drainage volume but contributed to the trap and reservoir configuration. The hydrocarbons within the Viola (!) Petroleum System are associated with a dilute kukersite chemistry to reflect the diverse assem-
blage of organisms that contributed to source facies.

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Figure 17. Fairway of opportunity (horizontal lines) for horizontal drilling targets in the Viola (f) Petroleum System.


