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Collecting, Preparing, and Synthesizing Well Log Data for Subsurface Mapping: Example from the Bakken Formation

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Collecting, Preparing, and Synthesizing Well Log Data for Subsurface

Mapping: Example from the Bakken Formation

by

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requirements for the degree of

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Abstract

Late Devonian and Early Mississippian Bakken Formation consists of three distinct members: the upper shale, middle, and lower shale. The upper and lower shales are excellent source rocks, rich in organic content. The organic material in the shales was derived from planktonic algae. Both the upper and lower shales were deposited during a transgressive event in hypoxic to anoxic conditions. The original total organic carbon content in the Bakken shales ranges from 20 to 22 weight percent, however; the content decreases to 10 to 17 weight percent as a result of maturation of hydrocarbons and primary expelling of oil. High contents of total organic carbon are also responsible for high resistivity response on the logs due to oil saturation during organic matter maturation.

In order to characterize organic rich source rocks in the Bakken Formation, total organic carbon content can be calculated from the density logs using an empirical equation and resistivity values obtained from the resistivity logs. The objectives of the study was to create a database of well logs and import it into a mapping software and produce a manual that will guide users to obtain and utilize well information from various sources.

Dedication

For my husband Lorin Jones. Thank you for your unconditional love and support.

Acknowledgements

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1. Introduction

The Bakken Formation of the Williston basin is one of the biggest unconventional onshore reservoirs in the United States. According to the latest U.S. Geological Survey assessment, the Bakken Formation contains 3.65 billion barrels of undiscovered technically recoverable oil (Pollastro and others, 2010). The formation, deposited during Late Devonian and Early Mississippian epochs, is a world-class petroleum source rock with low porosity and extremely low permeability characteristics. The Bakken Formation contains three uniformly recognized units: upper shale member, middle siltstone member, and lower shale member. The unit was originally described from the subsurface of North Dakota during early oil exploration of that state (Nordquist, 1953).

The Williston Basin is a bowl-shaped intracratonic basin with a history of petroleum production from anticlinal structural features like the Nesson, Billings, and Cedar Creek anticlines (LeFever, 1991; Figure 1). More than a dozen geologic units in the basin have proven productive, from the Pennsylvannian to the Cambrian (Anna and others, 2013), leading to 34,294 wells being drilled in the basin from mid-1950s through 12-08-2015 (IHS-Accumap database). The great number of publically available petrophysical logs from oil and gas wells in the Williston Basin, and throughout the continent, are a great resource for geologic studies.
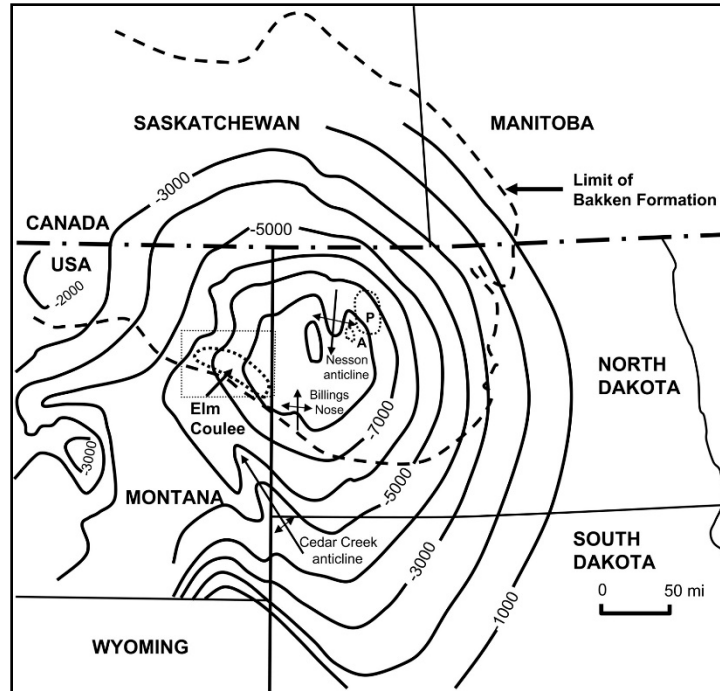
Figure 1: Location of the Williston basin and structure contour map of the Bakken Formation (modified from Webster, 1984).
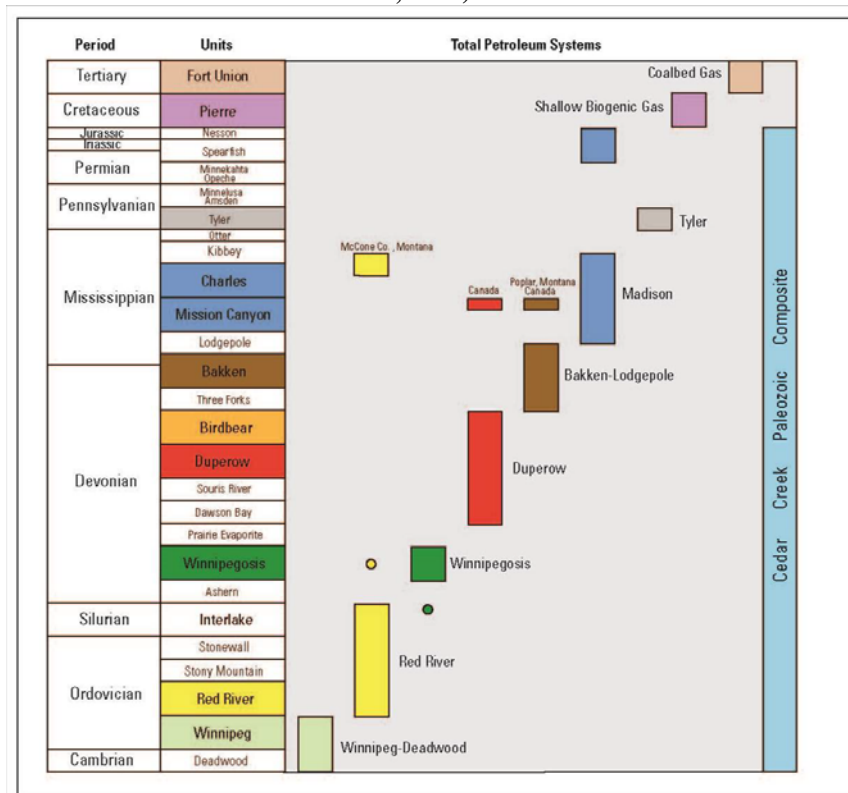
Figure 2: Generalized stratigraphic chart and associated total petroleum systems for the Williston Basin (from Anna and others, 2013).

Some regional mapping of the Bakken members from petrophysical logs of oil and gas wells and from cores has been done at small scales. These maps include structure contour maps, maps of the TOC content, hydrogen index maps, source potential rating index map, resistivity maps, density maps, and sonic transit times (Meissner, 1978; LeFever and others, 1991; Schmoker and Hester, 1983; Krystinik and Charpentier, 1987; Jin and Sonnenberg, 2013; Dembicki and Pirkle, 1985; Sperr, 1990). Most mapping has been done by private firms and have not been released except in presentations (e.g. Smith and others, 1992) or are for sale commercially (http://bakkenshale.com/buy-maps/).

Use of petrophysical logs is extremely valuable and cost effective in mapping unit thicknesses and rock properties across the basin. Some useful rock properties include bulk density, resistivity, and sonic velocity. The Bakken shales have distinct characteristics, such as high gamma-ray response, low sonic velocity, and high resistivity response (Meissner, 1978). The ability to map rock properties, TOC content, maturation data, and other Bakken shale characteristics and combine the maps with existing production data will give researchers, and petroleum companies an opportunity to integrate that data with other geologic features (such as sedimentary facies, depositional trends, etc.), proving a better petrophysical evaluation of the Bakken Formation. Regional petrophysical evaluation can help with estimating the oil reserves, target zones, and bounding layers, as well as helping with designing appropriate completion and stimulation designs (Parker and others, 2009).

Good understanding of the Bakken Formation will optimize the recovery of the reserves and benefit other unconventional reservoirs. In-depth analysis and evaluation of the Bakken shales though petrophysical logs will provide information that can enhance the hydraulic fracture stimulation design, increase productivity through improved field development, and give a better

description of the formation, which in turn will optimize oil recovery. The non-thesis project focuses on characterization of organic-rich source rocks, upper and lower shales, in the Bakken Formation. The scope of the study will focus on several objectives.

The first objective is to introduce the data sources in the order one would use them to gather relevant data for subsurface mapping. The available data sources in Montana and North Dakota are:

- IHS-Accumap (V25.02, December, 2015)

- Well logs from MJ Systems (V2.11.7.4, December, 2015)

- The North Dakota Industrial Commission (NDIC) (December, 2015)

- Montana Board of Oil and Gas (MBOG) (December, 2015)

Getting subsurface or well data from each of these resources into mapping software (ArcGIS or IHS-Petra) is important for analysis of those data and for updating the maps. All data and maps resulting from this work are stored in digital formats (spreadsheets and ArcGIS shapefiles) so they can be used by others in the future. Examples of the data that will be obtained from above mentioned sources are density logs, resistivity logs, and dipole sonic logs.

The second objective of the study is to create a user manual for obtaining and mapping data from the various databases mentioned above. In this manual, I will outline the steps necessary to integrate well data into a database. This will be useful to other students and professors to retrieve well data to produce their own maps or retrieve well logs for correlation. The manual will be created that will guide future users on the process of retrieving well data and incorporating it into ArcGIS and IHS-Petra projects.

2. Methodology

In order to map the thickness, structure, and petrophysical properties of the Bakken lower and upper shales, density, resistivity, and dipole sonic velocity logs need to be obtained and a proper database constructed. Such objective can be achieved by creating a "Batch Export" of well logs and well data from the MJ Logs database and downloading individual well logs in TIFF format from North Dakota Industrial Commission website. Then the logs will be imported to Petra software for correlations. Available top data from Hanley (2012) will be imported into Petra software and correlation of the Bakken units can be done.

In order to create a user manual for obtaining and mapping data, all the steps used to create a database will be outlined in detail and accompanied with figures and screenshots. The manual is provided in Appendix A.

2.1. Bakken

The Williston Basin is a large sedimentary basin that developed on the North American craton and along the western edge of the Canadian Shield (LeFever and others, 1991; Pollastro and others, 2010). It spans across 300,000 mi^2 occupying parts of North Dakota, Montana, South Dakota, Manitoba, and Saskatchewan (Pollastro and others, 2010).

The Bakken Formation was deposited during active subsidence in the Late Devonian and Early Mississippian Epochs. The deposition of carbonate and clastic sediments occurred during cyclical transgressions and regressions (LeFever and others, 1991). The Bakken Formation conformably overlies the Three Forks Formation in the deeper portions of the basin and unconformably along the basin flanks (Figure 2) (Webster, 1984; Meissner, 1978). The three units (upper shale member, middle member, and lower shale member) of the Bakken Formation exhibit onlapping relationship, where each younger member has a successively higher areal

distribution (LeFever and others, 1991). The overlapping relationship originated during Late Devonian to Early Mississippian time, where the basin margins were uplifted, exposed and eroded, and deposition of sediments continued in the deeper parts of the basin (LeFever and others, 1991).

The depositional environments were similar for the upper and lower shales; however it is complex and wide array of the ideas exist regarding the conditions of the deposition of the Bakken shales. Previous studies concerning the deposition environment of the Bakken Formation range from shallow water, coastal marine to deeper water (>200 m), and anaerobic water bottom conditions (Smith and Bustin, 1996). More recent studies propose that deposition of the black shales could have occurred in more active environment with significant current activity and at least dysoxic conditions (Egenhoff and Fishman, 2013). This work suggested that bedload transport process supplied the sediment that formed the upper shale member. Bioturbation and presence of fossils in the upper shale member suggests dysoxic conditions as opposed to anoxic (Egenhoff and Fishman, 2013).

The depositional environment of the middle member differs from that of the upper and lower Bakken shales. The middle member was deposited in the shallow, moderately well oxygenated water environments. The transgressive deposits prevail in the middle member; however the absence of the onlapping relationship with the lower shale member suggests that the lowest unit of the middle member was deposited during a regressive event (LeFever and others, 1991).

In the Late Cretaceous, during Laramide orogenic uplift of the Cedar Creek Anticline and subsidence in the Williston Basin, the Bakken Formation was buried to the point of heating to entering the "oil window". Structural deformation along the anticlines and synclines in the basin

(Figure 1) and regional compression produced tectonic fractures. Oil and gas was generated causing overpressuring and hydrofracturing along with smectites collapsing with illite, forming type II kerogen (Webster, 1978; Shepard, 1990).

The lithology of the upper shale member has been categorized into three distinctive facies associations: (1) siliceous mudstones, (2) quartz and carbonate bearing laminated mudstones, and (3) macrofossil-debris-bearing massive mudstones (Egenhoff and Fishman, 2013). The upper shale member is more fossiliferous than the lower shale member. The fossils include brachiopods, conodonts, fish scales and teeth, crinoid ossicles, echinoderms, arthropod remains, and terrestrial plant fragments (Smith and Bustin, 1996; LeFever and others, 1991). Calcite and pyrite minerals fill or partially fill existing microfractures in the layer. Pyrite is dispersed throughout both upper and lower shales but can also occur in form of lenses, nodules, and laminations (LeFever and others, 1991). The organic content is generally higher in the upper shale member as opposed to the lower shale (LeFever and others, 1991).

The middle member is made up of seven distinct lithofacies and generally consists of light grey to medium dark grey interbedded siltstones and sandstones. Shales, dolostones, and limestones might be present in lesser quantities (LeFever and others, 1991).

The lithology of the lower member is fairly uniform and consist of a dark grey to brownish-black to black, non-calcareous, fissile, slightly to highly (in the deeper portion of the basin) organic rich shale (LeFever and others, 1991). Traces of siltstone, limestone, and sandstone can be found in the lower shale member, but is non-existing in the upper shale member (LeFever and others, 1991).

2.2. TOC

Total organic carbon (TOC) is measured as the weight percent of organic material in the rock. TOC values in the Bakken Formation shales range widely across the basin. Compared to petroleum source rocks worldwide, original TOC values are high ranging from 20 to greater than 22 percent (Jin and Sonnenberg, 2013). These values are extreme compared to required 1 percent minimum TOC value for a possible source rock (Webster, 1984). Reduction in TOC values can be explained by maturation of the shales. As the source rock matures it generates hydrocarbons that are being expelled from the rock, which in turn lowers the TOC. Along the basin margins, in areas near the depositional edge, algal kerogen was not well preserved and was diluted by inorganic material. This resulted in the low TOC near the edges of the basin. After maturation TOC values ranges between 10-17 weight percent (Schmoker and Hester, 1983; Jin and Sonnenberg, 2013). Petrophysical logs have been used to estimate total organic carbon content in the Bakken source rocks by an empirical relation between formation density and TOC, as calibrated by core analyses. This relationship has been used to map average organic-carbon content of the upper and lower shales in North Dakota (Figure 3; Schmoker and Hester, 1983). Maps were recently updated by Jin and Sonnenberg (2013), by incorporating over three thousand TOC and pyrolysis results obtained from the Colorado School of Mines SRA lab and USGS Energy Geochemistry Database (Figure 4).
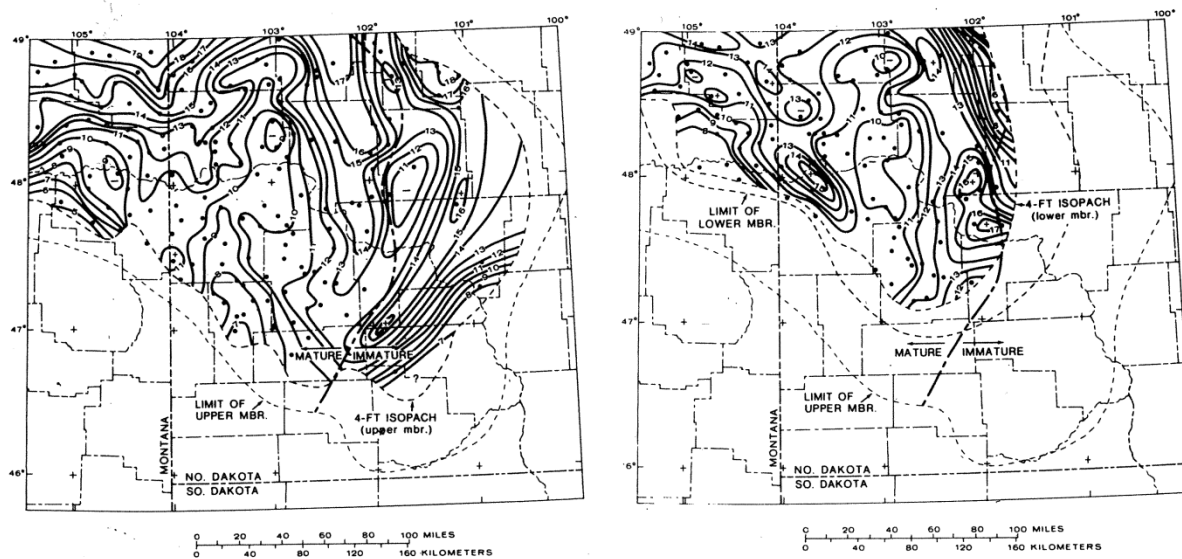
Figure 3: Organic-carbon content (wt. %) of upper and lower members of the Bakken Formation (Schmoker and Hester, 1983).
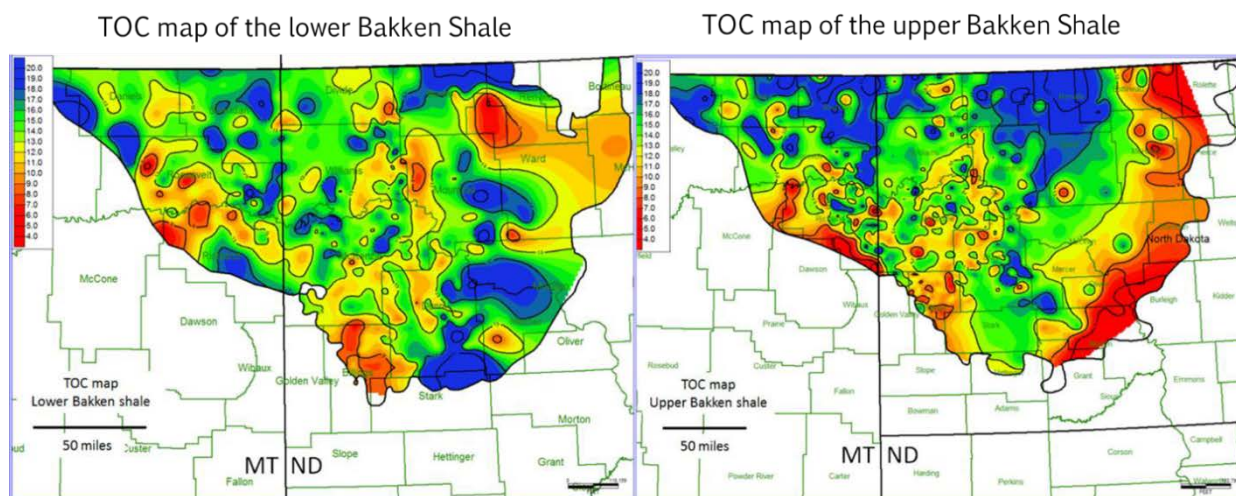
Figure 4: TOC map of the lower and upper Bakken shales. The key shows calculated values of TOC in weight percent from red (< 4 percent) to dark blue (>20 percent) in one percent gradations (from Jin and Sonnenberg, 2013).

Constructing a map of the TOC values for the Bakken shales may help identify hydrocarbon accumulations, and optimize the recovery of the Bakken oil.

TOC values can be calculated from formation density logs using an empirical equation derived by Schmoker and Hester (1983) from core and log data from the Bakken Formation:

2.3. Resistivity

Electrical resistivity logs measure how well the fluids and solids in the formation can conduct electric current. Oil does not conduct electricity which results in high resistivity response, whereas salty formation water is highly conductive, which lowers the resistivity response (Ellis and Singer, 2008). For these reasons, most fine-grained sedimentary rocks with high clay contents (shales) have very low resistivities, on the order of 2 to 10 ohm-m (Ellis and Singer, 2008).

Resistivities in petroleum source rock shales, such as the Bakken upper and lower shales, is typically high due to the retention of generated hydrocarbons in the pore spaces and absence of formation water (Meissner, 1978). In Bakken shales where the kerogen has not been converted to petroleum, resistivities are on the order of 35 ohm-m or lower (Schmoker and Hester, 1989). As kerogen converts to fluid hydrocarbons during source rock maturation, the formation water is expelled from the formation. The volume of oil increases by being stored in fractures and pore spaces, subsequently decreasing water saturation and significantly increasing resistivity (Schmoker and Hester, 1990). This process makes the resistivity well logs useful in mapping the formation of oil in source rocks. Bakken shales can reach resistivities exceeding 10,000 ohm-m.

High resistivities in shales is not governed by porosity, instead the high response directly correlated to the oil generation during organic matter maturation (Lu and others, 2015). Because porosity of the Bakken shales is low and fairly uniform, the porosity variations have very minimal effect on formation resistivity. Moreover, extremely low permeability of the shales prevents the presence of formation water, which minimizes the effect of formation water on resistivity readings (Schmoker and Hester, 1989).

In a study performed in the Upper Cretaceous Tuscaloosa marine shale shows that the high contents of TOC and type II kerogen are responsible for oil generation and in turn higher resistivity response in the logs (Lu and others, 2015). Fourteen samples were analyzed using Rock-Eval pyrolysis and LECO total organic carbon analysis (Lu and others, 2015). TOC content and S1 (free hydrocarbon) values increase with depth in the Tuscaloosa shales which coincides with the increase in the log resistivity (Lu and others, 2015). It was noted that increasing of S1 values during the onset of oil generation in Bakken shales samples (measured by Rock-Eval thermal analysis) occurs at a resistivity between approximately 15 and 35 ohm-m (Schmoker and Hester, 1989).

Sperr (1990) published low resolution maps of resistivity (Figure 5) and sonic transit time (Figure 6) for upper and lower members of the Bakken shale; as well as a density map (Figure 7) for the upper shale. The study area was the depositional edge of the Bakken play (south-eastern part of Montana and north-western part of North Dakota); the area was chosen to compare log responses to the existing production area. The resistivity maps show the areas of the study area where resistivity values exceed 1000 ohm-m.
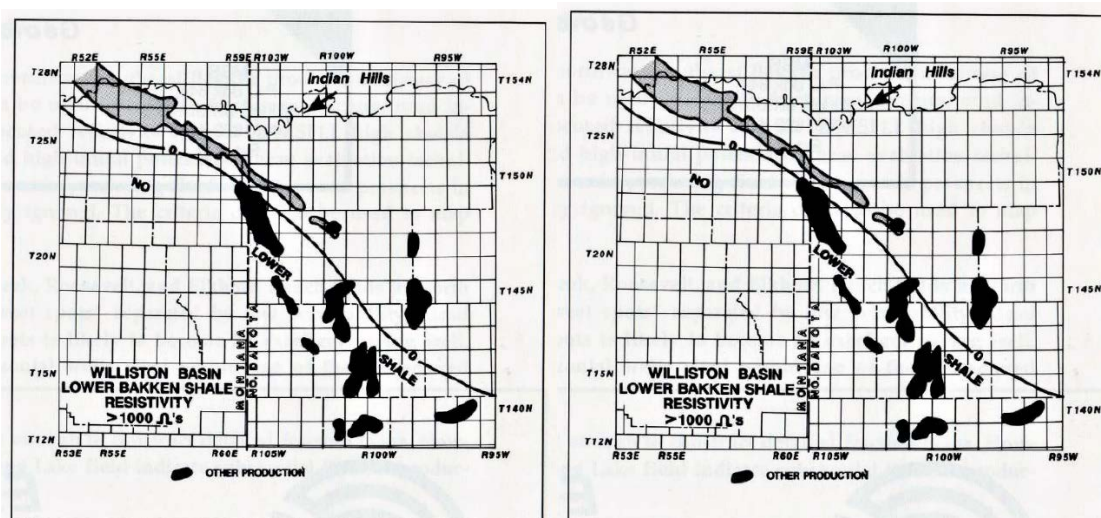
Figure 5: Upper (left) and Lower (right) Bakken shale resistivity. Grey shaded areas indicates resistivity greater than 1000 ohm-m (Sperr, 1990).
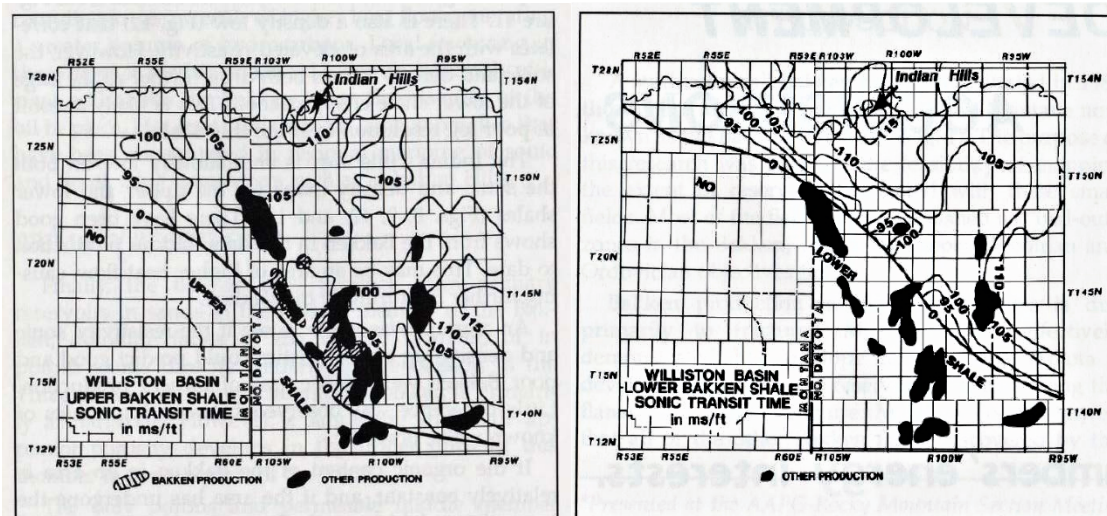
Figure 6: Upper (left) and Lower (right) Bakken shale sonic transit times (Sperr, 1990).
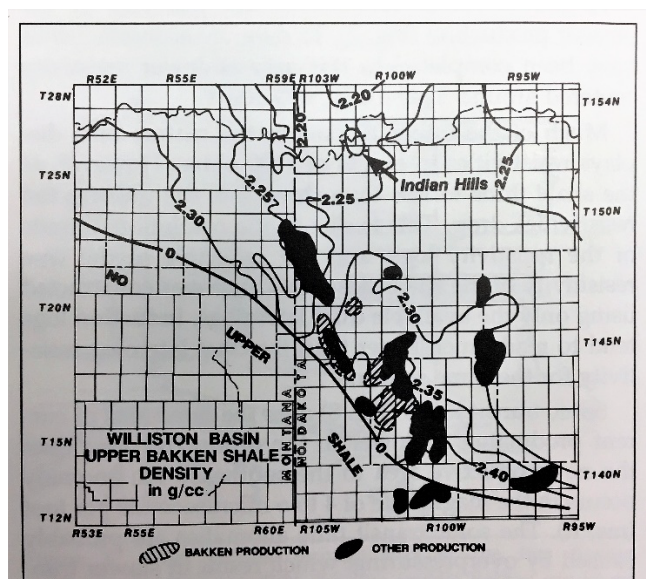
Figure 7: Map of density values in the Upper Bakken shale (Sperr, 1990).

The resistivity values for upper and lower Bakken shales are averaged from resistivity logs. After the values for TOC are calculated and resistivity values are estimated from the logs; both values can be mapped and compared.

2.4. Elastic Properties

A dipole sonic log generates an electric pulse at sonic frequencies, producing compressional (P-waves) and shear (S-waves) waves that travel from the transmitter to the formation and back to a receiver (Schlumberger Oilfield Glossary, 2015). Resulting well log displays the travel time of P- and S-waves versus depth along the XY ft increments in rocks around a wellbore. Elastic properties and bulk density of the rocks govern the travel time of the P- and S-waves; hence dipole sonic logs can be used to calculate elastic parameters in the Bakken shales. In addition, dipole sonic logs (as well as other advanced acoustic well logging tools) can be used to measure the degree of shear anisotropy in a formation. Anisotropy in shales is caused by the alignment of the grains, fractures, and stress. Shear anisotropy can be evaluated through slow and fast shear slowness (the reciprocal of the shear wave) obtained by the dipole sonic logs. In addition, shear slowness can be used to calculate rock stiffness and compressibility, important characteristics for stimulation design and avoiding sanding problems during production (Schlumberger, 1990). Characterization of the shear anisotropy can help with evaluation of the in-situ stresses in the formation, stress distribution around the wellbore, and natural fractures (Ostadhassan and others, 2011).

Elastic constants define the properties of material that undergoes stress, deforms, and then recovers and returns to its original shape after the stress ceases. Young's Modulus, shear modulus, Poisson's ratio, and bulk compressibility can be calculated from the data acquired from the dipole sonic logs (Parker and others, 2009). Young's modulus is the ratio of longitudinal stress to longitudinal strain. Shear modulus is the ratio of shear stress to shear strain. Poisson's ratio is a measure of the compressibility of material perpendicular to applied stress.

Elastic parameters (Young's Modulus and Poisson's ratio) can be derived from the dipole sonic velocity logs using the following equations (Ostadhassan and others, 2012):

$$E = \frac{\rho v_s{}^2 \left(3v_p{}^2 - 4v_s{}^2\right)}{\left(v_p{}^2 - v_s{}^2\right)}$$

$$v = \frac{\left(v_p{}^2 - 2v_s{}^2\right)}{2\left(v_p{}^2 - v_s{}^2\right)}$$

where ρ is the formation density, v_s is shear wave velocity, and v_p is compressional wave velocity.

Equation 2: Young's Modulus and Poisson's Ratio calculated from dipole sonic logs (Ostadhassan and others, 2012).

In addition, unconfined compressive stress can be calculated using the correlation developed by Horsrud in 2001 (Sayers and others, 2009):

$$C_0 = 0.77 \times v_p{}^{2.93}$$

where C_0 is the unconfined compressive stress in MPa and v_p is compressional wave velocity in km/s.

Equation 3: Unconfined compressive stress in relation to compressional wave (Sayers and others, 2009).

Vertical stress can be calculated using values for pore pressure and total vertical stress at a certain depth in the formation (Ostadhassan and others, 2012). Minimum and maximum horizontal stresses in the formation can be calculated using Young's modulus, Poisson's ratio, overburden stress, Biot's constant, and minimum and maximum horizontal strains. Conversion of type II kerogen to hydrocarbons in the upper and lower shales causes abnormal overpressure characteristics (decrease in the effective stress acting on the rock frame) (Ostadhassan and others, 2012). Change in the stress regime can also be mapped and compared to TOC and resistivity values, to see if there is any correlation between stress distribution and oil generation.

Data obtained from dipole sonic logs can be used to estimate stress state around wellbore and in the formation along with natural fracture characteristics. Therefore, determining elastic properties and shear anisotropy in the Bakken shales is crucial for understanding the horizontal drilling and hydraulic fracturing stimulation design.

Due to the limited number of dipole sonic logs available through North Dakota Industrial Commission database (only 27 raster logs), the stress data can be modeled across the basin using FLAC 7.0 finite-element geomechanical modeling software (Sayers and others, 2009).

3. Conclusions

Oil and gas well logs provide a wealth of information on the structure, stratigraphy, and rock and fluid properties of the subsurface environment. Usage of these databases is enhanced in the incorporation of digital databases. This overview and manual provides a valuable tool in learning how to navigate and collect data from the digital databases, and incorporating obtained well data into mapping software.

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Appendix A: Manual

1. Introduction

The following manual was created in order to help students and professors to navigate through databases such as MJ Systems (LogSleuth), AccuMap, NDIC, and MBOG. The manual will also provide information on how to import the gathered well data into a mapping software, in this case Petra.

2. LogSleuth

2.1. Getting started in LogSleuth

LogSleuth software operates in three main screens: **Project List screen, Well List screen,** and **Log View screen**. Project List screen is displayed when the LogSleuth program is first opened (Figure 8). Project List screen displays current projects located within a given folder. Projects can be created, edited, and deleted from the Project List screen. Well List Screen displays the wells contained in any given project. In Log View Screen one can correlate, annotate, export or print well logs.
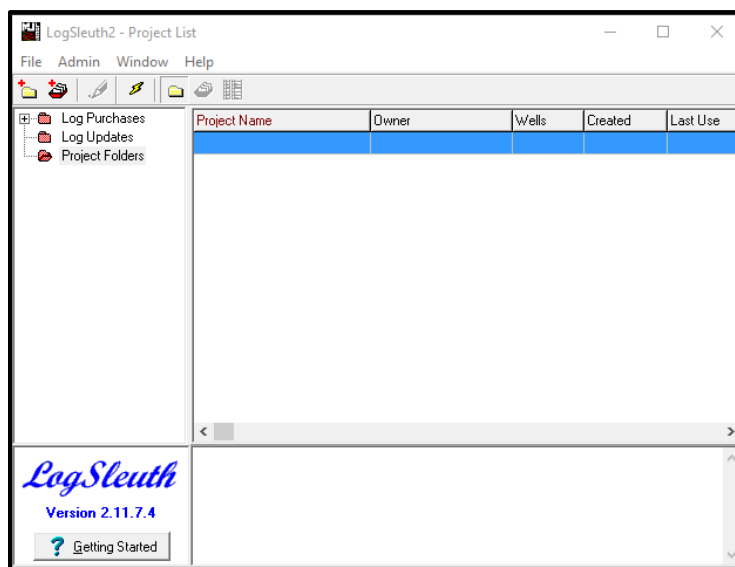

Figure 8: Project List screen.

2.2. Creating projects in LogSleuth

Step 1: Log images from MJ Systems for Montana, North Dakota, and Wyoming states have been purchased by the Geological Engineering department. Full log library can be accessed through the campus network services. In order to obtain the shared files, it is required to connect to \\mtsmefs\geoe457. To map a network drive on your computer, follow these instructions:

- Open "File Explorer"

- Right click on "This PC" in the left corner of the window. Choose "Map network drive".

- When the pop-up window appears, type \\mtsmefs\geoe457 and click "Finish".

Step 2: Open LogSleuth program. The first screen that opens is the Project List screen. To create a project containing desired well logs, numerous steps have to be taken in the following order:

- Select "Admin" tab on the upper panel. From the pull down menu choose "Load MJ Well Definitions" (red box in Figure 9). Navigate to the geoe457 drive and open the folder corresponding to the well logs you wish to add.
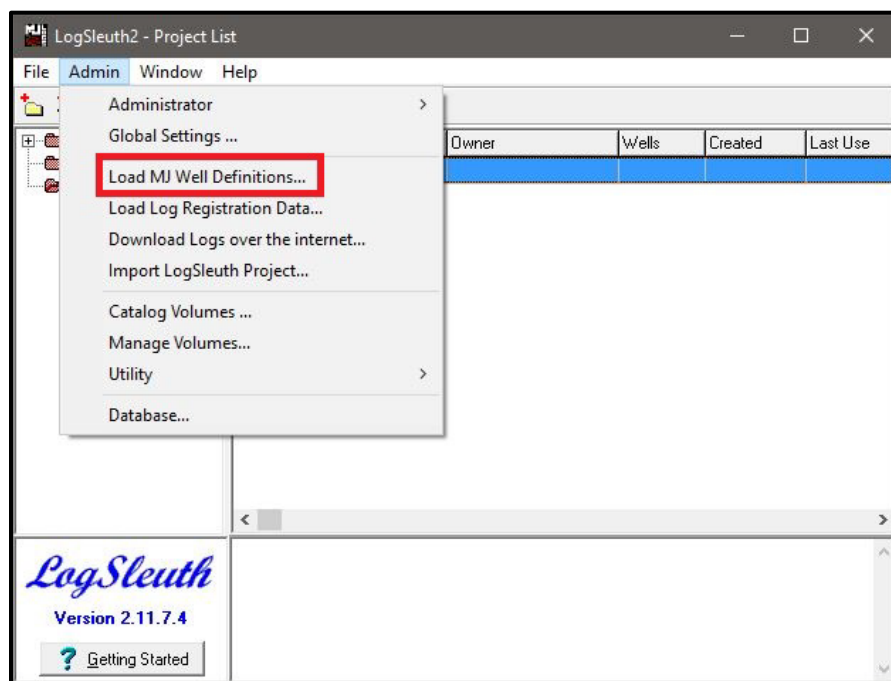

Figure 9: Loading MJ Definitions in LogSleuth.

- Select .LS4 file and click "Open". Continue this process until all the .LS4 files from all desired volumes are added to the project.

- Next select "File" tab and choose "New Project" from the pull down menu. Fill in "Name", "Owner", and "Description" fields under "Description" tab.

- Select "Area Definition" tab. Click next to "Country (US)" under "Area Definition Type". Click "New" and using "State" pull down menu select desired state. From the "County" pull down menu select "All". Close the window.

- To populate your project with well logs double click on the created project in the Project List Screen. Select "Search" from the new window. When the next window appears, select "US" from the upper tabs and "County" from the lower tabs. From the pull down menus select the desired state and "All" under county name. Click "Search" in the lower left part of the window. After search is complete and desired amount of "Wells Found" is reached, hit "OK" button (Figure 10).
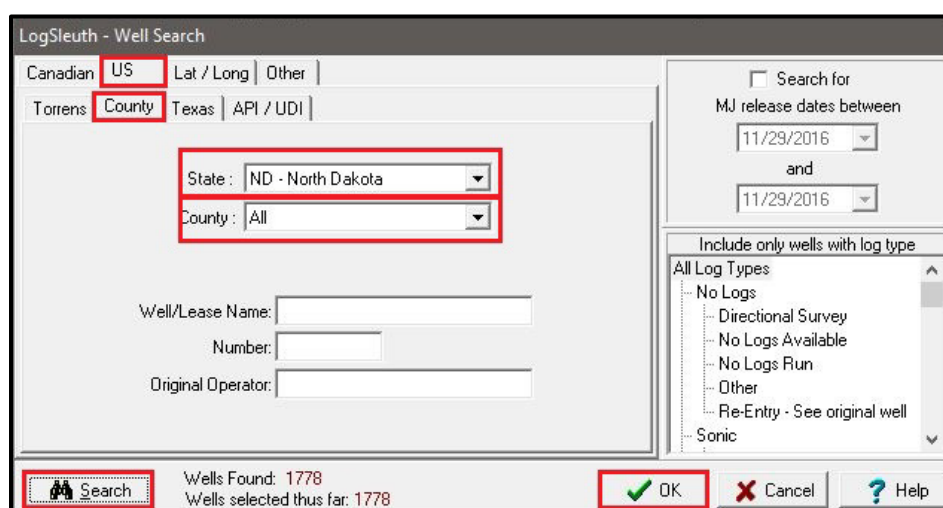

Figure 10: Defining well search.

- After well list is populated, you can either "Batch Export" well logs to be used in other programs (like Petra) or continue working with logs in LogSleuth.

2.3.   Batch Exporting well logs

Batch Export command allows you to select numerous wells from the Well List screen and

export them with minimal effort. To select and export well logs follow instructions below.

- In the main Project List screen, select "Window" on the upper panel and choose "Well

  List" or use shortcut Ctrl+W.

- In the Well List screen highlight the wells you wish to export. To select all wells in the

  list press Ctrl+A.

- After all the desired well logs are selected, click on "File" on the upper panel and choose

  "Batch Export Logs" (Figure 11). *Note:* if the "Batch Export Logs" option is greyed out

  (not highlighted) authentication have to be performed. To do so return to the Project List

  screen. Click on "File", then "Online Services" and "Authentication". The window will

  open and in the required fields (marked with *) enter Larry Smith under name, Montana

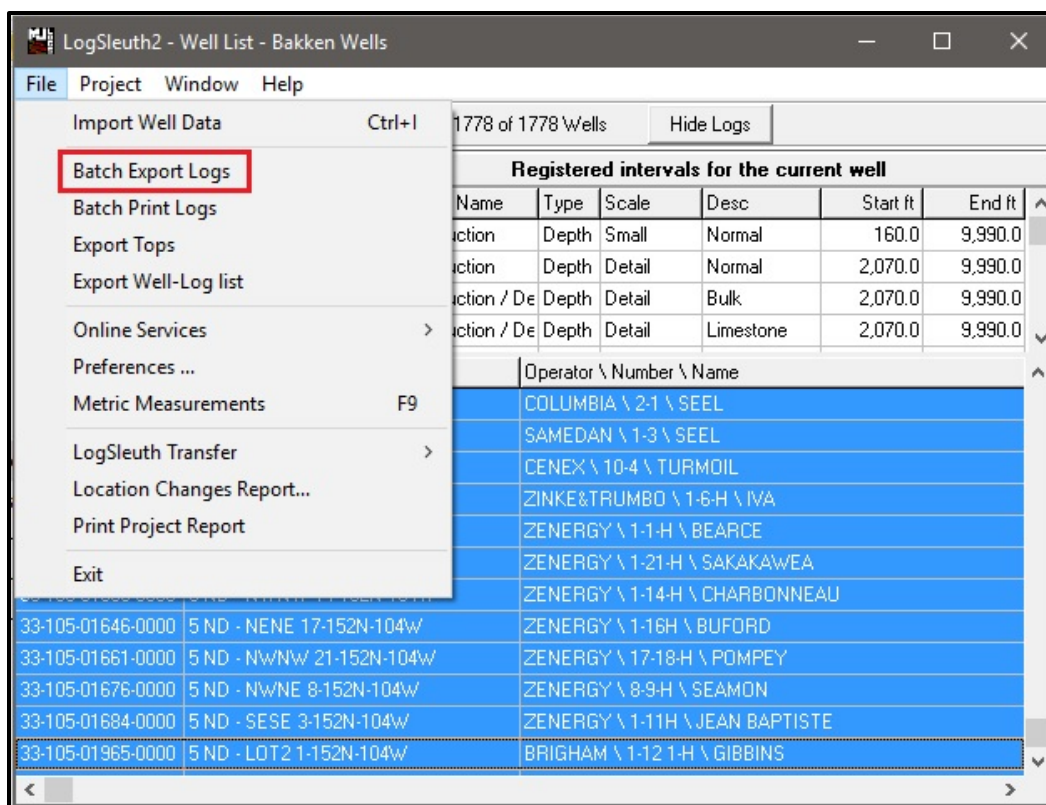 Tech under Company, and USA under Country.

Figure 11: Batch Export Logs option.

- When the "Batch Export" window appears, click through all the tabs to verify that all desired logs are loaded. Under "Export" tab, check the box marked "Include Headers" and then navigate export file to the desired folder through "Save to directory" field (Figure 12).
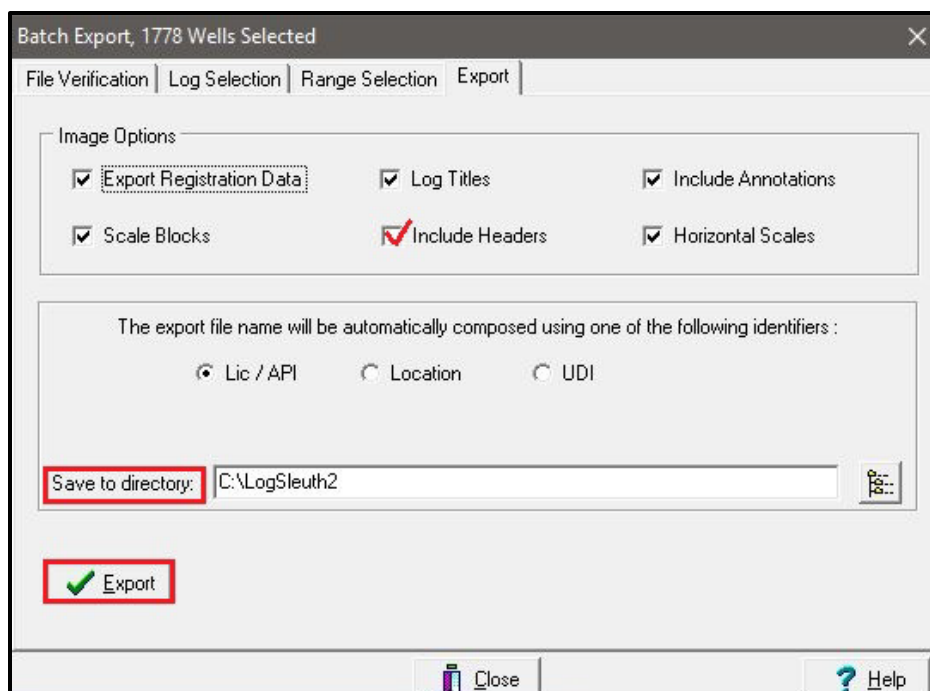
Figure 12: Batch Export window.

- Click "Export". The "Batch Export" usually takes some time, depending on the number of well logs you wish to export. After "Batch Export" is complete, the resulting file will have ".REG" file extension. How to import the ".REG" file into Petra is discussed in the "Petra" section of the manual.

2.4.   Correlating logs in LogSleuth

Start log correlation by defining formations you wish to correlate using LogSleuth. In the Project List Screen right click on the Project Name and select "Edit". In the Project Setting window choose the second tab labeled "Formations". Here you can create numerous marker names and change the color of the marker under the color pull down button. After you created the formation markers, click "Close" button to exit the menu.

Log correlation is performed in Log View Screen. To access Log View Screen, from the main Project List screen click on "Window" on the upper panel and select Log View or use Ctrl+L

shortcut. In the Log View Screen you can click on the desired well and then click on the specific

log (e.g. Laterolog, Density/Neutron, Sonic, Gamma Ray, Induction) under the "Logs for the

current well" section in the upper left corner. If you wish to view a single log for a particular

well, click "Ok". If you wish to correlate logs for numerous wells, click on every desired well

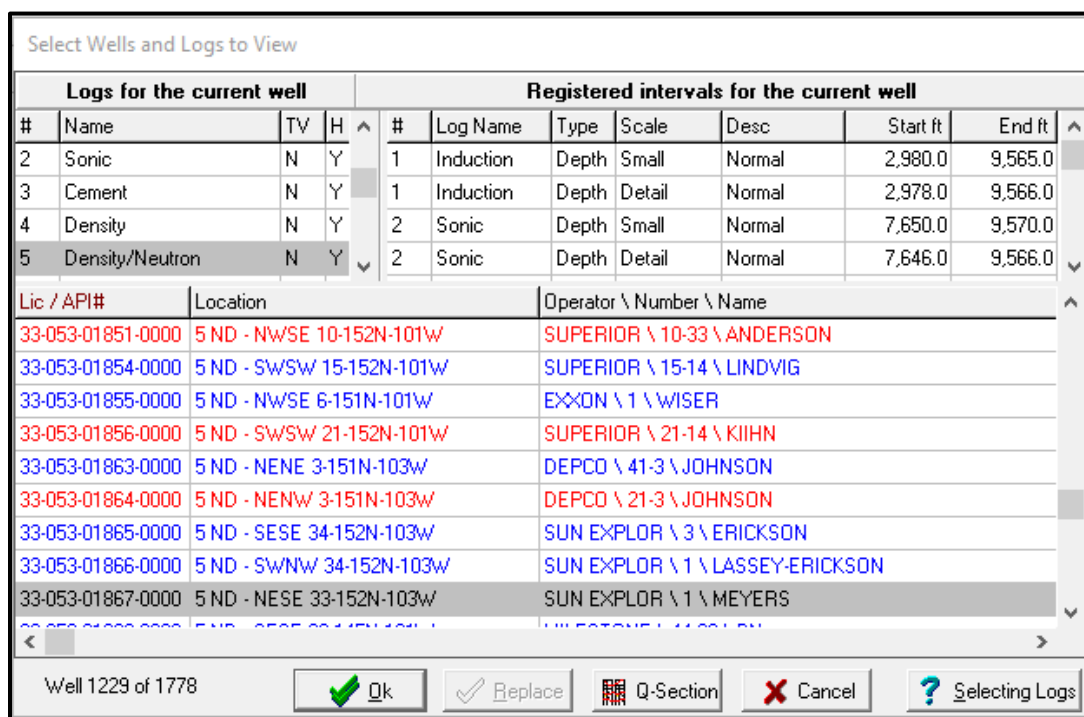and highlight the proper log, after which hit "Ok" (wells with selected logs will turn red as can

be seen in Figure 13).

Figure 13: Selecting logs to correlate.

The Log Viewer window will appear. To start correlating click on the "Display Annotations

editor" button ![icon] or use Ctrl+A shortcut. To pick the interval, select the designated formation

marker and click on "Action" button on the upper panel and select "Quick Pick" from the menu.

Navigate through the log and find the interval you wish to place the formation marker upon, then

simply click on the interval and the marker will be automatically placed. Repeat the process for

every remaining formation marker. If you wish to replace a certain log with a log from a

different well, select the log by clicking on the well header and click "Select a well log for

viewing" button (or press F4 button). The Select Wells and Logs to View screen will appear

from which you can select a different well log. After selecting a well log click on "Replace"

button instead of "Ok" button. You can also save current well log selection by choosing "File"

button on the upper pane and selecting "Save Quick Section" option from the menu.

Note: You can print a certain interval from the raster log by selecting "Clip interval from log

images for export or print" button or Ctrl+I shortcut. The function is similar to "Snipping

Tool" however you can add a page title and annotations when printing.

3. AccuMap

3.1. Getting started in AccuMap

Step 1: Start by opening IHS AccuMap IPL program. The start screen in AccuMap is shown in figure below with outline of the states in United States and provinces in Canada. The states include Montana, North Dakota, and Wyoming. The provinces in Canada are British Columbia, Alberta, Saskatchewan, Manitoba, and Northern Territories.
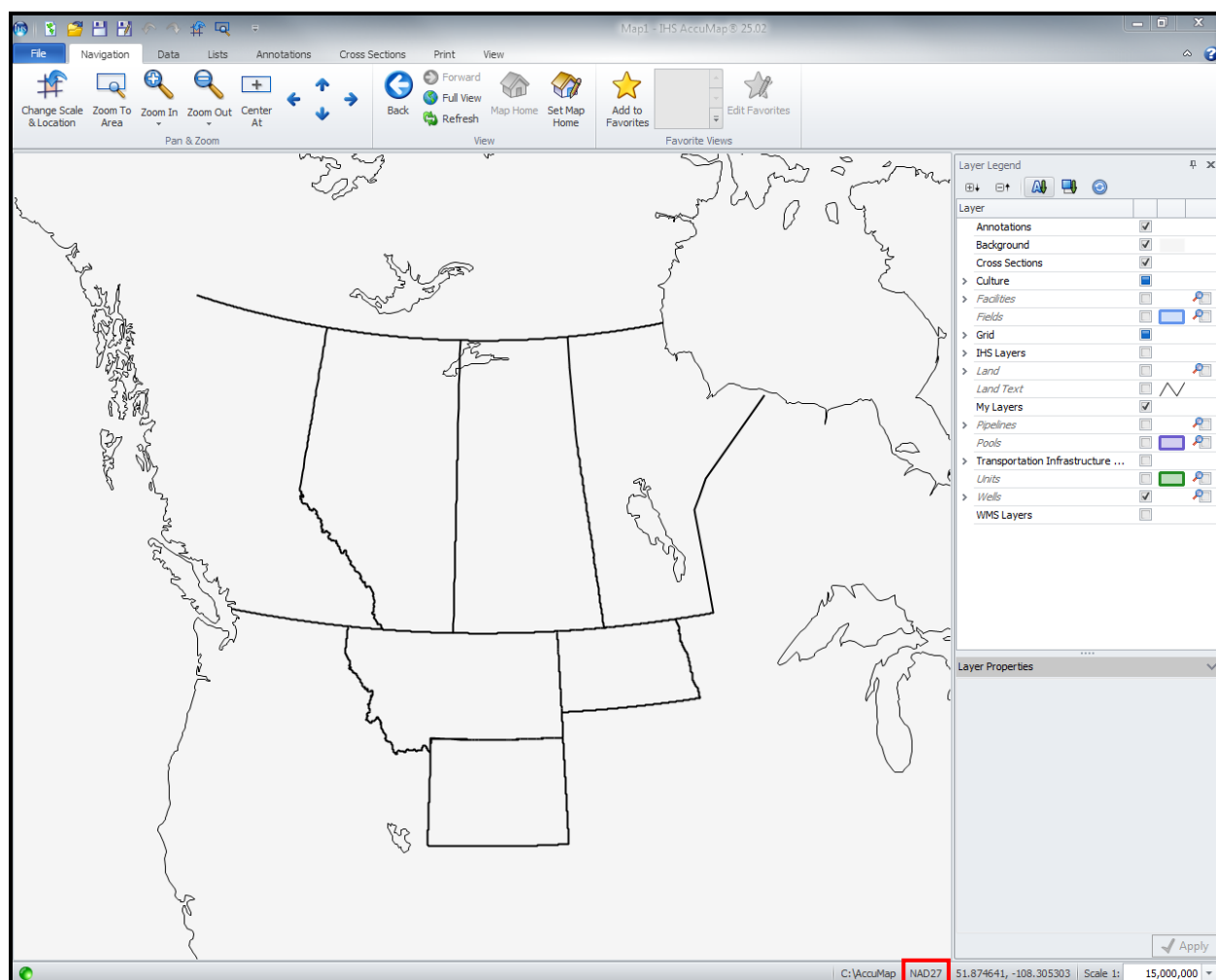

Figure 14: Default start window in AccuMap.

Step 2: Before starting the process of selecting wells, make sure that the map is projected in NAD27. You can find the projection in the lower right corner (red box in the Figure 14). After

the right projection is confirmed, follow the instruction to set the export process in the same

projection:

- Click on "File" tab in the right upper corner.

- Select "Settings" on the left side of the window.

- In "Application Settings" click on "Export" option on the left side of the window.

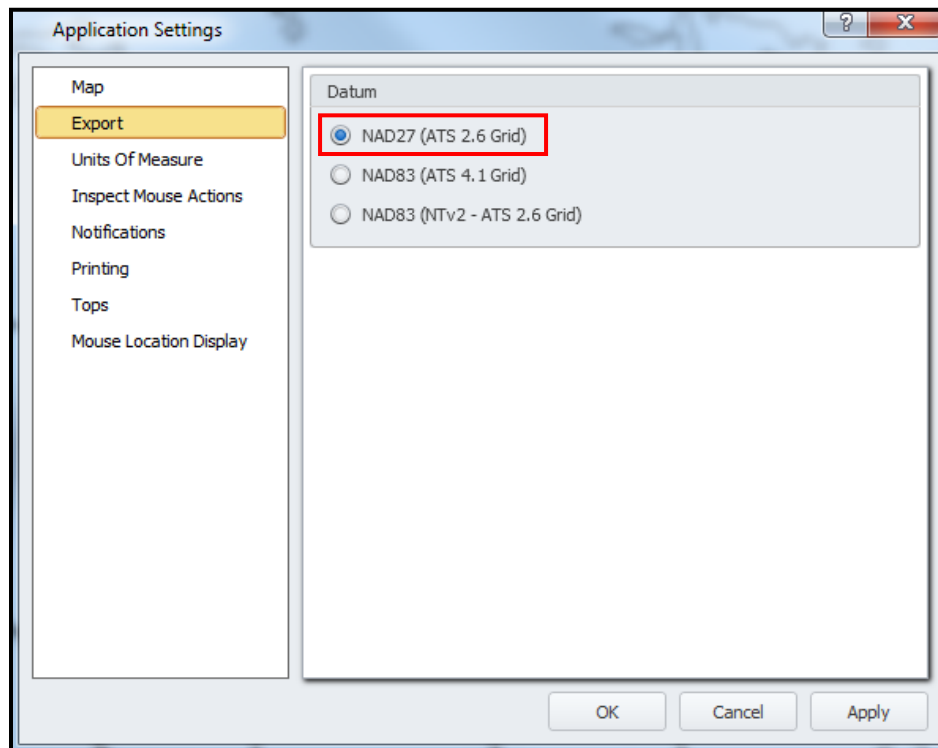- Under "Datum" select "NAD27 (ATS 2.6 Grid)" (first option).

Figure 15: Settings window with Export options.

- Click "OK"

This step is very important because if map projection and export projection are different, you

will not be able to export well data from AccuMap.

Step 3: Next step is to navigate to your area of interest. This manual uses North Dakota as an

example.

- Select "Navigation" tab on the upper panel.

- You can locate the area by using "Zoom In" and "Zoom Out" buttons. If you click on the down arrow below the button you can choose to zoom in or zoom out by 4x, 6x, or 10x.

- Other option is to choose "Zoom To Area" button. With "Zoom To Area" button you can draw a rectangle to choose a more precise area you wish to focus on.
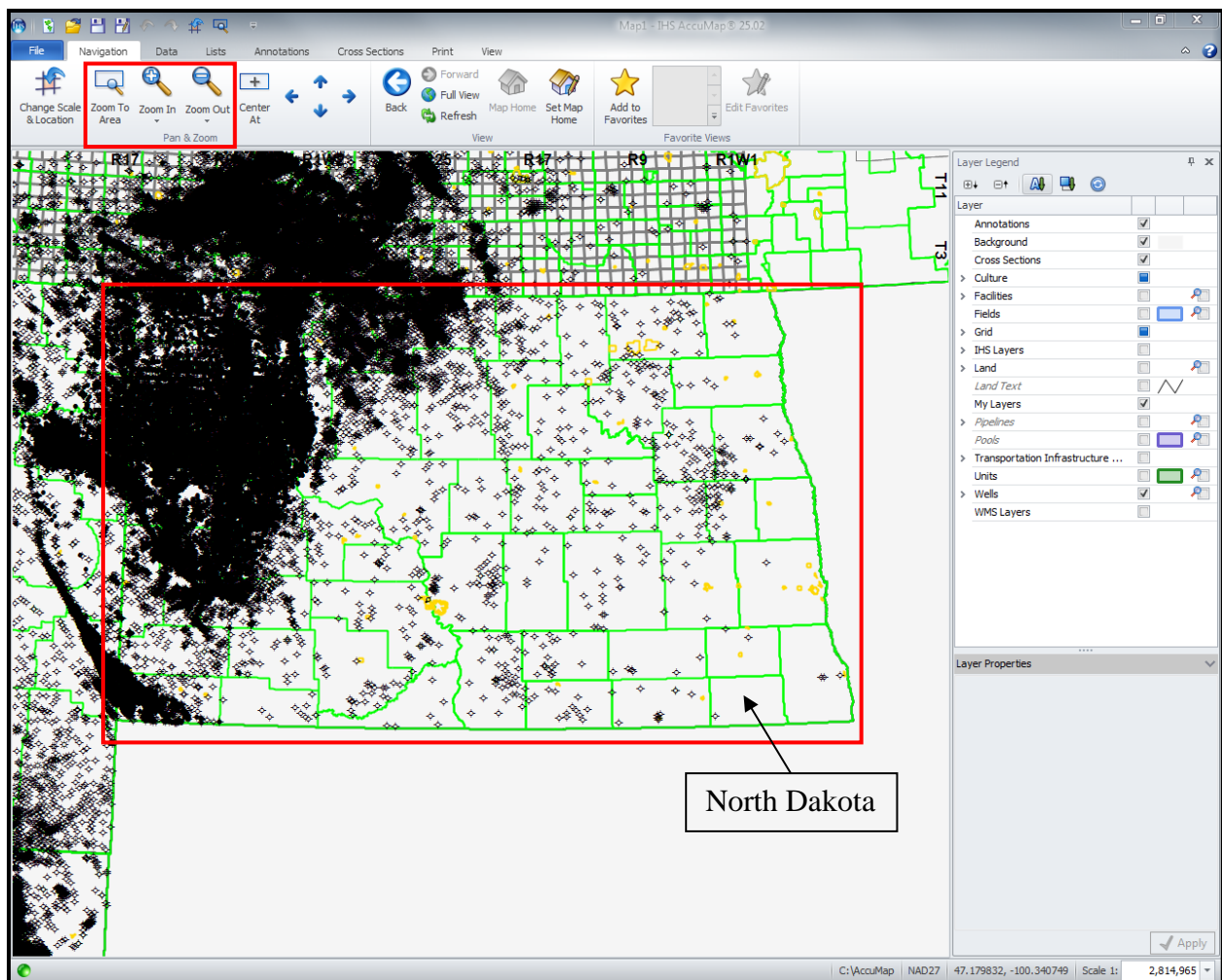

Figure 16: Zoomed in area of North Dakota.

- To return back and forth to the previous map extends, use "Back" and "Forward" buttons.

- To navigate throughout the map, press and hold the left click of the mouse.

- You can also use blue arrows in the center of the "Navigation" tab to pan the map upwards, downwards, to the right and to the left.

- To set the desired map view as a default home view, use "Set Map Home" button. This option only works if the map is saved. To return to the default home view at any time, press "Map Home" button.

- Save the map project by going to the "File" tab, then "Save" button or use "Save" icon on the uppermost left corner. The map saves into a default location: "Local Disk (C:) → AccuMap".

3.2. Creating and managing well lists in AccuMap

In order to use the extensive database in Accumap software, one must create well list that includes desired well data. The well list can be created by manually selecting the wells, or automatically by creating a query. Both processes are outlined below.

3.2.1. Creating well list by using "Select Wells" option

- Navigate to the area you wish to select wells from. In this manual we will use Billings County in North Dakota as an example. The county boundary is outlined in lime green.
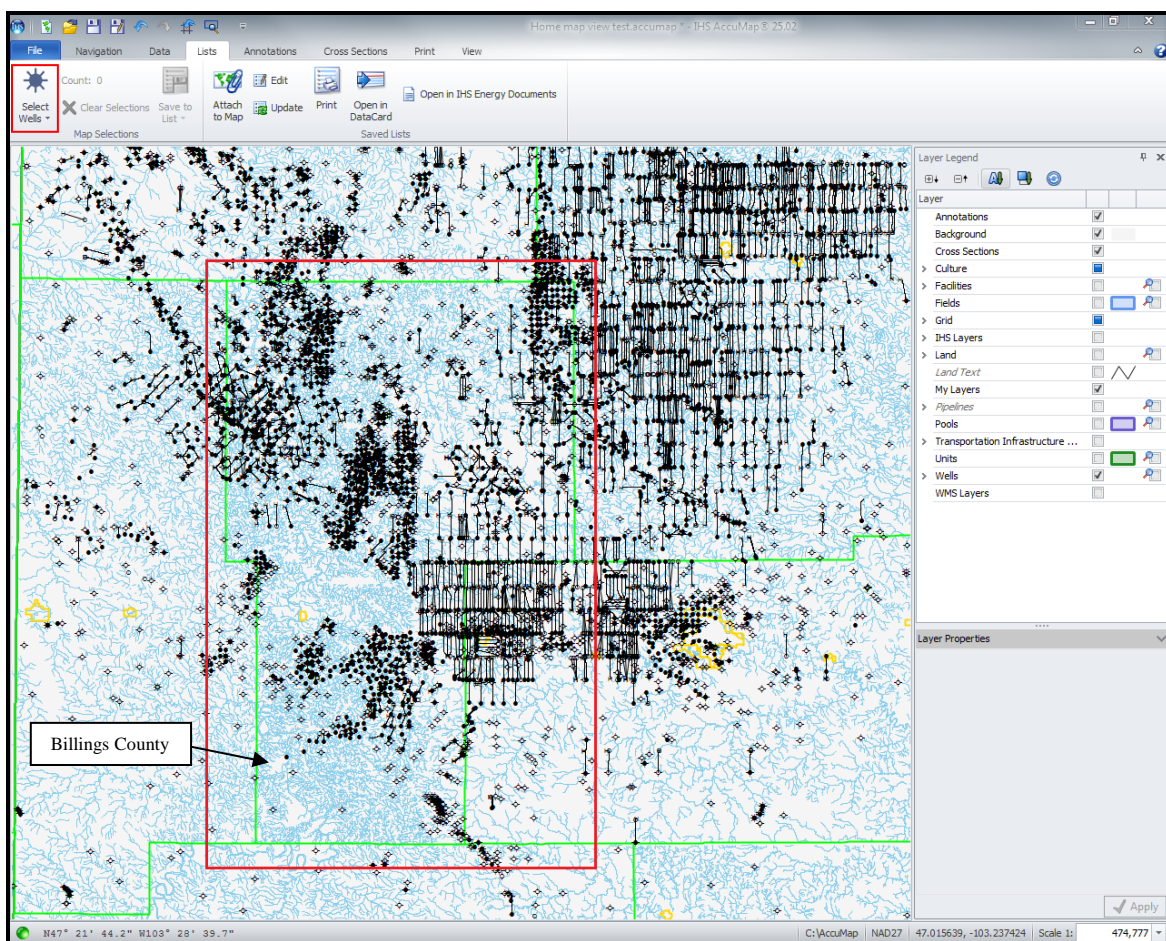
Figure 17: Selecting wells in Billings County, North Dakota.

- To select the wells, click on the "Select Wells" button in the upper left corner under the "Lists" tab (red box in Figure 17). *Note*: when you click "Select Wells" button, you can no longer navigate throughout the map using left click of the mouse. If you need to zoom in on a particular area (usually on the densely populated wells) use "Zoom In" or "Zoom To Area" buttons under the "Navigation" tab.

- After the wells are selected, the well symbols will turn blue.
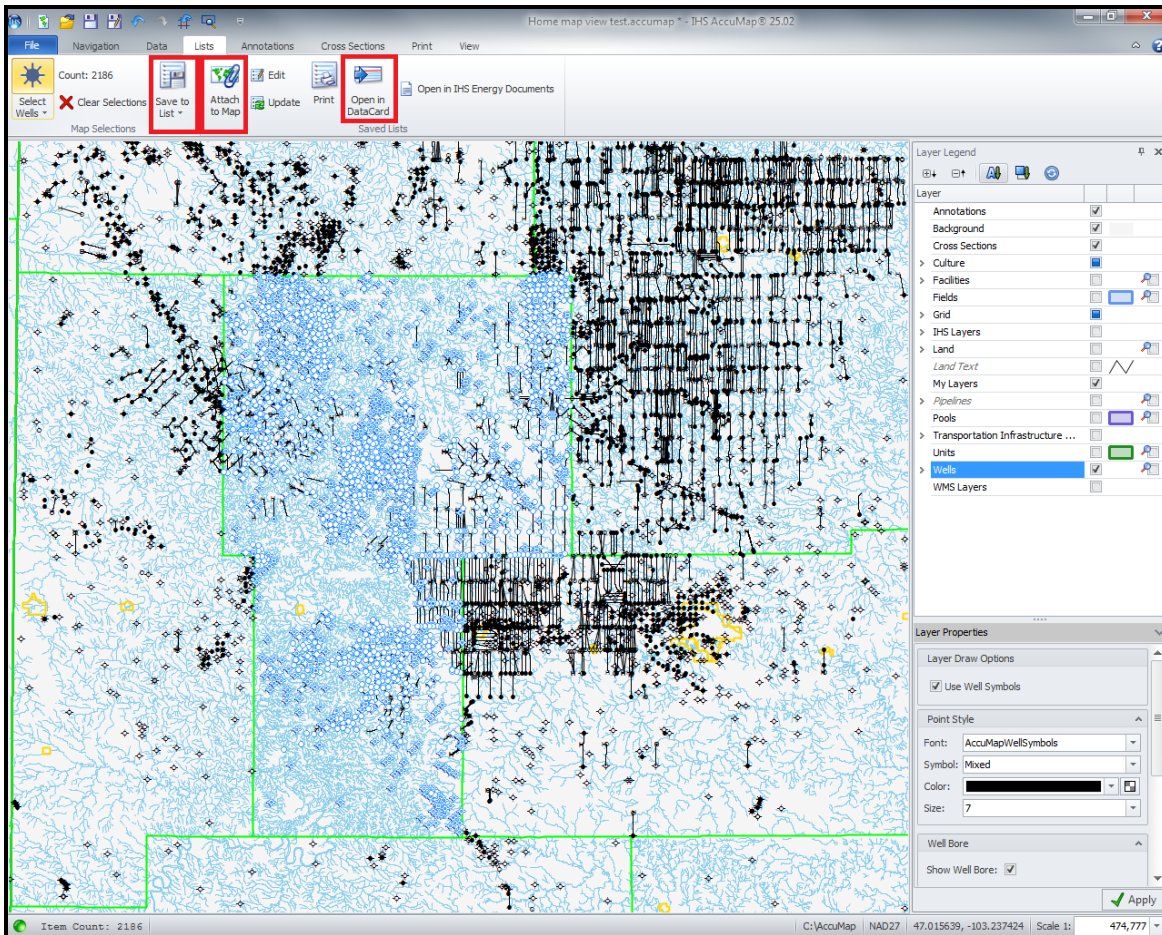
Figure 18: Wells selected using "Select Wells" button.

- After selecting wells, use "Save to List" button (red box in Figure 18), to save your well list. The "Enter Description" window will appear, enter the name you wish to assign to the well list. The well list will be saved in "Local Disk (C:) → AccuMap" directory with **LWELL File** extension. Click "Save"

- The well list will appear under the "Lists" layer in the "Layer Legend" on the right side of the map. The wells will turn red when the well list is saved.

3.2.2. Creating well list by using "Query" option

You can create well lists by two different methods using "Query" button. First method involves creating map annotations and the second involves using current map screen.

First method:

- Click on "Annotations" tab. Under the "Annotations" tab select "Polygon". Draw a desired shape that includes all the wells, you want to save in the well list.
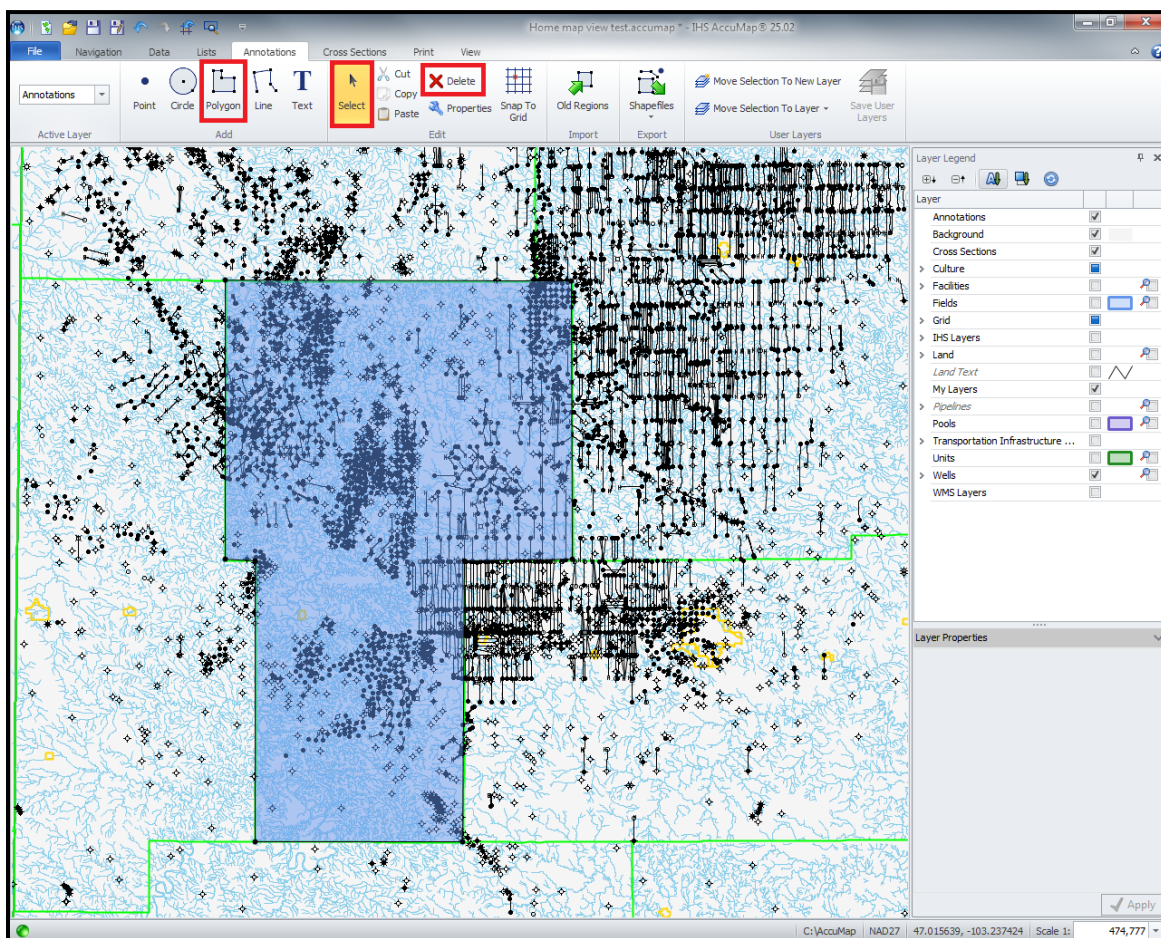

Figure 19: Selecting wells using "Polygon" button.

- Next, under "Data" tab, choose "Query" button. Query window will appear. Under "Region" pull down menu on the left side, choose "Map Annotation". Click "Add". After the query term "Region = Map Annotation" appears on the lower half of the window, click "Run Query" on the lower right corner.
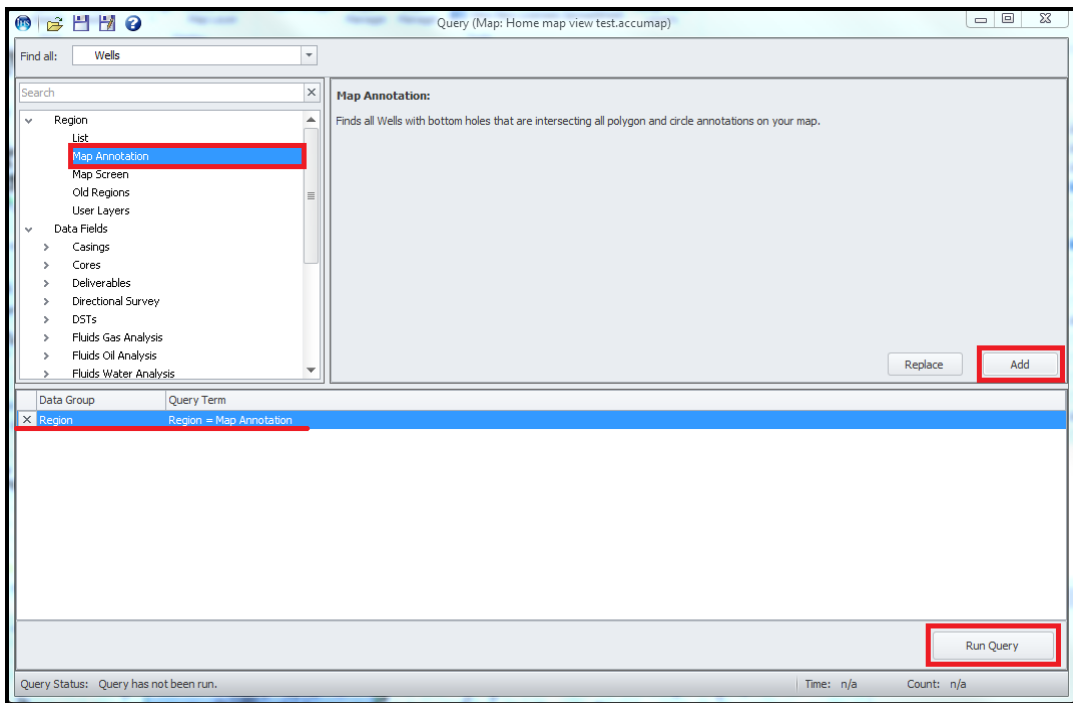
Figure 20: Query window.

- The query results will appear. Choose "Save to list" button, to save the well list, or choose "Save to list & attach" for well list to appear on the map screen.
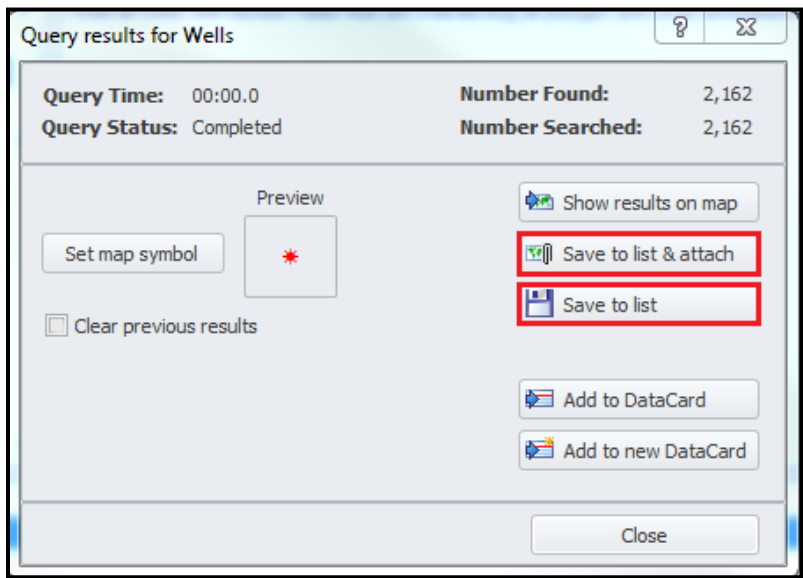

Figure 21: Query results window.

- After choosing "Save to list & attach" option, the selected wells will appear in red on the map screen. If you do not need the polygon, you can choose "Select" button from the "Annotations" tab menu, select the polygon on the map screen and press "Delete" button.

- Close the query window. Save the query if you wish to use it again.

Second method:

- Click on the "Data" tab. Choose "Query" button. Query window will appear. Under "Region" pull down menu on the left side, choose "Map Screen", then click "Add". After the query term "Region = Map Screen" appears on the lower half of the window, click "Run Query" on the lower right corner.

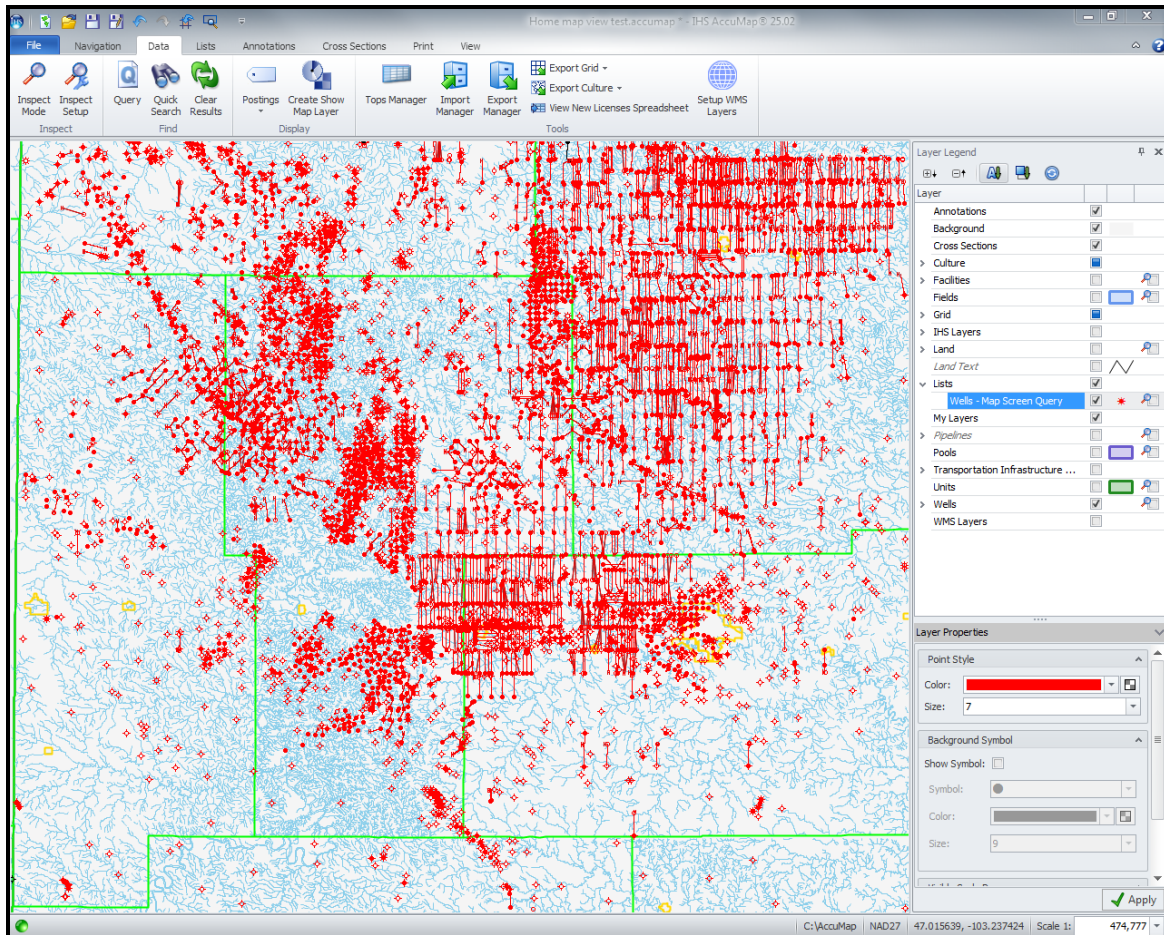- The "Query results for Wells" window will appear. Apply the same options as you would do in the first method.

Figure 22: Selected wells using "Map Screen" query.

- **WARNING**: using "Map Screen" query **ALL** wells that are visible on the map screen will be selected.

Lists containing fewer than 5,000 wells are preferred, in order to decrease the chance of Petra crashing during importing process.

3.2.3. Managing existing well lists

After well lists are created, you can display and edit saved well lists. You can also view well lists in DataCard. To manage existing well lists proceed with following steps:

Attach to Map:

- To display existing well lists on the screen, choose "Attach to Map" button under the

  "Lists" tab menu (second red box in Figure 18).

- "Attach List" window will appear. Choose well list you wish to attach to the map screen.
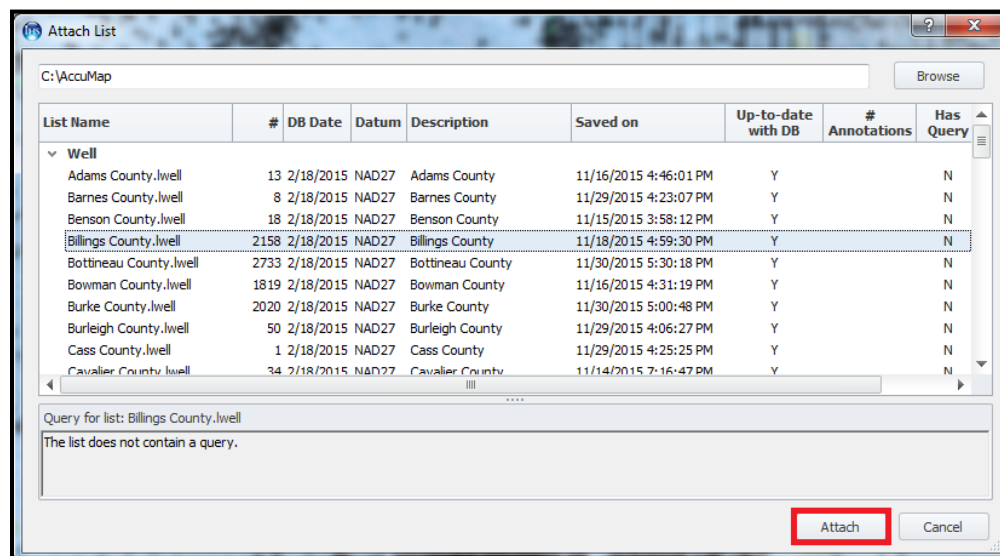
  Click "Attach".

Figure 23: "Attach List" window.

- Wells from the well list will appear in red on the map screen.

Edit Well List:

- To edit well list choose "Edit" button under the "Lists" tab.

- "List Editor" window will appear. Use "Open File" icon on the uppermost menu or right

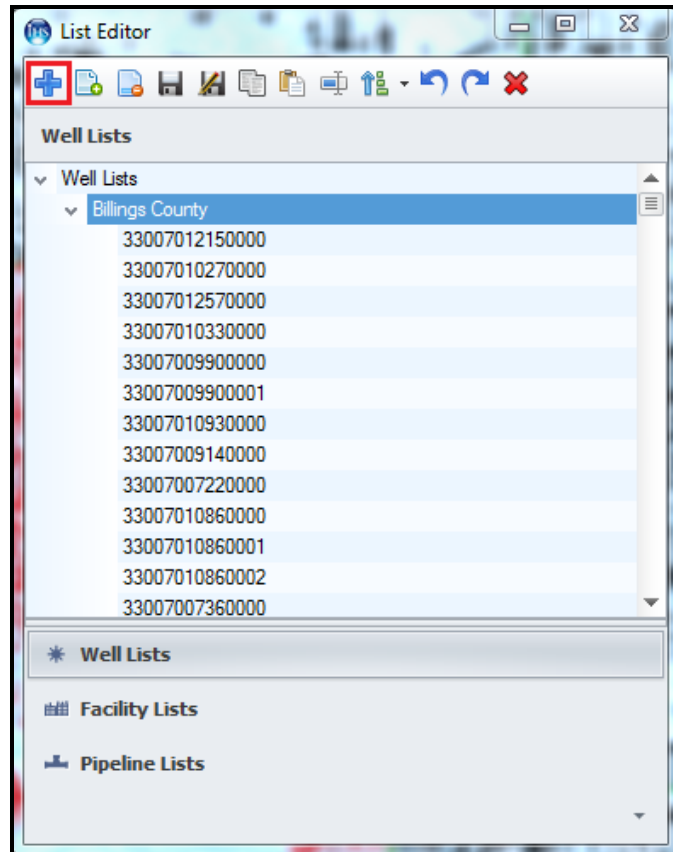 click on the highlighted line to open existing well lists.

Figure 24: List Editor window.

- You can add a well to the list using "Plus" icon on the uppermost menu (red box in figure
  24). "Add Well" window will appear. Under the "Area" menu choose the state or
  province. Enter the wells API number and click "Search", after the well API is found,
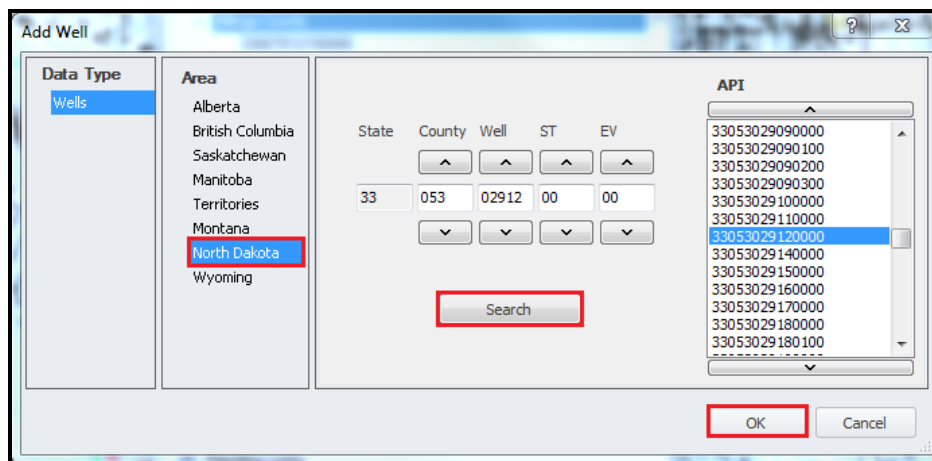 click "OK" and the well will be added to the well list.

Figure 25: Adding well to the well list.

- To delete well from the well list, click on the well API in the "List Editor", and choose the "Delete" icon from the uppermost menu.

- You can add additional lists to the well list, save well list, edit the description of the well list, and sort the well list using the icons on the uppermost menu of the "List Editor".

View Well List in DataCard:

- To view the well list in DataCard choose "Open in DataCard" button under the "Lists" tab.

- In "Open Lists" window, select desired well list and click "Open". The "DataCard" window will appear.
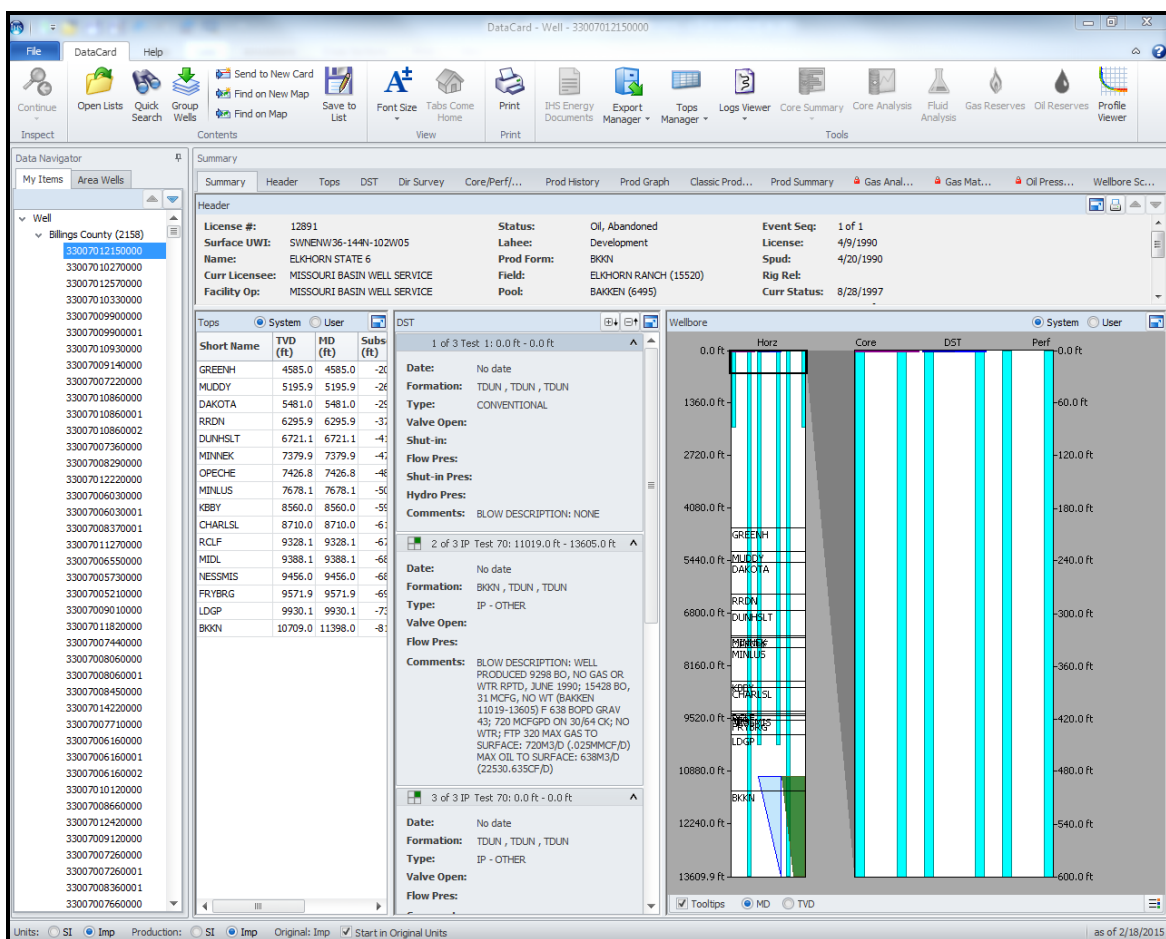
Figure 26: DataCard window.

- In DataCard window you can view and print detailed information from each well in the well list.

3.3.   Exporting well lists

To export well lists into the mapping software like IHS-Petra or into Excel spreadsheet, the "Export Manager" option will be used.

- Under the "Data" tab menu, click "Export Manager" button. "Export Manager" window will appear. Choose the program you wish to export your well list into from the uppermost row of tabs.

- To export well list into Excel spreadsheet, select "Excel" on the uppermost tab menu. Select "Well" category in Step 1. Select desired well list by clicking "Open" button in Step 2. Select one or several templates in Step 3. The most often selected templates are "Well Header" or "Production". Click "Export" button on the lower right corner.
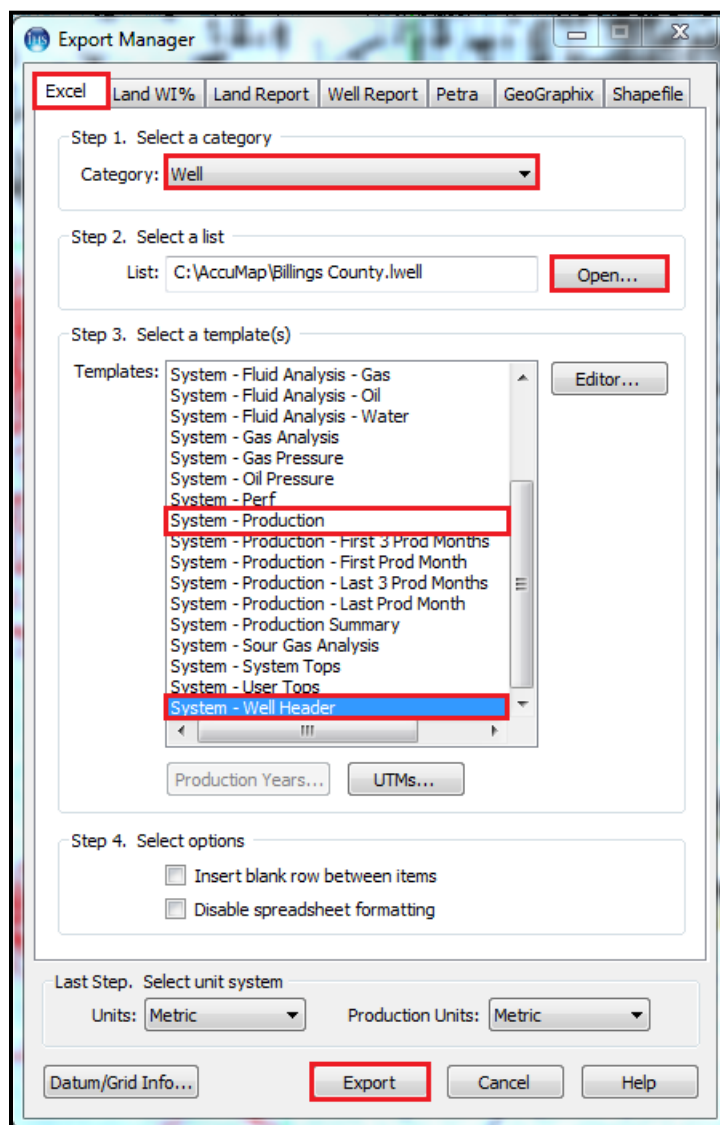

Figure 27: Export Manager window for Excel.

- Well list data will be exported into Excel spreadsheet.

- To export well list into Petra, select "Petra" on the uppermost tab menu. Select desired well list by clicking "Open" in "Select a list" step. Check the box next to "Launch Petra". Uncheck "Active User Tops" and "Additional User Tops" boxes in the "Well data" portion. Also uncheck "Grid data", "Culture data", and "Open Layers / Shapefiles" boxes in the "Production data" portion. Click "Launch".
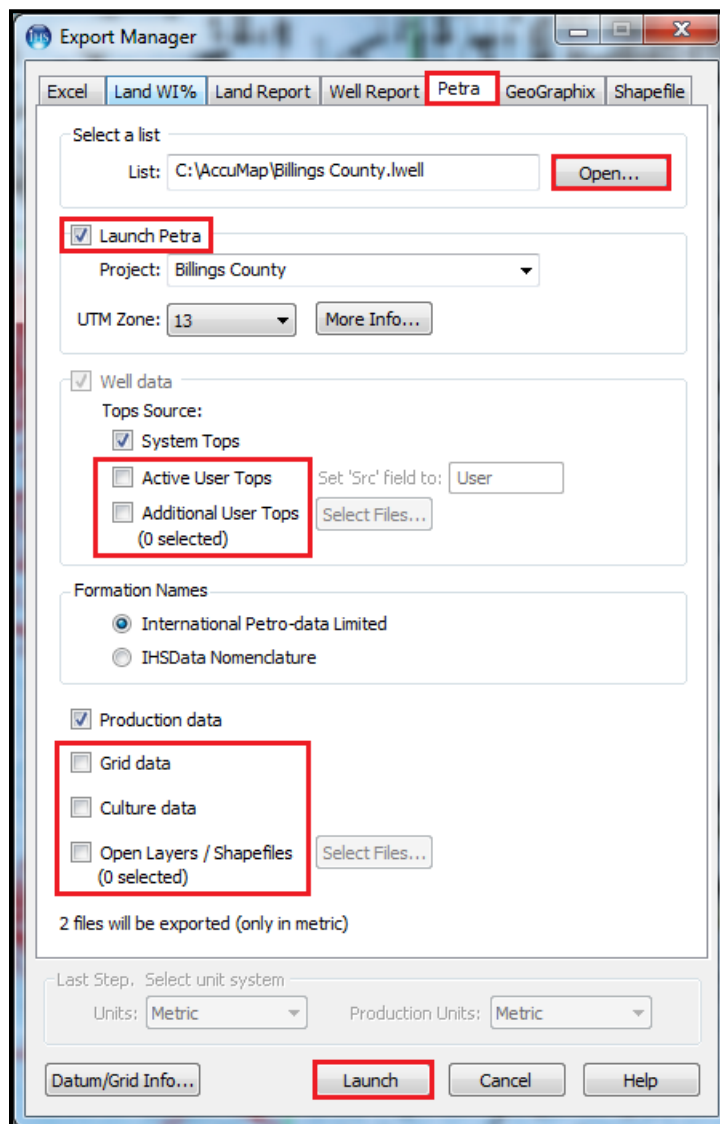

Figure 28: Export Manager window for Petra.

- After the "Launch" button is pressed, Petra will attempt to open the project containing the well list. However, an "Application Error" message will appear. The reason Petra cannot open a project containing the well list is the fact that AccuMap 25.02 version is not compatible with Petra 4.1.1 version, but is with version 3.9. Despite this fact, you should still proceed with exporting well list into Petra, because AccuMap still creates PXP file that can be later imported into Petra.

4. North Dakota Industrial Commission (NDIC) website

Well data can also be obtained from NDIC website. To navigate through the website and download required data use the following steps.

- Go to North Dakota Industrial Commission website: https://www.dmr.nd.gov/oilgas/. Click on "Premium Services". Click on "Well Search". When "Authentication Required" window appears, enter "MTech" as a login, and "Black8Gold" as a password. In the new window click on "Digital & Image Logs".

Figure 29: NDIC well search window.

- Search for wells by either selecting an Operator, Field or Section, Township, Range. Once you selected the criteria mentioned above, select the type of well logs you want to download in the "Log Type" drop line. Click "Submit".

- The list of digital logs will appear. Click on the file under the "Digital log" column (it will be blue and highlighted). The file will open as TIFF file. Save the file in the designated folder. *Note:* make sure you rename the raster TIFF file using well API number (it will be crucial when importing rasters into Petra). API number can be found by clicking "File No". Moreover, API numbers can be cross referenced with File No in

the "WellIndex" excel file downloaded from the "Well Index & Downloads". To obtain

the excel file, click on "Well Index & Downloads" located under "Well Data" section in

the Premium Services and download "well_index.zip" file.

4.1. Exporting Well Data from NDIC via ArcGIS

Well data (such as API number, well name, TD, location coordinates, field name, operator, etc.)

can be exported from NDIC in Excel spreadsheet through ArcGIS. Resulting spreadsheet will

contain extensive data for every well in North Dakota.

- Go to North Dakota Industrial Commission website: https://www.dmr.nd.gov/oilgas/

- From the menu on the left side choose GIS Map Server. A new window will appear that

  shows the map of North Dakota and the location of the wells using ArcIMS Viewer.

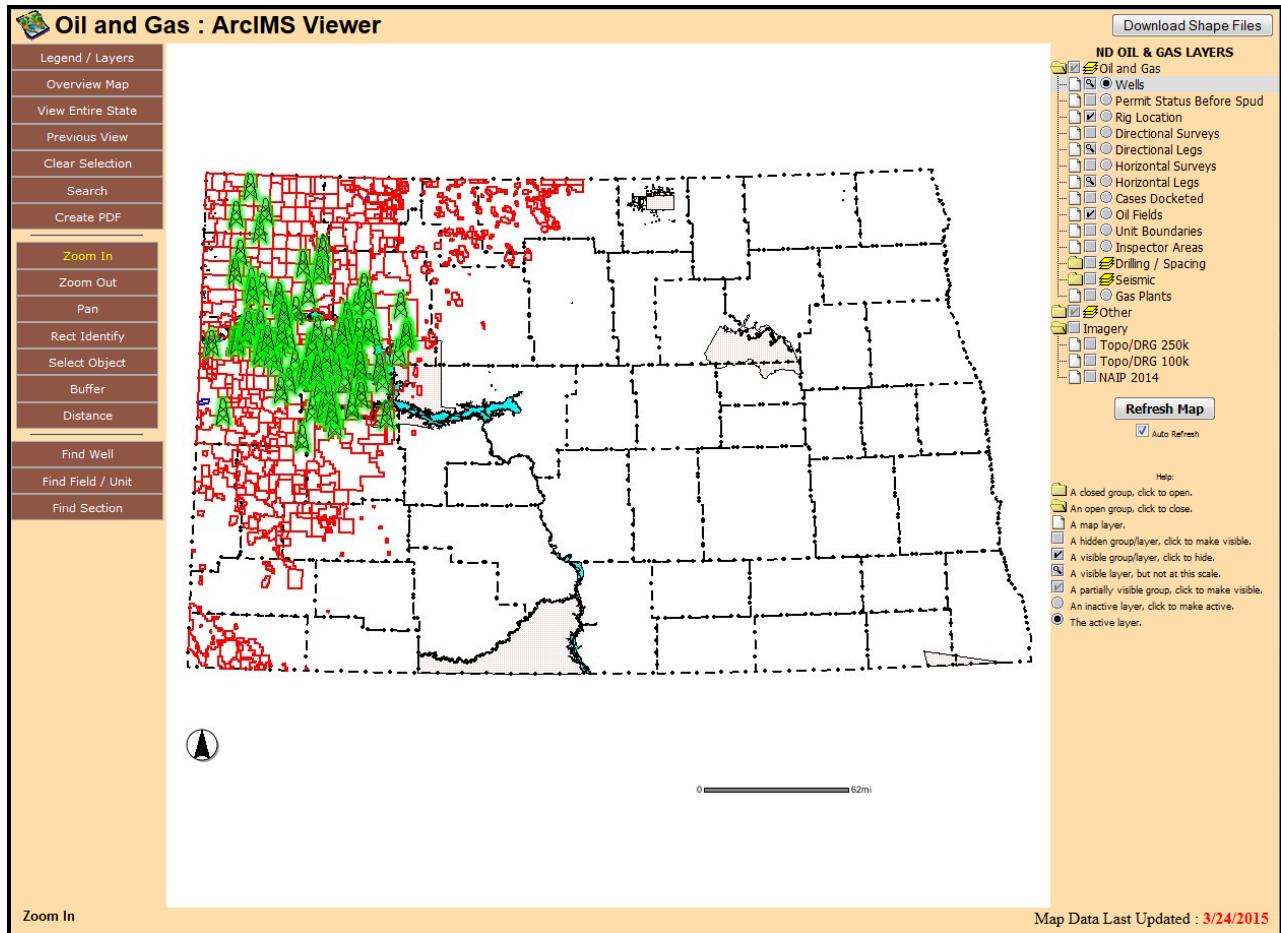 Zoom in on any particular part of the map to view individual well location.

Figure 30: Well location map.

- On the upper right side of the screen choose "Download Shape Files". When downloads appear, select "Wells" file at the bottom. Save file in designated location. The well data will be projected in NAD 1927.

- Open ArcMap program. Click on "Catalog" and click the button to connect to folder. Choose the "Wells" file from designated location and click ok. Drag "wells.shp" in the "Layers" window and well locations will appear.
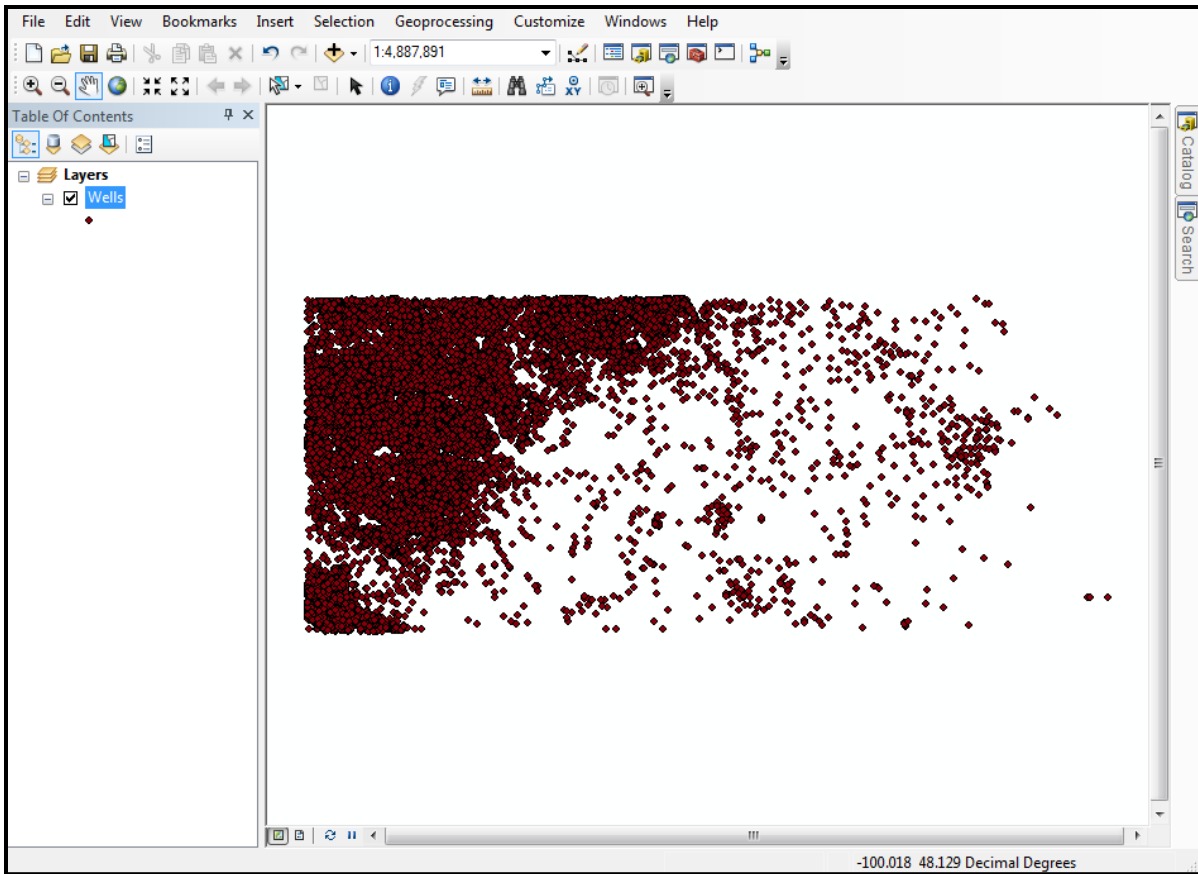
Figure 31: ArcGIS map screen showing the location of wells in North Dakota.

- Open the ArcToolbox window. Expand Conversion Tools option, then Excel option. Choose Table to Excel. When window appears, choose "Wells" for Input Table and choose designated location for Output Excel File.
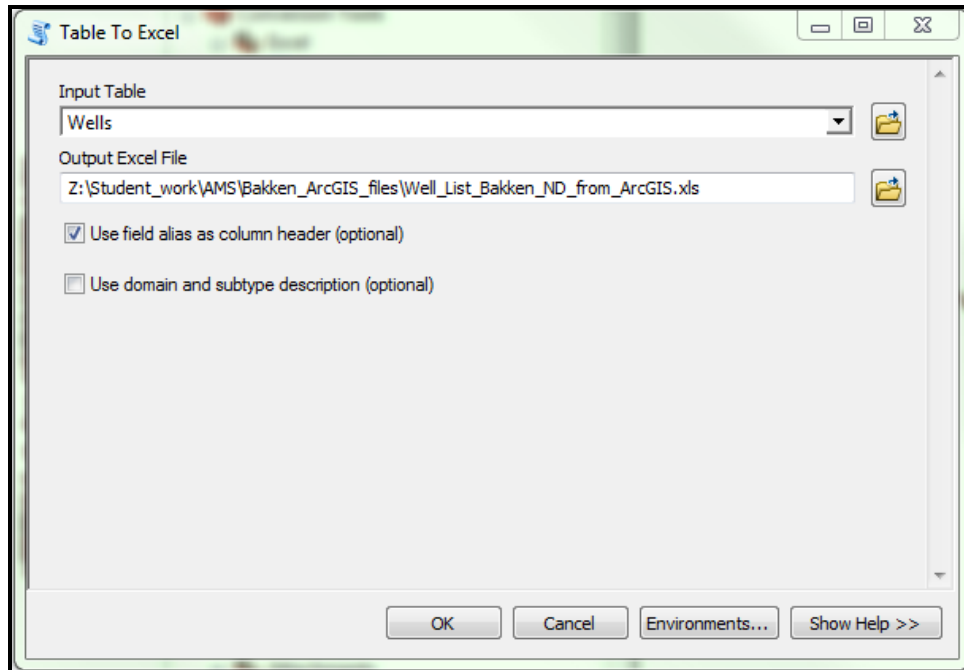
Figure 32: Table to Excel window.

- Resulting Excel file will contain the same information as in attribute table for "Wells" layer.

5. Petra

5.1. Getting started in Petra

Start by opening IHS Petra program. In the "Petra Main" window select "Start Petra in Private

Mode". Select "Create a NEW Project", click "OK". Enter the project NAME and

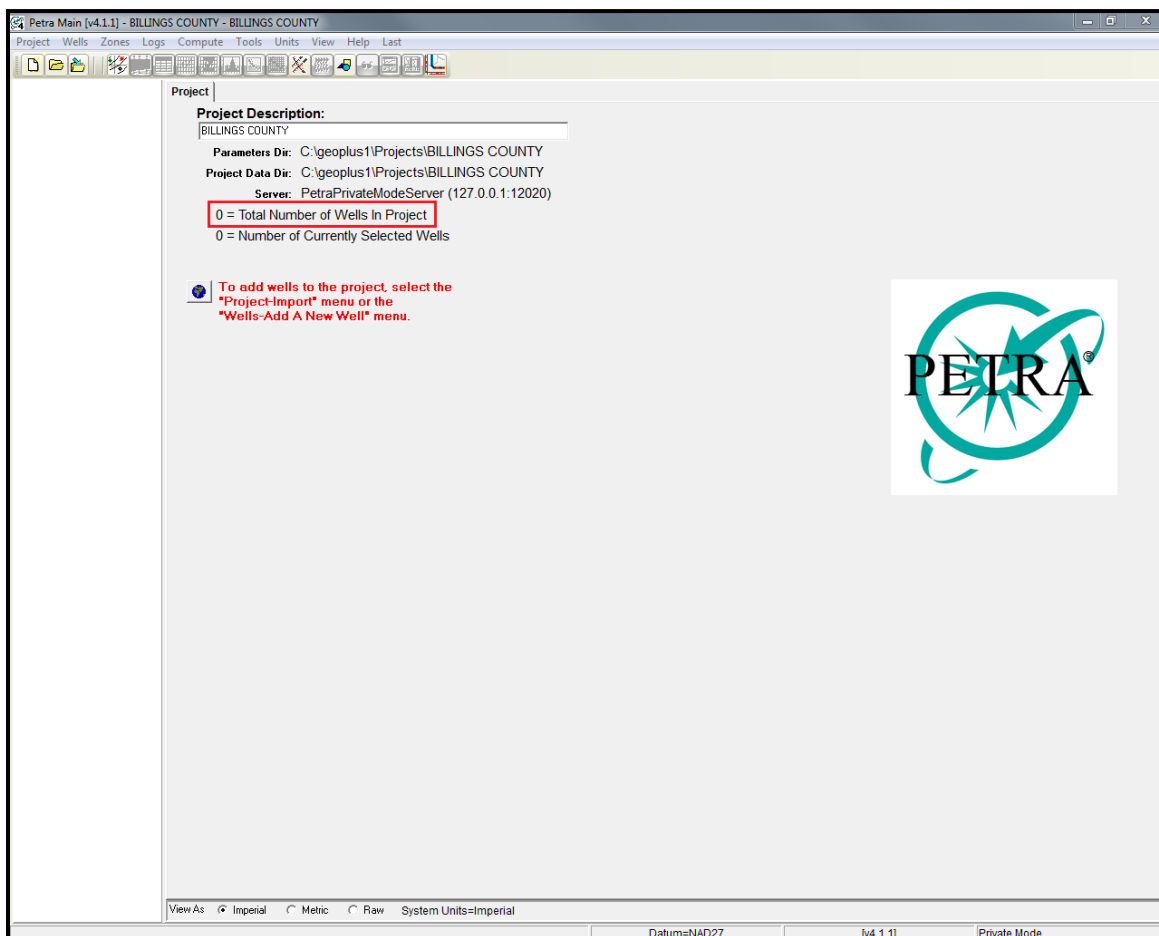DESCRIPTION, then save the project in the desired directory. "Petra Main" window will open.

Figure 33: Petra Main window.

5.2. Importing wells and well data from databases into Petra

Petra does not contain any well data as you can see in Figure 33. To be able to correlate and map

formation tops, the well data needs to be imported from the databases like AccuMap, MJ

Systems, and NDIC.

5.2.1. Importing well lists into Petra

5.2.1.1. From Accumap

- In "Petra Main" window, select "Project" in the uppermost tab menu. Under "Project" choose "Import", then "Accumap PETRA Well File".
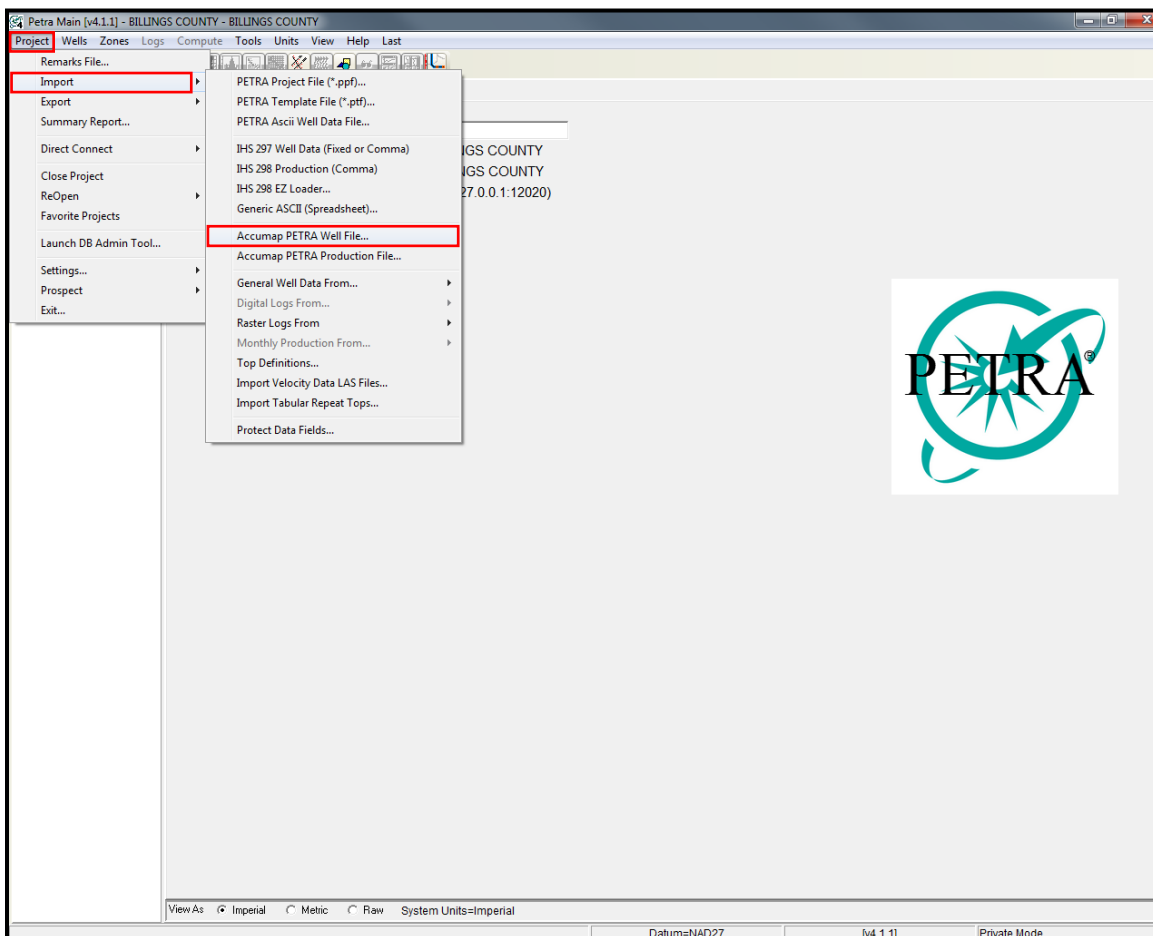

Figure 34: Importing AccuMap well list into Petra.

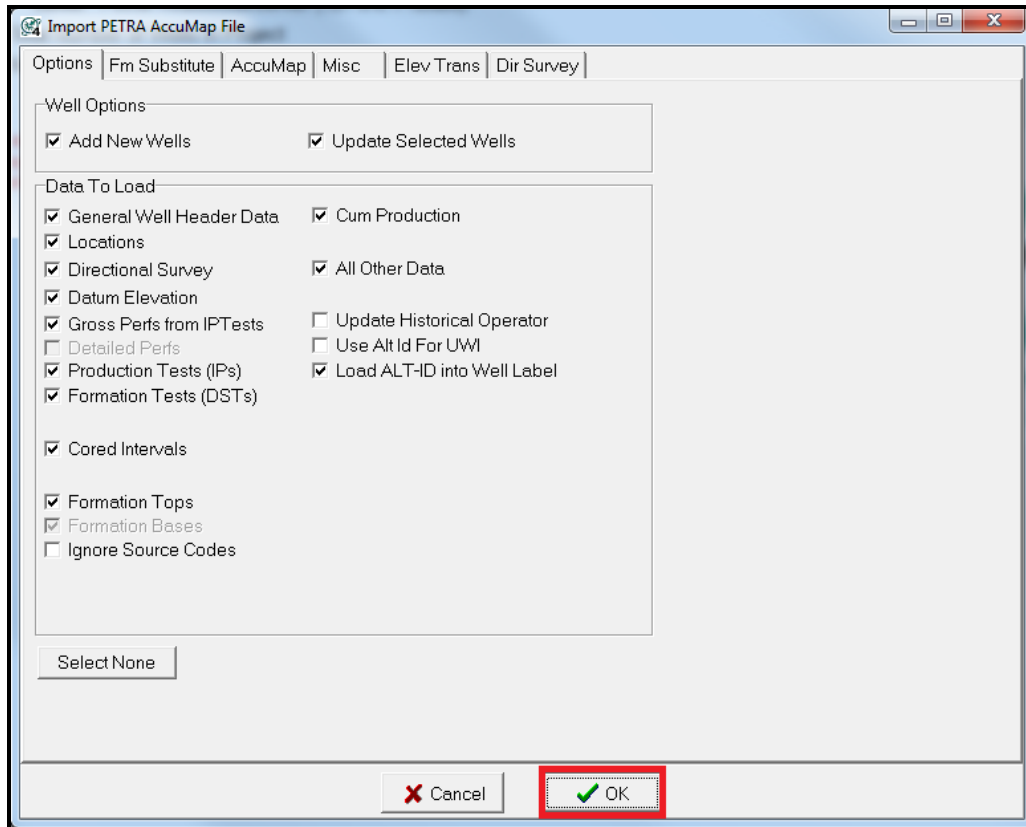- The "Import PETRA AccuMap File" will appear. Accept the default settings by pressing "OK".

Figure 35: Import PETRA AccuMap File window.

- The default folder that Petra will open, does not contain the well lists. Instead go to:

  "Computer → Local Disk (C:) → AccuMap". In AccuMap folder, find desired well list

  that is in PXP File format. Select that well list.

- When the import is complete, the resulting "Petra Main" window will be similar to

  Figure 35. Now Petra contains the exact same amount of wells as does your well list file
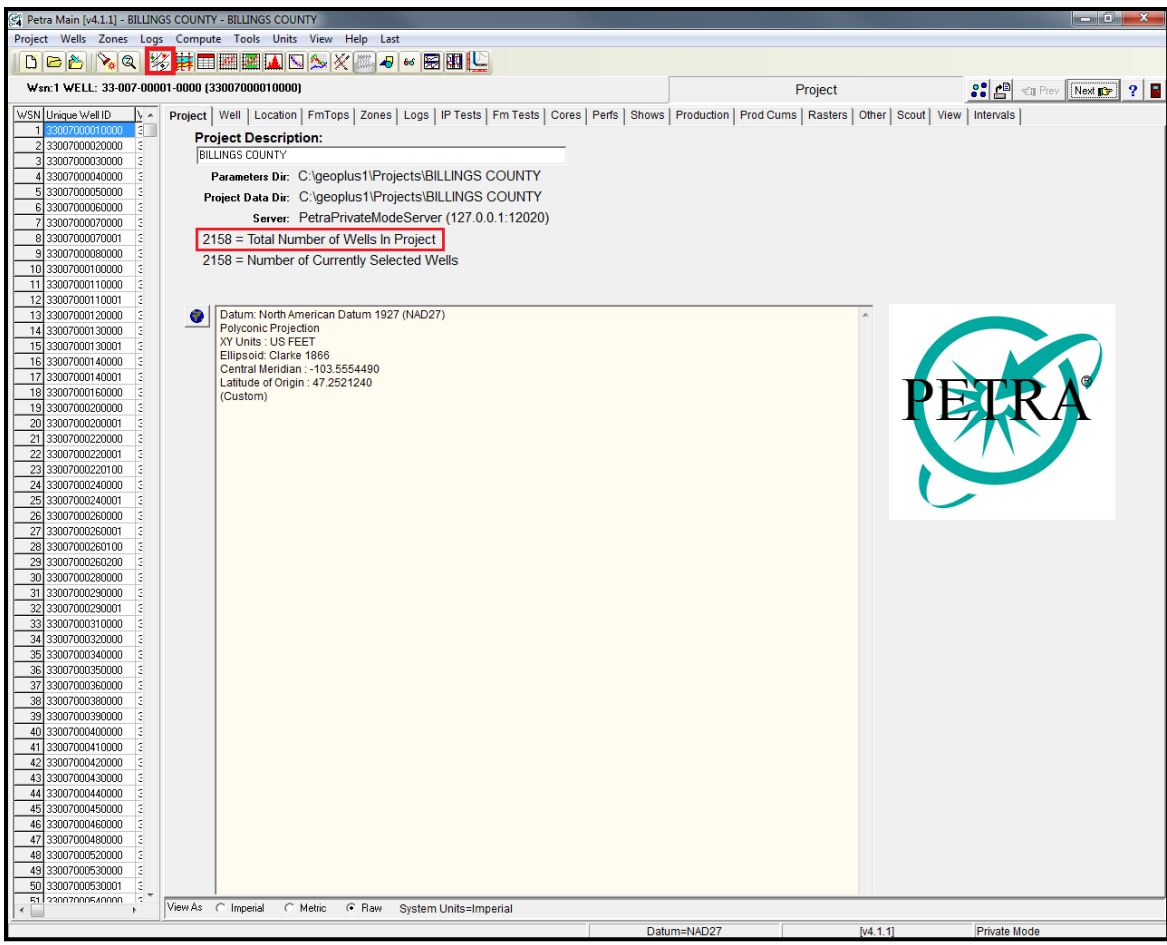
  in AccuMap.

Figure 36: Petra Main window after well list from AccuMap is imported.

- By clicking the map icon in the "Petra Main" window (red box in Figure 36, icon row in the upper left corner), you can view wells in map window (Figure 37).
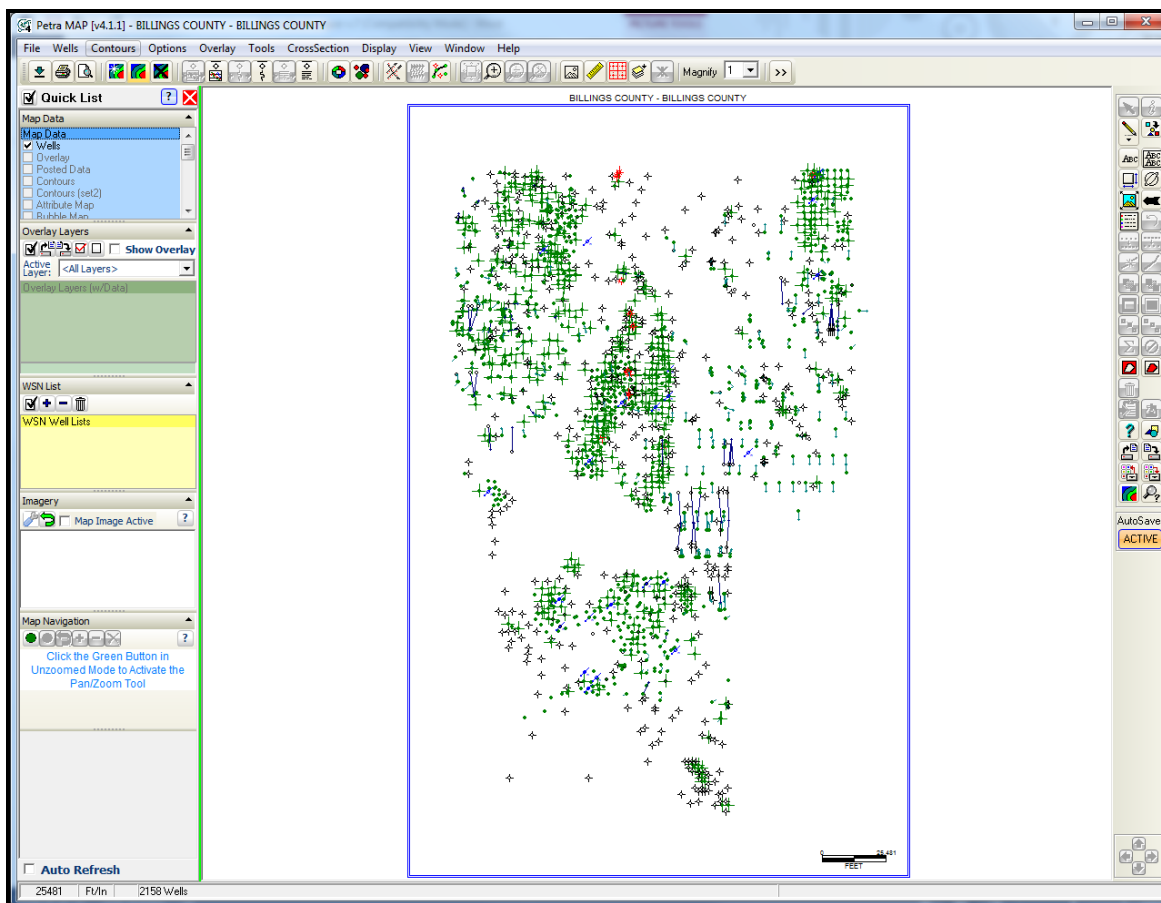
Figure 37: Petra MAP view of the wells in Billings County, North Dakota.

- From the "Petra MAP" window, the wells can be selected, and cross-sections can be created for future formation tops correlation.

5.2.1.2. Importing well files from spreadsheets (NDIC, MBOGC, etc.)

- Spreadsheets containing well data, downloaded from either NDIC or MBOGC, can be imported into Petra by selecting "Project" in the uppermost tab menu in "Petra Main" window. Under "Project" choose "Import", then "Generic ASCII (Spreadsheet)…".

- When the "Import Well Data From Tabular File Format" window appears, follow each tab to populate Petra with data from the spreadsheet.

5.2.2. Importing well logs into Petra

The well list imported from AccuMap only contains the well header data, and serves as an empty vessel designed to be filled with data from different sources. The well data that this project is focused on is well log rasters. Well log rasters can be obtained from NDIC for North Dakota and from Montana Board of Oil and Gas for Montana. Well log rasters can also be obtained for both states from the MJ Systems.

5.2.2.1. Importing well logs from MJ Systems:

- To import well log rasters from MJ Systems, select "Project" in the uppermost tab menu in "Petra Main" window. Under "Project" choose "Import", then "Raster Logs From", and finally "MJ Logs Exported From LogSleuth".
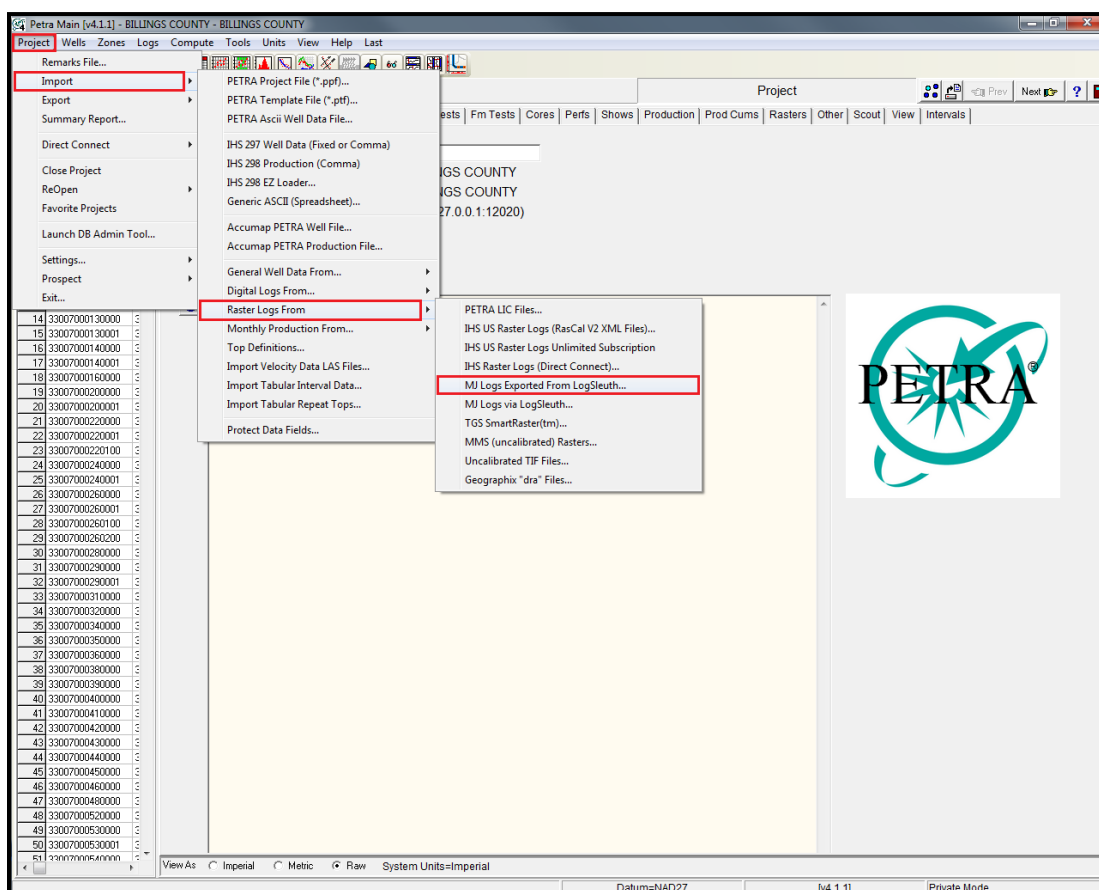

Figure 38: Importing well log rasters from MJ Systems into Petra.

- The "Batch Import MJ Systems Calibrated Raster Log" window will appear and ask you
  to "select one or more ".REG" files to load". Click "Select Files…" button.

- When the "Select MJ Logs to Import ("REG" Files)" window appears, navigate to the
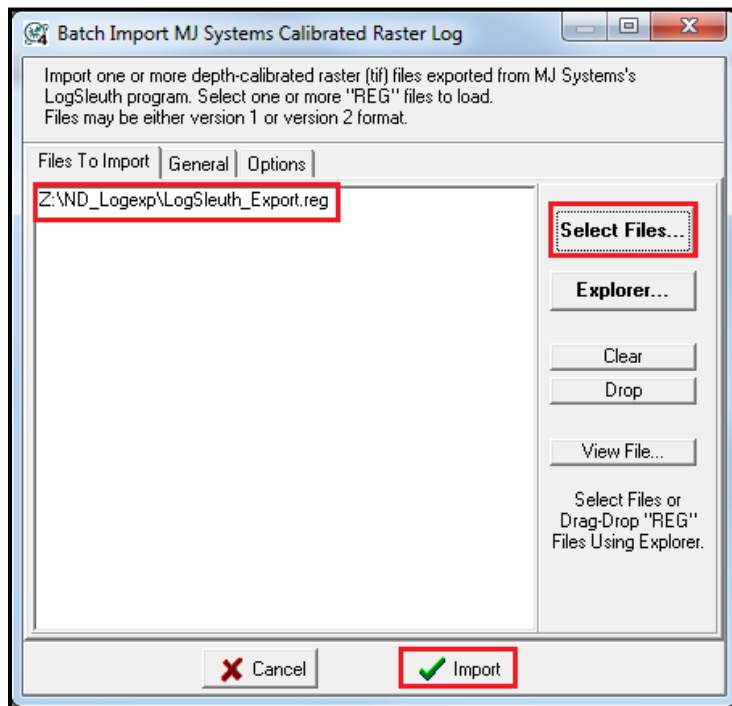 folder in which you saved the export file form the "Batch Export" in LogSleugh.

Figure 39: Importing ".REG" File into Petra.

- After the ".REG" file is loaded, click "Import". *Note*: only the well log rasters matching
  the wells in the project (from the AccuMap well list) will be loaded.

5.2.2.2.   Importing well logs from NDIC (or other TIF files – e.g. from Colorado or Wyoming):

- To import well log rasters from NDIC, select "Project" in the uppermost tab menu in
  "Petra Main" window. Under "Project" choose "Import", then "Raster Logs From", and
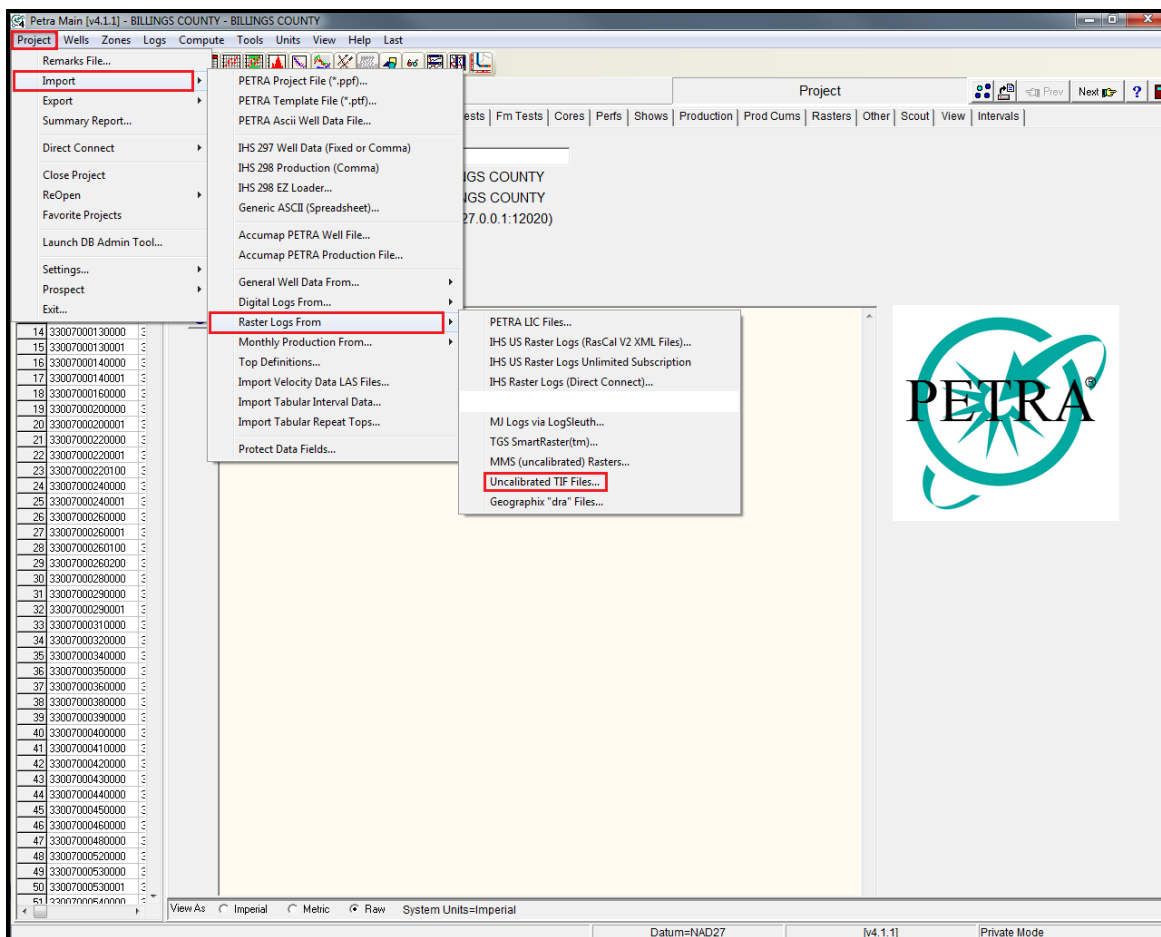 "Uncalibrated TIF Files".

Figure 40: Importing well log rasters from NDIC into Petra.

- *Note:* Make sure that the API of the raster you wish to import from NDIC matches the API of the well in Petra project.

5.3. Correlating formation tops from well logs in Petra

After the well logs have been imported into Petra, you can start correlating formation tops in Petra.

- Select "Wells" tab on the uppermost tab menu. Choose "Select" on the top of the list. Select "Wells By Data Criteria".
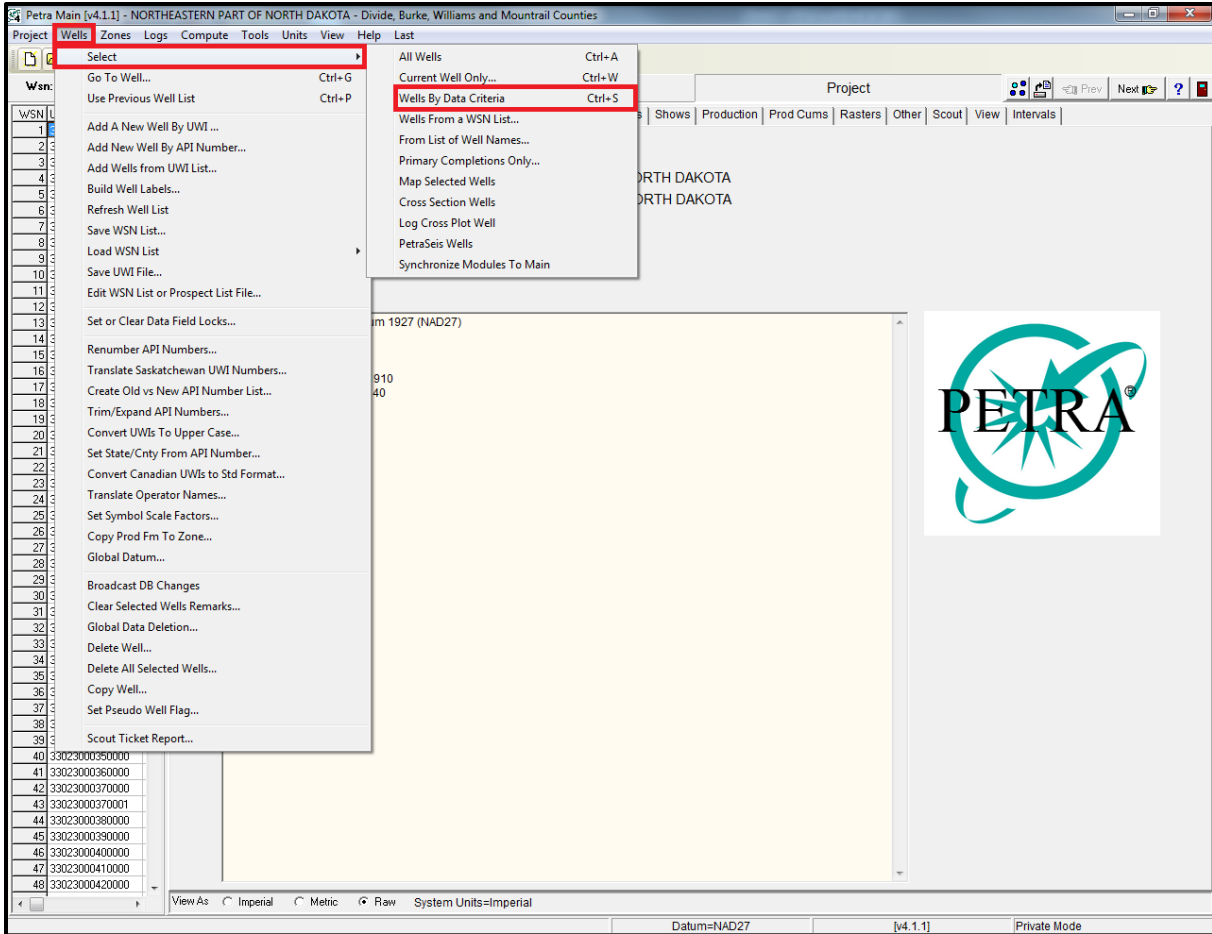
Figure 41: Selecting well by data criteria.

- After "Select Wells By Data" window appears, click on the "plus" button next to the "Logs". When the "Logs" option expands, click on the "plus" button next to "Raster Logs", when it expands, choose "Calibrated Rasters", and press "Accept" on the right upper corner.
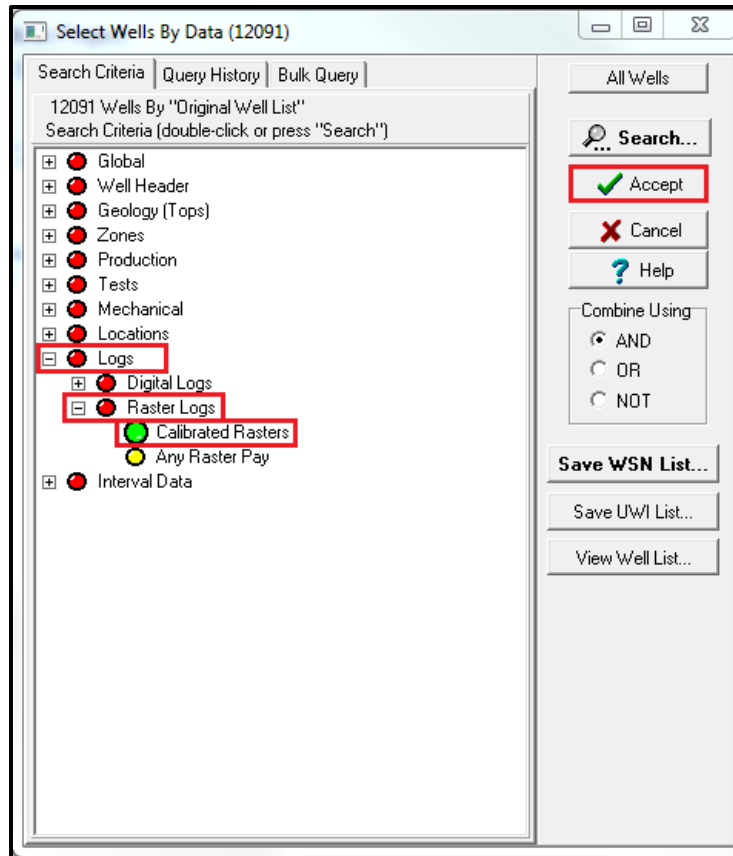
Figure 42: Select wells by data window.

- Next, the "Select Wells With Raster Log Images" window will appear. Under "Raster Logs" tab in the "Search Method", accept the default option "Find Wells With ANY Rasters". Click "Search".
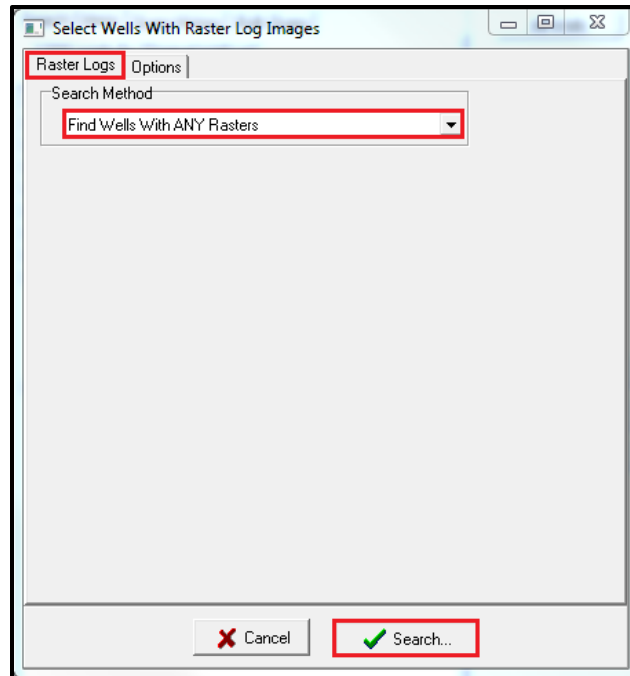
Figure 43: Select wells with raster log images window.

If you have any questions you can contact me at 661-444-5852 or asherimkulova@mtech.edu.