North Dakota Geological Survey

The subsurface storage potential in the Stutsman County Area

By

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INTRODUCTION

In the fall of 2014, plans were announced to construct a large fertilizer plant in the vicinity of Jamestown (Stutsman County), North Dakota. The proposed fertilizer plant design included converting natural gas into nitrogen fertilizer, a process that would have created waste that in turn would have needed to be periodically disposed of. One potential disposal method for waste fluid would be injection into buried layers of porous sedimentary rock, similar to the disposal of produced water from oil and gas wells in western North Dakota. The North Dakota Geological Survey (NDGS) began a project to identify potential zones of porous sedimentary rock that might be suitable for subsurface injection/disposal beneath Stutsman County and the surrounding area (Figs. 1 and 2). Although the proposed fertilizer plant construction plans were later tabled, the NDGS continued its project to completion in the event that a similar need for subsurface waste disposal in the Stutsman County area should arise again.

GEOLOGY

Stutsman County is positioned along the eastern margins of the oil and gas productive Williston Basin. Sedimentation within the Williston Basin began approximately 500 million years ago during the Cambrian with the deposition of the Deadwood Formation (Murphy et al., 2009). The majority of the older (Paleozoic), more deeply buried sedimentary formations consist of carbonate rock while the younger (Mesozoic-Cenozoic), shallower formations are predominantly clastic (Murphy et al., 2009). These various clastic and carbonate sedimentary layers all dip gently westwards towards the center of the basin. Beneath the sedimentary cover are igneous and metamorphic rocks of the Superior Province, which formed prior to and have been tectonically stable since at least 2.4 billion years before present (Nesheim, 2012).

METHODS

Wireline logs and lithological reports from the fifty-one wells within the study area were examined to identify relatively thick (10's of feet) and porous (>15% porosity) sedimentary rock intervals positioned below the Cretaceous Pierre Formation that display some level of regional continuity. The Pierre Formation is composed of upwards of 2,300 feet of marine shale that underlies most of the fresh water aquifers utilized across North Dakota (Murphy et al., 2009). Isopach (thickness) and structure contour (feet below sea level) maps were then completed for each identified interval using available wireline logs. Lithological descriptions for each porous zone were compiled using sample descriptions from available lithological reports associated with each well. Oil well files were then searched to find core plug porosity and permeability data for the porous zones from wells both within and surrounding the study area.

RESULTS

Three zones of interest were identified that appear to have good potential for subsurface disposal/injection: 1) discontinuous sandstones within the Inyan Kara Formation (Figs. 3 and 4), 2) a high-porosity carbonate zone within the base of the Lodgepole Formation (Figs. 5 and 6), and 3) sandstone beds within the Black Island and Deadwood Formations (Figs. 7-9). These three units vary in age and depth. The Inyan Kara Formation was deposited during the Cretaceous, approximately 140 to 130 million years ago, and is buried approximately 2,000 feet below the surface across the study area. The basal Lodgepole Formation is Mississippian in age and was deposited approximately 350 million years ago. Where present, it is buried 2,500 to 4,500 feet below the surface with burial depth increasing westward across the study area. The Black Island and Deadwood Formations were deposited between 450 and 550 million years ago, during the Ordovician to Cambrian, and are buried 2,500 to 5,500 feet below the surface with the burial depth increasing towards the west. These three units vary geologically such that the rock type of potential injection/disposal varies in lithology and distribution.

There may be some subsurface injection potential within additional units such as the Red River, Duperow, Mission Canyon/Charles Formations. Wireline logs and lithological (drilling) reports were examined from these and other units, and some porous-permeable intervals exist, but do not appear to be as thick and/or continuous as those identified within the Inyan Kara, Lodgepole, Black Island, and Deadwood Formations.

Inyan Kara Sandstones

Based on the review of available lithological reports from well files, most of the Inyan Kara sandstone was described as light to medium grey with variations including white, red, and/or brown as well as occasional salt-and-pepper or mottled coloration. Grain size ranges from silty/very fine grained to very coarse and even pebble-sized in places, although most of the grain size variation ranges from medium to coarse grained. Grain shape is commonly described as sub-angular to sub-rounded and less commonly ranging to angular or rounded. Mineral composition is predominantly quartz while mafic minerals and possibly feldspars are occasionally noted. Sand grains are sometimes described as frosted and/or pitted, but can also be translucent. Mineral grains range from being poorly indurated, unconsolidated to well indurated, hard/cemented. Calcite cement is periodically noted. Pyrite and/or glauconite are also present locally.

Porous sandstone intervals in the Inyan Kara Formation are discontinuous throughout the study area, and may resemble the Inyan Kara of western North Dakota (Bader, 2015; 2016). The Inyan Kara Formation is the primary unit used for salt water (by-product of oil production) disposal in western North Dakota. Contouring the net thickness of porous, injectable sandstone across the study area was considered, but the available well control was determined to be too limited. Instead, a bubble map was constructed depicting net injectable sandstone thickness for 18 wells across the study area which have available gamma ray wireline logs necessary to identify clean (low gamma ray) sandstone beds (Fig. 3). Two-thirds of these wells contain 50 feet or more of clean, porous sandstone that should be suitable for fluid injection. The remaining wells contain less than 50 feet of sandstone and have only moderate to minimal potential for fluid injection.

Basal Lodgepole Carbonate

The basal Lodgepole section consists of white to tan to grey and, in some places, pink limestone that sometimes transitions into dolomite within the basal portions of the interval. Occasionally this interval is described to contain shale fragments, chert, and/or anhydrite inclusions. The porosity is described as typically fair to good and can include inter-oolitic and/or pin point vuggy porosity. The grain size ranges from microcrystalline to occasionally course crystalline with both oolitic and fossil fragment grains. Crinoid fossils were mentioned within one well. The interval is often at least chalky in part and can also be very dense, non-chalky.

The high porosity carbonate interval within the basal portions of the Lodgepole Formation is typically 100 ft. thick or more where present and extends continuously across the western half of the study area (Figs. 5 and 6). This interval thins and subcrops (pinches out) in the sub-surface within a several mile stretch along a north-northeast to south-southwest trend. Thirteen sidewall cores were collected and analyzed from this interval from True Oil Company's Juliar 31-35 (NDIC: 11653, API: 33-103-00024-00-00, Sec. 35 - T148N - R70W), located north of the study area. The porosity of the samples ranged from 14.0% to 23.9% with permeability values of 0.5 to 14 millidarcies and a positive porosity-permeability trend (Fig. 10, Table 1).

Black Island Sandstones

Sandstone within the Black Island Formation is composed of transparent/colorless to white to light tan-brown, primarily fine grained, sub-rounded to rounded quartz grains. Grain size does range in places from very fine to coarse grained and occasionally sub-angular grains may be present. Porosity is described as fair to excellent inter-granular. Red dolomitic cement and shale along with pyrite occur in some places. Calcite cement may also be present, but in general Black Island sandstone in the study area appears to be poorly cemented and contains loose (friable) quartz sand grains.

The Black Island Formation is present throughout most of the study area and is only absent in the south-central portions of Stutsman County (Fig. 7). The area where the Black Island Formation (and the underlying Deadwood Fm.) is absent appears to correlate with the Stutsman High, a structural feature identified by Ballard (1963). The Black Island Formation is roughly 10-20 feet thick where present, and thins slightly towards the east. Sidewall core plug data for the Black Island from the Juliar 31-35 includes porosity values of 15.9 to 20.7% with permeability values of 1.2 to 4.5 millidarcies (Fig. 10, Table 1). However, the Black Island consists of shaly sandstone within the Juliar 31-35, whereas throughout the study area is mostly clean, non-shaly sandstone. The lower clay (shale) content across the study area should increase the permeability of the Black Island sandstone.

Deadwood Sandstones

Sandstone within the Deadwood Formation ranges from pale red to reddish orange-brown to white/clear in color. Grain size is typically fine to medium and sub-rounded in shape; although they can also be angular to sub-angular and/or rounded to well-rounded as well. Deadwood sandstone beds are also commonly glauconitic and sometimes dolomitic in part. Calcite cement is commonly noted and the sandstone ranges from friable to moderately consolidated. Porosity is described as fair to good.

Overall, the Deadwood Formation thins eastward across the study area, decreasing in thickness from over 200 feet to being absent along the eastern edges of the study area (Fig. 8). The Deadwood Formation is also absent over the Stutsman High in south-central Stutsman County, similar to the overlying Black Island Formation (Fig. 7). As the Deadwood thins eastward, it also appears to become more clay-rich (shaly) based on lithological reports and increasing gamma ray and SP wireline log signatures (Fig. 9). These changes likely decrease the overall permeability of Deadwood sandstone beds and their potential as a target for fluid injection.

The Deadwood Formation lies directly over the Precambrian basement (Figs. 8 and 9). Many of the faults within North Dakota likely originate within the Precambrian basement and extend upwards (to various degrees) into the overlying sedimentary cover. Fluid injection into rock within close lateral and vertical proximity to pre-existing faults can lead to induced seismicity (NAS, 2012). Fluid injection increases the pore pressure within the host rock, which in turn can alter the stress regime of a nearby fault and allow slippage or movement along the fault plane resulting in a seismic event (NAS, 2012). Therefore, additional study and extra precautions may be necessary before utilizing the Deadwood Formation for subsurface fluid injection within any area of North Dakota.

SUMMARY AND CONCLUSIONS

The Inyan Kara Formation is the shallowest potential injection unit identified and examined in this paper and extends across the entire study area. However, the variable net thickness of porous sandstone within the Inyan Kara means there is risk that the Inyan Kara could be barren of, or contain minimal, injectable sandstone within a given location. The Inyan Kara Formation is the primary unit for the disposal of produced water from oil and gas production across western and north-central North Dakota, and therefore should be suitable for similar subsurface injection in eastern North Dakota, provided it contains adequate net thicknesses of porous sandstone.

The basal carbonate section of the Lodgepole Formation is continuously thick and at least partially porous where present. However, it is absent in roughly the eastern third of the study area based upon the wireline logs and lithological information reviewed. Therefore, the eastern third of the study area has negligible potential for subsurface injection for this interval. The basal Lodgepole Formation (Madison Group) is utilized for subsurface injection in southwestern North Dakota (Bowman County) for the produced water from oil wells, and therefore may be similarly suitable in eastern North Dakota where present.

Both the Black Island and Deadwood Formations appear to contain some quantity of porous quartz sandstone across most of the study area. However, like the basal porous carbonate interval of the overlying Lodgepole Formation, the quantity and quality of porous sandstone within both these formations appear to decrease towards the eastern margins of the study area. These units are also buried below the Inyan Kara and Lodgepole Formations and therefore would be the most costly to drill and operate.

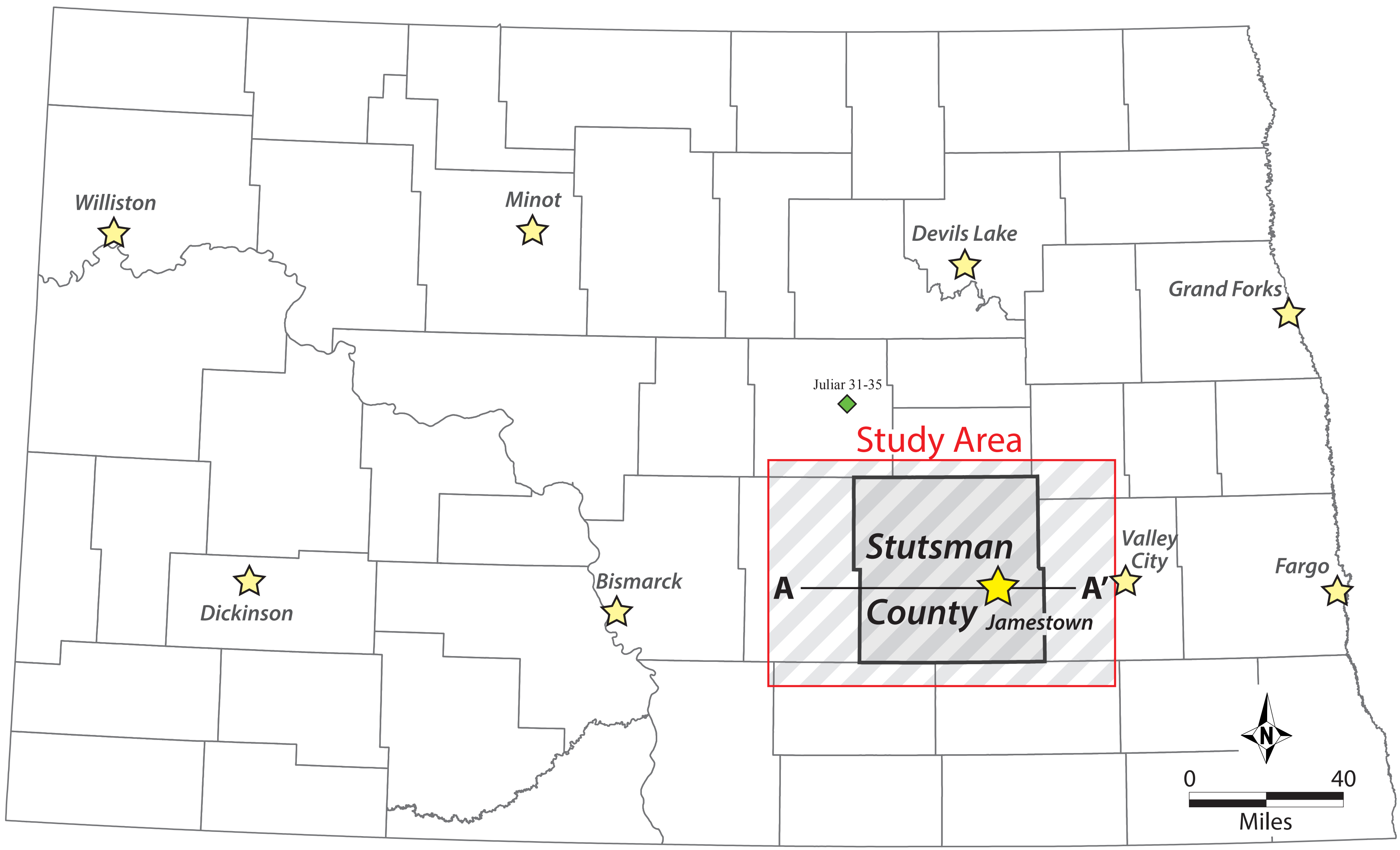

Figure 1. Map of North Dakota showing county outlines (grey lines), larger cities (yellow stars), and the study area centered on Stutsman County (red outline). A-A' depicts the location and extent of the Figure 2 schematic cross-section that displays the subsurface sedimentary units beneath the study area. The green diamond shows the location of the Julie 31-35 well, from which the sidewall core plug porosity and permeability data for the Lodgepole and Black Island Formation comes from.

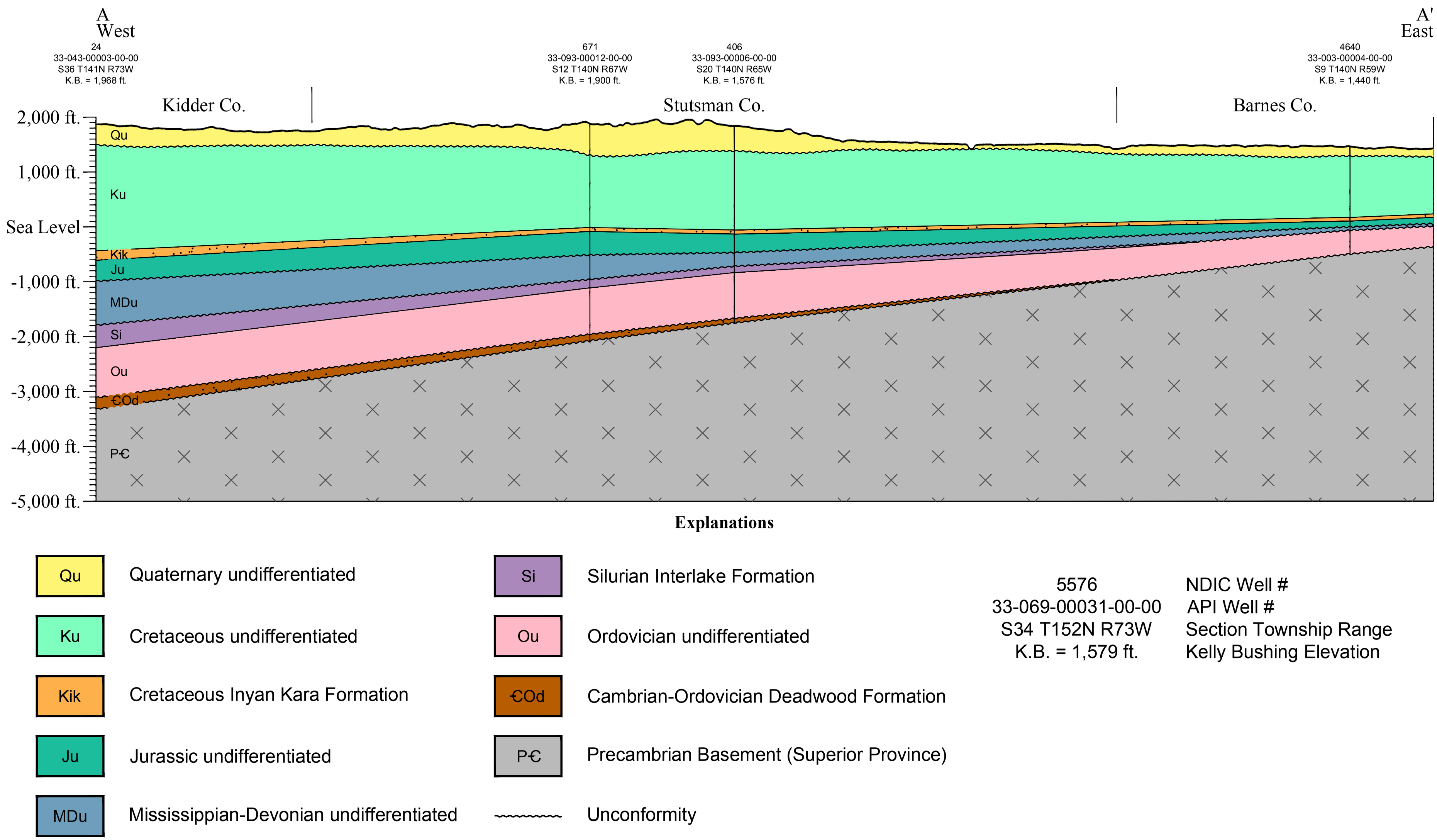

Figure 2. Schematic west to east cross-section of the study area modified from Nesheim (2016). Listed above each cross-section well in descending order includes: the North Dakota Industrial Commission well number, API well number, section-township-range, and kelly bushing elevation.

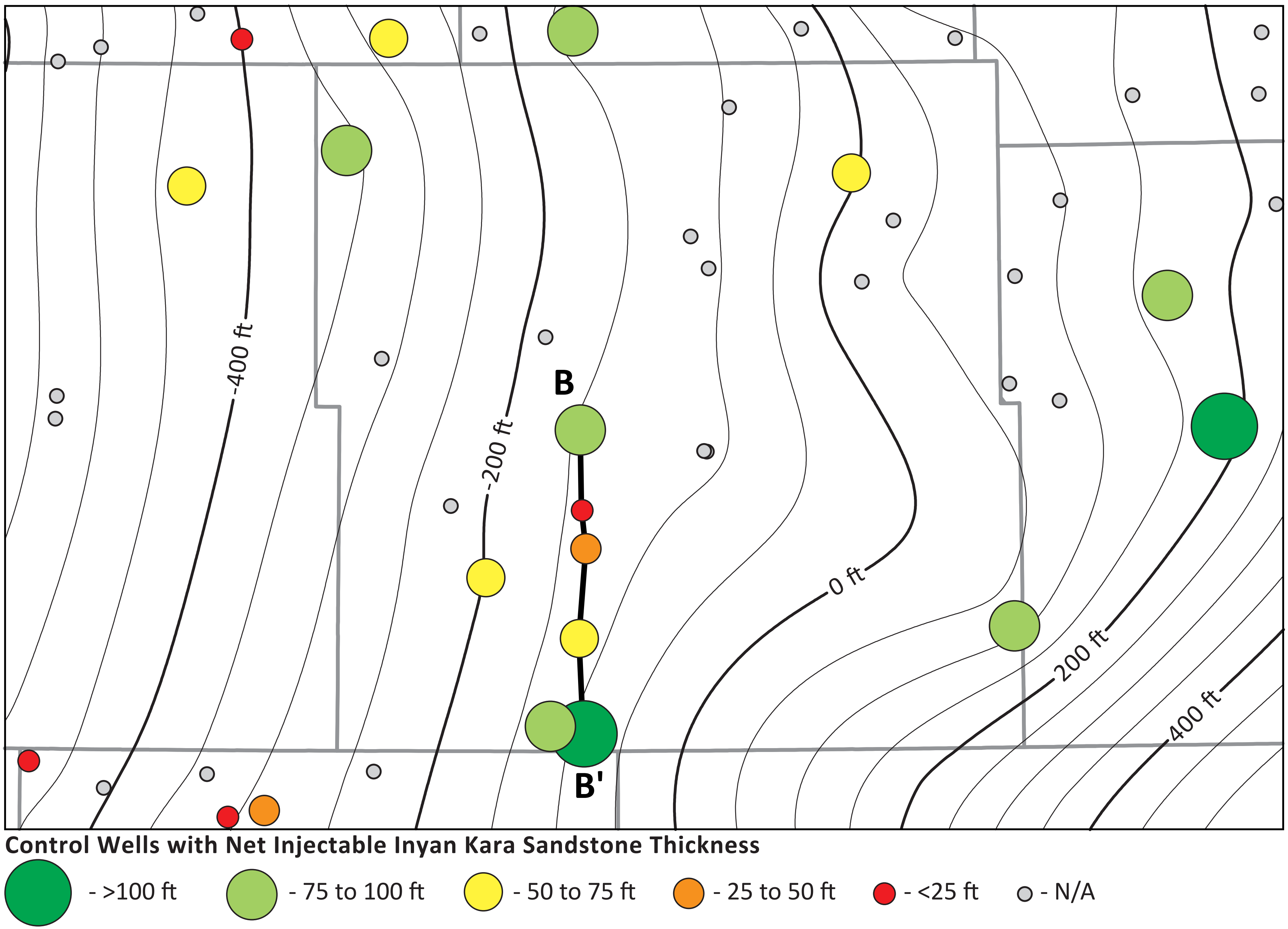

Figure 3. Structure contour map of the top of the Inyan Kara Formation (black lines) with bubbles depicting the estimated net thickness of injectable Inyan Kara sandstone using the methods of Bader (2015).

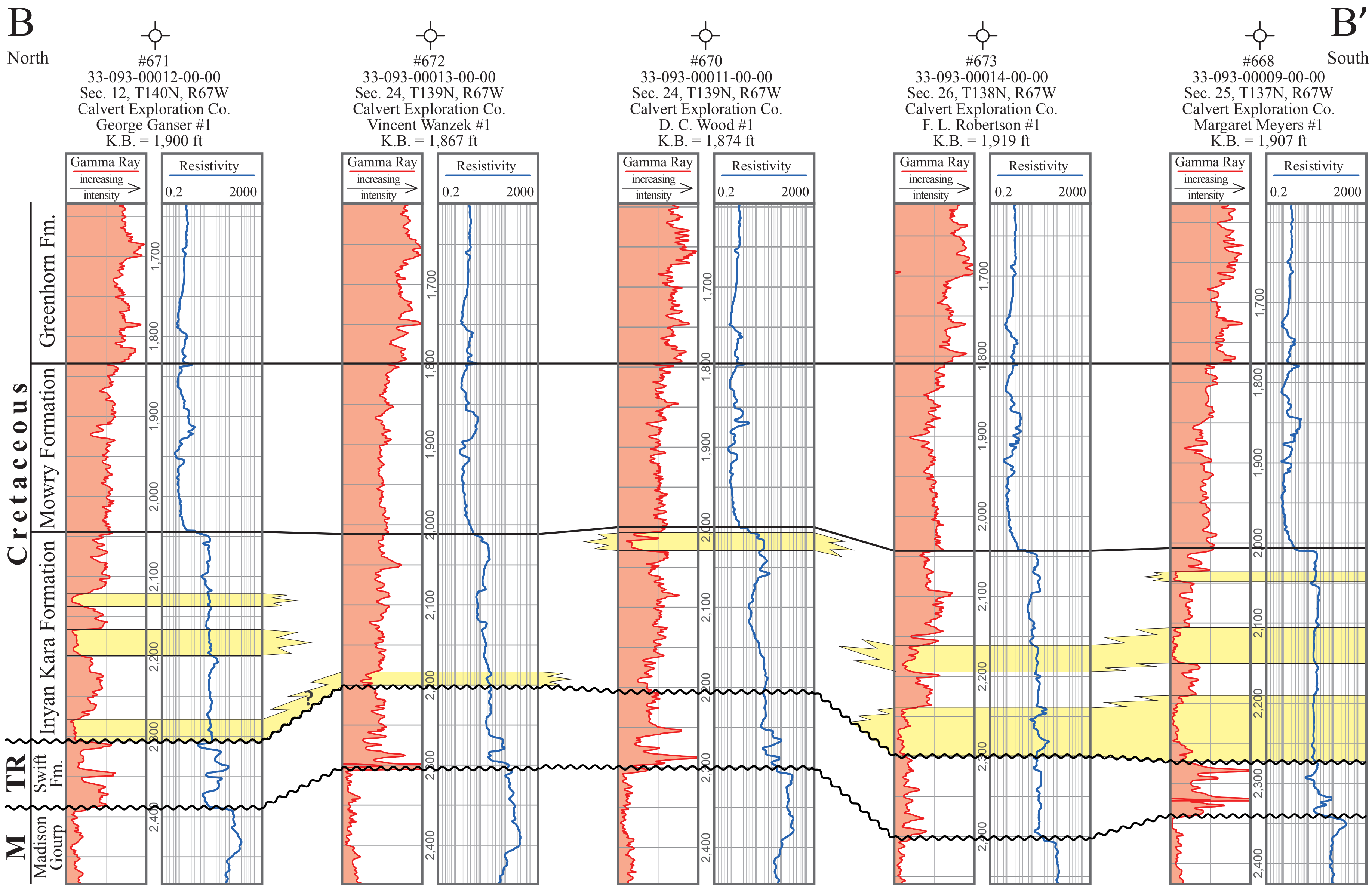

Figure 4. Cross-section of the Inyan Kara Formation highlighting potential sandstone intervals (yellow shading) that may be suitable for subsurface injection. Depths listed between the gamma ray and resistivity logs are in feet below sea level. The location of B-B’ is displayed on the Figure 3 Inyan Kara structure contour map. Listed above each cross-section well in descending order includes: the North Dakota Industrial Commission well number, API well number, original well operator, original well name, section-township-range, and kelly bushing elevation. Fm. = Formation; J = Jurassic; M = Mississippian

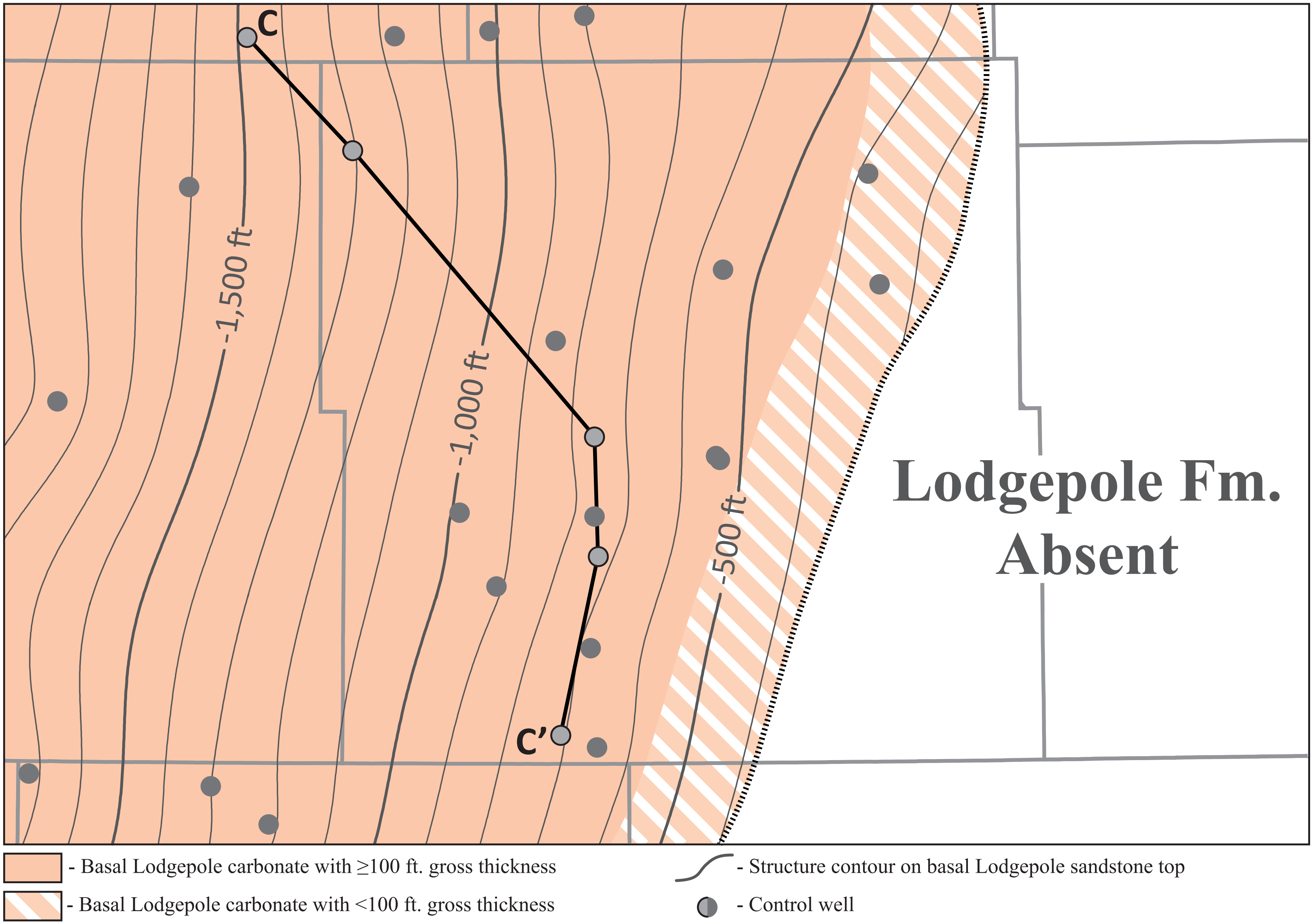

Figure 5. Map depicting the approximate extent and structure contours on the top of a porous carbonate interval located within the basal portions of the Lodgepole Formation. The extent of the Lodgepole Formation is from Anderson (1974).

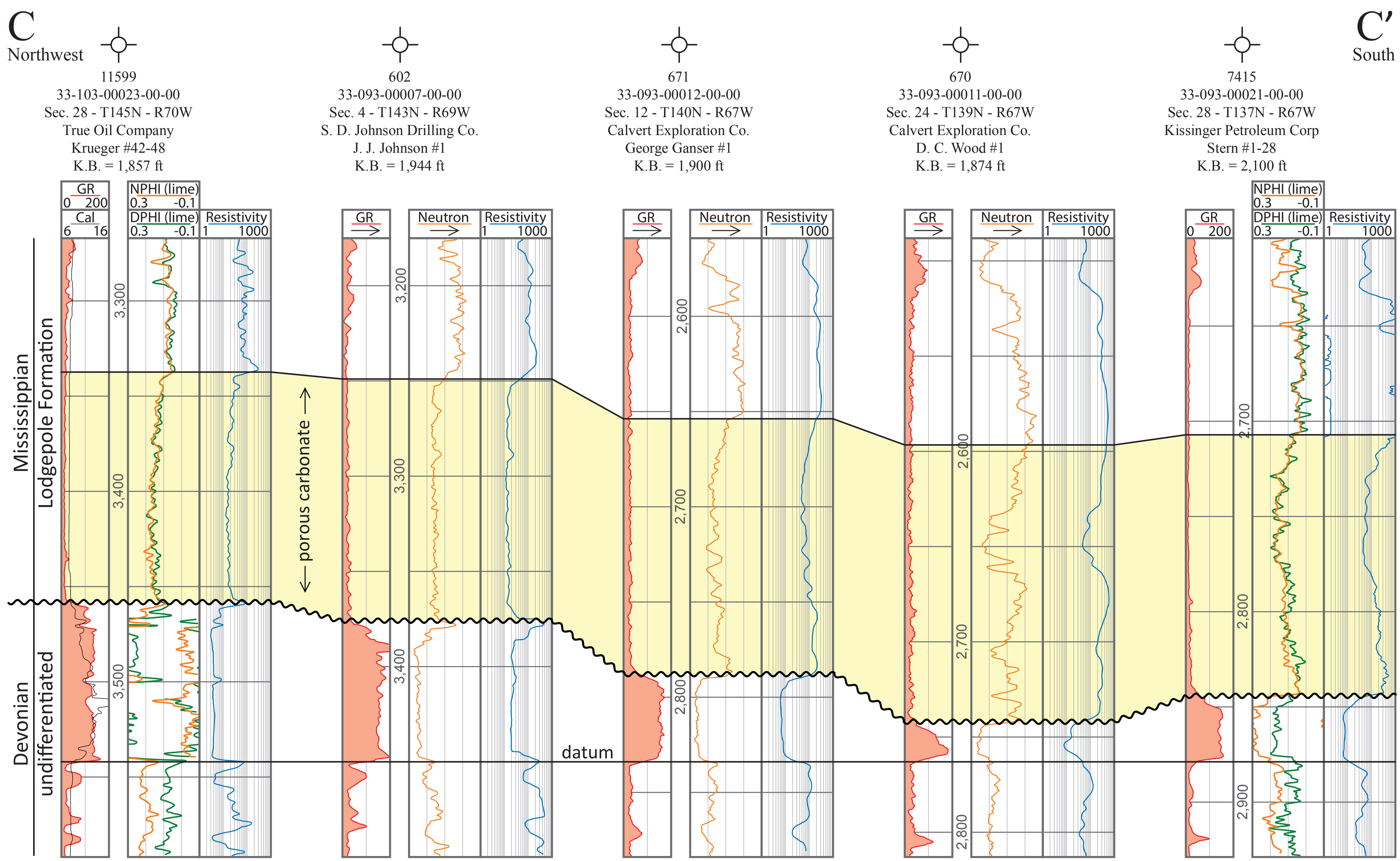

Figure 6. Cross-section of the lower Lodgepole Formation with the porous carbonate interval colored yellow. The location of C-C' is displayed on the Figure 5 map. Listed above each cross-section well in descending order includes: the North Dakota Industrial Commission well number, API well number, original well operator, original well name, section-township-range, and kelly bushing elevation.

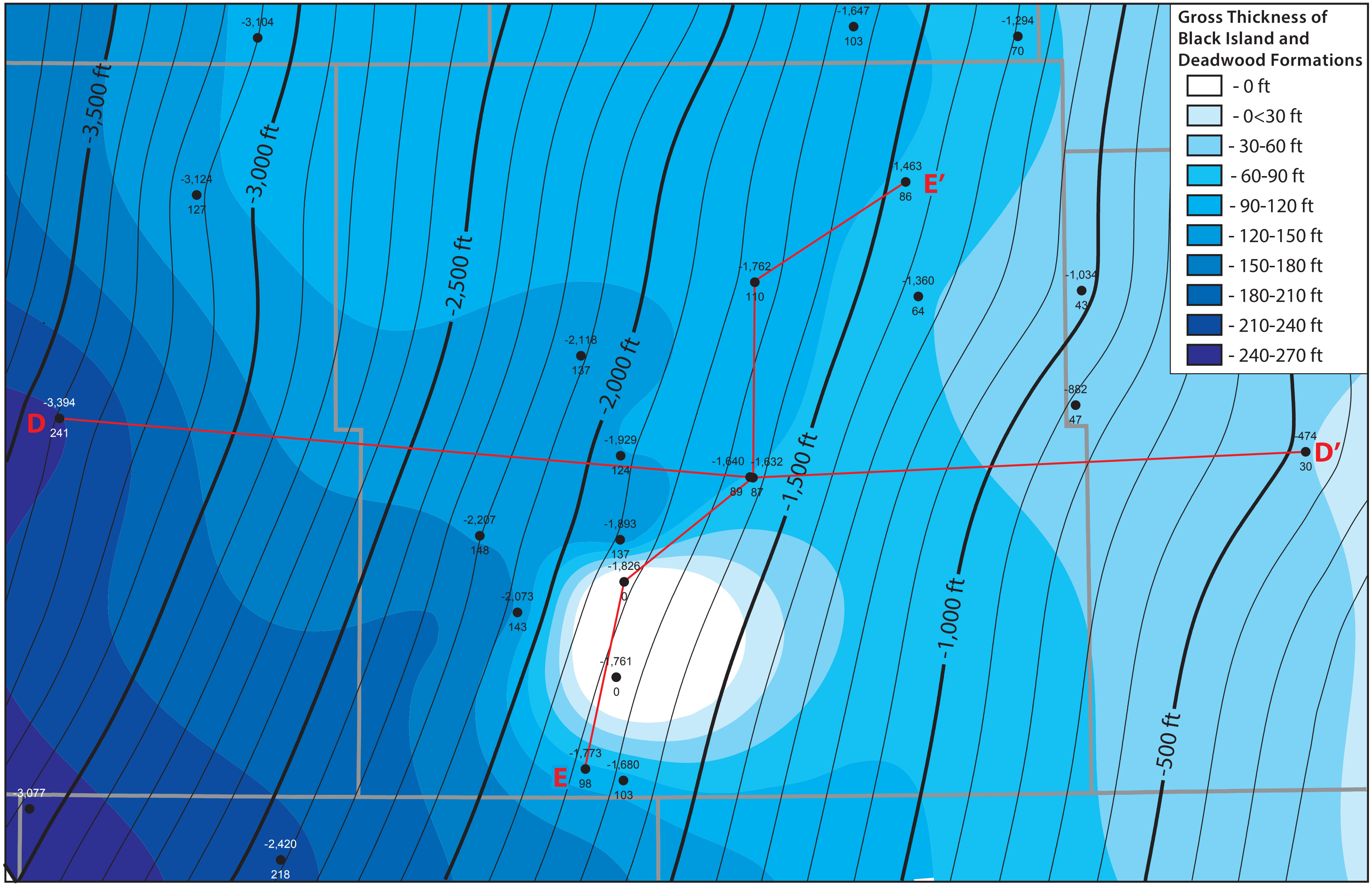

Figure 7. Isopach of the Black Island and Deadwood Formations (blue coloring) and structure contours on the Black Island Formation top (black lines). Black dots display well control with the sub-sea level depth in feet of the Black Island Formation top listed above each well and the combined Black Island-Deadwood Formation net thickness in feet listed below.

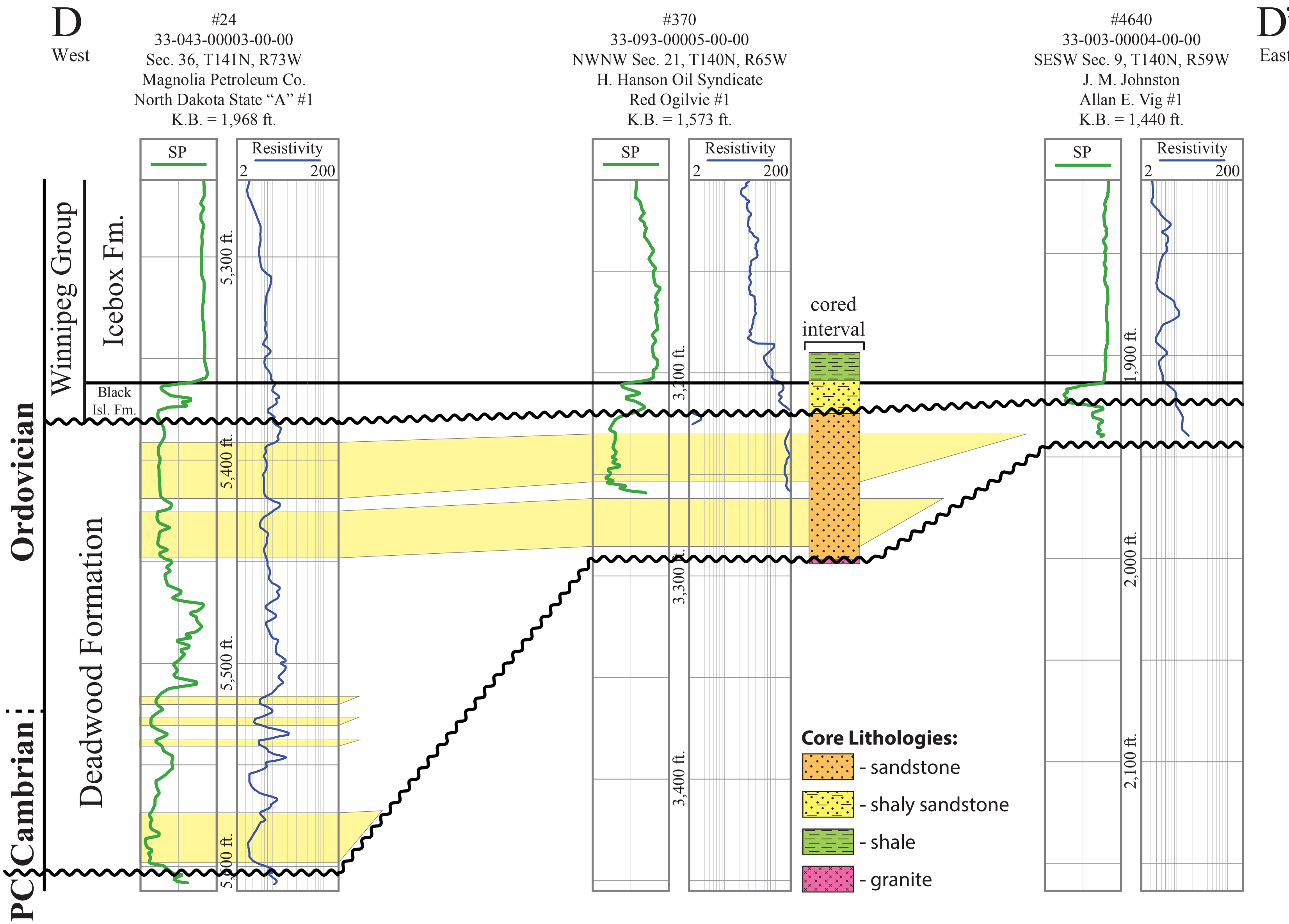

Figure 8. West to east cross-section of the Black Island and Deadwood Formations with potentially porous sandstone intervals colored in yellow. The location of D-D' is displayed on the Figure 7 map. Listed above each cross-section well in descending order includes: the North Dakota Industrial Commission well number, API well number, original well operator, original well name, section-township-range, and kelly bushing elevation.

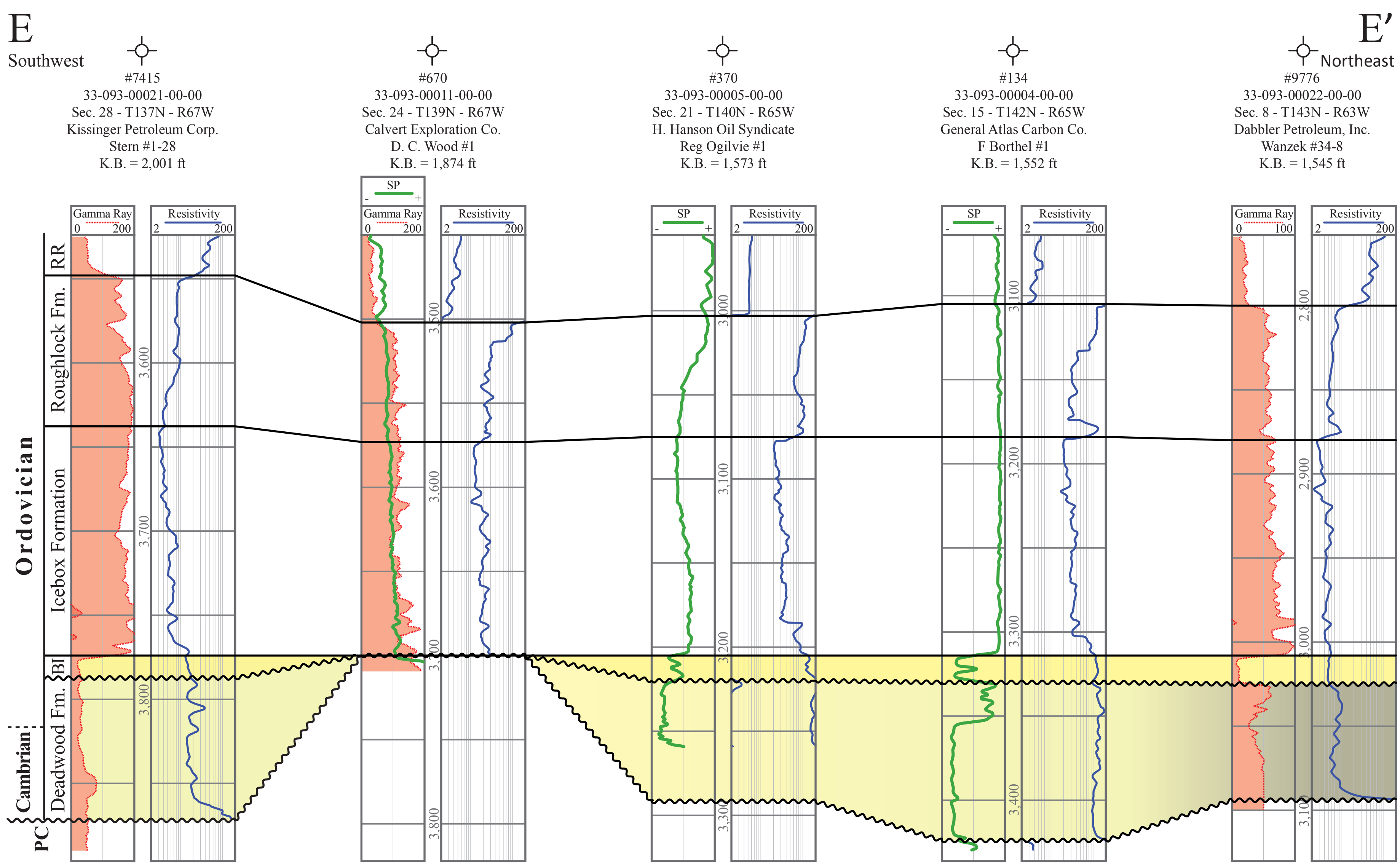

Figure 9. Southwest to northeast cross-section of the Black Island and Deadwood Formations with potentially porous sandstone intervals colored in yellow. Note how the gamma ray signature of the Deadwood Formation increases in the Wanzek #34-8, which indicates the interval may become more clay-rich and less suitable for subsurface injection. The location of E-E' is displayed on the Figure 7 map. Listed above each cross-section well in descending order includes: the North Dakota Industrial Commission well number, API well number, original well operator, original well name, section-township-range, and kelly bushing elevation.

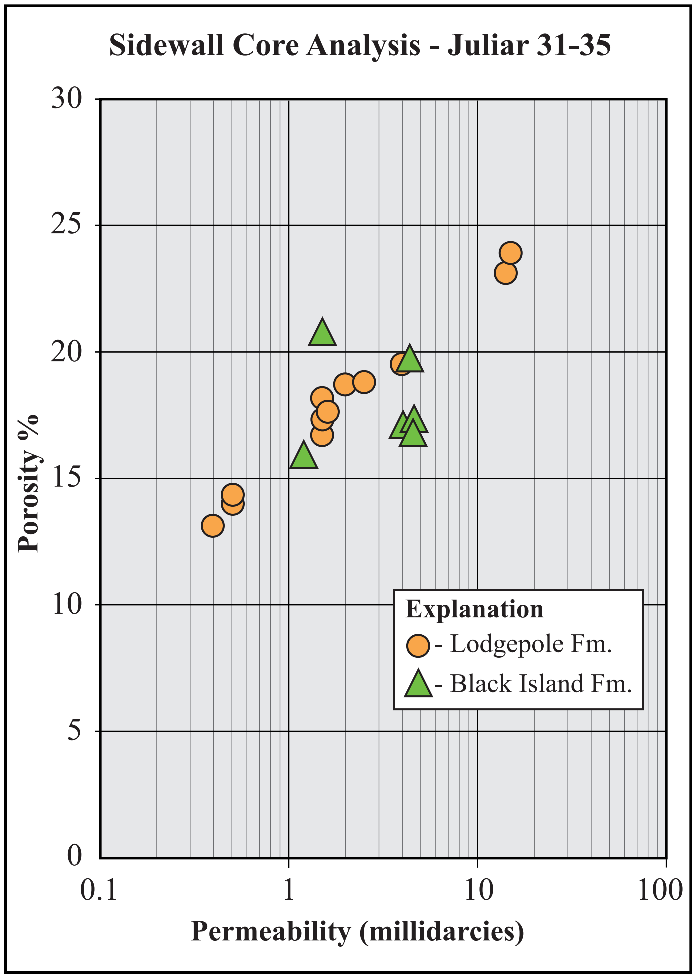

Figure 10. Porosity versus permeability of sidewall core plugs of various formations from the Juliar 31-35, located in northern Wells County, just to the north of the study area.

Table 1. Core analysis data from sidewall core plugs for the Lodgepole and Black Island Formations from the Juliar 31-35.

Depth (ft)	Perm. (md)	Porosity %	Oil Sat. %	Water Sat. %
Lodgepole Formation				
3,005	0.5	14.4	0	43.3
3,009	0.5	14	0	54.2
3,051	1.5	18.2	0	73.5
3,055	0.4	13.1	0	65.2
3,059	15	23.9	0	69.2
3,063	2	18.7	0	78.9
3,067	14	23.1	0	62.5
3,071	1.5	17.3	0	69.6
3,075	2.5	18.8	0	61.4
3,079	4	19.5	0	72.2
3,083	1.3	14.7	0	63
3,087	1.6	17.5	0	62.5
3,091	1.5	16.7	0	88.6
Black Island Formation				
4,739	4.5	16.7	0	85.7
4,741	1.5	20.7	0	84.8
4,743	4	17.1	0	84.5
4,745	4.4	19.7	0	76.7
4,747	4.6	17.3	0	86.5
4,749	1.2	15.9	0	86.5

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