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Technically Recoverable Shale Oil and Shale Gas Resources:

Other Eastern Europe

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Executive Summary

Introduction

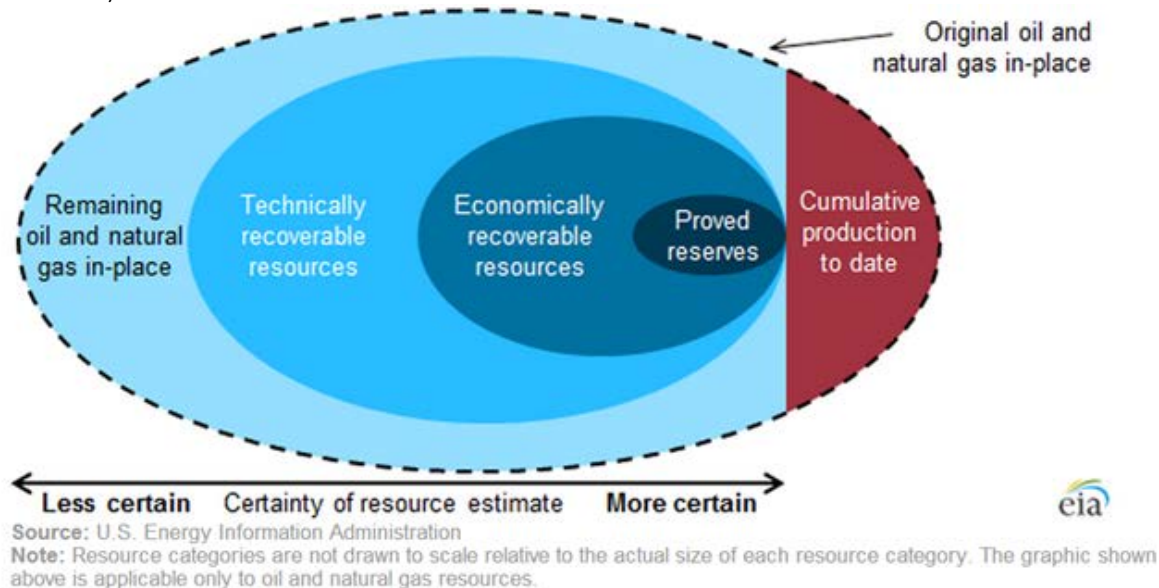
Although the shale resource estimates presented in this report will likely change over time as additional information becomes available, it is evident that shale resources that were until recently not included in technically recoverable resources constitute a substantial share of overall global technically recoverable oil and natural gas resources. This chapter is from the 2013 EIA world shale report [Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States](#).

Resource categories

When considering the market implications of abundant shale resources, it is important to distinguish between a technically recoverable resource, which is the focus of this supplement as in the 2013 report, and an economically recoverable resource. Technically recoverable resources represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs. Economically recoverable resources are resources that can be profitably produced under current market conditions. The economic recoverability of oil and gas resources depends on three factors: the costs of drilling and completing wells, the amount of oil or natural gas produced from an average well over its lifetime, and the prices received for oil and gas production. Recent experience with shale gas and tight oil in the United States and other countries suggests that economic recoverability can be significantly influenced by above-the-ground factors as well as by geology. Key positive above-the-ground advantages in the United States and Canada that may not apply in other locations include private ownership of subsurface rights that provide a strong incentive for development; availability of many independent operators and supporting contractors with critical expertise and suitable drilling rigs and, preexisting gathering and pipeline infrastructure; and the availability of water resources for use in hydraulic fracturing. See Figure 1.

Figure 1. Stylized representation of oil and natural gas resource categorizations

(not to scale)



Crude oil and natural gas resources are the estimated oil and natural gas volumes that might be produced at some time in the future. The volumes of oil and natural gas that ultimately will be produced cannot be known

ahead of time. Resource estimates change as extraction technologies improve, as markets evolve, and as oil and natural gas are produced. Consequently, the oil and gas industry, researchers, and government agencies spend considerable time and effort defining and quantifying oil and natural gas resources.

For many purposes, oil and natural gas resources are usefully classified into four categories:

- Remaining oil and gas in-place (original oil and gas in-place minus cumulative production at a specific date)
- Technically recoverable resources
- Economically recoverable resources
- Proved reserves

The oil and natural gas volumes reported for each resource category are estimates based on a combination of facts and assumptions regarding the geophysical characteristics of the rocks, the fluids trapped within those rocks, the capability of extraction technologies, and the prices received and costs paid to produce oil and natural gas. The uncertainty in estimated volumes declines across the resource categories (see figure above) based on the relative mix of facts and assumptions used to create these resource estimates. Oil and gas in-place estimates are based on fewer facts and more assumptions, while proved reserves are based mostly on facts and fewer assumptions.

Remaining oil and natural gas in-place (original oil and gas in-place minus cumulative production). The volume of oil and natural gas within a formation before the start of production is the original oil and gas in-place. As oil and natural gas are produced, the volumes that remain trapped within the rocks are the remaining oil and gas in-place, which has the largest volume and is the most uncertain of the four resource categories.

Technically recoverable resources. The next largest volume resource category is technically recoverable resources, which includes all the oil and gas that can be produced based on current technology, industry practice, and geologic knowledge. As technology develops, as industry practices improve, and as the understanding of the geology increases, the estimated volumes of technically recoverable resources also expand.

The geophysical characteristics of the rock (e.g., resistance to fluid flow) and the physical properties of the hydrocarbons (e.g., viscosity) prevent oil and gas extraction technology from producing 100% of the original oil and gas in-place.

Economically recoverable resources. The portion of technically recoverable resources that can be profitably produced is called economically recoverable oil and gas resources. The volume of economically recoverable resources is determined by both oil and natural gas prices and by the capital and operating costs that would be incurred during production. As oil and gas prices increase or decrease, the volume of the economically recoverable resources increases or decreases, respectively. Similarly, increasing or decreasing capital and operating costs result in economically recoverable resource volumes shrinking or growing.

U.S. government agencies, including EIA, report estimates of technically recoverable resources (rather than economically recoverable resources) because any particular estimate of economically recoverable resources is tied to a specific set of prices and costs. This makes it difficult to compare estimates made by other parties using different price and cost assumptions. Also, because prices and costs can change over relatively short periods, an estimate of economically recoverable resources that is based on the prevailing prices and costs at a particular time can quickly become obsolete.

Proved reserves. The most certain oil and gas resource category, but with the smallest volume, is proved oil and gas reserves. Proved reserves are volumes of oil and natural gas that geologic and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. Proved reserves generally increase when new production wells are drilled and decrease when existing wells are produced. Like economically recoverable resources, proved reserves shrink or grow as prices and costs change. The U.S. Securities and Exchange Commission regulates the reporting of company financial assets, including those proved oil and gas reserve assets reported by public oil and gas companies.

Each year EIA updates its report of proved U.S. oil and natural gas reserves and its estimates of unproved technically recoverable resources for shale gas, tight gas, and tight oil resources. These reserve and resource estimates are used in developing EIA's [Annual Energy Outlook](#) projections for oil and natural gas production.

- Proved oil and gas reserves are reported in EIA's [U.S. Crude Oil and Natural Gas Proved Reserves](#).
- Unproved technically recoverable oil and gas resource estimates are reported in EIA's [Assumptions](#) report of the Annual Energy Outlook. Unproved technically recoverable oil and gas resources equal total technically recoverable resources minus the proved oil and gas reserves.

Over time, oil and natural gas resource volumes are reclassified, going from one resource category into another category, as production technology develops and markets evolve.

Additional information regarding oil and natural gas resource categorization is available from the [Society of Petroleum Engineers](#) and the [United Nations](#).

Methodology

The shale formations assessed in this supplement as in the previous report were selected for a combination of factors that included the availability of data, country-level natural gas import dependence, observed large shale formations, and observations of activities by companies and governments directed at shale resource development. Shale formations were excluded from the analysis if one of the following conditions is true: (1) the geophysical characteristics of the shale formation are unknown; (2) the average total carbon content is less than 2 percent; (3) the vertical depth is less than 1,000 meters (3,300 feet) or greater than 5,000 meters (16,500 feet), or (4) relatively large undeveloped oil or natural gas resources.

The consultant relied on publicly available data from technical literature and studies on each of the selected international shale gas formations to first provide an estimate of the “risked oil and natural gas in-place,” and then to estimate the unproved technically recoverable oil and natural gas resource for that shale formation. This methodology is intended to make the best use of sometimes scant data in order to perform initial assessments of this type.

The risked oil and natural gas in-place estimates are derived by first estimating the volume of in-place resources for a prospective formation within a basin, and then factoring in the formation's success factor and recovery factor. The success factor represents the probability that a portion of the formation is expected to have attractive oil and natural gas flow rates. The recovery factor takes into consideration the capability of current technology to produce oil and natural gas from formations with similar geophysical characteristics. Foreign shale oil recovery rates are developed by matching a shale formation's geophysical characteristics to U.S. shale oil analogs. The resulting estimate is referred to as both the risked oil and natural gas in-place and the technically recoverable resource. The specific tasks carried out to implement the assessment include:

1. Conduct a preliminary review of the basin and select the shale formations to be assessed.

2. Determine the areal extent of the shale formations within the basin and estimate its overall thickness, in addition to other parameters.
3. Determine the prospective area deemed likely to be suitable for development based on depth, rock quality, and application of expert judgment.
4. Estimate the natural gas in-place as a combination of *free gas*¹ and *adsorbed gas*² that is contained within the prospective area. Estimate the oil in-place based on pore space oil volumes.
5. Establish and apply a composite success factor made up of two parts. The first part is a formation success probability factor that takes into account the results from current shale oil and shale gas activity as an indicator of how much is known or unknown about the shale formation. The second part is a prospective area success factor that takes into account a set of factors (e.g., geologic complexity and lack of access) that could limit portions of the prospective area from development.
6. For shale oil, identify those U.S. shales that best match the geophysical characteristics of the foreign shale oil formation to estimate the oil in-place recovery factor.³ For shale gas, determine the recovery factor based on geologic complexity, pore size, formation pressure, and clay content, the latter of which determines a formation's ability to be hydraulically fractured. The gas phase of each formation includes dry natural gas, associated natural gas, or wet natural gas. Therefore, estimates of shale gas resources in this report implicitly include the light wet hydrocarbons that are typically coproduced with natural gas.
7. Technically recoverable resources⁴ represent the volumes of oil and natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs. Technically recoverable resources are determined by multiplying the risked in-place oil or natural gas by a recovery factor.

Based on U.S. shale production experience, the recovery factors used in this supplement as in the previous report for shale gas generally ranged from 20 percent to 30 percent, with values as low as 15 percent and as high as 35 percent being applied in exceptional cases. Because of oil's viscosity and capillary forces, oil does not flow through rock fractures as easily as natural gas. Consequently, the recovery factors for shale oil are typically lower than they are for shale gas, ranging from 3 percent to 7 percent of the oil in-place with exceptional cases being as high as 10 percent or as low as 1 percent. The consultant selected the recovery factor based on U.S. shale production recovery rates, given a range of factors including mineralogy, geologic complexity, and a number of other factors that affect the response of the geologic formation to the application of best practice shale gas recovery technology. Because most shale oil and shale gas wells are only a few years old, there is still considerable uncertainty as to the expected life of U.S. shale wells and their ultimate recovery. The recovery rates used in this analysis are based on an extrapolation of shale well production over 30 years. Because a shale's geophysical characteristics vary significantly throughout the formation and analog matching is never exact, a shale formation's resource potential cannot be fully determined until extensive well production tests are conducted across the formation.

Key exclusions

In addition to the key distinction between technically recoverable resources and economically recoverable resources that has been already discussed at some length, there are a number of additional factors outside of the scope of this report that must be considered in using its findings as a basis for projections of future

¹ Free gas is natural gas that is trapped in the pore spaces of the shale. Free gas can be the dominant source of natural gas for the deeper shales.

² Adsorbed gas is natural gas that adheres to the surface of the shale, primarily the organic matter of the shale, due to the forces of the chemical bonds in both the substrate and the natural gas that cause them to attract. Adsorbed gas can be the dominant source of natural gas for the shallower and higher organically rich shales.

³ The recovery factor pertains to percent of the original oil or natural gas in-place that is produced over the life of a production well.

⁴ Referred to as risked recoverable resources in the consultant report.

production. In addition, several other exclusions were made for this supplement as in the previous report to simplify how the assessments were made and to keep the work to a level consistent with the available funding.

Some of the key exclusions for this supplement as in the previous report include:

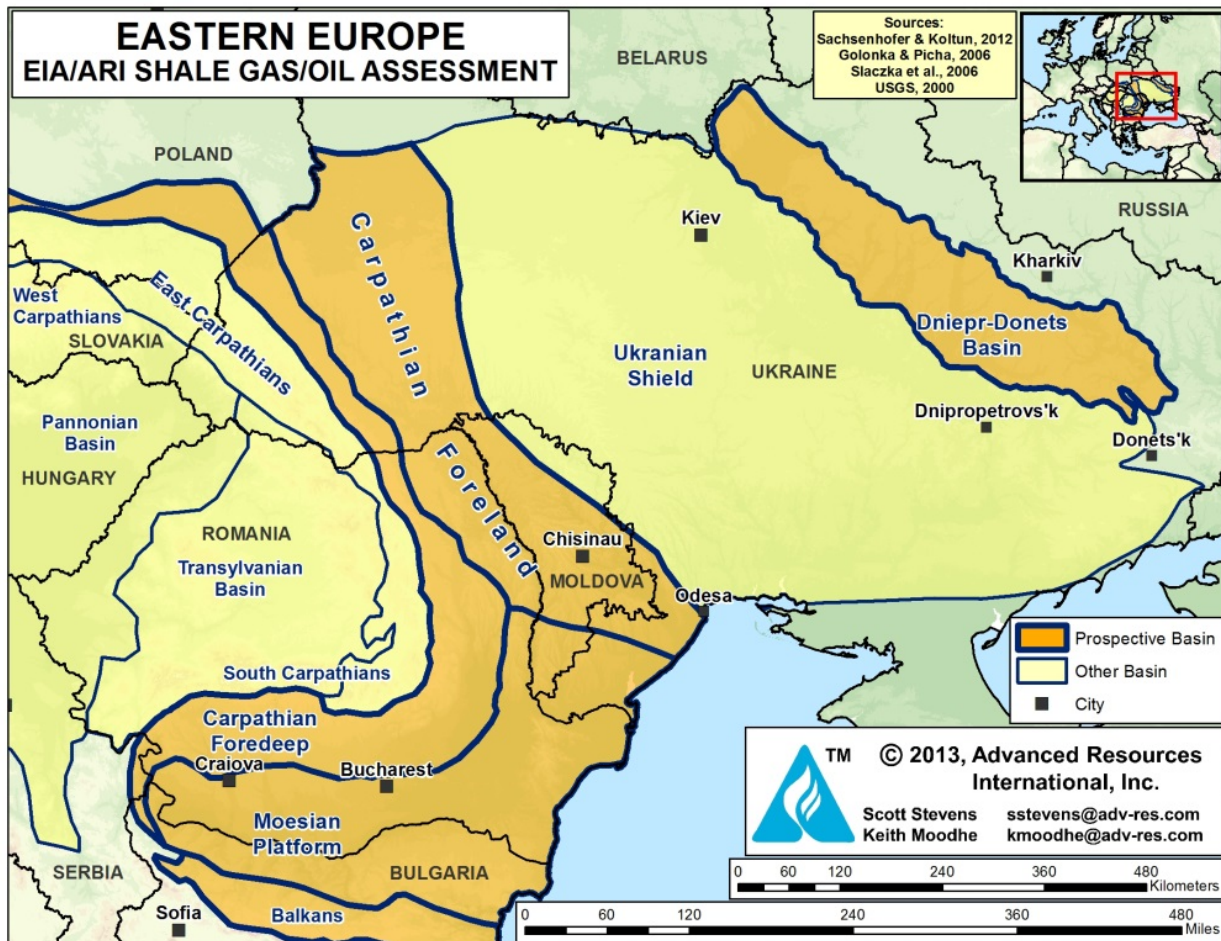
1. **Tight oil produced from low permeability sandstone and carbonate formations** that can often be found adjacent to shale oil formations. Assessing those formations was beyond the scope of this supplement as in the previous report.
2. **Coalbed methane and tight natural gas** and other natural gas resources that may exist within these countries were also excluded from the assessment.
3. **Assessed formations without a resource estimate**, which resulted when data were judged to be inadequate to provide a useful estimate. Including additional shale formations would likely increase the estimated resource.
4. **Countries outside the scope of the report**, the inclusion of which would likely add to estimated resources in shale formations. It is acknowledged that potentially productive shales exist in most of the countries in the Middle East and the Caspian region, including those holding substantial non-shale oil and natural gas resources.
5. **Offshore portions of assessed shale oil** and shale gas formations were excluded, as were shale oil and shale gas formations situated entirely offshore.

X. EASTERN EUROPE (BULGARIA, ROMANIA, UKRAINE)

SUMMARY

Eastern Europe (ex. Poland, assessed separately) has significant prospective shale gas and oil resources in three sedimentary basins: the Dniepr-Donets Basin, the Carpathian Foreland Basin, and the Moesian Platform, Figure X-1. Shale exploration is underway in Ukraine and Romania, while Bulgaria currently has a moratorium on shale development.

Figure X-1: Prospective Shale Basins of Eastern Europe



Source: ARI, 2013.

The total risked, technically recoverable shale resource potential for the three basins is estimated at 195 Tcf of shale gas and 1.6 billion barrels of shale oil and condensate, Tables X-1 and X-2. Our new, larger interpretation of the shale resource is based on recent shale leasing, drilling, and seismic activities that were stimulated in part by the 2011 EIA/ARI study.

Table X-1: Shale Gas Reservoir Properties and Resources, Eastern Europe.

Basic Data	Basin/Gross Area	Carpathian Foreland (70,000 mi ²)	Dniepr-Donets (23,200 mi ²)			Moesian Platform (45,000 mi ²)			
	Shale Formation	L. Silurian	L. Carboniferous			L. Silurian	Etopole		
	Geologic Age	L. Silurian	L. Carboniferous			L. Silurian	L. Jurassic		
	Depositional Environment	Marine	Marine			Marine		Marine	
Physical Extent	Prospective Area (mi ²)	16,080	1,460	2,680	6,010	840	760	7,940	
	Thickness (ft)	Organically Rich	1,000	700	700	700	600	600	650
		Net	400	350	350	350	450	450	260
	Depth (ft)	Interval	3,300 - 16,400	3,300 - 16,400	3,300 - 16,400	3,300 - 16,400	6,600 - 16,400	13,000 - 16,400	5,000 - 16,400
Average		10,000	11,000	12,000	13,000	11,000	14,000	10,000	
Reservoir Properties	Reservoir Pressure	Normal	Normal	Mod. Overpress.	Mod. Overpress.	Normal	Normal	Highly Overpress.	
	Average TOC (wt. %)	2.0%	4.5%	4.5%	4.5%	3.0%	3.0%	3.0%	
	Thermal Maturity (% Ro)	2.50%	0.90%	1.15%	2.00%	1.15%	2.00%	1.15%	
	Clay Content	Medium	Low	Low	Low	Medium	Medium	Medium	
Resource	Gas Phase	Dry Gas	Assoc. Gas	Wet Gas	Dry Gas	Wet Gas	Dry Gas	Wet Gas	
	GIP Concentration (Bcf/mi ²)	112.7	49.2	118.5	195.2	121.9	154.4	106.7	
	Risked GIP (Tcf)	362.5	14.4	63.5	234.6	22.5	25.8	148.2	
	Risked Recoverable (Tcf)	72.5	1.4	15.9	58.6	4.5	5.2	37.1	

Source: ARI 2013.

Table X-2: Shale Oil Reservoir Properties and Resources, Eastern Europe.

Basic Data	Basin/Gross Area	Dniepr-Donets (23,200 mi ²)		Moesian Platform (45,000 mi ²)		
	Shale Formation	L. Carboniferous		L. Silurian	Etopole	
	Geologic Age	L. Carboniferous		L. Silurian	L. Jurassic	
	Depositional Environment	Marine		Marine	Marine	
Physical Extent	Prospective Area (mi ²)	1,460	2,680	840	7,940	
	Thickness (ft)	Organically Rich	700	700	600	650
		Net	350	350	450	260
	Depth (ft)	Interval	3,300 - 16,400	3,300 - 16,400	6,600 - 16,400	5,000 - 16,400
Average		11,000	12,000	11,000	10,000	
Reservoir Properties	Reservoir Pressure	Normal	Mod. Overpress.	Normal	Highly Overpress.	
	Average TOC (wt. %)	4.5%	4.5%	3.0%	3.0%	
	Thermal Maturity (% Ro)	0.90%	1.15%	1.15%	1.15%	
	Clay Content	Low	Low	Medium	Medium	
Resource	Oil Phase	Oil	Condensate	Condensate	Condensate	
	OIP Concentration (MMbbl/mi ²)	45.3	18.1	8.9	5.0	
	Risked OIP (B bbl)	13.2	9.7	1.6	7.9	
	Risked Recoverable (B bbl)	0.66	0.48	0.08	0.40	

Source: ARI 2013.

The main shale targets in Eastern Europe are marine-deposited black shales within the Lower Carboniferous of the Dniepr-Donets Basin (TRR of 76 Tcf and 1.2 billion barrels); the Silurian of the Carpathian Foreland Basin (73 Tcf); and the Silurian and Jurassic Etropole shale deposits of the Moesian Platform (47 Tcf and 0.5 billion barrels). By country, the estimates are Ukraine (128 Tcf and 1.2 billion barrels); Romania (51 Tcf and 0.3 billion barrels); and Bulgaria (17 Tcf and 0.2 billion barrels). Compared with North America, the shale geology of Eastern Europe is more complex, although faulting appears less prevalent than in other parts of Europe.

Shale resource assessments are reported to be underway in Ukraine, Romania, and Bulgaria but no official assessments have been published yet. To date only one shale-focused exploration core well has been drilled in the region (Bulgaria); no production testing has occurred. In Ukraine, Shell recently signed a Production Sharing Agreement in the Dniepr-Donets Basin, committing at least \$200 million for exploration, while Chevron reportedly has been negotiating for a block in the Ukraine portion of the Carpathian Foreland Basin. Chevron's previously awarded shale blocks in Romania and Bulgaria have been put on hold.

INTRODUCTION

Since EIA/ARI's initial shale assessment first defined the potential in 2011, several Eastern European countries have begun to investigate their shale gas/ and shale oil resource potential. International oil and gas companies, including Chevron and Shell, have negotiated shale exploration licenses in Bulgaria, Romania, and Poland. The countries of Eastern Europe are taking various approaches to shale exploration. Ukraine currently welcomes shale investment. On the other hand, Bulgaria and Romania have placed shale exploration on hold, after initially proceeding with shale leasing.

Ukraine. The Ukraine State Service of Geology and Mineral Resources (Gosgeonedra) has announced shale gas resources in the country of 7 trillion m³ (Tm³) or 247 Tcf.¹ However, the basis for this estimate has not been released and the figure includes some tight gas resources. The newly created Geological Research and Production Center in Poltava plans to coordinate shale gas studies in Ukraine, while monitoring water quality in drilling areas. Ukraine's current Production Sharing Agreement (PSA) involves a 5-year exploration period and up to 45 years for development. Tender fees are modest: \$60,000 for the tender and \$10,000 for the geologic information package.

On February 23, 2012 the Ukraine government announced a tender for shale exploration and development in the Oleska and Yuzovska blocks of western and eastern Ukraine, respectively. Shell, ExxonMobil, Chevron, ENI, and TNK-BP initially responded to the tender. In January 2013, Ukraine awarded the first shale gas PSA, signing with Shell at the World Economic Forum in Davos, Switzerland. Shell's 50-year PSA permit at Yuzovska in the eastern Dniepr-Donets Basin covers an area of 7,886 km² and assigns oil and gas rights to all strata to a depth of 10 km, including tight and basin-centered gas. The contract allows for 70% investor recovery and a 16.5% government revenue share.

Chevron has been in negotiations with the government for a PSA at the Oleska field in western Ukraine. This block is along strike with Poland's Lublin basin, where Chevron already holds shale licenses. Duration and terms likely would be similar to those granted to Shell.

Bulgaria. While the country lacks a shale-specific investment regime, Bulgaria's conventional oil and gas production terms are attractive. Production licenses extend for 35 years, with royalties ranging from 2.5% to 30% on a sliding scale, with a 10% corporate income tax. The Economy and Energy Minister has suggested that Bulgaria's shale gas resources could be in the range of 0.3 to 1.0 Tm³ (11 to 35 Tcf), but no supporting study has been released. The Shale Gas Research Group, a newly formed consortium of Sofia University and Bulgaria's Institutes of Geology and Organic Chemistry, is conducting long-term studies of organic-rich shale deposits in Bulgaria.²

However, during the past year public opposition to shale gas development has increased dramatically in Bulgaria. This opposition has been led by environmental organizers, with no effective counter-balancing information campaign offered by the petroleum industry or the government, such as exists in Poland. In January 2012 the government banned all shale gas exploration and production, whether or not it involves hydraulic fracturing. The performance of the shale industry in Poland and the UK is expected to influence the future political acceptance and government policies in Romania and Bulgaria.³

Romania. Romania also recently banned shale gas exploration and production, although some local observers believe its ban would be easier to reverse than Bulgaria's. In May 2012 the newly elected Romanian government began an informal (i.e., not legislated) ban on shale gas exploration activities, pending the outcome of European-level studies on the health, safety, and environmental aspects of shale gas development.

Romania lacks specific regulations for shale gas development, thus shale applications fall under the country's conventional petroleum terms. In 2011 the National Agency for Mineral Resources, which regulates petroleum operations in Romania, initiated a study of the country's shale gas deposits, in cooperation with the national research institute GeoEcoMar and three universities (Bucharest, Iasi and Cluj). No further details are available.

More than a dozen companies have expressed interest in shale gas exploration in Romania. Beginning in March 2012 Chevron was awarded four shale gas exploration licenses totaling 9,000 km², three blocks located in Dobruja and one in the Moldova region. Hungary's MOL was awarded three shale gas permits in northwestern Romania (Voivozi, Adea, and Curtici). Sterling Resources and partner TransAtlantic Petroleum jointly hold the 5,800-km² Sud Craiova license of southwest Romania. Finally, state-owned energy firm Romgaz reported that it discovered shale gas resources in 5 out of 20 of its exploration wells in Transylvania, noting that it had applied hydraulic fracturing technology in Romania as early as the mid-1990's. All of these projects are on hold due to Romania's shale ban.

GEOLOGIC OVERVIEW

Eastern Europe has three distinct shale-prospective areas with shale gas and oil potential in Paleozoic and Mesozoic marine-deposited black shales. Within the Paleozoic, the Carboniferous and Silurian black shales are most prospective, while the mid-Jurassic shales are most prospective for oil and gas within the Mesozoic. Other organic-rich shales exist locally but these tend to be less widespread and/or are thermally less mature, and thus were not assessed.

- **Carpathian Foreland Basin.** The moderately complex Lviv-Volyn Basin of western Ukraine is similar to the Lublin Basin in southeast Poland. However, the Silurian black shale belt becomes structurally simpler as it trends towards the southeast across southwestern Ukraine and northern Romania until it reaches the Black Sea. This deep Paleozoic belt north of the Carpathian Foldbelt is called the Carpathian Foreland Basin.
- **Dniepr-Donets Basin.** This well-defined Late Paleozoic basin in eastern Ukraine and southern Belarus contains prospective organic-rich L. Carboniferous black shales.
- **Moesian Platform.** Silurian and Jurassic black shales are present across Romania and Bulgaria. Note that the Moesian Platform shale plays are less well defined than the previous two plays and may be considerably larger than assessed here.

Other basins in Eastern Europe contain organic-rich source rock shales but these were deemed to be less prospective. The large Pannonian-Transylvanian basin of Hungary, Romania, Serbia and Montenegro, Slovenia, and Bosnia and Herzegovina has Paleozoic shale which appears too deep for shale development. The Carpathian, Balkan, and related fold belts appear much too structurally complex to be prospective.

1. CARPATHIAN FORELAND BASIN (UKRAINE-ROMANIA-MOLDOVA)

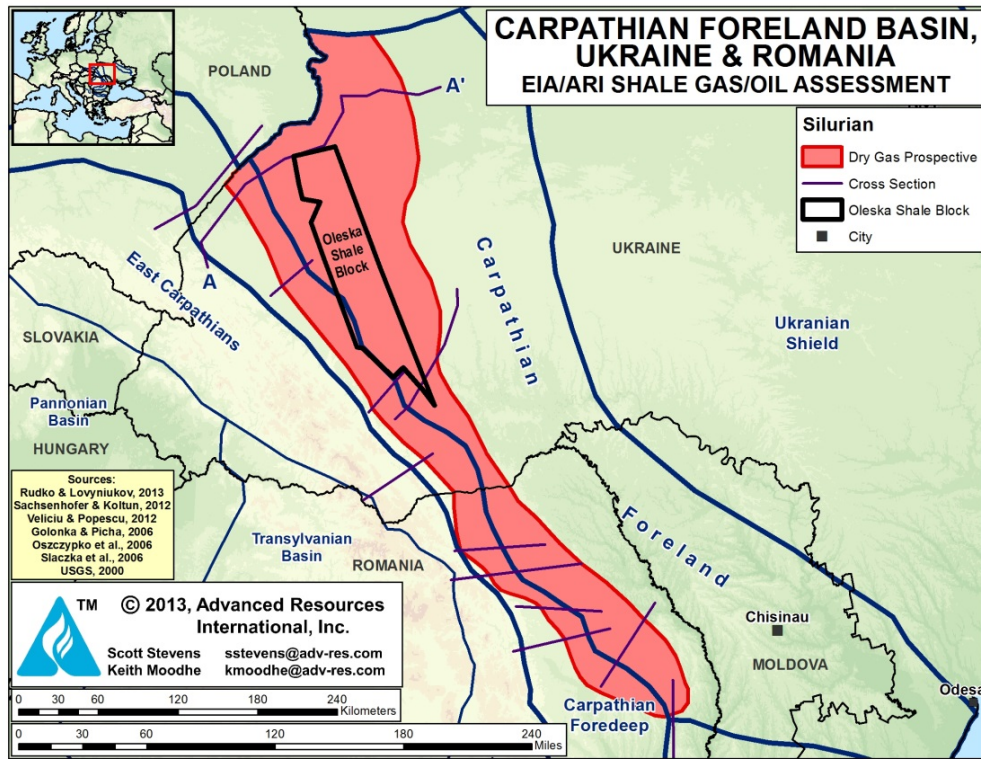
1.1 Introduction and Geologic Setting

Prospective marine black shales of Silurian age extend continuously within a 50- to 200- km wide Paleozoic belt, from Poland all the way to the Black Sea. In western Ukraine, Silurian deposits of southeast Poland's Lublin Basin continue into the adjoining Lviv-Volyn Basin, where 62 conventional oil and gas fields have been developed. Much of the Lviv-Volyn Basin appears to be too deep and faulted for shale development.

However, the Silurian belt becomes wider and structurally simpler as it continues further to the southeast across western Ukraine and northern Romania, Figure X-2. After some tectonic disturbance, the Silurian belt re-enters southern Ukraine and eastern Romania in the Scythian Platform before heading out into the Black Sea. It then briefly re-emerges onto land on the Crimean Peninsula near Odessa before continuing offshore. The North Dobrogea Orogen separates this belt from the Silurian of the Moesian Platform to the south⁴, which was separately assessed. We refer to the Silurian belt as the Carpathian Foreland Basin, but other researchers have named it the Lviv-Moldava Slope.⁵

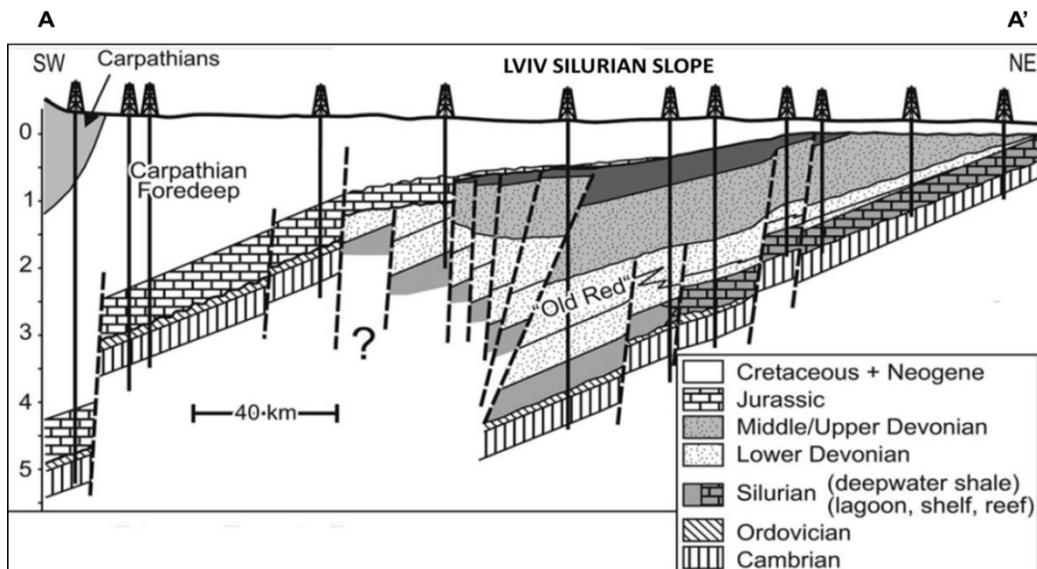
The Carpathian Foreland Basin has good shale gas development potential in Silurian black shales. As the foreland basin to the Carpathian thrust belt, this shale belt dips gently to the southwest and is characterized by mostly simple structure with few faults, Figure X-3. Further to the south, the structurally complex Carpathian region also contains multiple rich marine source rocks. These include the 500-m thick Jurassic Kokhanivka Formation with up to 12% TOC, the 200-m thick L. Cretaceous Spas and Shypot formations with 2-7% TOC, and the Oligo-Miocene Lower Menilite Formation with up to 20% TOC. However, the Carpathian region is intensely faulted with complex nappe tectonics, Figure X-4,^{6,7} and was not assessed.

Figure X-2: Carpathian Foreland Basin Showing Shale-Prospective Areas.



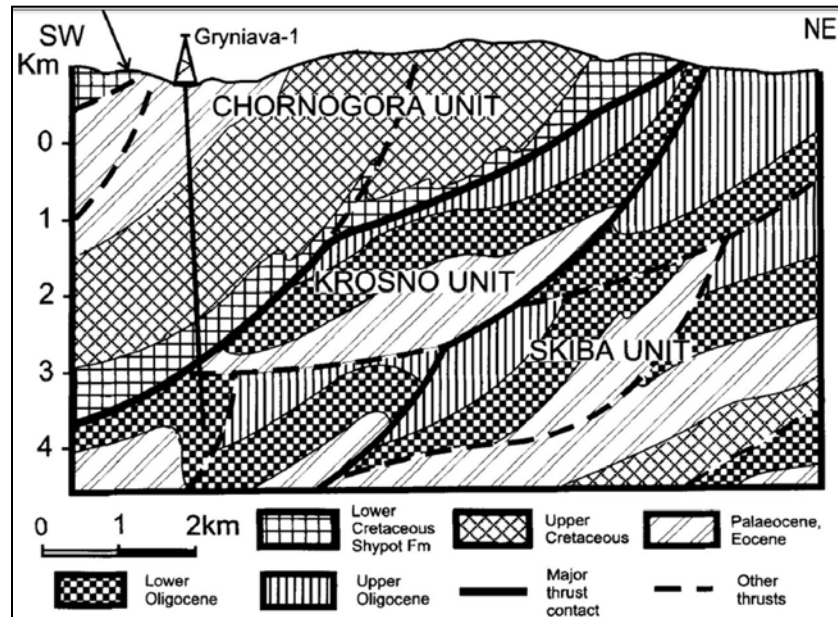
Source: ARI 2013

Figure X-3: Cross-Section of Lviv Slope Portion of the Carpathian Foreland Basin in Western Ukraine



Source: Sachsenhofer et al., 2012

Figure X-4: Cross-Section of a Nappe Structure in the Carpathian Thrust Belt

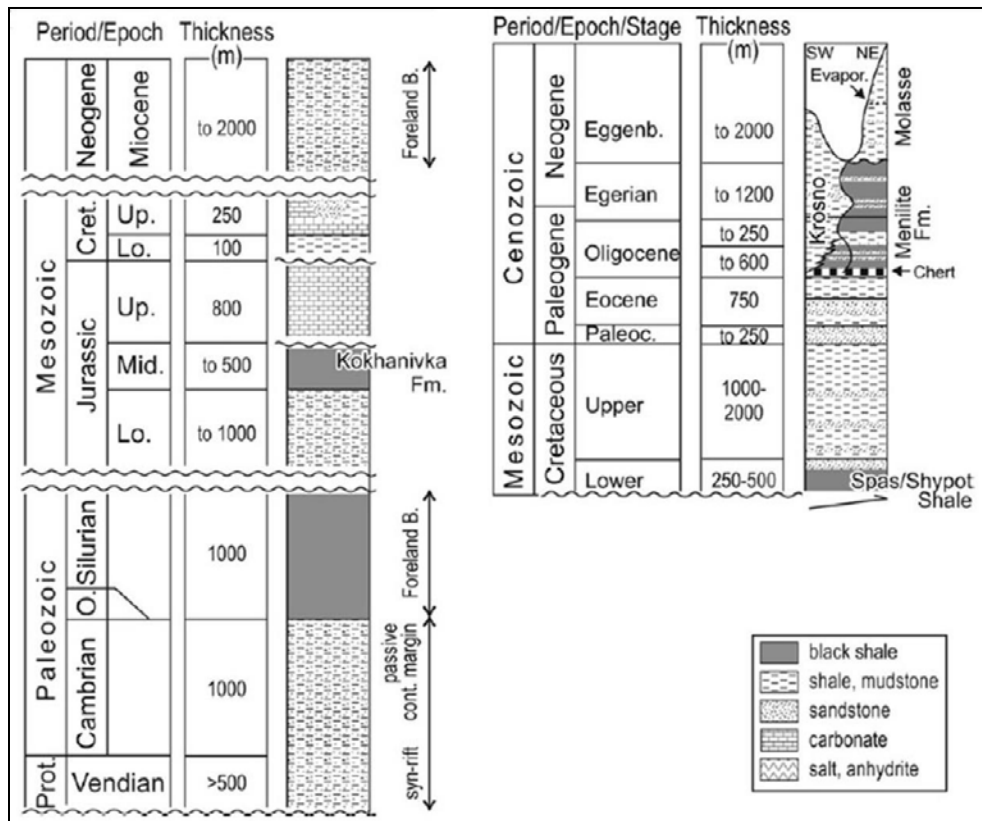


Source: Koltun et al., 1998

The Silurian is the main petroleum source rock and shale gas exploration targets in the Carpathian Foreland Basin, Figure X-5. Compared with Poland, the reservoir characteristics of the Silurian shale in western Ukraine are less certain. About 400 to 1,000 m of deep-water Silurian shale is present, transitioning eastward into thinner, shallow-water carbonates. The Ludlow member of the Silurian is considered the most prospective interval. The Ludlow ranges from 400 to 600 m thick and occurs at depths of 2 to 3 km in western Ukraine.

Silurian shale TOC may be lower in Ukraine than in Poland, at least based on the single well data point available (IS-1). Most TOC measurements at a depth range of 1,400 to 1,592 m in this well were less than 1%. However, the original TOC is estimated at 3% prior to thermal alteration. Given the depositional environmental of the Silurian, it is likely that higher TOC exists in places. Thermal maturity mapping, calculated from conodont alternation index, indicates the Silurian is entirely in the dry gas window (R_o of 1.3% to 3.5%). Several (possibly spurious) over-mature values of 5% R_o also were measured. Maturation is believed to have occurred prior to the Mesozoic. As Sachsenhofer and Koltun (2012) noted: “additional investigations are needed to investigate lateral and vertical variations of TOC contents and refine the maturity patterns in Lower Paleozoic rocks.”

Figure X-5: Stratigraphy of Carpathian Foreland Basin Showing Thick Black Shales of Silurian and Mid-Jurassic-Age (left). L. Cretaceous and Paleogene Source Rocks Occur in the Carpathians (right).



Source: Sachsenhofer et al., 2012

The Kovel-1 petroleum well is a key stratigraphic test drilled during the late 1980s in western Volynia, northwestern Ukraine. The well is located along the transition between the structurally complex Lublin-Lviv basins on the west and the less deformed Volynia region of the Slope. The Kovel-1 well cored Ordovician at a depth of about 250 m; Silurian apparently had been eroded in this uplifted location.⁸

1.2 Reservoir Properties (Prospective Area)

Based on geologic control from regional cross-sections, the total estimated shale gas prospective area in the Carpathian Foreland Basin is estimated to be approximately 16,080 mi², of which 11,520 mi² is in Ukraine and 4,560 mi² in Romania. The target organic-rich portion of the 500-m thick Ludlow Member of the Silurian is estimated to average 1,000 ft thick gross and 10,000 ft deep within the prospective region, and have 4% porosity. TOC averages a relatively

low 2.0% and is in the dry gas window (R_o average 2.5%). The pressure gradient is assumed to be hydrostatic (0.43 psi/ft).

1.3 Resource Assessment

Risked, technically recoverable resources from Silurian black shale in the Carpathian Foreland Basin are estimated to be 73 Tcf (52 Tcf in Ukraine and 21 Tcf in Romania), out of a risked shale gas in-place of 363 Tcf, Table X-1. The play has a moderately high resource concentration of about 113 Bcf/mi², reflecting the significant thickness of the organic-rich shale that is present.

Ukraine's State Commission on Mineral Resources has estimated that the Oleska shale gas license area in the Lviv-Volyn Basin has about 0.8 to 1.5 trillion m³ (28 to 53 Tcf) of shale gas resources. Whether this estimate reflects in-place or recoverable resources was not specified.

An independent assessment of Silurian shale gas resources in the Romanian portion of the Carpathian Foreland Basin arrived at a Mean Estimate of 5.6 Tcf technically recoverable out of 279 Tcf of gas in-place. This estimate utilized EIA/ARI's 2011 methodology, but key assumptions (thickness, porosity, risk) were not specified, nor was Ukraine evaluated.⁹

1.4 Recent Activity

Chevron reportedly is in negotiations with the government to develop a shale gas project in the Oleska block of western Ukraine. The government recently removed its self-imposed deadline of May 2013 for completing this deal. Chevron also initially acquired the 6,257-km² Barlad shale gas permit in northeastern Romania close to Moldova, but the status of this block is unclear following the shale ban in Romania.

In 2012 ENI acquired half of LLC WestGasInvest, which controls nine unconventional gas licenses totaling 3,800-km² in the Lviv Basin of western Ukraine, which may include shale gas potential. The company and its partners, including UK-based Cadogan Petroleum, plan to spend about \$55 million exploring for shale gas in the Lviv basin from 2012 through 2015.

2. DNEIPR-DONETS BASIN (EAST UKRAINE)

2.1 Introduction and Geologic Setting

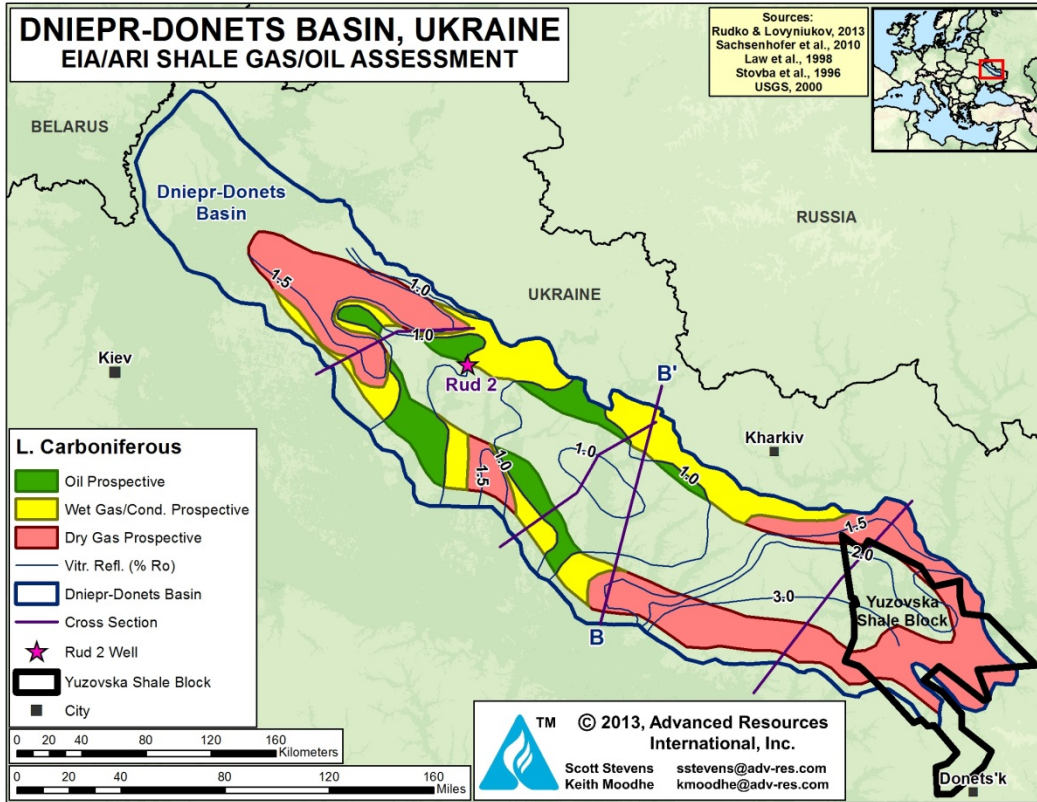
The Dniepr-Donets Basin (DDB) in eastern Ukraine is a Mid-to Late-Devonian failed rift basin on the Eastern European Craton, Figure X-6. The basin contains a thick sequence of Lower Carboniferous black shale which may be prospective for oil and gas development. Economically important Carboniferous coal deposits and tight sands of the Moscovian overlie these shales,¹⁰ but this coaly sequence does not appear to be a prospective shale target.

The DDB accounts for most of Ukraine's onshore petroleum reserves and is comparatively well understood, with several thousand oil and gas wells, some of which reached depths of over 5 km. Lower Carboniferous black shales and coal seams are the main source rocks, while overlying clastic Carboniferous sandstones provide conventional reservoirs within mainly structural traps. To the northwest the DDB continues into the Pripyat Trough of southern Belarus, which appears to be too shallow and low in TOC for shale development. To the southeast the basin continues into the Donbas Foldbelt of southwestern Russia.

Roughly symmetrical, the DDB is about 700 km long, 40 to 70 km wide, and trends northwest-southeast.¹¹ It comprises a series of half grabens bounded by large-displacement faults ($h = 100$ m to 2 km). The individual blocks are quite sizeable (50-100 km by 20-40 km), although numerous smaller faults are locally present. The basin contains as much as 15 km of Devonian and younger sedimentary rocks, which includes 1 to 2 km of mostly Devonian (Frasnian) salt deposited under restricted rift conditions. Figure X-7 is a structural cross-section showing depth to the L. Carboniferous (L. Visian) black shale as well as salt flows in the basin.¹²

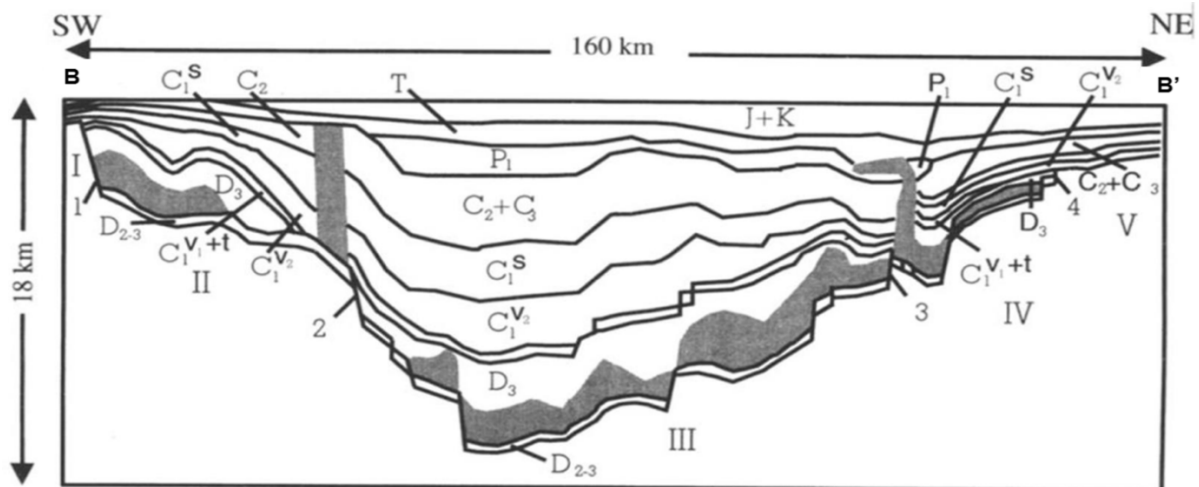
L. Carboniferous black shale overlies the Devonian salt interval. This black shale and the overlying coal seams sourced most of the conventional oil and gas fields in the basin. The entire Carboniferous section ranges up to 11 km thick in the DDB and is up to 15 km deep near its base along the basin axis. In the northwest portion of the DDB the Carboniferous is continental in origin, but transitions into partly shallow marine depositional cycles, each of which is typically 50 m thick and contains an organic-rich shallow marine shale layer.

Figure X-6: Dniepr-Donets Basin Showing Shale-Prospective Areas



Source: ARI, 2013

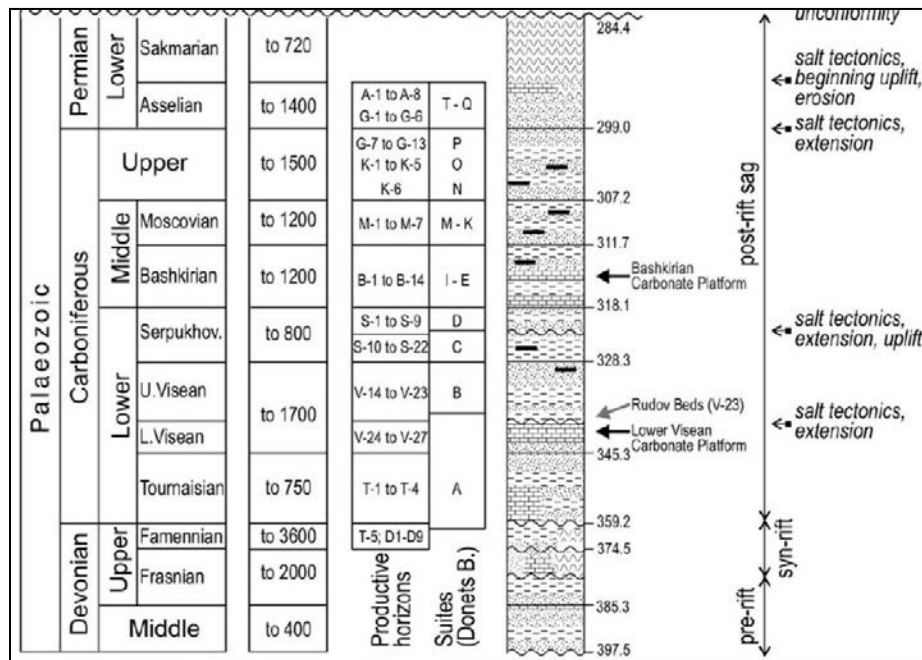
Figure X-7: Cross-Section of Dneipr-Donets Basin Showing Depth to the L. Carboniferous (L. Visian) Black Shale



Source: Stovba et al., 1996

Several black shale targets occur within the L. Carboniferous sequence, Figure 8.¹³ The Upper Visean Rudov Beds are considered the best quality source rock and shale gas target. These black shales are up to 70 m thick, but more typically 30-40 m, and particularly well developed in the Srebnen and Zhdanivske depressions where they are quite deep and dry gas prone. The Rudov Beds are rich in siliceous radiolaria, making them potentially brittle, while the lower part of the formation is high in calcite as well as clay. The organic-rich middle section of the Rudov Beds has 3.0% to 10.7% TOC (average 5%), mostly Type III with some Type II kerogen. Additional slightly leaner (TOC of 3.0% to 3.5%) but still quite prospective source rocks occur in the Upper Visean above the Rudov Beds, while the lower Serpukhovian contains black shales with up to 5% TOC.

Figure X-8: Stratigraphy of Dniepr-Donets Basin. Black shales Occur in L. Carboniferous Rudov and U. Visean.

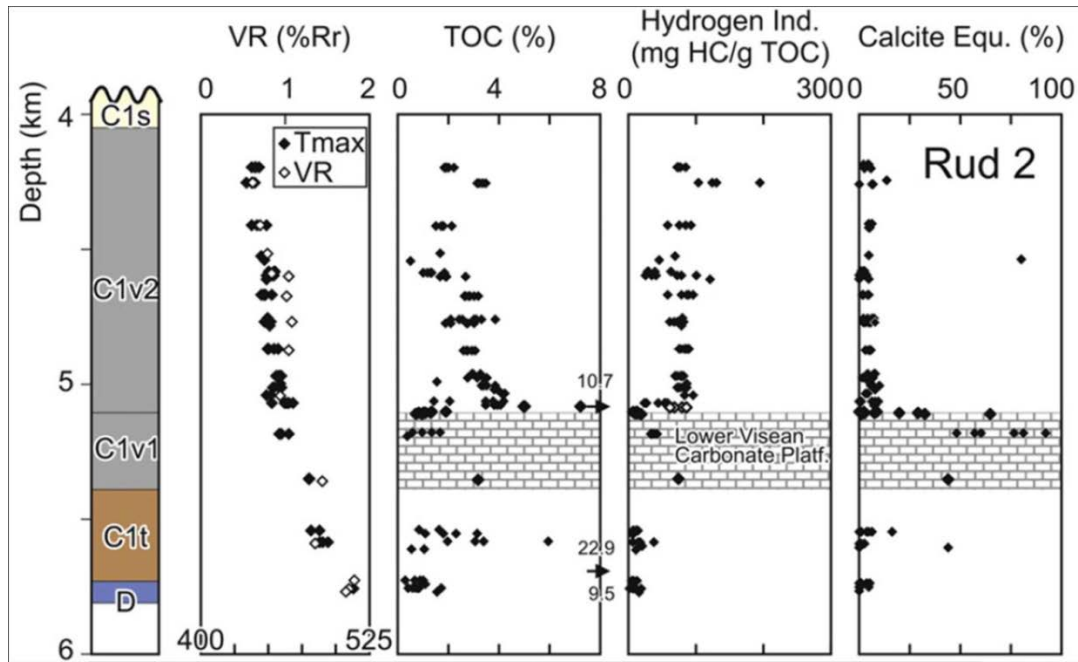


Source: modified from Sachsenhofer et al., 2010

Thermal maturity of the Rudov Beds and the overlying Upper Visean is mainly in the oil window (R_o 0.8-1.0%) in the central and northwestern DDB, increasing to dry gas maturity (R_o 1.3-3.0%) in the southeast. For example, the Rud-2 petroleum well in the Dniepr-Donets Basin penetrated a nearly 1-km thick Carboniferous Upper Visean shale interval at a depth of 4 to 5 km, **Figure X-9**. TOC of up to 4% in this interval is within the oil thermal maturity window (R_o 0.8-1.0%). The oil window in this basin appears to be normally to under-pressured, while the

dry gas window is likely to be over-pressured due to ongoing gas generation, although pressure data control is poor.¹⁴

Figure X-9: Rud-2 Well in the Dniepr-Donets Basin, Showing the Carboniferous Upper Visean Shale (C1v2) with TOC up to 4% in the Oil Window (Ro 0.8 to 1.0%).



Source: Sachsenhofer et al., 2012

The southwest flank of the Dniepr-Donets Basin is characterized by a structurally simple dip slope, where thick L. Carboniferous black shale tilts gently to the NNE towards the basin axis. The L. Carboniferous is at ideal depth for shale development (1-5 km) over a broad belt. The northeast flank of the DDB has thinner L. Carboniferous that is structurally more complex. Lacking a detailed depth map on the Carboniferous, we constrained the depth-prospective area using basement contours and multiple published cross-sections, yielding good control on the prospective area. Note that salt intrusions up to 15 km thick may negatively impact shale potential along various parts of the slope.

2.2 Reservoir Properties (Prospective Area)

Lower Carboniferous black shales (Rudov Beds, Lower Visean, and Lower Serpukhovian) are prospective within a 10,150-mi² depth-controlled belt that surrounds the axis of the Dniepr-Donets Basin. These shales are estimated to total about 1 km in thickness but are relatively deep (3-5 km). They largely consist of siliceous or calcareous lithologies rich in

radiolarian and thus are expected to be brittle with high porosity (6%). Gas recovery rates also should be favorable (30%) due to the inferred frackability of the shale. TOC appears favorable, averaging about 4.5%. Thermal maturity ranges from oil to dry gas. On the negative side, salt intrusions may sterilize some of the mapped prospective area (10%).

2.3 Resource Assessment

Dry Gas Window. The mapped prospective area for the dry shale gas window in southeastern Dniepr-Donets Basin is estimated at 6,010 mi². Lower Carboniferous shale (comprising the Rudov Beds and portions of the overlying Upper Visian) has a highly favorable resource concentration of approximately 195 Bcf/mi². Risked, technically recoverable shale gas resources are estimated to be 59 Tcf, out of a risked shale gas in-place of 235 Tcf.

Wet Gas Window. The wet gas prospective area of the DDB extends over about 2,680 mi². Risked, technically recoverable resources are estimated at 16 Tcf of shale gas and 0.5 billion barrels of condensate from in-place shale gas and shale oil resources of 63 Tcf and 10 billion barrels.

Oil Window. The smaller oil window in the northwestern Dniepr-Donets Basin covers a prospective area of about 1,460 mi². Risked technically recoverable resources are estimated to be about 0.7 billion barrels of shale oil and condensate and 1 Tcf of associated shale gas, out of risked in-place shale oil resources of 13 billion barrels.

Ukraine's State Commission on Mineral Resources has estimated that the Yuzovska shale gas license in the eastern Dniepr-Donets Basin has 2-3 Tm³ (71-107 Tcf) of shale gas and tight gas resources. Whether this estimate reflects in-place or recoverable resources was not specified.

2.4 Recent Activity

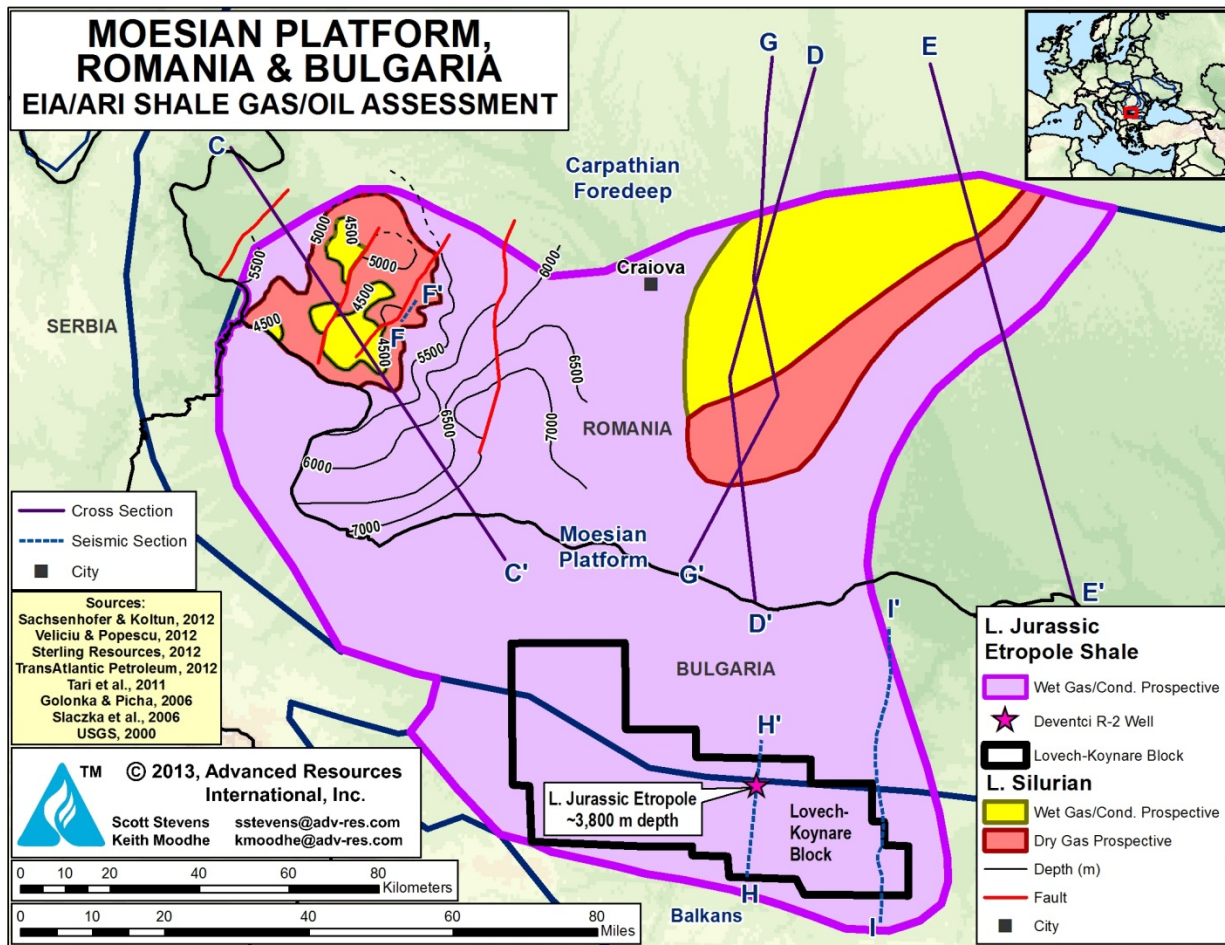
In early 2013 Shell was awarded Ukraine's first formal shale gas exploration license, the 7,800-km² Yuzovska PSA located on the south flank of the Dniepr-Donets Basin. Shell's first-stage investment commitment is \$200 million. Previously in 2011, ENI acquired from Cadogan Petroleum portions of the Zagoryanska and Pokroskoe conventional licenses in the DDB, which may include shale potential.

3. MOESIAN PLATFORM (ROMANIA, BULGARIA)

3.1 Introduction and Geologic Setting

The Moesian Platform is a comparatively simple (for Europe) foreland basin that stretches across southern Romania and north-central Bulgaria, Figure X-10. The Platform is overthrust by the Balkan thrust system to the south, while the Carpathian thrust system forms the northern boundary; both are Cenozoic features related to Alpine tectonics. To the east, the Moesian Platform is separated from the Carpathian Foreland Basin and on the north by the North Dobrogea Orogen. The adjacent Getic Basin of Romania, the foreland of the South Carpathians, contains similar source rocks but is more deformed by Tertiary tectonic events and considered less prospective.

Figure X-10: Moesian Platform Region Showing Shale-Prospective Areas.



Source: ARI 2013

Up to 12 km of mostly flat-lying, carbonate-rich Paleozoic and Mesozoic sedimentary rocks are present on the Moesian Platform, Figure X-11. The relatively few conventional oil and gas fields that have been discovered in this region produce mainly from mid-Triassic dolomite and occasionally from basal Jurassic sandstone.^{15,16}

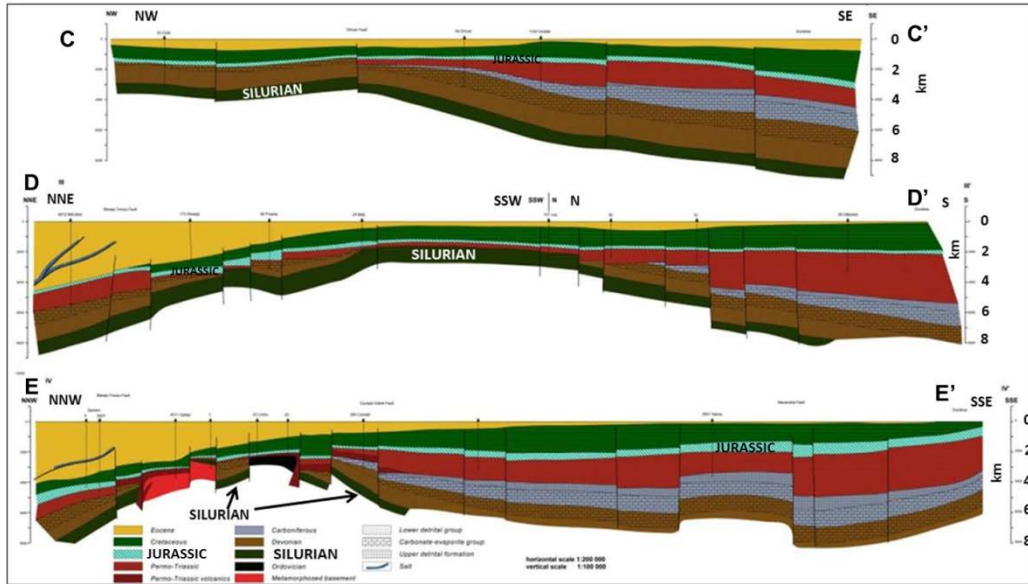
The Moesian Platform contains multiple organic-rich source rock shales that are prospective for shale gas development, Figure X-12. These include the Ordovician to Upper Carboniferous Tandarei, Vlasin, and Calarasi formations, including Silurian shales; the Jurassic Etropole Shale; the Bathonian (Dogger) shales (Bals Formation); and Mid-Miocene marls and shales (Badenian to Sarmatian). The main targets for shale gas exploration are the Silurian shale and Jurassic Etropole Shale.

The Silurian shale in the Moesian Platform is broadly similar to that targeted in Poland and the Carpathian Foreland Basin further to the north. Regional cross-sections show the Silurian ranges from 2 to over 5 km deep across the Moesian Platform. At the South Craiova Block in southwest Romania, the Silurian Llandovery Shale is at least 160 m thick, 4,050 to 4,200 m deep, and has about 3% TOC, Figures X-13 and X-14.¹⁷ At the Bulgarian Arch in eastern Bulgaria, thick (650-m), organic-rich Silurian shales reportedly are at prospective depths of 1 to 5 km, but data were not sufficient to map this portion of the play.

The other main target in the Moesian Platform is the Jurassic Etropole Shale, considered the main petroleum source rock in northwest Bulgaria, Figure X-15. In particular its organic-rich lower portion, the Stefanetz Member, contains thick, carbonate-rich (40-50%) black shale with interbeds of marl and limestone that was deposited in a marine environment, not dissimilar to the Upper Jurassic Haynesville Shale.¹⁸ TOC ranges from 1.0% to 4.6%,¹⁹ with Type II kerogen predominating.²⁰ The Etropole Shale generally ranges from 2.5 to >5 km deep²¹ and is over-pressured in much of the region, with an elevated pressure gradient of 0.78 psi/ft. Thermal maturity falls in the oil window in the north, increasing to wet and dry gas in the south near the Balkan thrust belt (R_o 1.0% to 1.5%).²²

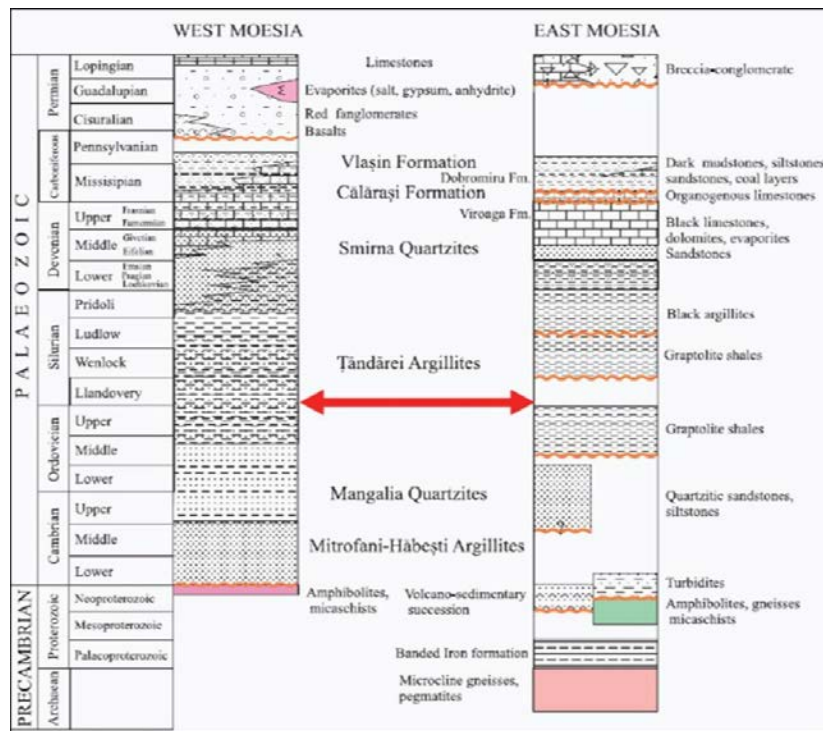
Oil and gas has been produced from conventional silty, sandy, and carbonate intervals within the Etropole Formation, such as the Peshtene R-5 well which reportedly flowed gas at an unstimulated rate of 530,000 ft³/d. In addition, oil produced from the Jurassic Dolni Lukovit and Mid-Triassic Dolni Dabnik fields has been chemically linked back to the Etropole Shale.

Figure X-11: Regional Cross-Sections in of the Moesian Platform In Romania Showing Jurassic and Paleozoic Shale at Mostly Moderate Depth with Relatively Simple Structure.



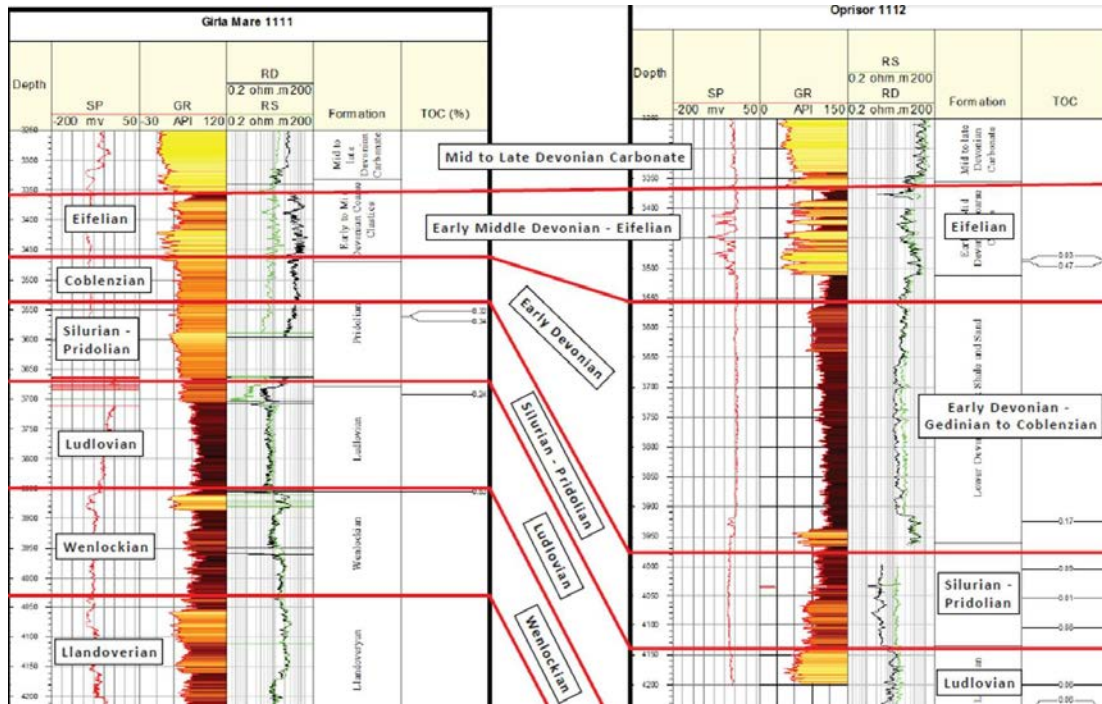
Source: Veliciu and Popescu, 2012

Figure X-12: Stratigraphic Column Showing L. Silurian Llandovery Shales in Southwest Romania.



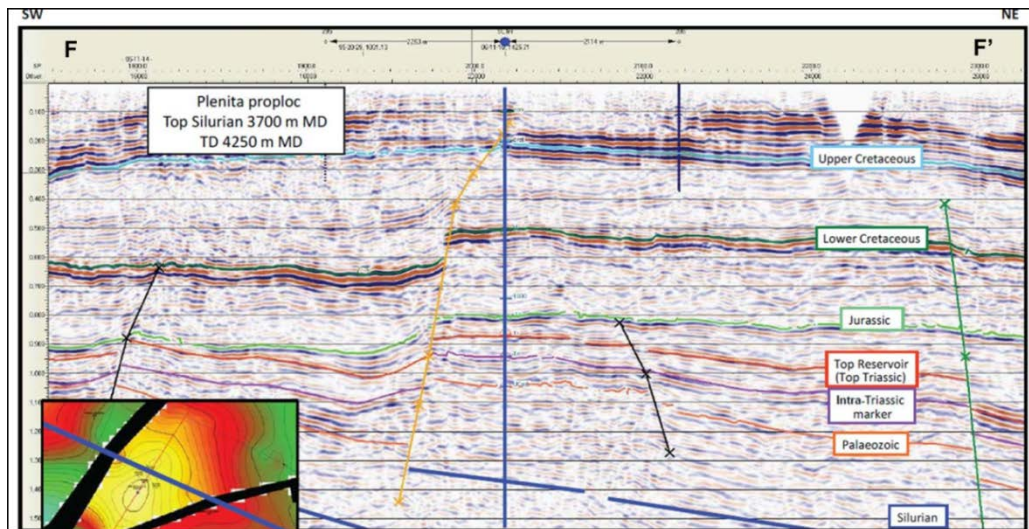
Source: Sterling Resources, 2013

Figure X-13: Well Logs Showing Paleozoic Section Including L. Silurian Llandovery Shales at the South Craiova Block (EIII-7) in Southwest Romania.



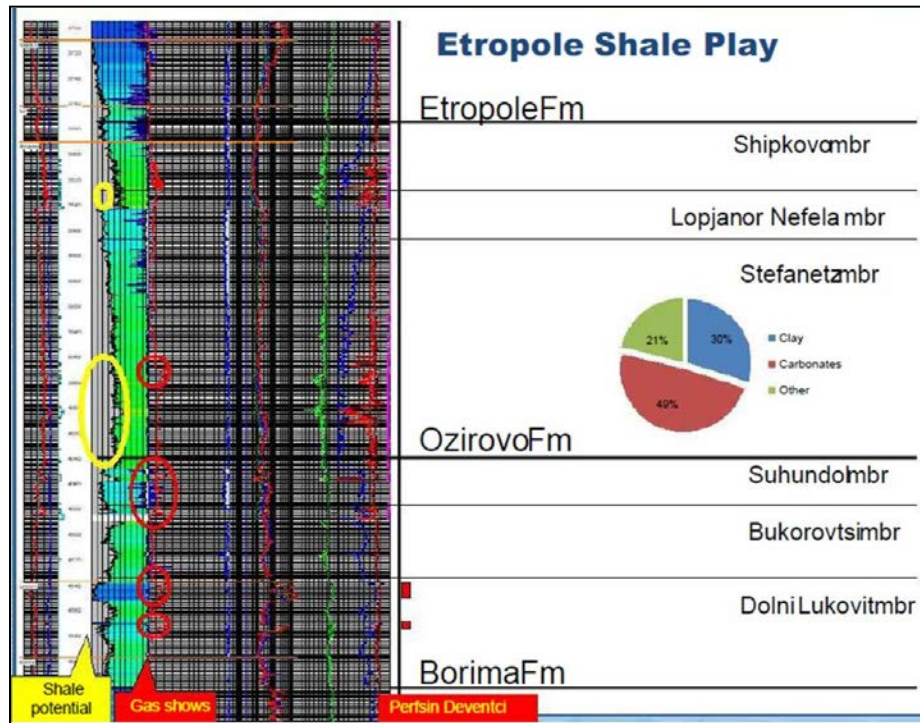
Source: Sterling Resources, 2013

Figure X-14: SW-NE Trending Seismic Line Showing Paleozoic Section Including L. Silurian Llandovery Shales at the South Craiova Block in Southwest Romania. Structure is Relatively Simple But Faults are Present.



Source: Sterling Resources, 2013

Figure X-15: Well log across the Jurassic Etropole Shale in Bulgaria

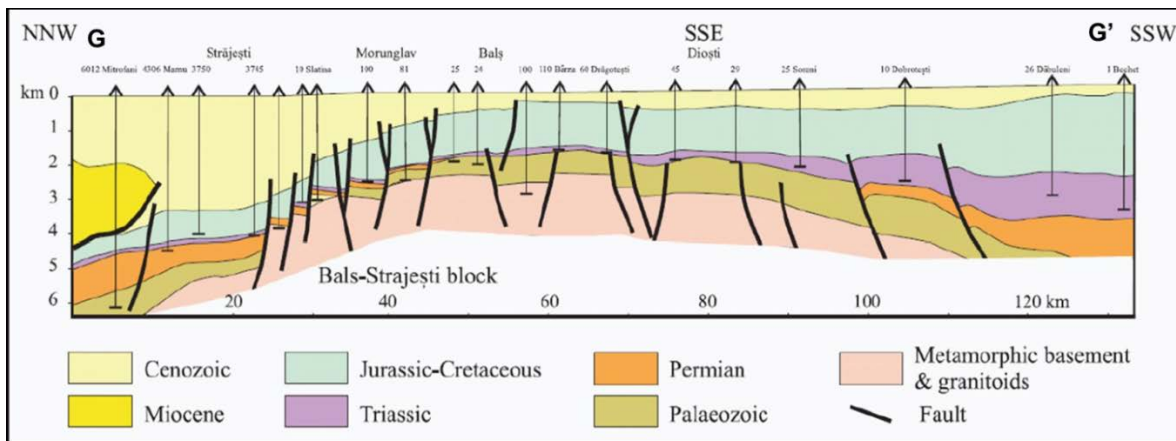


Source: TransAtlantic Petroleum Ltd, February 2011

At the Sud Craiova license in southwest Romania, operated by Sterling and TransAtlantic, the Etropole Shale ranges from 115 to over 700 m thick and 3,700 to 4,500 m deep across the block, Figure X-16. At the Lovech block in northwest Bulgaria the Etropole Shale is about 3,800 m deep, Figure X-17. Structure is fairly simple in this region, with flat lying dips cut by several faults. Other portions of the Moesian Platform lacking data control also were assumed to have relatively similar structure.

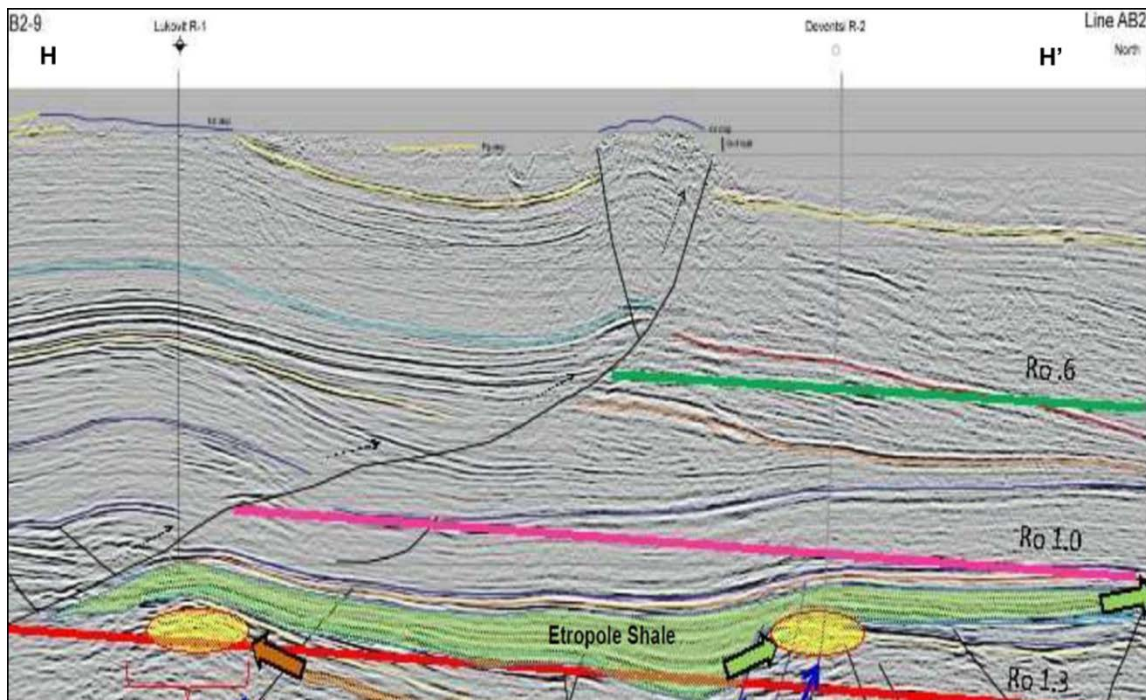
The eastern continuation of the Jurassic Etropole Shale is unclear and could not be rigorously mapped. Two time-structure transects suggest the Etropole may be present in eastern onshore Bulgaria at two-way seismic times of 0.5 to 3.0 seconds, deepening to the east into the Black Sea, Figure X-18. The Central Dobrogea Green Schist Zone, comprising uplifted blocks of Proterozoic basement blocks north of the Palazu Fault, has only a thin or no Jurassic sequence. On the other hand, the North Bulgarian Arch -- where Chevron initially was awarded a shale gas license -- holds preserved Jurassic to Tertiary sedimentary sequences.²³

Figure X-16: Regional Seismic Section Showing Jurassic and L. Silurian Llandovery Shales at the South Craiova Block in Southwest Romania. The Structural Dip is Relatively Gentle but Numerous Faults are Present.



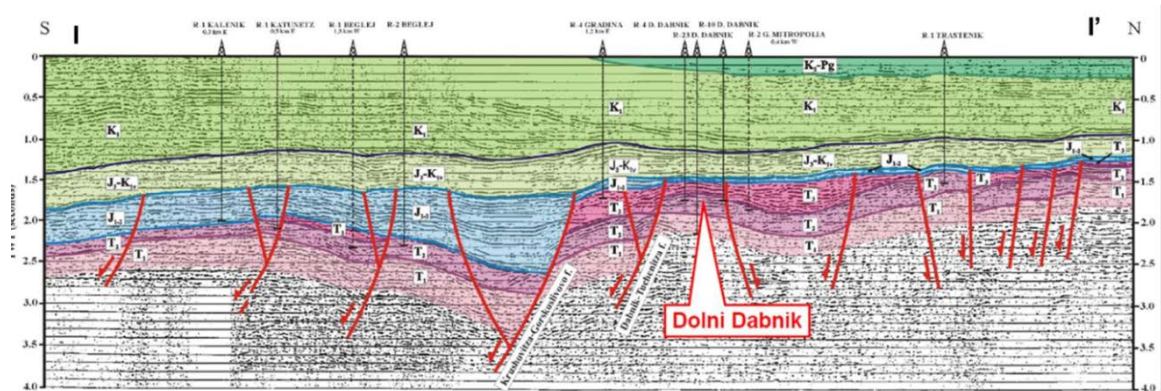
Source: Sterling Resources, 2013

Figure X-17: Jurassic Etropole Shale is about 3,800 m Deep with 1.0% to 1.3% Ro at TransAtlantic Petroleum’s Lovech Block in Northwest Bulgaria.



Source: TransAtlantic Petroleum, 2011

Figure X-18: Regional Cross-Section Showing Thick Jurassic Lias and Dogger Shale Deposits in Northern Bulgaria Which Thin Markedly to the North into Romania.



Source: Tari et al., 2011

3.2 Reservoir Properties (Prospective Area)

L. Silurian Shale. The mapped prospective area for black shales in the L. Silurian totals 1,600 mi², all of which is located in Romania. No prospective area was identified in Bulgaria due to data limitations, although there could be prospective Silurian areas in northeast Bulgaria. Depth ranges from 2 to 5 km. Organic-rich thickness averages about 600 ft (gross). Thermal maturity ranges from wet to dry gas. TOC is estimated at 3%, porosity at about 4%.

Jurassic Etropole Shale. Black shales in the Mid-Jurassic Etropole Shale are prospective within an estimated 7,940-mi² area of the Moesian Platform, in northwest Bulgaria and southwest Romania. The most organic-rich shales are estimated to total about 250 m thick (gross) at moderate depth of about 10,000 ft. Porosity is assumed to be moderately high (5%). Gas recovery rates also could be favorable based on the inferred brittle lithology. TOC appears moderate, averaging about 3% in the more prospective intervals. Thermal maturity is wet gas (R_o 1.0% to 1.3%). The pressure gradient is estimated at 0.7 psi/ft.

3.3 Resource Assessment

Risked, technically recoverable shale resources in the Moesian Platform region of Romania and Bulgaria are estimated to be 47 Tcf of shale gas and 0.5 billion barrels of shale condensate, out of a risked shale gas and shale oil in-place of 196 Tcf and 10 billion barrels, respectively. Romania's share is approximately 30 Tcf and 0.3 billion barrels while Bulgaria's share is estimated at 16 Tcf and 0.2 billion barrels.

Silurian Llandovery Shale. Risked, technically recoverable shale gas resources in the Silurian shale of the Moesian Platform of Romania and Bulgaria are estimated to be 10 Tcf, out of a risked shale gas in-place of 48 Tcf.

Jurassic Etropole Shale. Risked, technically recoverable shale resource in the Jurassic Etropole Shale within the Moesian Platform of Romania and Bulgaria are estimated to be 37 Tcf out of a risked shale gas in-place of 148 Tcf, while shale oil/condensate resources are estimated at 0.4 billion barrels of condensate out of 7.9 billion barrels of risked oil in-place.

Separately, in northeastern Bulgaria, the government has estimated the 4,400-mi² Novi Pazar block has 0.3 to 1.0 Tm³ (11 to 35 Tcf) of shale gas resource potential in the Devonian-Silurian silty shale. The Devonian-Silurian was reported in the study to be up to 2 km thick, 800 to 2,800 m deep, and have 3.5% sapropelic organic matter with TAI from 2 to 5.²⁴ However, it was not possible to map this play due to lack of data.

At the 1,500-mi² Sud Craiova license in southwest Romania, Sterling and TransAtlantic have estimated that the Silurian shale has gross recoverable prospective resources of approximately 3 Tcf (Best Estimate). Including the Jurassic Etropole, TransAtlantic has estimated its blocks hold a total of 0.3 Tm³ (11 Tcf) of unrisked, recoverable shale gas prospective resources (gross; Best Estimate).²⁵

Independent researchers in Romania recently estimated the technically recoverable resources in the Silurian shale of the southern Romanian portion of the Moesian Platform to be 26 Tcf, out of 1,295 Tcf of OGIP (Mean Estimate). The Jurassic was not assessed, nor was the Silurian potential in Bulgaria.²⁶

3.4 Recent Activity

Several companies have pursued shale gas leasing in Bulgaria but only one shale test well has been drilled. In June 2011, Chevron received a 5-year shale gas exploration permit for the 4,400-km² Novi Pazar block of northeastern Bulgaria. However, since the shale ban of January 2012 Chevron can only pursue conventional targets in the block without hydraulic fracturing.

US-based TransAtlantic Petroleum, through its subsidiary Direct Petroleum Bulgaria, holds a shale gas exploration license at the 2,300-km² Lovech block, located in the southern Moesian Platform north of the Balkan forelands in northwest Bulgaria. TransAtlantic recently was also awarded the adjacent 648-km² Koynare block.

In November 2011 TransAtlantic and Canada-based partner LNG Energy drilled the 3,190-m deep Goljamo Peshtene R-11 exploration well at Lovech to core and test the Mid-Jurassic Etropole Shale. The R-11 well was drilled in 56 days and cost \$7.5 million. It was located near the Peshtene R-5 well, which had flowed 530,000 ft³/d from a conventional interval in the Jurassic Etropole. The R-11 well penetrated 354 m of Etropole argillite with numerous gas shows (C1-C3) and cored 289 m of the Jurassic Etropole and Ozirovo formations. LNG described rock properties as similar to those of productive US shale plays. The well was not fracture stimulated as Bulgaria has a ban in place. TransAtlantic plans to test the Etropole Shale elsewhere on the Lovech block where it is about 3,800-m deep.²⁷

Canada's Park Place Energy received an exploration permit in northwest Bulgaria's Dobruja province (blocks Vranino 1 to 11). In June 2011 Chevron won a tender to explore for shale gas at the Novi Pazar field, also located in Dobruja, but the permit was cancelled in January 2012 when the shale gas ban came into effect. Bulgaria's state gas company Bulgargaz has not disclosed any shale-related activity.

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