Appendix I

Remis (2018): Reservoir characterization of the Gantz and Gordon sandstones, Linden Field, North Strabane Township, Washington County, Pennsylvania

RESERVOIR CHARACTERIZATION OF THE GANTZ AND GORDON SANDSTONES, LINDEN FIELD, NORTH STRABANE TOWNSHIP, WASHINGTON COUNTY, PENNSYLVANIA

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Submitted to the Department of Geology at Allegheny College in partial fulfillment of the requirements of the degree of Bachelor of Science in Geology

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I hereby recognize and pledge that I have fulfilled my responsibilities, as defined in the Honor Code, and maintained the integrity of both myself and Allegheny College

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Abigail E. Remis

Acknowledgments

I would like to thank Kris Carter and everyone at the Pennsylvania DCNR, Bureau of Topographic and Geologic Survey, Petroleum and Subsurface Geology Section in Pittsburgh for the opportunity to work on the Midwest Regional Carbon Sequestration Partnership. I learned a great deal over the course of my internship and I truly enjoyed working with such kind, helpful, and intelligent people.

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I would like to thank my family for always encouraging me to pursue my passions and for providing a strong support network.

I would like to thank my fellow geology majors and friends who always encouraged me to pursue my interests and tolerate my geology-related jokes and puns. I would especially like to thank Chris for all of the late night laughs in Alden Hall. You all rock and I will always cherish the memories we share.

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ABSTRACT

This desktop study used geophysical logs and well completion reports to characterize certain reservoir properties of the Venango Group's Gantz and Gordon sandstones in Linden Field, North Strabane Township, Washington County, Pennsylvania. Characterization work included the correlation of rock units via cross-sections, mapping depth and thicknesses via gross isopach maps, net thicknesses, and quantification of porosities. The Gantz and Gordon formations were siliciclastic sediments that exist throughout the Appalachian Basin as a product of a Devonian-age shallow marine environment that underwent multiple sea level transgressions and regressions. The Gantz and Gordon were sandstones with inferred porosities of 11% (Carter et al. 2015) and 2-11% respectively (Fettke, Stephenson, and Tignor 1946) and a history of oil and gas recovery. The Gantz sandstone was calculated to have a volume of 1.30 x 10^9 ft^3 and a pore space of 143 million ft^3. The Gordon sandstone was calculated to have a volume of 4.93 x 10^{10} ft^3 and a pore space ranging from 986 million to 5.4 billion ft^3. The goal of this study was to determine the total pore space volume of the Gantz and Gordon sandstones based on total formation volume and porosity with respect to the study region. It was determined that the Gantz and Gordon have a significant volume of pore space and thus, potential oil and gas volume.

INTRODUCTION

Motivation:

Recovering domestic oil and gas contributes to energy independence in the United States. This helps protect the industry from unstable international relations and import costs. Multiple small-scale (county-level) domestic oil production efforts are necessary in order to increase industry protection. The United States imported approximately 2.9 billion barrels of oil in 2017 costing 130 billion dollars (Energy Information Administration). Therefore, there is a great opportunity to alleviate some of these costs.

This project was completed in contribution to the Department of Energy-funded Midwest Regional Carbon Sequestration Partnership (MRCSP) in accordance with Phase III, subtask 1.2. The overall goal of the MRCSP is to assess the technical potential, economic viability, and public acceptability of carbon sequestration (Battelle 1). The goal of this subtask was to identify potential new carbon capture, utilization, and storage (CCUS) opportunities through primarily desktop analysis. Venango and Bradford group sandstones are the CCUS areas of interest where the anticipated minimal depths for carbon dioxide storage exist (Figure 1). The goal of this project was to characterize the Gantz and Gordon sandstones in the Linden field and eventually deliver the results to Battelle Memorial Institute, a private, nonprofit applied science and technology development company.

The Linden field is an extension of the Washington-Taylorstown field (Figure 2). The Washington oil field produced oil since 1861 (Clapp 44). Drillers began primary oil extraction here, where the pressure of reservoir and gravity combined with pumps brought oil to the surface (Department of Energy). However, only a few derricks remained in operation by the early 20th century as a result of wells running dry (Clapp 46). It is estimated that about 10% of the original oil in place (OOIP) is extracted via primary recovery. Enhanced oil and gas recovery (EOR) methods allow for 30-60% of the OOIP to be recovered (Department of Energy). Therefore, EOR methods are necessary to extract part of the remaining OOIP.

Enhanced Oil Recovery can be accomplished with many fluids, including carbon dioxide (CO_2) (Figure 3). First, carbon dioxide and water are injected into the reservoir. CO_2 acts as a solvent and dissolves hydrocarbons. The oil swells as a result, reducing its viscosity and allowing it to move more freely through pore space to a production well. Remaining CO_2 displaces crude oil from its pore spaces. Water and CO_2 are alternated during EOR to prevent the less-viscous CO_2 from passing crude oil and breaking through to the production well.

Research Question:

What are the basic reservoir characteristics of the Gantz and Gordon sandstones in Linden Field, North Strabane Township, Washington County, Pennsylvania?

METHODS

The study area was Linden Field in Washington County, Pennsylvania (Figure 2). Well data composed of gamma ray logs, driller's logs, formation tops, and formation bottoms were collected from EDWIN and added to formation data in PETRA® for analysis. Formation thicknesses were calculated based on formation top and bottom data using Microsoft Excel. In addition, four wells in the study area contained gamma ray logs that were used to identify the tops and bottoms of the Gantz and Gordon. The gamma ray logs recorded radioactivity in micrograms radium equivalent per ton as a function of well depth (Figure 4). Higher gamma ray log readings corresponded to shales which have greater traces of radioactive elements such as radium. The depths of the Gantz and Gordon sandstones were supported by well records and by distinct decreases in radioactivity indicative of sandstone. The Exploration and Well Development Information Network (EDWIN) is a database containing well data for over 180,000 wells. EDWIN is maintained by the Pennsylvania Department of Conservation of Natural Resources. PETRA® is geologic interpretation software that enables users to manipulate and represent well data. EDWIN and PETRA licenses were available on a computer in Alden hall. In addition, porosity values of underlying Bradford sandstones were recorded from a laboratory report.

A base map of wells with thickness data was generated (Figure 5). Elevation maps of the Gantz and Gordon tops were generated (Figures 6 & 7). Gross isopach maps for each formation were generated using calculated thicknesses (Figures 8 & 9). Cross-sections were generated in order to cover the greatest areal extent of the study region (Figures 10 & 11).

RESULTS

Maps

Location and geologic data for 290 Linden Field oil and gas wells were imported into PETRA® for mapping and interpretive purposes. Formation top and bottom depths (Appendices A-C) were used to generate top elevation and isopach maps for both the Gantz and Gordon sandstones (Figures 6-9).

The one hundred and sixty-seven wells containing Gantz formation top data were used to generate the Gantz top elevation map. It showed a general increase in formation top depth from north to south (Figure 6).

The one hundred and seventeen wells containing Gordon formation top data were used to generate the Gordon top elevation map (Figure 7).

The one hundred and forty-nine wells that contained both Gantz top and bottom data were used to generate the Gantz isopach map (Figure 8). The Gantz top elevation ranged from 2032-2550 feet and the average Gantz top elevation was 2255 feet. The bottom elevation ranged from 2082-2580 feet and the average was 2294 feet. The Gantz thickness ranged from 4-119 feet and the average was 47 feet (Table 1). The Gantz gross isopach map revealed no observable lateral thickness trends (Figure 8). However, four areas exhibited a sudden increase in thickness values.

The one hundred and six wells that contained both Gordon top and bottom data were used to generate the Gordon isopach map (Figure 9). The Gordon top elevation ranged from 2205-2725 feet and the average Gordon top elevation was 2514 feet. The bottom elevation ranged from 2300-2753 and the average was 2556 feet. The Gordon thickness ranged from 4-180 feet and the average was 42 feet (Table 1).

Cross-sections

Two cross-sections were generated using PETRA®. Overall, the Gantz did not pinch out at the selected wells, but thinned to 50 feet less than the thickness at adjacent wells (Figures 10 & 11). Gantz thickness in the cross sections ranged from 15 feet to 89 feet (Figure 10).

The Gordon top elevation map showed increases in formation top depth in multiple locations (Figure 7). One location where the formation top depth was increasing was in the northwestern section of Linden Field. It did not laterally extend. A second location was located in the eastern section of the Linden Field. This increased top depth extended from the northeast to southeast. The top depth rapidly decreased to the east and west of this trend. The northwest to southeast cross-section (Figure 10) showed a sharp increase in formation top depth from well number 3712592982 to well number 3712593007 that coincided with the formation top contour map (Figure 7).

It is important to note that the north-south trend of increasing formation top depths existed in both the Gantz and Gordon sandstones. Also, isolated locations of abnormally low formation top depths for both sandstones shared similar geographic locations and abrupt changes as their isolated locations of sudden increased thicknesses.

Cross-section A-A’ ran northwest-southeast through Linden Field and showed an increase in Gantz formation top depth from 2254 feet to 2371 feet and a gradual increase in Gordon formation top depth from 2500 feet to 2650 feet (Figure 10).

Cross-section B-B’ ran northeast-southwest through Linden Field and showed an increase in Gantz formation top depth from 2,163 feet to 2,426 feet (Figure 11) and a gradual increase in Gordon formation top depth from 2455 feet to 2693 feet (Figure 11).

Formation Volume and Porosity Data

Volume data for the Gantz and Gordon sandstones were calculated in PETRA® based on formation thicknesses. The Gantz formation had a volume of 1.30 x 10^9 ft^3 (Figure 12). The Gordon formation had a volume of 4.93 x 10^{10} ft^3 (Figure 13).

Porosities for the Gordon and Gantz were derived from the M-28 Mineral Resource Report and the Open File Oil and Gas Report 15-01.1 respectively. The porosity of the Gantz in Pennsylvania was 11%. The porosity of the Gordon ranged from 2-11%. Given the calculated volumes for the Gantz and Gordon sand and porosities for sandstones similar in age, the sandstone volume was multiplied by the maximum and minimum porosity values to generate a range of pore space. The Gantz was estimated to have a pore space of 143 million ft^3. The Gordon was estimated to have a pore space ranging from 986 million to 5.4 billion ft^3.

Initial Flow Volume Data

Available initial production and flow volumes were gathered from EDWIN for the Gantz and Gordon formations (Appendices D and E). Thirty-three wells contained production data for the Gantz formation (including the year of production and initial volume). The earliest recorded production was in 1913 and the latest in 1986. Eleven wells contained production data for the

Gordon formation (including the year of production and initial volume). The earliest recorded production was in 1912 and the latest in 1955 (Appendix E).

DISCUSSION

Trends in the Gantz and Gordon

Although there are no pinch-outs in cross-section, field-level thinning and thickening of the Gantz and Gordon sandstones indicated a stratigraphic type of trap containing hydrocarbons (Figure 14). However, structural controls may have also played a role in deposition (The Atlas of Major Appalachian Gas Plays 1995). In 1904, United States Geological Survey's Chief Geologist David White argued that the northeast-southwest anticlinal trend was responsible for oil and gas deposits (White 1904). In addition, Harper and Laughrey (1987) proposed that the differential subsidence of basement faults along the Rome Trough, which also runs roughly northeast-southwest, control the location of hydrocarbons. However, most Venango plays were dominantly stratigraphically or stratigraphically-structurally controlled (The Atlas of Major Appalachian Gas Plays 1995). Stratigraphic traps in this region resulted from an alternation in depositional environments between fluvial, deltaic, interdeltaic shoreline, shelf and shelf slope environments at the western margin of the Catskill Clastic Wedge (the Atlas of Major Appalachian Gas Plays 1995). The Venango Group sandstones and shales were deposited during the Acadian Orogeny in middle to late Devonian time and were affected by sedimentation and compression from the Acadian Orogeny (Figure 14).

Elevation top depths for the Gantz and Gordon became shallower towards the northern section of Linden Field. Cross-sections showed that other Venango sandstones (Squaw, Fourth, and Fifth) follow this trend as well. While oil and gas migrated only until it encounters a cap rock, the same alternating layers of shale and sandstone present in the southern section of the field existed at shallower depths in the northern section of the field, decreasing the depths of the layers overall (Figure 15). Therefore, the northern section of the field should be prioritized with respect to enhanced oil recovery efforts.

The gross isopach maps revealed isolated areas where the Gantz and Gordon significantly increase in thickness. One area was located in the northern section of the field where the Gantz and Gordon are relatively shallower. Within the northern section of the field, this location was the most ideal because the Gantz and Gordon are the thickest here with shallow elevation tops. While a report by Ingham (1956) supported the northward thickening of the sands, the isolated locations in Linden Field only represented local anomalies.

The porosity of sandstones with conventionally recoverable hydrocarbons ranged from 5-25% (Kobrynich 1) which overlapped with published Gantz and Gordon porosities. However, wells in the Linden Field previously underwent primary oil and gas recovery. Enhanced oil recovery methods should be implemented to extract remaining oil in place.

It is important to reiterate that the total formation volume and total pore space values did not provide a volumetric measurement for oil and gas present. Oil and gas only occupy a fraction of the total pore space in sandstone. However, a pore space of 143 million ft^3 for the Gantz and 986 million to 5.4 billion ft^3 for the Gordon shows promising potential for hydrocarbon recovery.

Future Work

The remaining oil in place should be calculated in order to determine if enhanced recovery efforts should occur. Generally, conventional recovery efforts only retrieve about 10% of the total oil in place and 30-60 of the total oil in place is retrievable through unconventional recovery methods (Department of Energy 2018). Articles from the Department of Internal

Affairs, Topographic and Geologic Survey such as Crude Oil Reserves in Pennsylvania (Lytle 1950) and Oil fields of the Greater Pittsburgh region (Lytle 1976) should be included in future data-mining efforts.

CONCLUSION

The overall Gantz and Gordon thicknesses were consistent, bar several local thickness abnormalities. This consistency is beneficial to oil recovery. The elevation top depths increased southward. Therefore, the northern section of the field should be the primary focus.

Data generated from this study will be used by the MRCSP to better understand the local reservoir characteristics and potential carbon sequestration opportunities. However, more characterization efforts are necessary in order to determine if there is a significant amount of ROIP available for recovery.

It is unclear whether the Gantz and Gordon sandstones exist at every well in Linden field but was not recorded in every well record. However, the Gantz and Gordon have average thicknesses of 47 feet and 42 feet (respectively), have provided previous successful oil recovery attempts, and are at the minimum depths required for carbon sequestration. This study began to characterize the Venango formations in Linden Field and illustrated the significant amount of analysis remaining for oil recovery and carbon sequestration in the region.

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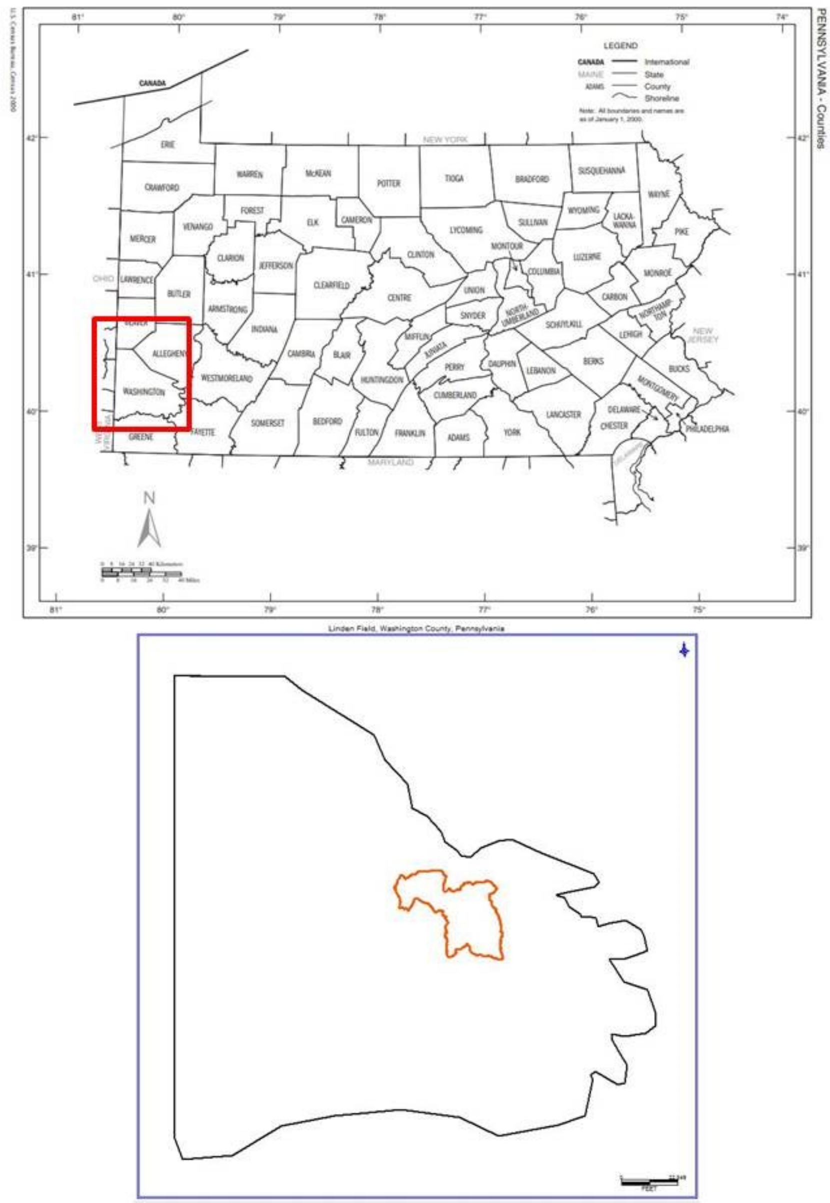
FIGURES

Figure 1. Generalized Devonian and Mississippian-aged subsurface stratigraphy of the MRCSP study area.



Figures 2a and 2b. Map of counties in Pennsylvania. The study area is in Washington County, which is located in the red box in Figure 1a. The perimeter of Linden Field is outlined in red in Figure 2b.

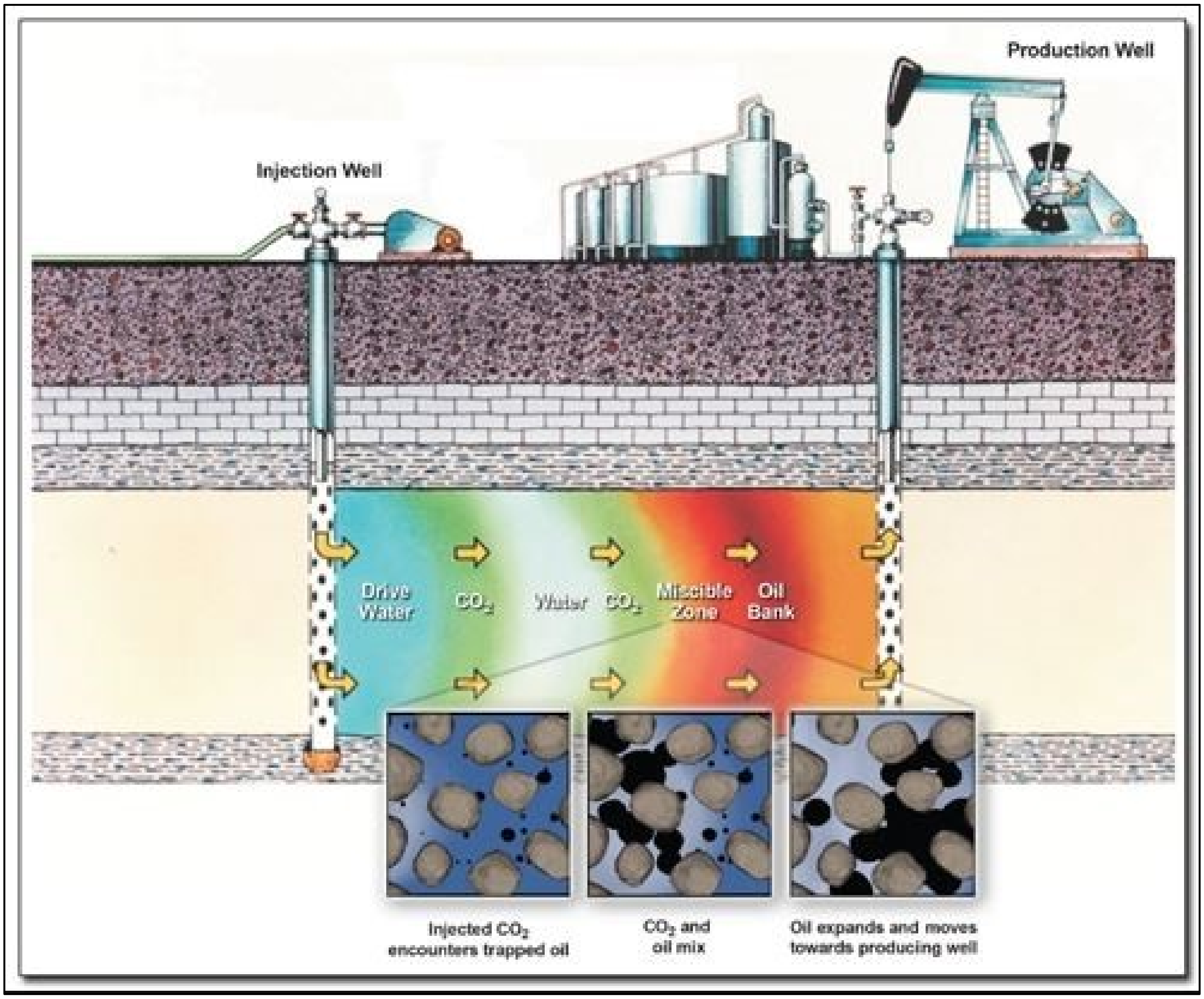


Figure 3. Enhanced oil recovery diagram using a water-alternating-gas (or WAG) approach (from the Department of Energy).

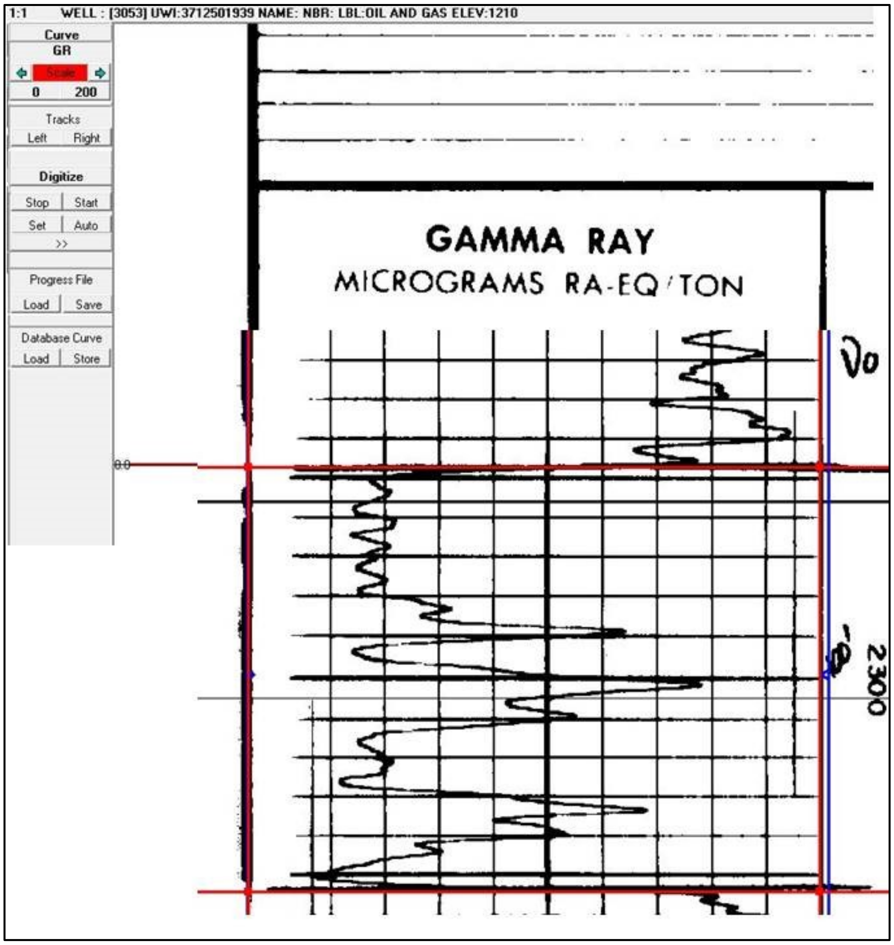


Figure 4. Gamma ray log in PETRA. Red lines represent the Gantz formation top and bottom. Units are micrograms Radium equivalent per ton.

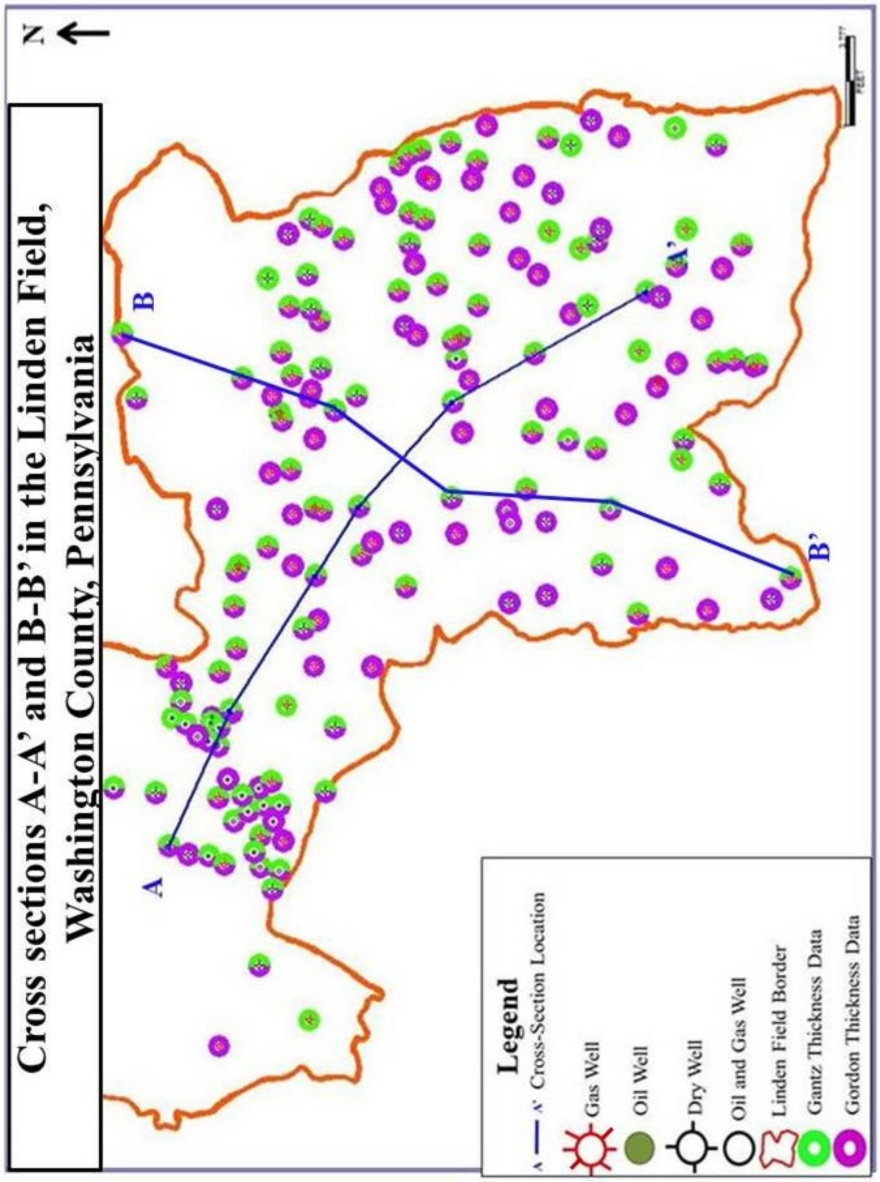


Figure 5. Baseline map of the Linden oil and gas field with cross sections A-A' and B-B' in North Strabane Township, Washington County, Pennsylvania.

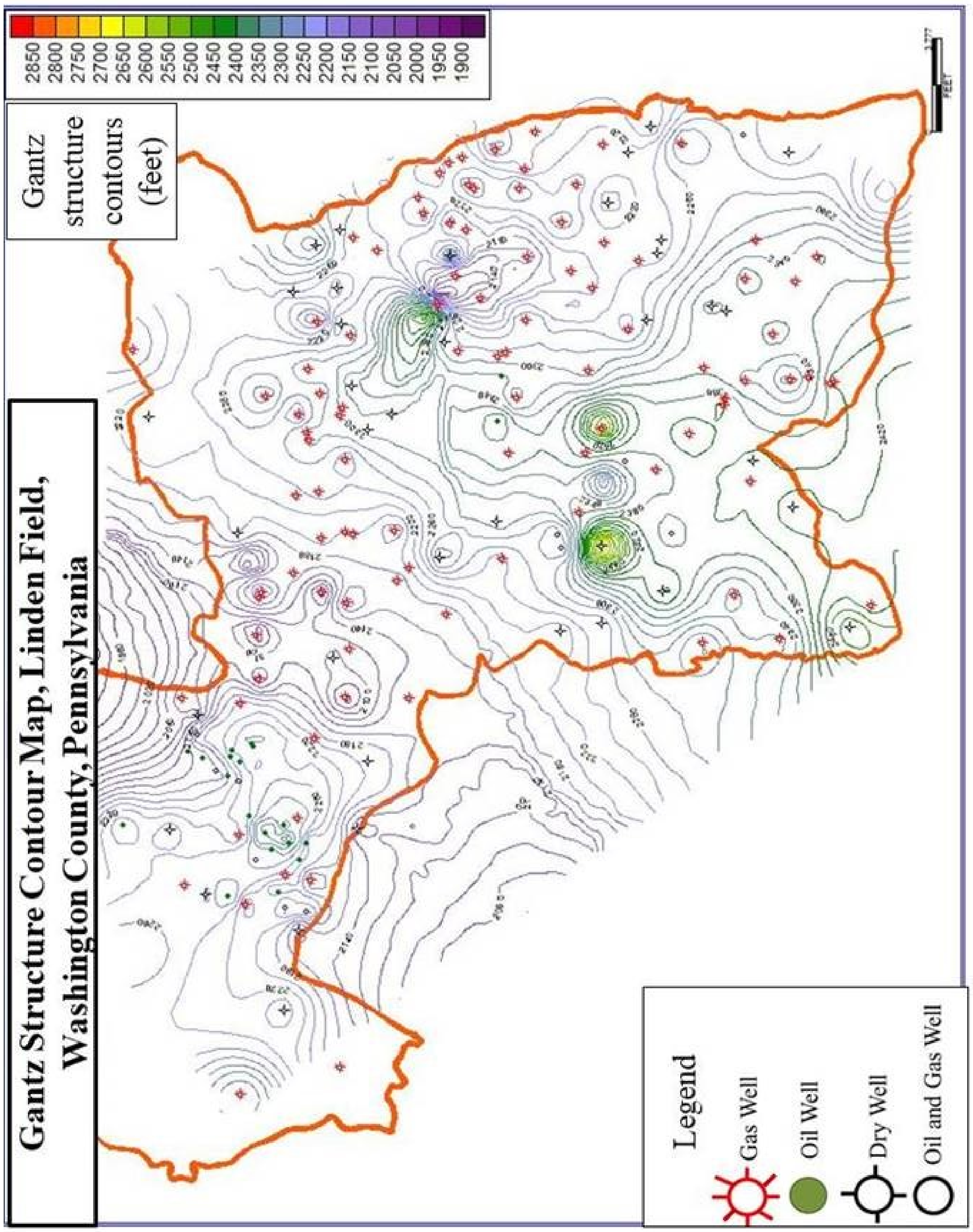


Figure 6. Gantz top elevation map in the Linden field constructed from existing formation top data.

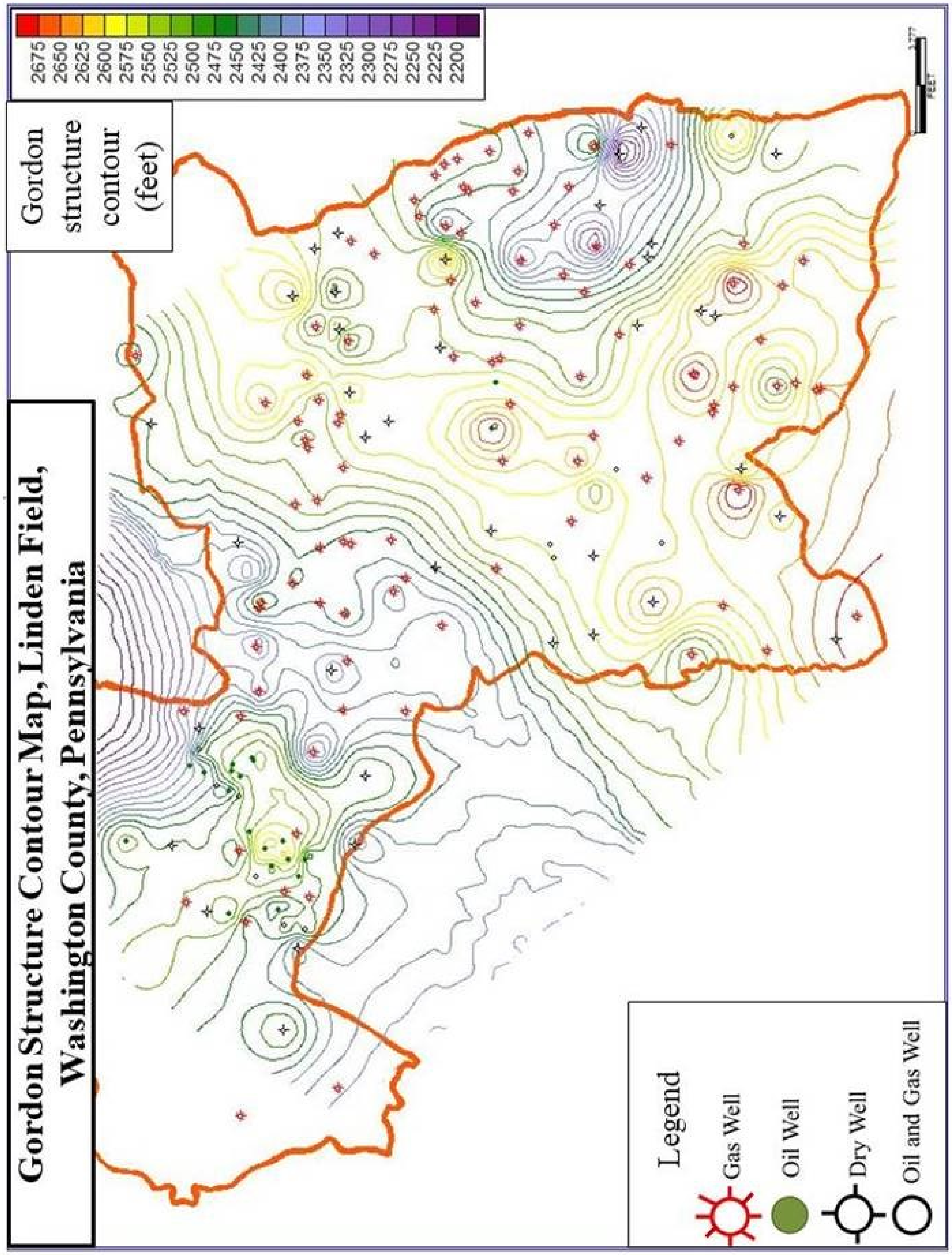


Figure 7. Gordon top elevation map in the Linden field constructed from existing formation top data.

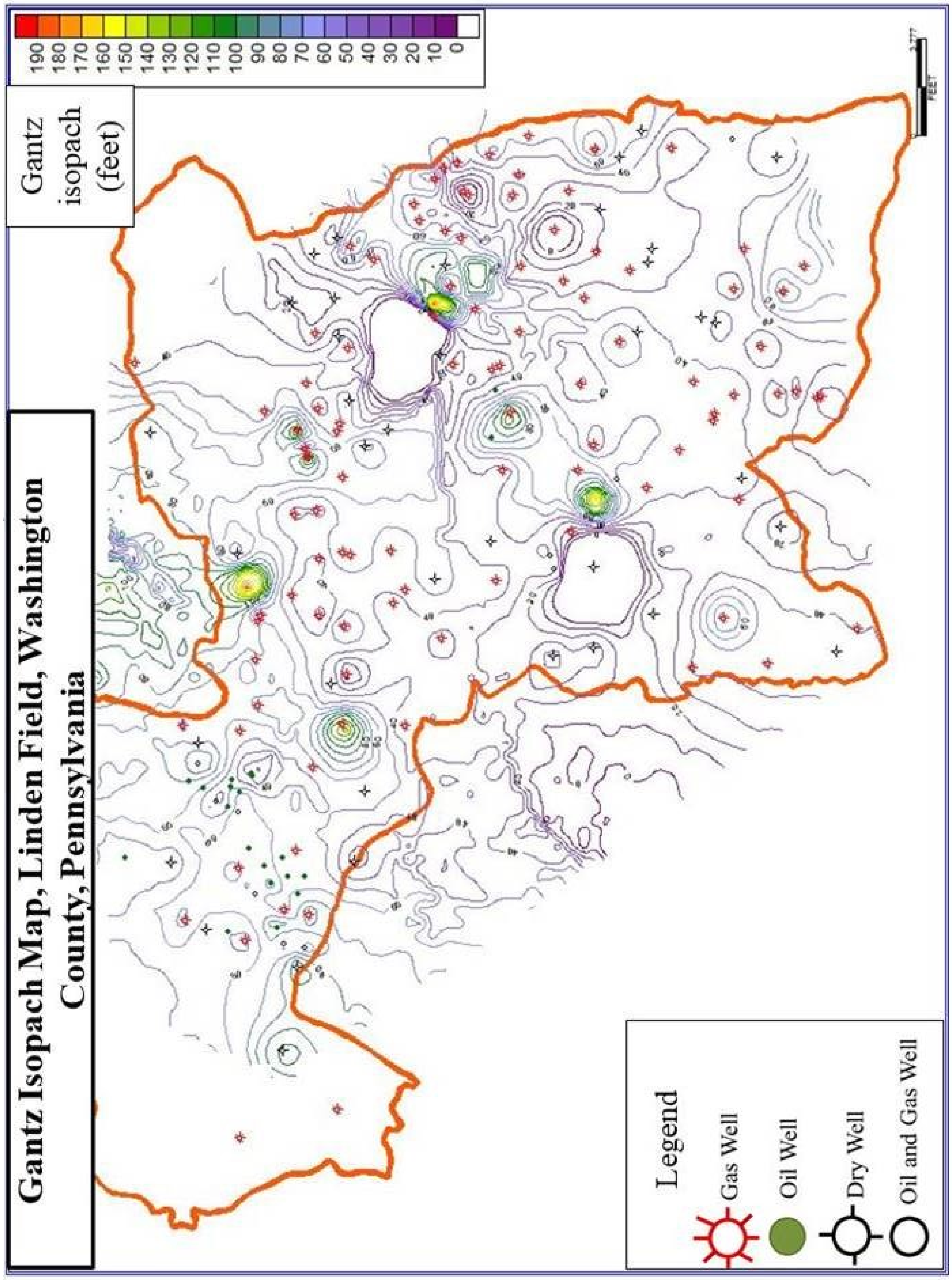


Figure 8. Gantz gross isopach map in the Linden field constructed from existing formation top and bottom data.

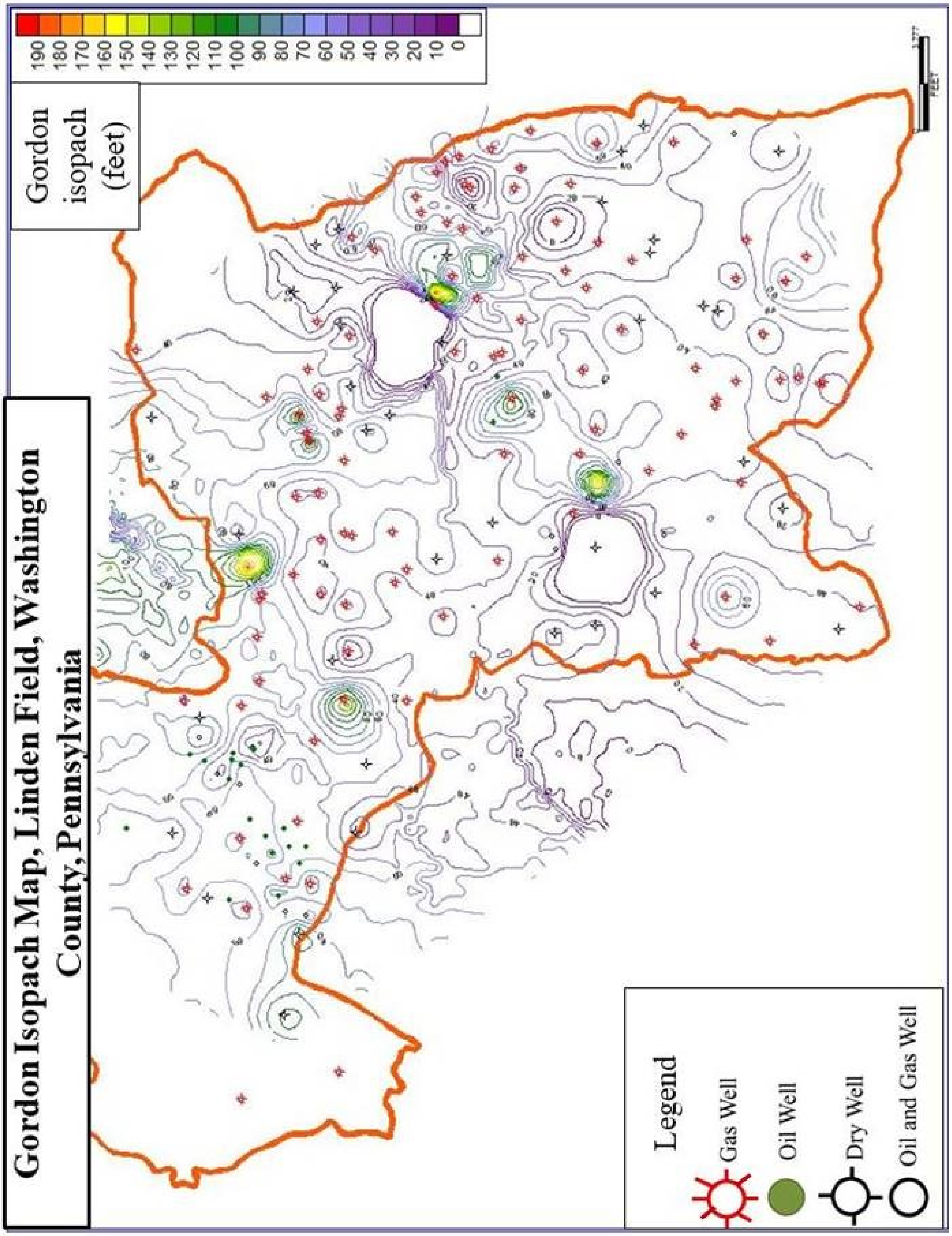


Figure 9. Gordon gross isopach map in the Linden field constructed from existing formation top and bottom data.

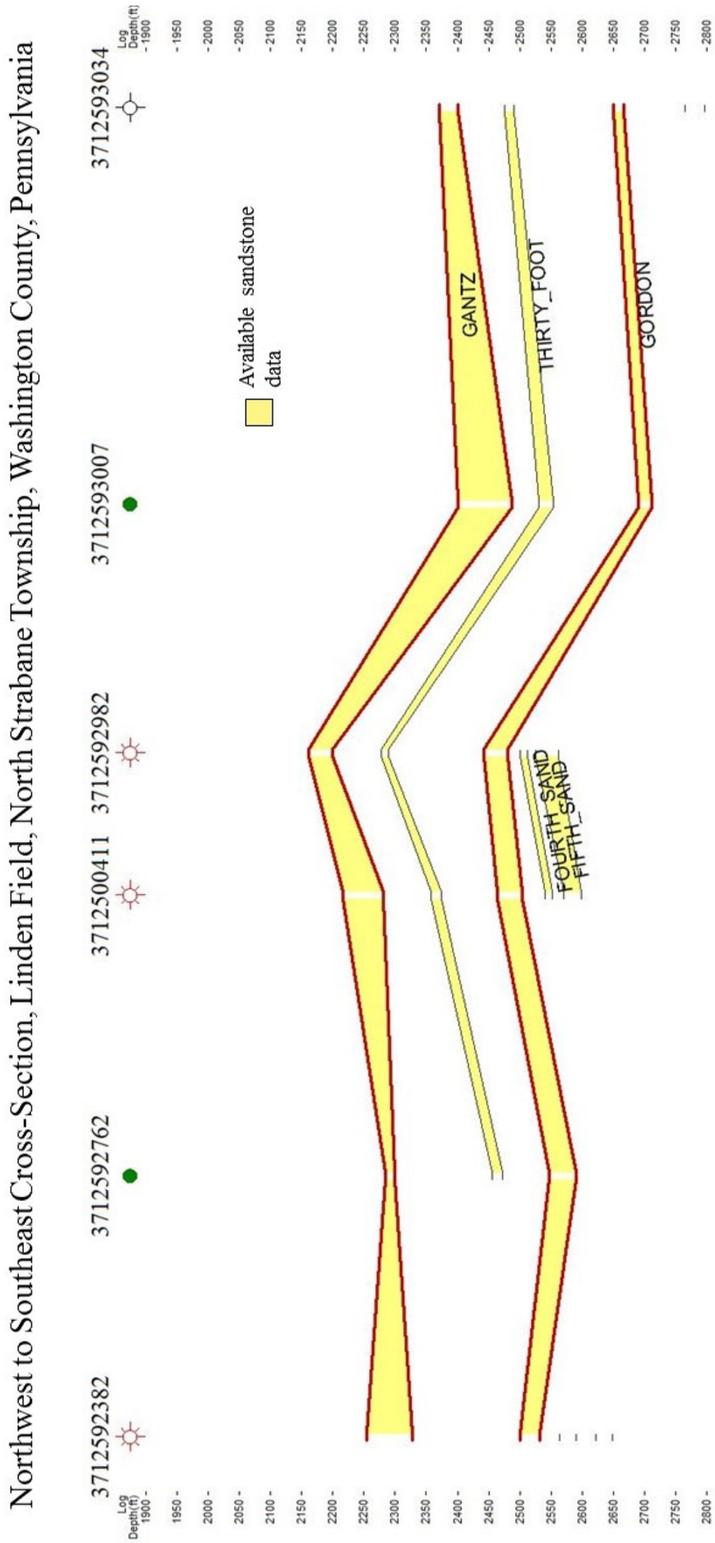


Figure 10. Cross-section A-A' (northwest-southeast) through Linden field with additional formation data.

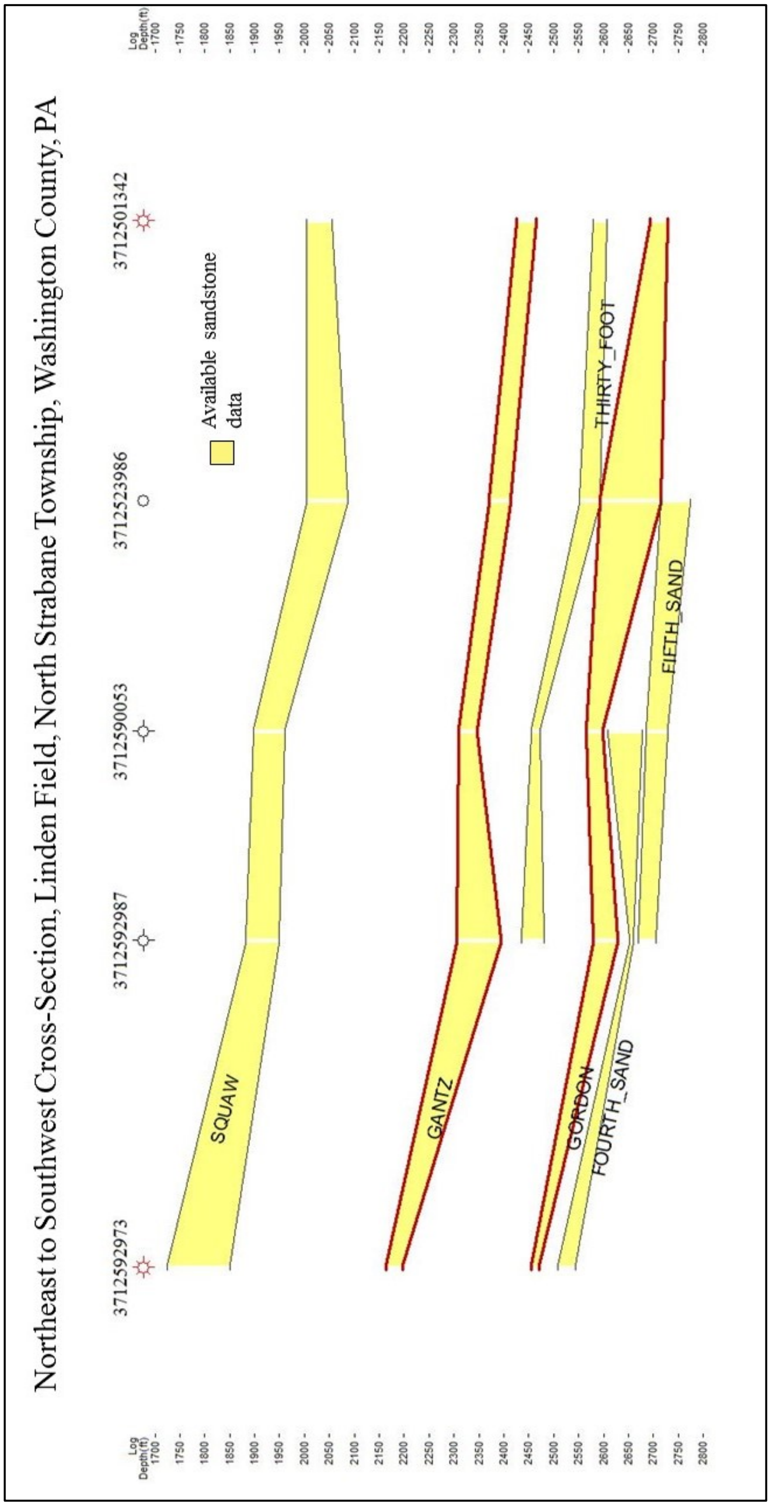


Figure 11. Cross-section B-B' (northeast-southwest) through Linden field with additional formation data.

GANTZ_isopach_7.VOL - Notepad

File Edit Format View Help

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Grid File: GANTZ_isopach_7.GRD
Title     : ISOPACH
XY Units : FEET
Z Units   : FT


Volumes Computed Between 0 and 1E30
Minimum Thickness Allowed Is 0.000
Grid Refinement Is 1


      Polygon:  All Polygons Combined
            Polygon Area:              1,867,979,793.05 (FT x FT)
                                       1,867,979,793.05 (SQRFT)
                                         173,541,348.52 (SQRMTR)
                                              42,882.92 (ACRES)

               Data Area:                 30,217,202.09 (FT x FT)
                                          30,217,202.09 (SQRFT)
                                           2,807,275.55 (SQRMTR)
                                                 693.69 (ACRES)

                  Volume:              1,300,433,830.79 (FT x FT x FT)


      Polygon:  ENTIRE GRID
              Total Area:              1,867,979,793.05 (FT x FT)
                                       1,867,979,793.05 (SQRFT)
                                         173,541,348.52 (SQRMTR)
                                              42,882.92 (ACRES)

              Data  Area:                 30,217,202.09 (FT x FT)
                                          30,217,202.09 (SQRFT)
                                           2,807,275.55 (SQRMTR)
                                                 693.69 (ACRES)


                  Volume:              1,300,433,830.79 (FT x FT x FT)



      Definitions:
          Total Area = Polygon Area
          Data  Area = Polygon Area covered by contours used in volumes


Notes:
       43560.0000 SqFt/Acre
       4046.8490 SqMtr/Acre
       7758.000000 BBL/AcFt
       62.42796061 Convert G/CC to LBS/CUFT

       Raw Area is SqFt
       Raw Volume is SqFt x FT


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Figure 12. Gantz formation volume calculation performed by PETRA

Gordon_isopach_7.VOL - Notepad

File Edit Format View Help

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Volumes Computed Between 0 and 1E30
Minimum Thickness Allowed Is 0.000
Grid Refinement Is 1


      Polygon:  All Polygons Combined
            Polygon Area:              1,867,979,793.05 (FT x FT)
                                       1,867,979,793.05 (SQRFT)
                                         173,541,348.52 (SQRMTR)
                                              42,882.92 (ACRES)

               Data Area:                848,596,534.56 (FT x FT)
                                         848,596,534.56 (SQRFT)
                                          78,837,355.47 (SQRMTR)
                                               19,481.1 (ACRES)

                  Volume:             49,259,790,052.45 (FT x FT x FT)


      Polygon:  ENTIRE GRID
              Total Area:              1,867,979,793.05 (FT x FT)
                                       1,867,979,793.05 (SQRFT)
                                         173,541,348.52 (SQRMTR)
                                              42,882.92 (ACRES)

              Data  Area:                848,596,534.56 (FT x FT)
                                         848,596,534.56 (SQRFT)
                                          78,837,355.47 (SQRMTR)
                                               19,481.1 (ACRES)


                  Volume:             49,259,790,052.45 (FT x FT x FT)



      Definitions:
          Total Area = Polygon Area
          Data  Area = Polygon Area covered by contours used in volumes


Notes:
       43560.0000 SqFt/Acre
       4046.8490 SqMtr/Acre
       7758.000000 BBL/AcFt
       62.42796061 Convert G/CC to LBS/CUFT

       Raw Area is SqFt
       Raw Volume is SqFt x FT


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possibility of such damages, or for any claim by any third party.
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Figure 13. Gordon formation volume calculation performed by PETRA®.

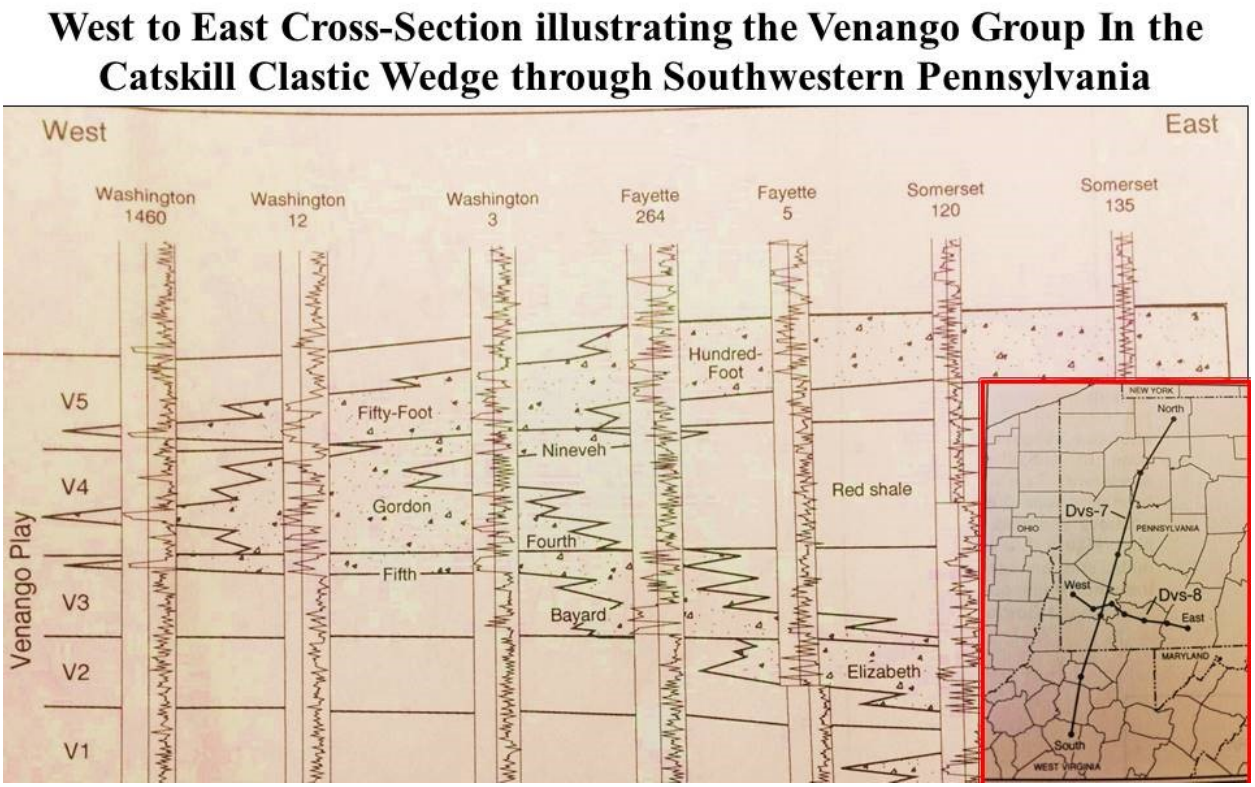

Figure 14. West to East gamma-ray cross-section of the Venango Play, adapted from Harper and Laughrey (1987) and Mcglade (1967).

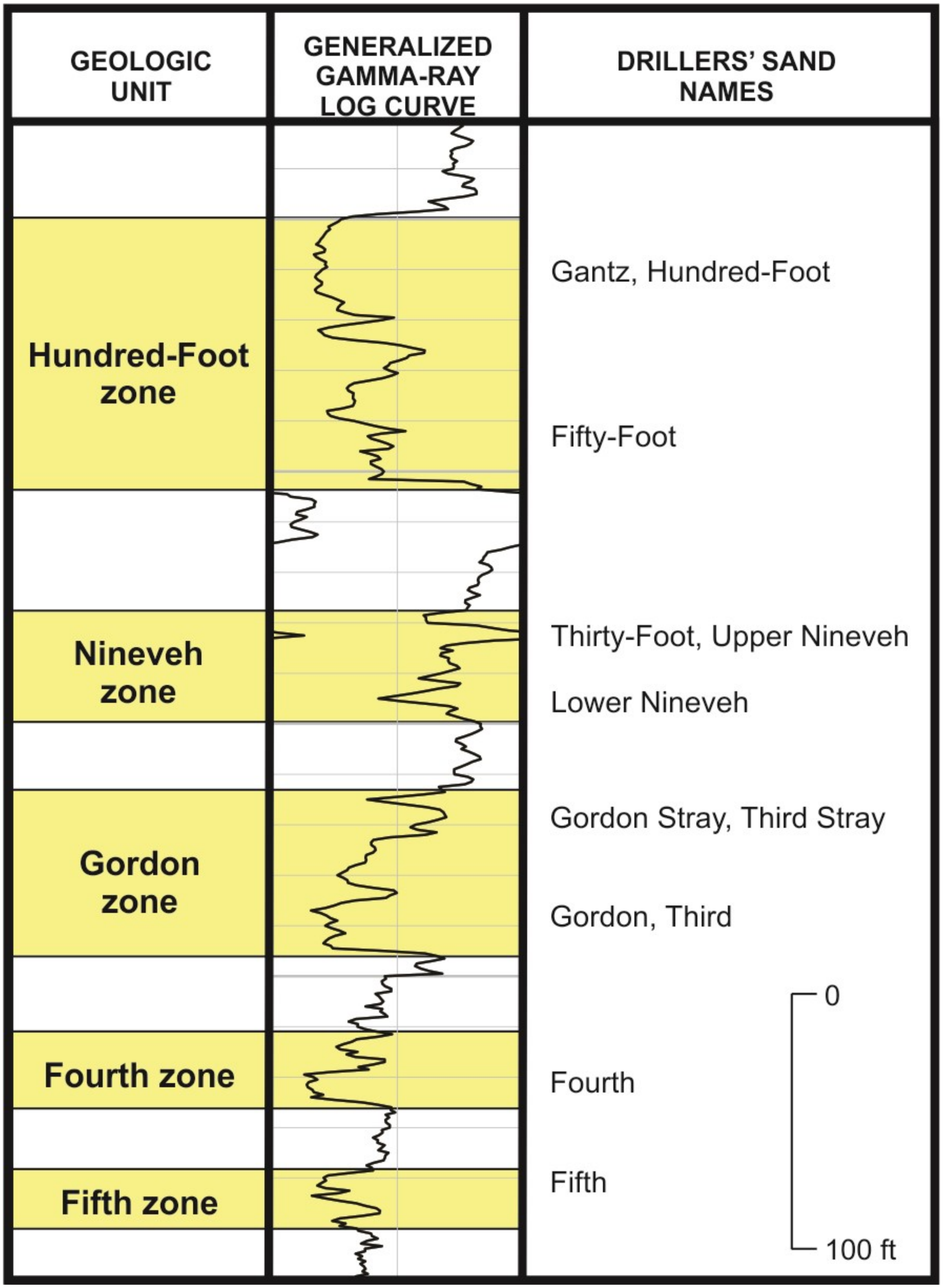

Figure 15. Venango Group gamma ray log reading from Carter, personal communication 2018.

TABLES

Table 1. Summary table of Gantz and Gordon formation averages and ranges.

Statistic (feet)	Gantz	Gordon
Top Depth Range	2032-2250	2205-2725
Average Top Depth	2255	2514
Bottom Depth Range	2082-2580	2300-2753
Average Bottom Depth	2294	2556
Thickness Range	4-119	4-180
Average Thickness	47	42

APPENDICES

Appendix A. All 290 wells in the Linden field and corresponding Gantz and Gordon formation tops, bottoms, and thicknesses.

UWI (APINum)	Gantz Top (Feet)	Gantz Bottom (feet)	Gantz Thickness (Feet)	Gordon Top (Feet)	Gordon Bottom (Feet)	Gordon Thickness (Feet)
3712501342	2426	2465	39	2693	2729	36
3712501457	2076	2150	74	2353	2385	32
3712501458	2205	2255	50	2480	2527	47
3712501908	2418	2463	45	-	-	-
3712520774	2374	2392	18	2519	-	-
3712521259	-	-	-	-	-	-
3712521342	-	-	-	-	-	-
3712521626	2500	2550	50	-	-	-
3712522035	2140	2165	25	2344	2364	20
3712523256	-	-		2445	2545	100
3712523610	2370	2413	43	2592	2715	123
3712523699	2166	2210	44	2393	2500	107
3712523830	2370	2413	43	2592	2715	123
3712523986	2370	2413	43	2592	2715	123
3712590050	-	-	-	-	-	-
3712590054	2407	2452	45	2547	2632	85
3712592378	2363	-	-	-	-	-
3712592381	2273	2318	45	2510	-	-
3712500037	2230	2282	52	-	-	-
3712500119	2300	2347	47	2613	2640	27
3712500141	2229	2281	52	2493	2515	22
3712500229	2170	2195	25	2385	2411	26
3712500230	-	-	-	-	-	-
3712500342	2285	2313	28	2500	2508	8
3712500411	2216	2281	65	2464	2504	40
3712500835	2263	2316	53	2507	2558	51
3712501063	2280	2320	40	2510	2522	12
3712501067	2295	2352	57	-	-	-
3712501072	-	-	-	-	-	-
3712501073	2286	2318	32	2500	2536	36
3712501074	2221	2288	67	-	-	-
3712501075	2232	2283	51	-	-	-
3712501076	2199	2257	58	2458	2638	180
3712501077	2305	-	-	-	-	-
3712501078	2283	2302	19	2537	2572	35

3712501079	2165	2196	31	2390	2407	17
3712501453	2048	-	-	-	-	-
3712501455	-	-	-	-	-	-
3712501456	2251	2285	34	2502	2546	44
3712501467	2113	2117	4	-	-	-
3712501468	2205	-	-	-	-	-
3712501473	-	-	-	-	-	-
3712501474	2117	2121	4	-	-	-
3712501476	-	-	-	-	-	-
3712501495	-	-	-	-	-	-
3712501497	2032	2107	75	2315	2328	13
3712501512	2243	-	-	-	-	-
3712501513	-	-	-	-	-	-
3712501514	2228	2240	12	-	-	-
3712501515	2175	2240	65	2452	2485	33
3712501516	-	-	-	2545	2599	54
3712501517	2395	2440	45	2637	2694	57
3712501518	2267	2318	51	-	-	-
3712501519	2065	2132	67	-	-	-
3712501534	2159	2192	33	-	-	-
3712501570	-	-	-	-	-	-
3712501571	-	-	-	-	-	-
3712501632	-	-	-	-	-	-
3712501644	-	-	-	-	-	-
3712501646	-	-	-	-	-	-
3712501647	-	-	-	-	-	-
3712501648	-	-	-	-	-	-
3712501649	-	-	-	-	-	-
3712501650	-	-	-	-	-	-
3712501702	-	-	-	-	-	-
3712501703	-	-	-	-	-	-
3712501796	-	-	-	-	-	-
3712501810	-	-	-	-	-	-
3712501818	2240	2319	79	2516	2539	23
3712501819	-	-	-	-	-	-
3712501820	2250	2326	76	2511	2549	38
3712501856	2260	2357	97	2567	2571	4
3712501866	2057	2082	25	-	-	-
3712501939	2273	2335	62	2547	2580	33
3712501940	2270	2348	78	2510	2552	42
3712501941	2268	2321	53	2522	-	-

3712501958	-	-	-	-	-	-
3712501974	-	-	-	-	-	-
3712501993	-	-	-	-	-	-
3712502030	-	-	-	-	-	-
3712502081	-	-	-	2375	-	-
3712520003	2249	2301	52	2495	2538	43
3712520047	2239	2282	43	-	-	-
3712520090	-	-	-	-	-	-
3712520127	2362	2376	14	2578	2593	15
3712520144	-	-	-	-	-	-
3712520153	2135	2180	45	2385	2412	27
3712520155	-	-	-	-	-	-
3712520703	2254	2288	34	2522	2566	44
3712520764	-	-	-	-	-	-
3712521074	2374	2392	18	-	-	-
3712521171	2195	-	-	2524	-	-
3712521266	-	-	-	-	-	-
3712521548	-	-	-	-	-	-
3712521641	2188	2215	27	2472	2490	18
3712521653	-	-	-	-	-	-
3712521661	-	-	-	-	-	-
3712521665	-	-	-	-	-	-
3712521668	2312	2395	83	-	-	-
3712521681	2340	2430	90	2640	2660	20
3712521682	2189	2258	69	2438	2480	42
3712521700	-	-	-	-	-	-
3712521851	-	-	-	-	-	-
3712521950	-	-	-	-	-	-
3712521966	-	-	-	-	-	-
3712521977	-	-	-	-	-	-
3712522007	-	-	-	-	-	-
3712522475	-	-	-	-	-	-
3712522917	-	-	-	-	-	-
3712524346	-	-	-	2604	2670	66
3712590048	2230	2253	23	2450	2550	100
3712590053	2310	2346	36	2566	2598	32
3712590059	-	-	-	-	-	-
3712590060	-	-	-	-	-	-
3712590061	2280	-	-	-	-	-
3712590082	-	-	-	-	-	-
3712590083	2425	2455	30	2656	2660	4

3712592375	-	-	-	-	-	-
3712592376	-	-	-	-	-	-
3712592377	-	-	-	-	-	-
3712592379	-	-	-	-	-	-
3712592380	-	-	-	-	-	-
3712592382	2254	2328	74	2500	2532	32
3712592383	-	-	-	-	-	-
3712592384	2306	2355	49	2556	2590	34
3712592385	2180	2225	45	2440	2474	34
3712592386	-	-	-	-	-	-
3712592402	-	-	-	2384	-	-
3712592403	-	-	-	-	-	-
3712592409	2250	2353	103	2500	2597	97
3712592410	-	-	-	-	-	-
3712592411	2125	2228	103	2380	2425	45
3712592412	2150	2250	100	2410	2450	40
3712592422	2132	2225	93	-	-	-
3712592740	2209	2295	86	2474	-	-
3712592743	2115	2205	90	2376	-	-
3712592744	-	-	-	-	-	-
3712592745	-	-	-	-	-	-
3712592746	2110	-	-	2376	-	-
3712592749	2234	2302	68	-	-	-
3712592750	-	-	-	-	-	-
3712592751	-	-	-	-	-	-
3712592752	-	-	-	-	-	-
3712592754	2190	2265	75	2447	2498	51
3712592755	2128	2189	61	2382	2428	46
3712592756	2255	2296	41	2512	2529	17
3712592757	2243	-	-	2480	2553	73
3712592758	2395	2458	63	2660	2702	42
3712592759	-	-	-	-	-	-
3712592760	2251	2291	40	2482	2520	38
3712592761	2097	2155	58	2355	-	-
3712592762	2285	2300	15	2547	2590	43
3712592774	2196	2250	54	2499	2537	38
3712592775	-	-	-	-	-	-
3712592776	-	-	-	-	-	-
3712592777	-	-	-	-	-	-
3712592778	2089	2128	39	2346	2391	45
3712592779	-	-	-	-	-	-

3712592780	-	-	-	-	-	-
3712592781	-	-	-	2330	-	-
3712592782	2116	2140	24	2370	2465	95
3712592783	2193	2250	57	2441	2487	46
3712592784	2223	2285	62	-	-	-
3712592785	2297	2357	60	2559	2592	33
3712592805	-	-	-	-	-	-
3712592811	-	-	-	-	-	-
3712592813	2205	2249	44	-	-	-
3712592815	-	-	-	-	-	-
3712592816	2136	2157	21	-	-	-
3712592822	2257	2299	42	2488	2563	75
3712592824	-	-	-	-	-	-
3712592830	2315	2360	45	-	-	-
3712592831	-	-	-	-	-	-
3712592960	2207	2247	40	-	-	-
3712592961	2050	-	-	2340	-	-
3712592967	-	-	-	-	-	-
3712592968	-	-	-	-	-	-
3712592971	-	-	-	-	-	-
3712592972	-	-	-	-	-	-
3712592973	2163	2198	35	2455	2470	15
3712592974	2237	2321	84	2480	2515	35
3712592975	-	-	-	-	-	-
3712592976	-	-	-	-	-	-
3712592978	-	-	-	-	-	-
3712592979	2210	-	-	-	-	-
3712592980	-	-	-	-	-	-
3712592981	2199	2257	58	2438	2458	20
3712592982	2161	2200	39	2442	2480	38
3712592983	-	-	-	-	-	-
3712592984	-	-	-	-	-	-
3712592985	2286	2405	119	2540	2578	38
3712592986	-	-	-	-	-	-
3712592987	2306	2395	89	2580	2628	48
3712592988	2234	2269	35	-	-	-
3712592989	-	-	-	-	-	-
3712592990	2317	2377	60	2576	2610	34
3712592991	2345	2400	55	2595	2660	65
3712592992	-	-	-	-	-	-
3712592993	2316	2355	39	2623	2639	16

3712592994	2205	-	-	-	-	-
3712592995	2263	2294	31	2520	2604	84
3712592996	2235	2294	59	2465	2521	56
3712592997	2305	-	-	-	-	-
3712592998	2125	2140	15	2490	2505	15
3712592999	2283	2323	40	2586	2597	11
3712593000	-	-	-	-	-	-
3712593001	-	-	-	-	-	-
3712593002	2203	2253	50	-	-	-
3712593003	2167	2202	35	2465	2505	40
3712593004	2320	2378	58	-	-	-
3712593005	2431	2446	15	2612	2630	18
3712593006	2380	2412	32	-	-	-
3712593007	2400	2487	87	2690	2712	22
3712593008	-	-	-	-	-	-
3712593009	-	-	-	-	-	-
3712593010	2330	2375	45	2588	2628	40
3712593011	-	-	-	-	-	-
3712593012	-	-	-	2687	2729	42
3712593013	2250	2285	35	2542	2560	18
3712593014	2280	2305	25	-	-	-
3712593015	2283	2302	19	2537	2572	35
3712593016	2283	-	-	-	-	-
3712593017	2272	2320	48	-	-	-
3712593018	2239	2282	43	-	-	-
3712593019	-	-	-	-	-	-
3712593021	-	-	-	-	-	-
3712593022	-	-	-	-	-	-
3712593023	-	-	-	-	-	-
3712593024	2390	2460	70	2639	2660	21
3712593025	2550	2580	30	-	-	-
3712593026	2405	2450	45	-	-	-
3712593027	2335	2385	50	2553	2570	17
3712593028	2335	2385	50	-	-	-
3712593029	2232	2296	64	-	-	-
3712593030	-	-	-	-	-	-
3712593031	-	-	-	2570	2581	11
3712593032	-	-	-	-	-	-
3712593033	-	-	-	-	-	-
3712593034	2371	2400	29	2650	2666	16
3712593038	-	-	-	2725	2753	28

3712593042	2280	2300	20	2490	2510	20
3712593043	-	-	-	-	-	-
3712593044	-	-	-	-	-	-
3712593045	-	-	-	-	-	-
3712593046	2368	2385	17	-	-	-
3712593047	2415	2432	17	2642	2652	10
3712593048	2354	2402	48	-	-	-
3712593050	-	-	-	-	-	-
3712593055	-	-	-	-	-	-
3712593098	2268	2284	16	2532	2550	18
3712593099	-	-	-	2643	2658	15
3712593100	2355	2389	34	-	-	-
3712593101	2255	2280	25	2540	2591	51
3712593102	-	-	-	-	-	-
3712593103	2203	2213	10	2465	2479	14
3712593104	-	-	-	-	-	-
3712593116	-	-	-	-	-	-
3712593117	2280	-	-	-	-	-
3712593118	2280	-	-	-	-	-
3712593119	2242	2275	33	-	-	-
3712593120	2285	2318	33	-	-	-
3712593121	2145	2212	67	2494	2520	26
3712593124	2200	2283	83	2487	2530	43
3712593125	2230	2283	53	2500	2588	88
3712593129	2250	2277	27	-	-	-
3712593140	2215	2250	35	-	-	-
3712593141	2208	2233	25	-	-	-
3712593142	2230	2253	23	-	-	-
3712593143	-	-	-	2275	2300	25
3712593144	2185	2205	20	-	-	-
3712593146	-	-	-	2205	2345	140
3712593147	2304	2324	20	-	-	-
3712593148	2233	2316	83	2500	2566	66
3712593149	-	-	-	-	-	-
3712593155	2180	2235	55	-	-	-
3712593181	-	-	-	-	-	-
3712593182	2346	2428	82	-	-	-
3712593183	2227	2250	23	2480	2560	80
3712593184	2361	2410	49	2630	2640	10
3712593207	-	-	-	2520	2550	30
3712593208	2374	2396	22	2709	2746	37

3712593211	2237	2246	9	2485	2495	10
3712593365	2158	2190	32	2485	2505	20
3712593366	2245	2350	105	2542	2564	22
3712593367	-	-	-	-	-	-
3712593661	2260	-	-	-	-	-
3712593662	-	-	-	-	-	-
3712593663	2248	2284	36	-	-	-
3712593664	-	-	-	-	-	-
3712593668	2193	2250	57	-	-	-
Average	2252	2302	47	2505	2556	42
Minimum	2032	2082	4	2205	2300	4
Maximum	2550	2580	119	2725	2753	180

Appendix B. Wells in the Linden field with Gantz tops, bottoms, calculated thicknesses, averages, and range of formation depth.

UWI (APINum)	Gantz Top (Feet)	Gantz Bottom (Feet)	Gantz Thickness (Feet)
3712501342	2426	2465	39
3712501457	2076	2150	74
3712501458	2205	2255	50
3712501908	2418	2463	45
3712520774	2374	2392	18
3712521626	2500	2550	50
3712522035	2140	2165	25
3712523610	2370	2413	43
3712523699	2166	2210	44
3712523830	2370	2413	43
3712523986	2370	2413	43
3712590054	2407	2452	45
3712592381	2273	2318	45
3712500037	2230	2282	52
3712500119	2300	2347	47
3712500141	2229	2281	52
3712500229	2170	2195	25
3712500342	2285	2313	28
3712500411	2216	2281	65
3712500835	2263	2316	53
3712501063	2280	2320	40
3712501067	2295	2352	57
3712501073	2286	2318	32
3712501074	2221	2288	67
3712501075	2232	2283	51
3712501076	2199	2257	58
3712501078	2283	2302	19
3712501079	2165	2196	31
3712501456	2251	2285	34
3712501467	2113	2117	4
3712501474	2117	2121	4
3712501497	2032	2107	75
3712501514	2228	2240	12
3712501515	2175	2240	65
3712501517	2395	2440	45
3712501518	2267	2318	51
3712501519	2065	2132	67
3712501534	2159	2192	33

3712501818	2240	2319	79
3712501820	2250	2326	76
3712501856	2260	2357	97
3712501866	2057	2082	25
3712501939	2273	2335	62
3712501940	2270	2348	78
3712501941	2268	2321	53
3712520003	2249	2301	52
3712520047	2239	2282	43
3712520127	2362	2376	14
3712520153	2135	2180	45
3712520703	2254	2288	34
3712521074	2374	2392	18
3712521641	2188	2215	27
3712521668	2312	2395	83
3712521681	2340	2430	90
3712521682	2189	2258	69
3712590048	2230	2253	23
3712590053	2310	2346	36
3712590083	2425	2455	30
3712592382	2254	2328	74
3712592394	2306	2355	49
3712592385	2180	2225	45
3712592409	2250	2353	103
3712592411	2125	2228	103
3712592412	2150	2250	100
3712592422	2132	2225	93
3712592740	2209	2295	86
3712592743	2115	2205	90
3712592749	2234	2302	68
3712592754	2190	2265	75
3712592755	2128	2189	61
3712592756	2255	2296	41
3712592758	2395	2458	63
3712592760	2251	2291	40
3712592761	2097	2155	58
3712592762	2285	2300	15
3712592774	2196	2250	54
3712592778	2089	2128	39
3712592782	2116	2140	24
3712592783	2193	2250	57

3712592784	2223	2285	62
3712592785	2297	2357	60
3712592813	2205	2249	44
3712592816	2136	2157	21
3712592822	2257	2299	42
3712592830	2315	2360	45
3712592960	2207	2247	40
3712592973	2163	2198	35
3712592974	2237	2321	84
3712592981	2199	2257	58
3712592982	2161	2200	39
3712592985	2286	2405	119
3712592987	2306	2395	89
3712592988	2234	2269	35
3712592990	2317	2377	60
3712592991	2345	2400	55
3712592993	2316	2355	39
3712592995	2263	2294	31
3712592996	2235	2294	59
3712592998	2125	2140	15
3712592999	2283	2323	40
3712593002	2203	2253	50
3712593003	2167	2202	35
3712593004	2320	2378	58
3712593005	2431	2446	15
3712593006	2380	2412	32
3712593007	2400	2487	87
3712593010	2330	2375	45
3712593013	2250	2285	35
3712593014	2280	2305	25
3712593015	2283	2302	19
3712593017	2272	2320	48
3712593018	2239	2282	43
3712593024	2390	2460	70
3712593025	2550	2580	30
3712593026	2405	2450	45
3712593027	2335	2385	50
3712593028	2335	2385	50
3712593029	2232	2296	64
3712593034	2371	2400	29
3712593042	2280	2300	20

3712593046	2368	2385	17
3712593047	2415	2432	17
3712593048	2354	2402	48
3712593098	2268	2284	16
3712593100	2355	2389	34
3712593101	2255	2280	25
3712593103	2203	2213	10
3712593119	2242	2275	33
3712593120	2285	2318	33
3712593121	2145	2212	67
3712593124	2200	2283	83
3712593125	2230	2283	53
3712593129	2250	2277	27
3712593140	2215	2250	35
3712593141	2208	2233	25
3712593142	2230	2253	23
3712593144	2185	2205	20
3712593147	2304	2324	20
3712593148	2233	2316	83
3712593155	2180	2235	55
3712593182	2346	2428	82
3712593183	2227	2250	23
3712593184	2361	2410	49
3712593208	2374	2396	22
3712593211	2237	2246	9
3712593365	2158	2190	32
3712593366	2245	2350	105
3712593663	2248	2284	36
3712593668	2193	2250	57
Average	2255	2294	47
Minimum	2032	2082	4
Maximum	2550	2580	119

Appendix C. Wells in the Linden field with Gordon tops, bottoms, calculated thicknesses, averages, and range of formation depth.

UWI (APINum)	Gordon Top (Feet)	Gordon Bottom (Feet)	Gordon Thickness (Feet)
3712501342	2693	2729	36
3712501457	2353	2385	32
3712501458	2480	2527	47
3712522035	2344	2364	20
3712523256	2445	2545	100
3712523610	2592	2715	123
3712523699	2393	2500	107
3712523830	2592	2715	123
3712523986	2592	2715	123
3712590054	2547	2632	85
3712500119	2613	2640	27
3712500141	2493	2515	22
3712500229	2385	2411	26
3712500342	2500	2508	8
3712500411	2464	2504	40
3712500835	2507	2558	51
3712501063	2510	2522	12
3712501073	2500	2536	36
3712501076	2458	2638	180
3712501078	2537	2572	35
3712501079	2390	2407	17
3712501456	2502	2546	44
3712501497	2315	2328	13
3712501514	2485	2510	25
3712501515	2452	2485	33
3712501516	2545	2599	54
3712501517	2637	2694	57
3712501818	2516	2539	23
3712501820	2511	2549	38
3712501856	2567	2571	4
3712501939	2547	2580	33
3712501940	2510	2552	42
3712520003	2495	2538	43
3712520127	2578	2593	15
3712520153	2385	2412	27
3712520703	2522	2566	44
3712521641	2472	2490	18
3712521681	2640	2660	20

3712521682	2438	2480	42
3712524346	2604	2670	66
3712590048	2450	2550	100
3712590053	2566	2598	32
3712590083	2656	2660	4
3712592382	2500	2532	32
3712592384	2556	2590	34
3712592385	2440	2474	34
3712592409	2500	2597	97
3712592411	2380	2425	45
3712592412	2410	2450	40
3712592754	2447	2498	51
3712592755	2382	2428	46
3712592756	2512	2529	17
3712592757	2480	2553	73
3712592758	2660	2702	42
3712592760	2482	2520	38
3712592762	2547	2590	43
3712592774	2499	2537	38
3712592778	2346	2391	45
3712592782	2370	2465	95
3712592783	2441	2487	46
3712592785	2559	2592	33
3712592822	2488	2563	75
3712592973	2455	2470	15
3712592974	2480	2515	35
3712592981	2438	2458	20
3712592982	2442	2480	38
3712592985	2540	2578	38
3712592987	2580	2628	48
3712592990	2576	2610	34
3712592991	2595	2660	65
3712592993	2623	2639	16
3712592995	2520	2604	84
3712592996	2465	2521	56
3712592998	2490	2505	15
3712592999	2586	2597	11
3712593003	2465	2505	40
3712593005	2612	2630	18
3712593007	2690	2712	22
3712593010	2588	2628	40

3712593012	2687	2729	42
3712593013	2542	2560	18
3712593015	2537	2572	35
3712593024	2639	2660	21
3712593027	2553	2570	17
3712593031	2570	2581	11
3712593034	2650	2666	16
3712593038	2725	2753	28
3712593042	2490	2510	20
3712593047	2642	2652	10
3712593099	2643	2658	15
3712593101	2540	2591	51
3712593103	2465	2479	14
3712593121	2494	2520	26
3712593124	2487	2530	43
3712593125	2500	2588	88
3712593143	2275	2300	25
3712593146	2205	2345	140
3712593148	2500	2566	66
3712593183	2480	2560	80
3712593184	2630	2640	10
3712593207	2520	2550	30
3712593208	2709	2746	37
3712593211	2485	2495	10
3712593365	2485	2505	20
3712593366	2542	2564	22
Average	2514	2556	42
Minimum	2205	2300	4
Maximum	2725	2753	180

Appendix D. Wells in the Linden field with Gantz initial production and flow volumes from completion reports in EDWIN.

UWI (APINum)	Gantz Known Producing Horizons
3712501073	YEAR 1986
3712501074	YEAR 1986, 2279-2282', 465MCF SLOW TO 355MCF
3712501075	YEAR 1937
3712501076	YEAR 1937, 2248-2249', 127MCF
3712501534	YEAR 1947, GAS 2170-2174', 184MCF
3712501818	YEAR 1945, OIL AND GAS 2265-2270', OIL 2275'
3712501820	YEAR 1946, OIL AND GAS SHOW 2281', PRODUCING 2295-2300', OIL SHOW AT 2541 AND 2544'
3712501866	YEAR 1937, GAS 2069-2072', 800MCF/DAY BLOWING DOWN TO 60MCF/D
3712501939	YEAR 1945, GAS 2286'
3712520003	YEAR 1955, GAS AND OIL SHOW 2286-2291'
3712520153	YEAR 1966, OIL AT 2157-2161'
3712590083	YEAR 1946, GAS 2446'
3712592382	YEAR 1944, GAS SHOW 2307-2309'
3712592411	YEAR 1944, GAS 2154-2155', OIL 2170-2175'
3712592412	YEAR 1946, OIL 2204-2209',
3712592749	YEAR 1948, OIL OR GAS, INITIAL VOLUME 5BBL? (difficult to read)
3712592756	YEAR 1945, OIL AND GAS SHOW 2264-2266'
3712592816	YEAR 1946, OIL AT 2157'
3712592822	YEAR 1953, GAS 2282'
3712592830	YEAR 1953, GAS 2330-2340'
3712592960	YEAR 1937, GAS 2223-2228', 35,000 CU FT GAS
3712592973	YEAR 1940, GAS 2198'
3712592981	YEAR 1943, GAS 2248-2249', 127 MCF
3712592982	YEAR 1944, GAS 2165-2167', 296MCF
3712592985	YEAR 1941, GAS 2294'
3712592988	YEAR 1943, GAS 2236-2268, 115,000 CU FT
3712593003	YEAR 1946, GAS 2192'-2195'
3712593010	YEAR 1945, GAS 2356-2361'
3712593100	YEAR 1948, GAS 2388', 6MCF
3712593124	YEAR 1921, GAS 2219'
3712593125	YEAR 1926, GAS 2262'
3712593140	YEAR 1913, GAS 2232'

Appendix E. Wells in Linden field with Gordon initial production and flow volumes from completion reports in EDWIN.

UWI (APINum)	Gordon Known Producing Horizons
3712501939	YEAR 1945, OIL SHOW 2556', OIL PAY 2572'
3712501940	YEAR 1945, BULK TAR OIL SHOW 2532', OIL 2542-2550', PAY WAS HARD
3712520003	YEAR 1955, OIL 2517-2519
3712592384	YEAR 1946, OIL 2571-2574'
3712592409	YEAR 1946, SLIGHT OIL AND GAS SHOW 2536-2538'
3712592411	YEAR 1944, OIL 2412-2415'
3712592412	YEAR 1946, OIL 2441-2443'
3712592755	YEAR 1948, OIL 2394-2403'
3712592783	YEAR 1945, OIL 2458-2470', 2474-2480'
3712593012	YEAR 1951, GAS 20MCF
3712593365	YEAR 1912, LITTLE GAS 2495'