New Technology Applied in the North Carpathians Results in Significant Estimated Resource Growth

Introduction

The Carpathian thrust belt of the Czech Republic, Poland, the Slovak Republic, Ukraine and Romania is one of the oldest oil and gas producing provinces in the world. The first Carpathian oil well was established at Bóbka Field in southern Poland on 31 July 1853, initiating a bonanza for the oil found as shallow as 50 meters. In the neighboring town of Ulaszowice, Ignacy Łukasiewicz developed the process of obtaining kerosene in 1854 and, together with Tytus Trzecieski, founded the world’s first oil company and oil refinery in 1856. To a large extent, modern exploration techniques have not been applied, leaving much significant, un-drilled resource.

This project is located just 70 km south from this Bóbka Field, in the relatively small portion of the Carpathians within extreme northeastern Slovakia (see Figure 1). About 600,000 acres of this area was originally licensed in 2006. Prior to that, about 30 historical wells were drilled, largely based on surface seeps and rudimentary geology, 16 of which were in the only commercially produced field (Mikova) at 52m to 1,502m, and three (3) of which were “modern, deeper tests” based on approximately 50km of poor quality 2-D seismic. During the period of 2008 to 2013, analysis was intensified with a pseudo-grid of approximately 770 km of newly acquired 2-D seismic; a Full Tensor Gravity survey over the entire area and merged with a Polish survey for correlation purposes; a complete geological survey, which also identified seeps and sampled outcrops; a geochemical study to evaluate hydrocarbon maturity; an aerial mapping analysis using satellite data; and a gathering of historical records, with some dating back into the 1800s.

Although these data indicated many prospective areas for crude oil and/or natural gas resources, additional data were needed to more fully delineate the depth, thickness and scope of these reservoirs and their potential resources in preparation for drilling. Because of our extensive experience with “single-point magneto-tellurics” (“SPMT”), we considered it an optimal tool to refine and delineate the configuration of these potential resources.

Three SPMT acquisition campaigns were undertaken in 2014-2015, resulting in the recording of more than 500 gridded survey stations in three separate grids. Of these, data for approximately 174 stations have been processed over several specific shallow intervals. The purpose of this processing was to identify initial drilling prospects, to initiate exploration and development of the project. More than 15 high quality drilling prospects were identified, each with multiple reservoirs.

Data Acquisitions

Seismic: Very limited seismic data was available at the time of obtaining the first licenses in 2006, acquired to support the drilling of the Smilno-1 (1978) to 5,700m and Zborov-1 (1986) to 5,500m, the Alexander-1 (1998) to 1,000m, and the Zboj-1 (1978) to 5,000m (see Figure 2). Those seismic data were of limited value, as the “primitive” processing did not reveal much subsurface detail. In fact, the newer seismic shows that none of those wells were drilled anywhere near apex of a structure.

To support the more extensive exploration and development drilling plan and evaluate the license for the best possible prospect areas, new 2-D seismic was needed over the project area, which began in 2008 (see Figure 2). The new seismic surveys were laid out to evaluate the full extent of the licenses, using both dip lines and strike lines over most of the important subsurface control points (i.e. wells). These data were acquired initially using vibrator sources. But, it was soon discovered that this did not provide enough subsurface energy to image the strong structural features. So, dynamite was thereafter utilized.
Great care was taken to use processing techniques that would adequately image below 1,500m. As a result, processing of the new seismic data was not completed until 2014. The resulting quality is fair, showing most of the larger structural features, and showing distinct amplitude anomalies in the prospective reservoir areas. This amplitude response is seen all through producing areas elsewhere in the Carpathians, as the contrast between these generally thick porous and non-porous rock intervals supports good amplitude contrast.

A general structural character mapping of the Silesian, Dukla and Magura Nappes at about 1,000m is shown in Figure 3, using the 2-D seismic. This map clearly shows the linear nature of these structures, with “strings of pearls” along the crests. But the seismic also clearly shows amplitude anomalies on the flanks of structures, like the proven, prolific hydrocarbon producers in the Pannonian Basin of Hungary. The western area of the licenses, around the Smilno tectonic window, is gas-prone, while the eastern area is more oil prone.

**Full Tensor Gravity:** A gradiometric survey (FTG) was acquired in support of the seismic, to aid in the selection of processing and re-processing of the lines; to establish a structural interpretation of the “deeper” targets; and to steer exploration efforts by identifying potentially positive features. These data have proven very helpful in determining prospective areas.

**Field Mapping:** The lack of glacial or depositional cover over much of this area allows the subsurface geology to generally be expressed and exposed at the surface over much of the project area. As a result, this area is especially conducive to analysis at outcrop and via Google Earth maps, with the anti-forms typically represented by much higher, tree-covered topographic relief.

In addition, the area is prolific with oil and gas seeps, almost always related to faults, many of which were mapped and analyzed. These seeps underscore the area’s high hydrocarbon saturations, and their continuing migration. Because these anti-forms tend to fold into their furthest thrust extents, the seeps also show that these anti-forms are filled to their spill points.

**Historical Wells and Geochemistry:** All of the 30 historical wells in the area encountered hydrocarbons. But most were drilled close to surface seeps. These wells were located, and most of them were found to be still not plugged, including one which was actually in the basement of a house! The records for virtually all of these wells are sparse and incomplete, since they were drilled so long ago, and regional political upheavals made it very difficult for data to be retained. However, from these data and outcrop samples, geochemical analysis was used to determine the age, sourcing and maturity of the oils and in-situ organic materials. Generally, an Ro of 0.5 to 1.0 indicated that a majority of the oil and gas has migrated into these structures.

**Single Point Magneto Tellurics:** There are several types of magneto-tellurics (“MT”) in use today. Most often referenced in the literature is ElectroMagnetic (“EM”), which actively introduces electric current and is used to collect a relatively coarse, regional view of resistivity variances across a fairly large area, often helpful in interpreting the major structural and stratigraphic changes.
Single Point Magneto-Tellurics technology is a very specialized MT application, using only naturally occurring electrical and magnetic energy passing through the earth’s near-surface from atmospheric lightning strikes and solar radiation, and radiating from the earth’s core. These signals have a predictable frequency-to-depth ratio, modulated much like an AM/FM radio frequency carrier-wave when passing through variations in the layers of near surface rock layers (above 15,000 feet).

With proper acquisition and processing, these SPMT data, when analyzed by a well-trained geoscientist, can be used to differentiate the top, bottom and thickness of discrete reservoir layers within the rock column (usually <10 feet tolerance for depth, and <5 feet tolerance for thickness). For example, the coal industry regularly utilizes this technology to determine the top, bottom and thickness of coal measures prior to mining activities. These data have, in our 30 years of using this technology, proven to be remarkably accurate in reservoirs as thin as 4 feet.

When utilized in a line or grid, this signal can also yield the relative reservoir porosity of individual rock layers as it varies laterally. Further, it can yield a reliable indication of the presence or absence of oil, gas and/or water with the right reservoir conditions. This method is almost 100% accurate at predicting the absence of hydrocarbons in a particular reservoir. The reliability of all of these readings increases with reservoir homogeneity, and decreases with complexity of reservoir lithology and porosity types, which the addition of other types of supporting data serve to incrementally overcome. Because SPMT operates on the basis of relative resistivity and magnetics, clastic depositional environments (sandstones, siltstones and shales) like those in the project area are well suited for application of this technology.

For example, SPMT was used very successfully in the Middle Bakken Play in Elm Coulee Field by Lyco Energy Corporation. In particular, a large field extension area (about 15 square miles) was developed solely on the merits of the SPMT results. The Middle Bakken reservoir is a 5 to 8 foot thick porous dolomite (8% to 12% porosity) embedded in a fairly complex marl, proving that this tool can be very helpful and reliable even under difficult circumstances, especially when supported by additional reservoir information. This topic will be more fully developed in the full paper.

In the subject Slovakian project, the layered frameworks of data types described above did not provide sufficient information to resolve reservoir information, or reliable depth for the prospective zones. So, where all of the other technologies indicated prospectivity, a SPMT grid was used to augment these data and define the predicted depth, thickness, relative reservoir quality and presence of oil, gas and/or water within those prospective reservoirs. Using the data described above, a number of prospects and leads were developed over the license area, some of which are described here.

**Prospects**

The Smilno-1 well, on the northwestern end of the licenses, tested an absolute open flow of 4.8 MMCFGPD from the “Test Interval” shown in purple on Figure 5. The tested interval was significantly damaged while drilling (the interval was exposed to drilling fluids for many months), so was misinterpreted as having insufficient longterm flow potential, and plugged. Note the excellent correlation of SPMT data with the actual well log, including the gas pay interval. Based on the new seismic, this well is significantly down dip from several large, gas-filled structures which present significant opportunities for gas resource exploration and development.

A SPMT grid over the **AOG Zborov #1 Prospect** indicates a total of 272 feet (83m) of Probable Gas in 11 distinct zones, from 10 feet (3m) to 59 feet (18m) thick, to a depth of about 6,500 feet. Structural mapping of the SPMT data ties nicely to the structural interpretation from the 3 intersecting seismic lines over the prospect, which include supportive amplitude anomalies (see Figure 6). The prospect is also on a strong FTG anomaly (Figure 4), with nearby gas seeps and historical shallow gas tests. It
is the SPMT data that provided the reservoir parameters needed to make these calculations. Without these surveys, only the general structure of the anomaly could be interpreted, with very little data to predict reservoir thickness or depth.

A potentially bigger structure, the SPMT grid over the AOG Cierne #1 and #2 Prospect indicates a total of 318 feet (97m) of Probable Gas in 10 distinct zones, from 10 feet (3m) to 59 feet (18m) thick (same zones as at the AOG Zborov #1), to a depth of about 7,500 feet. Again, structural mapping of the SPMT data ties nicely to the structural interpretation from the 3 intersecting seismic lines over the prospect, which include supportive amplitude anomalies (see Figure 6). The prospect is also on a strong FTG anomaly (Figure 4), with the same nearby gas seeps and historical shallow gas tests as with AOG Zborov #1. Mapping indicates an in-place volume of at least 286 BCFG under a mapped area of 5,900 surface acres. If the gas column is interpreted further down, closer to the base of the gas zone tested in the Smilno-1 well (a reasonable assumption), the in-place volume would easily become more than 450 BCFG for just this single prospect.

Smaller than the gas prospects, numerous oil prospects are present in the eastern 2/3rds of the project. The Poruba Prospect is representative of many of those, with a total of 256 feet (78m) of Probable Oil in 8 distinct zones, from 6 feet (2m) to 58 feet (18m) thick, down to a depth of about 5,000 feet. Although this prospect is located on only one seismic line (a dip line), it is proximal to a strike line that supports the presence of this anomaly. FTG data also indicates an anomaly at this location. Mapping indicates an in-place volume of at least 16 Million BO over a mapped area of 520 acres. Numerous oil seeps and very old oil wells are also present in the immediate area.

Conclusions

Newly acquired surveys, including SPMT (magneto-tellurics) and FTG gravity, integrated with carefully collected and processed new seismic, were applied in the North Carpathians of Slovakia between 2007 and 2016. We have employed this integrated geological/geophysical approach very successfully elsewhere, particularly in the Middle Bakken Play in the Williston Basin. This extensive work has resulted in significant estimated gas and oil resource growth since 2014. Unfortunately, non-technical (above ground) issues in the project area effectively blocked new drilling efforts that might generate significant value in this area, which is rife with hydrocarbon-rich clastic sequences of relatively porous, permeable, and thick prospective sandstone reservoirs.

References

Pawlewicz, Mark, 2006, Total Petroleum Systems of the North Carpathian Province of Poland, Ukraine, Czech Republic, and Austria: U.S. Geological Survey Bulletin 2204–D, 26 p.; available at <http://pubs.usgs.gov/b/2204d> (used for Figure 1 in this paper).