Tensleep Formation Project Report

Prepared for:

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Prepared by:

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Cover Letter

This report is a final report done by EKO Oil Company regarding the Tensleep Formation in the Teapot Dome Basin in Natrona County, Wyoming. EKO Oil Company developed a static and dynamic model of the Tensleep formation. With the static and dynamic models, EKO Oil Company ran EOR simulations utilizing CO_2 flooding of the formation and presented an EOR plan recommendation. The team members who worked on this project are listed below.

Brent Kebert

Bismarck Echegile

Rostin Okamba

Executive Summary

The project is to develop a static and dynamic model of the Tensleep formation in the Teapot Dome Basin northeast of Casper, WY in Natrona County. With the static and dynamic models, CO_2 injection simulations were run as a potential EOR solution. With the results of the simulations, a potential CO_2 injection plan is proposed.

The project was completed through four major steps: creating the static reservoir model, creating the dynamic reservoir model, running CO_2 injection simulations, and preparing the presentation. The project needs to be completed systematically in that respective order. The static and dynamic reservoir models were estimated to take the longest amount of time.

The static reservoir model was completed within the Petrel program a few days behind schedule. Luckily, the schedule allowed make up time which allowed the group to still be able to finish the project on time. The static model did not completely match the seismic data associated with the formations although the group felt as though there was enough information from the well and wells log data to continue forward.

After the static model was built in Petrel, the dynamic model was build using the CMG program. The static model was used to create the surface and formation model. After the dynamic model was built CO_2 injection EOR simulations were run using the dynamic model within CMG.

The recommendation for the EOR plan was based off of production numbers and set prices for the hydrocarbons, as well as the amount of production water needed to be disposed of and CO_2 bought to be injected. During the process the group reviewed the State of Wyoming's laws and regulations to determine the safest, most ethical, and most efficient plan within the legal constraints.

The team determined that the best EOR CO_2 injection plan would be to inject 300 MCF/D into both injection wells within the Tensleep formation, equaling 600 MCF of CO_2 injected daily. This injection plan is estimated to be the most profitable plan proposed after three years of the injection plan. Approximately 1.1 million dollars is pessimistically estimated to be the profit of the EOR plan after the first three years of injections. The recommended plan is also estimated to cut down on the operational costs the most out of any other plan proposed.

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Nomenclature

CMG	Computer Modeling Group
CO_2	Carbon Dioxide
EOR	Enhanced Oil Recovery
MCF	Thousand Standard Cubic Feet
MCF/D	Thousand Standard Cubic Feet per Day
SPE	Society of Petroleum Engineers
STB	Stock Tank Barrel
WBS	Work Breakdown Structure
WOGCC	Wyoming Oil and Gas Conservation Commission

Acknowledgements

Team Leader

Brent Kebert – bkebert@uwyo.edu

Brent is an American who grew up in Indonesia, Venezuela, and Casper, WY and is scheduled to graduate with a Bachelors of Science in Petroleum Engineering with a Concentration in Unconventional Reservoirs in December 2017. Brent's father has worked as a Petroleum Engineer for 35 years which promoted Brent's desire to follow in that direction. Brent hopes to utilize his concentration in Unconventional Reservoirs and find work in Production Engineering, Reservoir Engineering, or Consulting.

Team Members

Bismarck Echegile – bechegil@uwyo.edu

Bismarck is a Nigerian who spent most of his childhood in Lagos, Nigeria and is set to graduate with a Bachelors of Science in Petroleum Engineering. Bismarck grew up in a country rich in petroleum resources but wastefully managed.It has always been a desire for Bismarck to one day have a hand in affecting Nigeria's oil and gas industry.

Rostin Okamba – rokamba@uwyo.edu

Rostin is a Congolese from the Democratic Republic of Congo who grew up in Kinshasa and set to graduate with a Bachelors of Science in Petroleum Engineering with a Concentration in Unconventional Reservoirs. Rostin grew up in a country rich of natural resources and his father has an oil distribution business in the D.R.Congo. He always wanted to work alongside his father and use his knowledge in the oil industry to expand his father business.

Introduction

Project objective:

The project objective was to develop a static and dynamic model of the Tensleep formation in the Teapot Dome basin North East of Casper, WY in Natrona County. With the static and dynamic models, CO_2 injection simulations were ran as a potential EOR solution. With the results of the simulations, a potential CO_2 injection plan was proposed in a presentation.

Literature Search and Review:

The project began by doing a literature search and review of the Tensleep formation as well as the Teapot Dome Basin as a whole. The team had several literature sources so we began by reviewing those. Within that literature search it was found that the Tensleep formation was producing because of a strong water drive. The formation has been producing for a very long time with production dated back to 1922.

Below is a figure showing the location of the Teapot Dome Field.

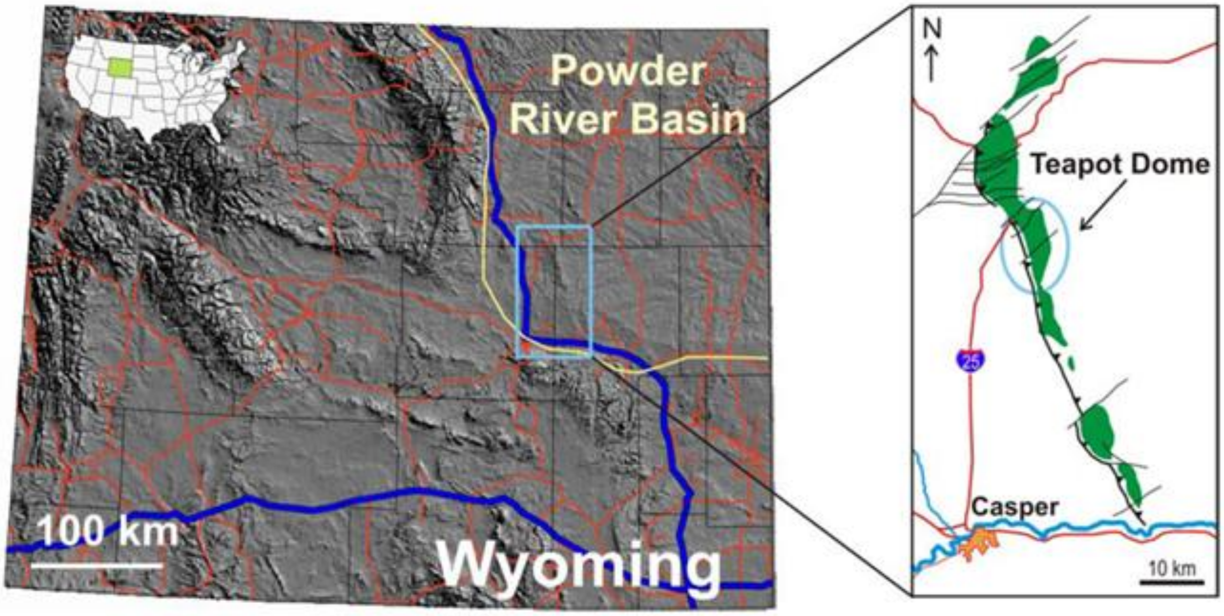


Figure 1 –Map of Teapot Dome.

In figure one, there are two blue lines that represent interstates. The line running up and down (North/South) is Interstate-25 and the line running right to left (East/West) is Interstate-80. From the smaller image it is possible to identify that the field is located just North-East of Casper, WY. The location of the Teapot Dome Basin is important in understanding why CO_2 injection is utilized.

Below is a figure of the CO_2 pipeline running from Rock Springs, WY to the Teapot Dome Basin.

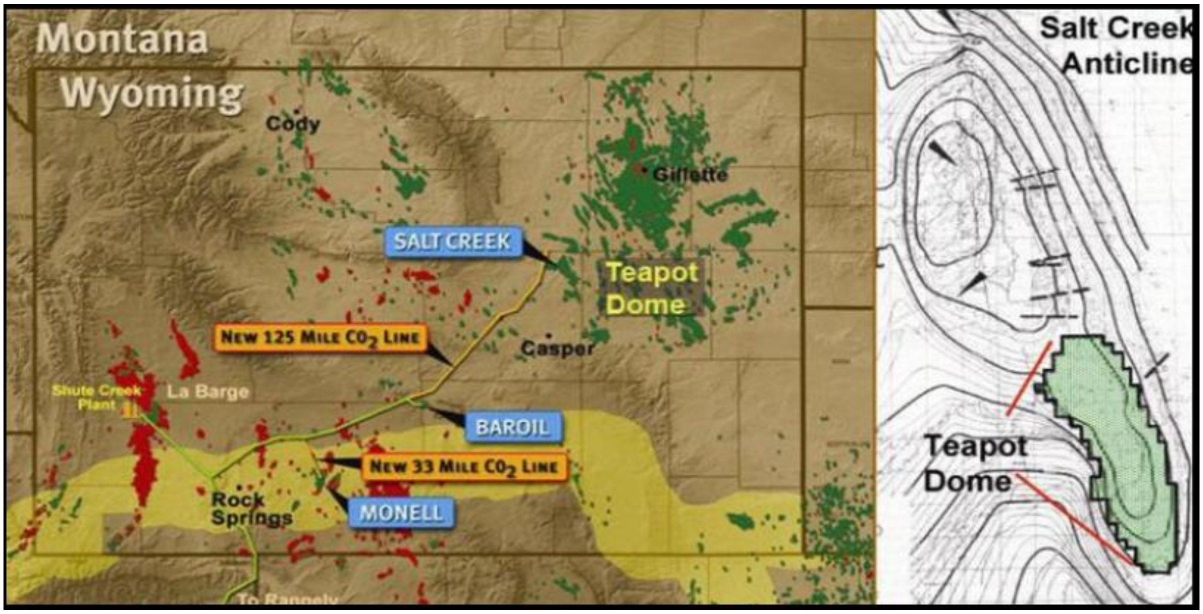


Figure 2 –Map of CO2 Pipeline to the Teapot Dome.

From figure two, it is possible to see that injecting CO_2 as an EOR method is very possible. There are reservoirs in Rock Springs, WY that produce an enormous amount of CO_2 which makes the supply very consistent. Water flooding the reservoir would have been the second EOR option although with Wyoming not having a large amount of water available to be injected, and the pipeline being put in, CO_2 injections are the easiest option.

Below is a simple figure of how CO_2 flooding working within the formation.

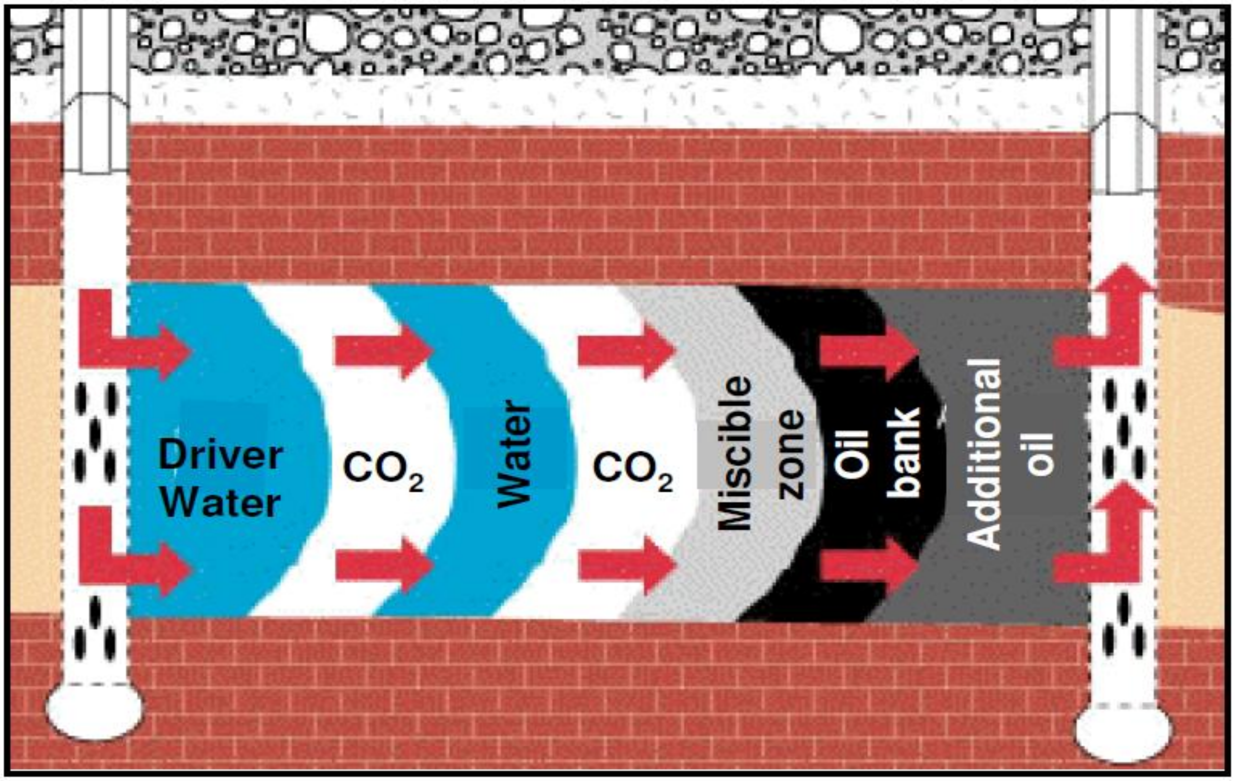
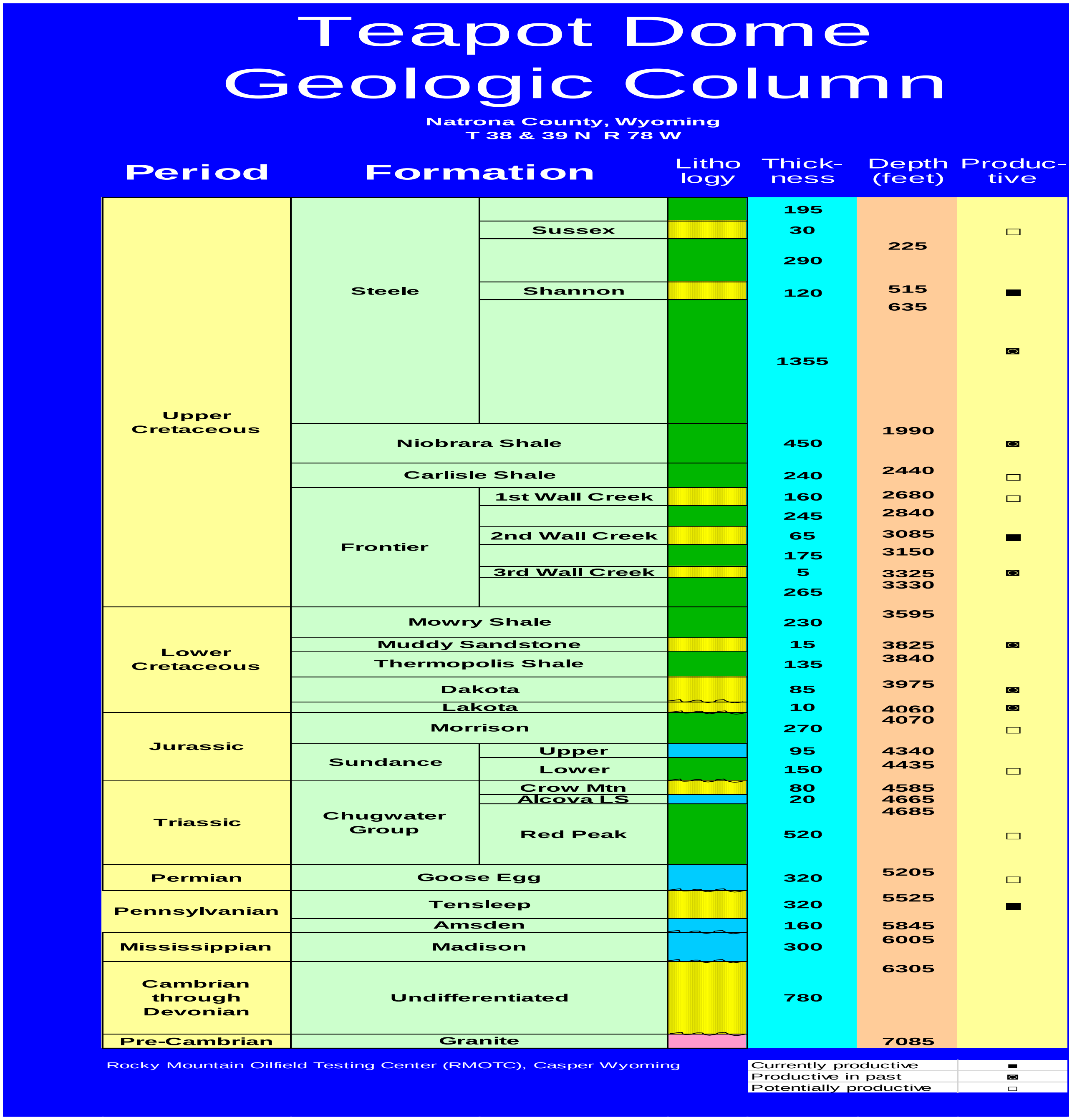


Figure 3 –How CO2 flooding a formation with injection wells works.

In figure three, the well on the left is acting as the injection well and the well on the right is acting as the producing well. The injection well forced CO_2 into the formation. Similar to water flooding the reservoir, the CO_2 aides the initial water drive of the formation to hopefully “push” the hydrocarbons to the wellbore.

Below is a figure of the geologic column of the Teapot Dome Basin.



Teapot Dome Geologic Column

Natrona County, Wyoming
T 38 & 39 N R 78 W

Period	Formation		Litho logy	Thick- ness	Depth (feet)	Produc- tive
Upper Cretaceous	Steele		🟩	195		
		Sussex	🟨	30	225	☐
			🟩	290	515	
		Shannon	🟨	120	635	■
			🟩	1355	1990	◙
	Niobrara Shale		🟩	450	2440	◙
	Carlisle Shale		🟩	240	2680	☐
	Frontier	1st Wall Creek	🟨	160	2840	☐
			🟩	245	3085	
		2nd Wall Creek	🟨	65	3150	■
			🟩	175	3325	
		3rd Wall Creek	🟨	5	3330	◙
			🟩	265	3595	
Lower Cretaceous	Mowry Shale		🟩	230	3825	
	Muddy Sandstone		🟨	15	3840	◙
	Thermopolis Shale		🟩	135	3975	
	Dakota		🟨	85	4060	◙
	Lakota		🟨	10	4070	◙
Jurassic	Morrison		🟩	270	4340	☐
	Sundance	Upper	🟦	95	4435	
		Lower	🟩	150	4585	☐
Triassic	Chugwater Group	Crow Mtn	🟨	80	4665	
		Alcova LS	🟦	20	4685	
		Red Peak	🟩	520	5205	☐
Permian	Goose Egg		🟦	320	5525	☐
Pennsylvanian	Tensleep		🟨	320	5845	■
	Amsden		🟦	160	6005	
Mississippian	Madison		🟦	300	6305	
Cambrian through Devonian	Undifferentiated		🟨	780	7085	
Pre-Cambrian	Granite		🟪			

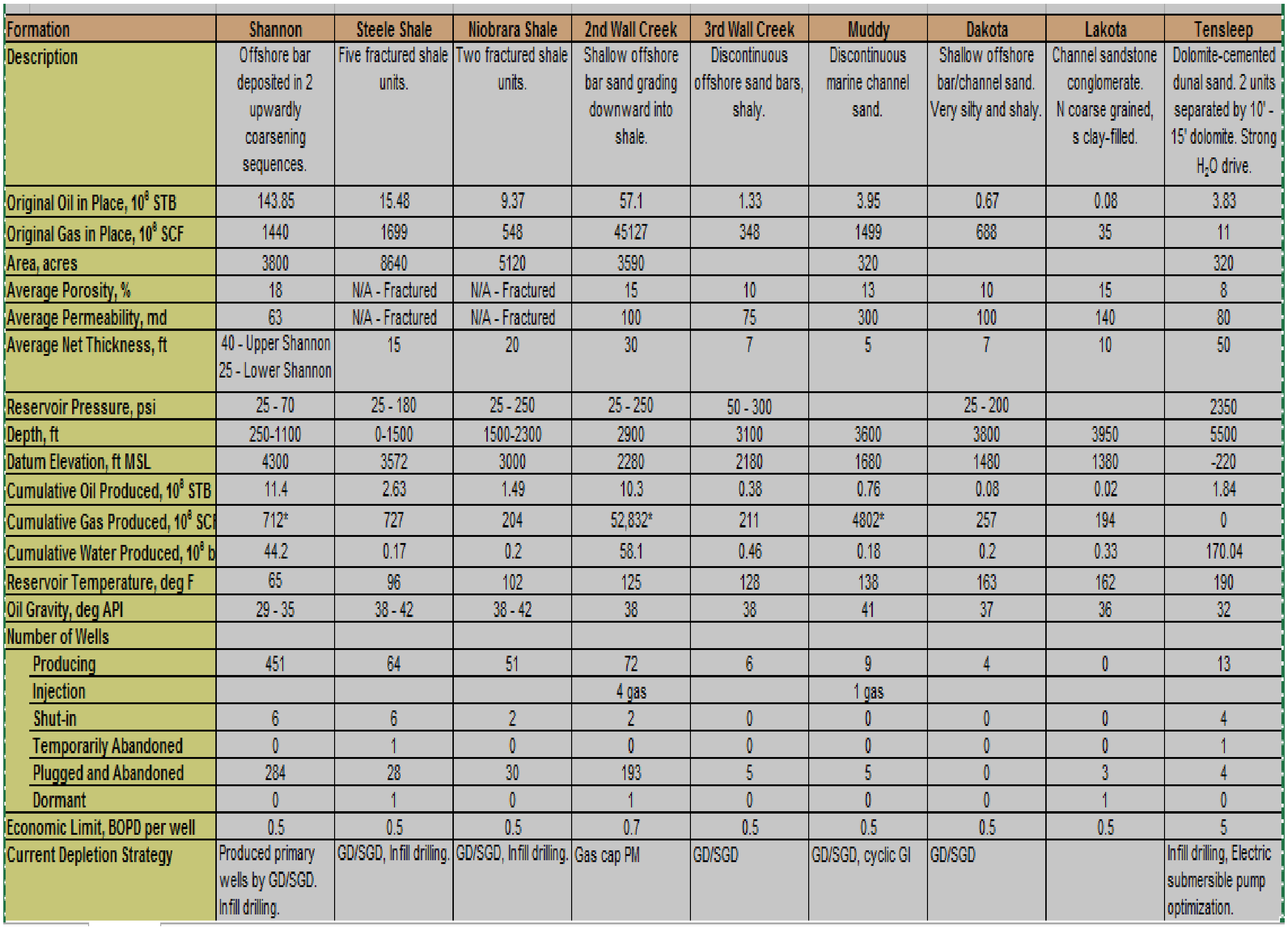
Rocky Mountain Oilfield Testing Center (RMOTC), Casper Wyoming

Currently productive	■
Productive in past	◙
Potentially productive	☐

Figure 4 – Teapot Dome Geologic Column.

Figure four shows the entire geological column of the Teapot Dome Basin. The Teapot Dome has multiple layers that produce hydrocarbons and operating companies have taken advantage of that. The Tensleep formation is fairly deep and buried under many layers, those of which also produce oil and gas. With the added expense of drilling deeper it is necessary to produce a large volume of hydrocarbons.

Below is a table pointing out production information for each layer in the Teapot Dome Basin.



Formation	Shannon	Steele Shale	Niobrara Shale	2nd Wall Creek	3rd Wall Creek	Muddy	Dakota	Lakota	Tensleep
Description	Offshore bar deposited in 2 upwardly coarsening sequences.	Five fractured shale units.	Two fractured shale units.	Shallow offshore bar sand grading downward into shale.	Discontinuous offshore sand bars, shaly.	Discontinuous marine channel sand.	Shallow offshore bar/channel sand. Very silty and shaly.	Channel sandstone conglomerate. N coarse grained, s clay-filled.	Dolomite-cemented dunal sand. 2 units separated by 10' - 15' dolomite. Strong H_2O drive.
Original Oil in Place, 10^6 STB	143.85	15.48	9.37	57.1	1.33	3.95	0.67	0.08	3.83
Original Gas in Place, 10^6 SCF	1440	1699	548	45127	348	1499	688	35	11
Area, acres	3800	8640	5120	3590		320			320
Average Porosity, %	18	N/A - Fractured	N/A - Fractured	15	10	13	10	15	8
Average Permeability, md	63	N/A - Fractured	N/A - Fractured	100	75	300	100	140	80
Average Net Thickness, ft	40 - Upper Shannon 25 - Lower Shannon	15	20	30	7	5	7	10	50
Reservoir Pressure, psi	25 - 70	25 - 180	25 - 250	25 - 250	50 - 300		25 - 200		2350
Depth, ft	250-1100	0-1500	1500-2300	2900	3100	3600	3800	3950	5500
Datum Elevation, ft MSL	4300	3572	3000	2280	2180	1680	1480	1380	-220
Cumulative Oil Produced, 10^6 STB	11.4	2.63	1.49	10.3	0.38	0.76	0.08	0.02	1.84
Cumulative Gas Produced, 10^6 SC	712*	727	204	52,832*	211	4802*	257	194	0
Cumulative Water Produced, 10^6 b	44.2	0.17	0.2	58.1	0.46	0.18	0.2	0.33	170.04
Reservoir Temperature, deg F	65	96	102	125	128	138	163	162	190
Oil Gravity, deg API	29 - 35	38 - 42	38 - 42	38	38	41	37	36	32
Number of Wells									
Producing	451	64	51	72	6	9	4	0	13
Injection				4 gas		1 gas			
Shut-in	6	6	2	2	0	0	0	0	4
Temporarily Abandoned	0	1	0	0	0	0	0	0	1
Plugged and Abandoned	284	28	30	193	5	5	0	3	4
Dormant	0	1	0	1	0	0	0	1	0
Economic Limit, BOPD per well	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	5
Current Depletion Strategy	Produced primary wells by GD/SGD. Infill drilling.	GD/SGD, Infill drilling.	GD/SGD, Infill drilling.	Gas cap PM	GD/SGD	GD/SGD, cyclic GI	GD/SGD		Infill drilling, Electric submersible pump optimization.

Table 1 – Reservoir Data -- Rocky Mountain Oilfield Testing Center (RMOTC) -- NPR-3/Teapot Dome

With table one pointing out that each formation in the Teapot Dome has production, as well as extremely different production, it is important to look at the specific lithology of the Tensleep formation which in itself is layered.

Below is a figure that shows the different lithology within the Tensleep formation.

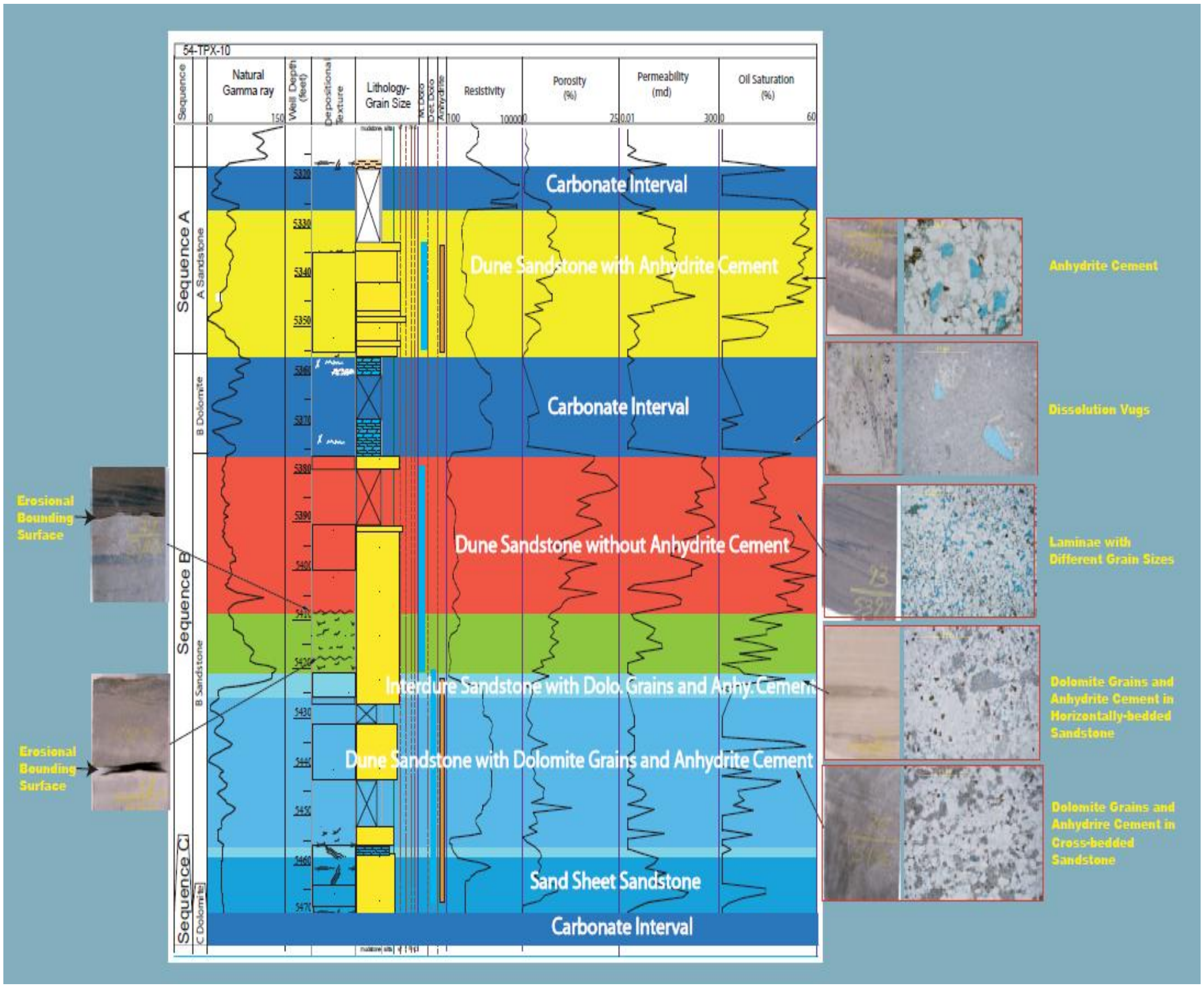


Figure 5 – Lithology of the Tensleep formation per layer within the formation.

Figure five is based off of coring data taken from each layer of the Tensleep Formation. Luckily with production lasting approximately 100 years there is a good deal already known about the formation. Looking closer at the figure it is also possible to see that there is a huge variation throughout the properties even within each layer. With properties that change that much in such a small amount of time it will be difficult to build models that accurately represent the formation.

Team Dynamics:

The team got together on Sundays, Tuesdays, and Thursdays due to previous scheduling conflicts. As a team we discussed progress and how to improve, reallocate, or continue the work being done, minimally every two weeks. Quickly we discovered our own individual talents that we could bring to the group. To work the most efficiently, each of the team members "specialized" in a particular type of the data provided. For example, one team member could take the seismic data and “specialize” to the point where they are the go to member for implementing and reading seismic data.

Communication Plan:

The team communicated primarily through email. To share documents, the team created a group on Outlook in which we can have a location to access and work on the most up-to-date files. The team also utilized SMS text messaging to quickly and easily create additional meeting times.

Main Body

Project Work Breakdown Structure

Below is the project Work Breakdown Structure (WBS).

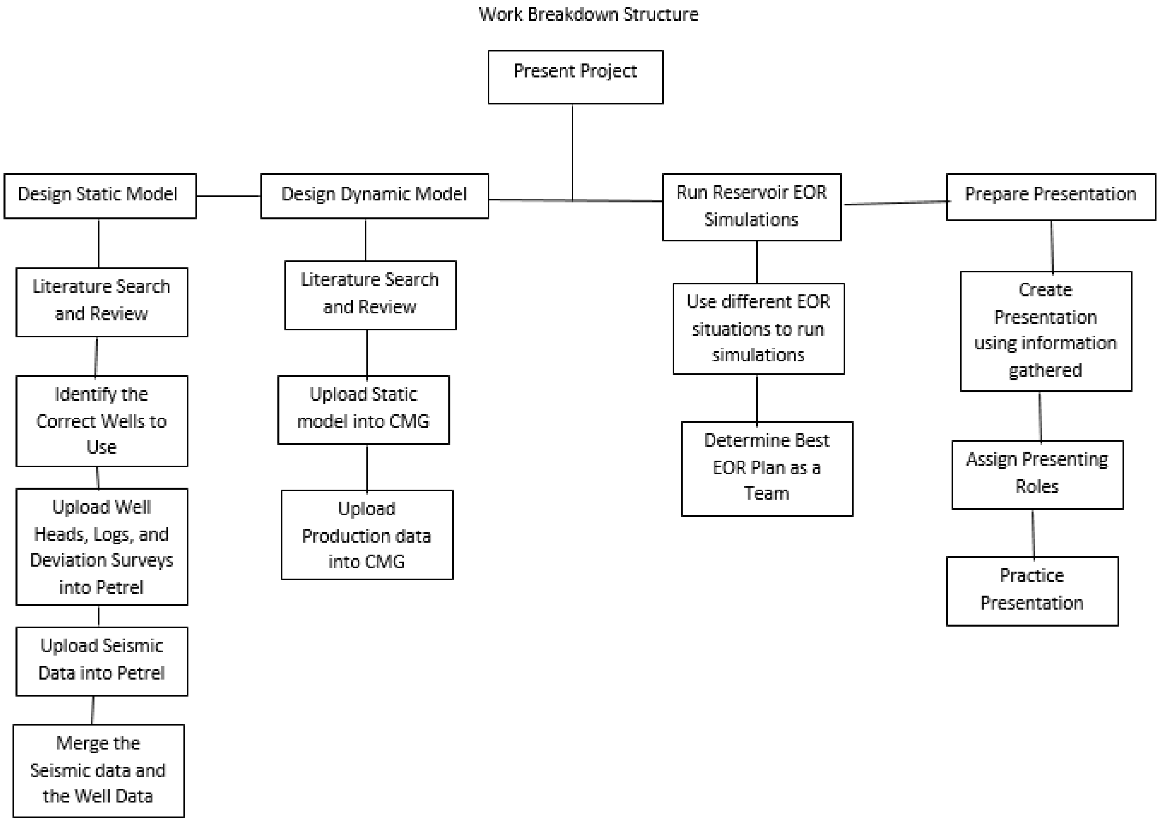


Figure 6 – Work Breakdown Structure of the project.

A literature search was necessary to become familiar with what the expected product would be when it came to both the static and dynamic model. The group was given over 1400 wells and their logs which meant initially the correct wells needed to be selected. After the correct well data was selected, the group uploaded the well heads, logs, and deviations into Petrel. Then, seismic data had been merged into Petrel.

Once the static model was complete it was time to start on the dynamic model in the CMG (Computer Modeling Group) program. The dynamic model was started by loading the static model's A sand surface from Petrel into CMG. After the surface was uploaded, small details about the reservoir were added such as porosity, permeability, saturations, etc. Then, the group added the wells and production data so that there is validity to where the properties of the formation are at today.

After the dynamic model was built in CMG, the group used CMG to run reservoir simulations of CO_2 injections as an EOR plan. After the simulations were complete, a consensus was made about which EOR injection plan to recommend and a presentation was made compiling all the information found and data obtained.

Project Workflow

Below is the Workflow for the project done on the Tensleep formation.

Work Flow Chart

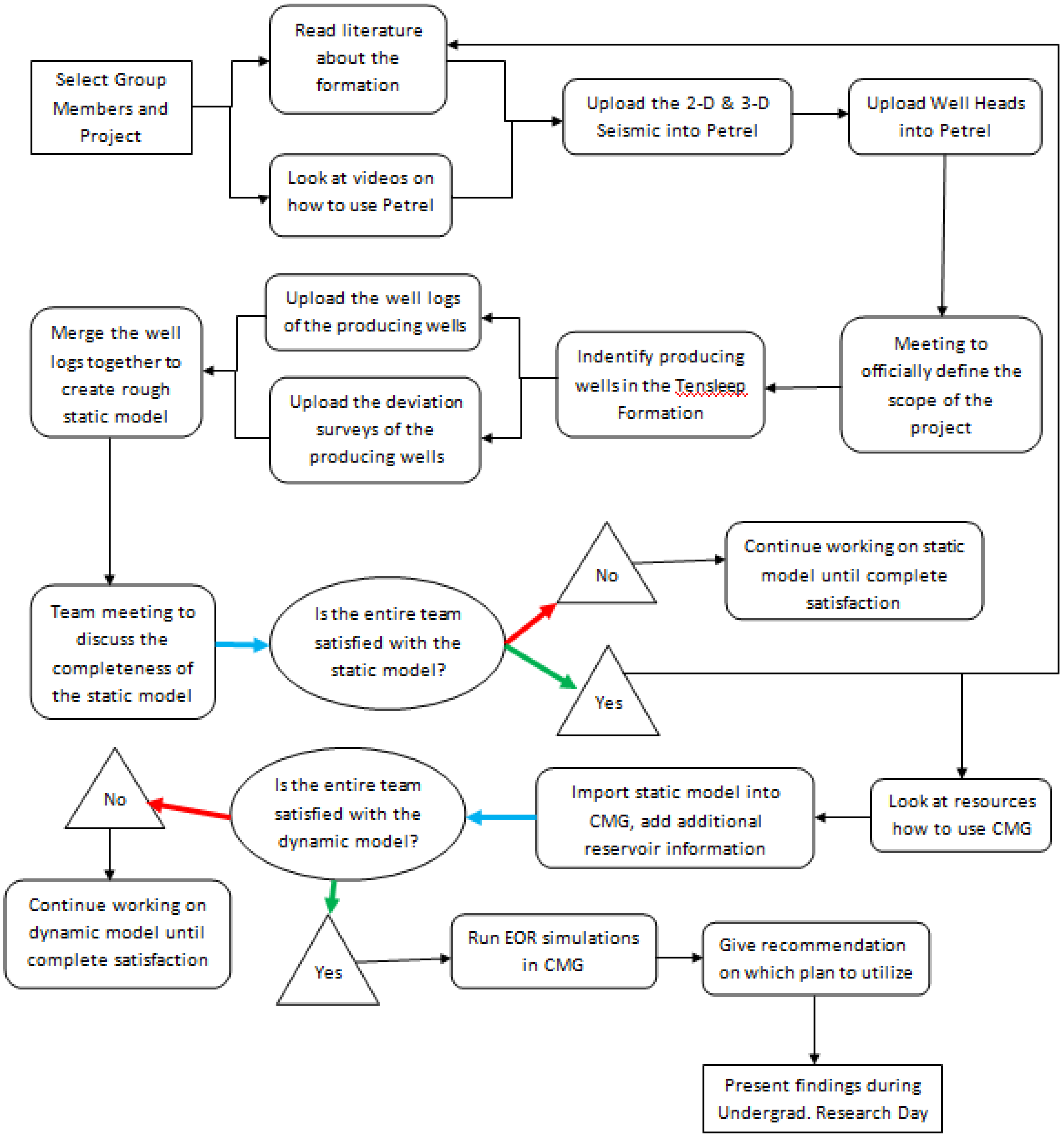


Figure 7 – Work flow chart of the project.

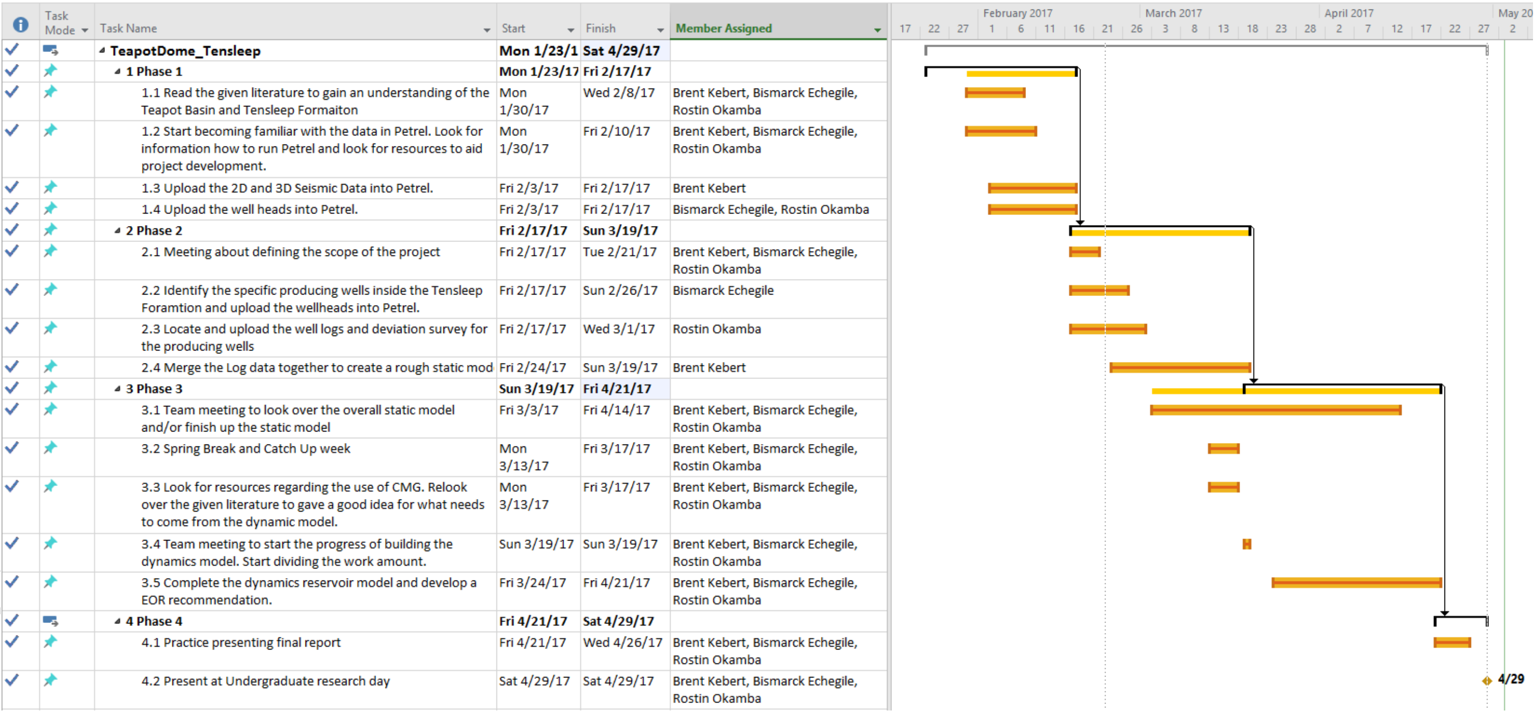
The project workflow can be seen in figure 7. The actual work of the project began by creating a static model of the reservoir. The group was given the raw reservoir data; priority number one was to convert the raw data into Petrel. After the static model is created in the Petrel software, we focused on the dynamic model. Before the dynamic model was built, the team revisited the literature found and replicate the process of assigning work based off interest. The dynamic model was created in the CMG program.

Once the dynamic model started to develop, as a team we started discussing the possible CO_2 injection systems to utilize. We again reviewed the literature to get an idea and came together as a team to run simulations to determine the best possible avenue. After the simulations had been complete, the team came together to discuss the best possible CO_2 injection plan to recommend.

Once a CO_2 EOR injection plan was decided on, the team will gather and put together a presentation to recommend the injection plan. The presentation was compiled of all the information gathered as well as the data obtained.

Project Schedule

Below is the Gantt chart for the project



ⓘ	Task Mode	Task Name	Start	Finish	Member Assigned
✓		**TeapotDome_Tensleep**	**Mon 1/23/1**	**Sat 4/29/17**	
✓		**1 Phase 1**	**Mon 1/23/17**	**Fri 2/17/17**	
✓		1.1 Read the given literature to gain an understanding of the Teapot Basin and Tensleep Formaiton	Mon 1/30/17	Wed 2/8/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		1.2 Start becoming familiar with the data in Petrel. Look for information how to run Petrel and look for resources to aid project development.	Mon 1/30/17	Fri 2/10/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		1.3 Upload the 2D and 3D Seismic Data into Petrel.	Fri 2/3/17	Fri 2/17/17	Brent Kebert
✓		1.4 Upload the well heads into Petrel.	Fri 2/3/17	Fri 2/17/17	Bismarck Echegile, Rostin Okamba
✓		**2 Phase 2**	**Fri 2/17/17**	**Sun 3/19/17**	
✓		2.1 Meeting about defining the scope of the project	Fri 2/17/17	Tue 2/21/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		2.2 Identify the specific producing wells inside the Tensleep Foramtion and upload the wellheads into Petrel.	Fri 2/17/17	Sun 2/26/17	Bismarck Echegile
✓		2.3 Locate and upload the well logs and deviation survey for the producing wells	Fri 2/17/17	Wed 3/1/17	Rostin Okamba
✓		2.4 Merge the Log data together to create a rough static mod	Fri 2/24/17	Sun 3/19/17	Brent Kebert
✓		**3 Phase 3**	**Sun 3/19/17**	**Fri 4/21/17**	
✓		3.1 Team meeting to look over the overall static model and/or finish up the static model	Fri 3/3/17	Fri 4/14/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		3.2 Spring Break and Catch Up week	Mon 3/13/17	Fri 3/17/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		3.3 Look for resources regarding the use of CMG. Relook over the given literature to gave a good idea for what needs to come from the dynamic model.	Mon 3/13/17	Fri 3/17/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		3.4 Team meeting to start the progress of building the dynamics model. Start dividing the work amount.	Sun 3/19/17	Sun 3/19/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		3.5 Complete the dynamics reservoir model and develop a EOR recommendation.	Fri 3/24/17	Fri 4/21/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		**4 Phase 4**	**Fri 4/21/17**	**Sat 4/29/17**	
✓		4.1 Practice presenting final report	Fri 4/21/17	Wed 4/26/17	Brent Kebert, Bismarck Echegile, Rostin Okamba
✓		4.2 Present at Undergraduate research day	Sat 4/29/17	Sat 4/29/17	Brent Kebert, Bismarck Echegile, Rostin Okamba

Figure 8 – Gantt chart of the project.

Below is the schedule for the project.

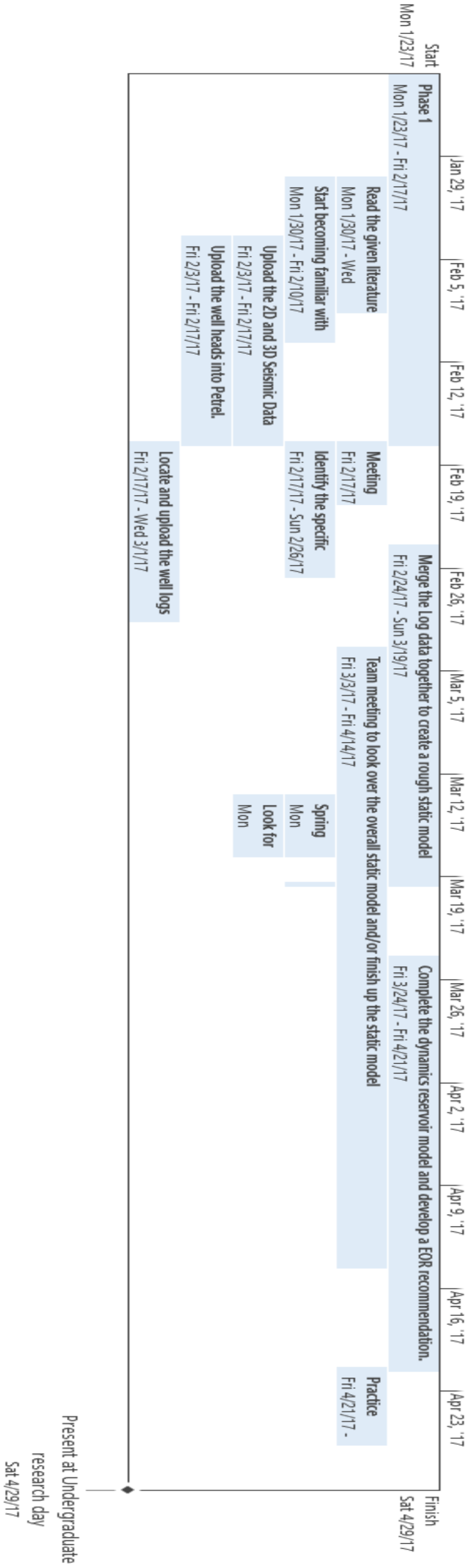


Figure 9 – Schedule of the project.

The project schedule and duties can be seen in the Gantt chart in figure eight as well as a broad over view of the schedule in figure nine. The project is followed the estimated pace. There was enough additional time built in to make up for the lagging time frame during the development of the static model and adjusted the schedule so it was possible to complete the project in the same amount of time as originally estimated.

Data Review

The data acquired was the raw data from the well logs mainly. There was literature available discussing the reservoir type and properties; although, our team was primarily interested in building the static and dynamic reservoir with the raw logging data. With the static and dynamic models, seismic data was used to develop the reservoir and create uniformity in the properties. Unfortunately the seismic data was unable to be tied into the reservoirs for the z-direction which did not make it possible to check our logging data with the seismic data.

The team suffered time and man power constraints so it was necessary to assume and neglect certain information. The primary assumption used was homogeneity throughout the formation. As seen earlier in figure five about the lithology on the formation, there are significant inconsistencies. Along with assuming homogeneity, factors like fracture systems and faults were completely ignored in order to complete the project within the necessary period of time.

Below is an example of why the assumptions where taken throughout the formation due to inconsistencies of properties. The graph shows how inconsistent the permeability and porosity are even within different locations of the formation.

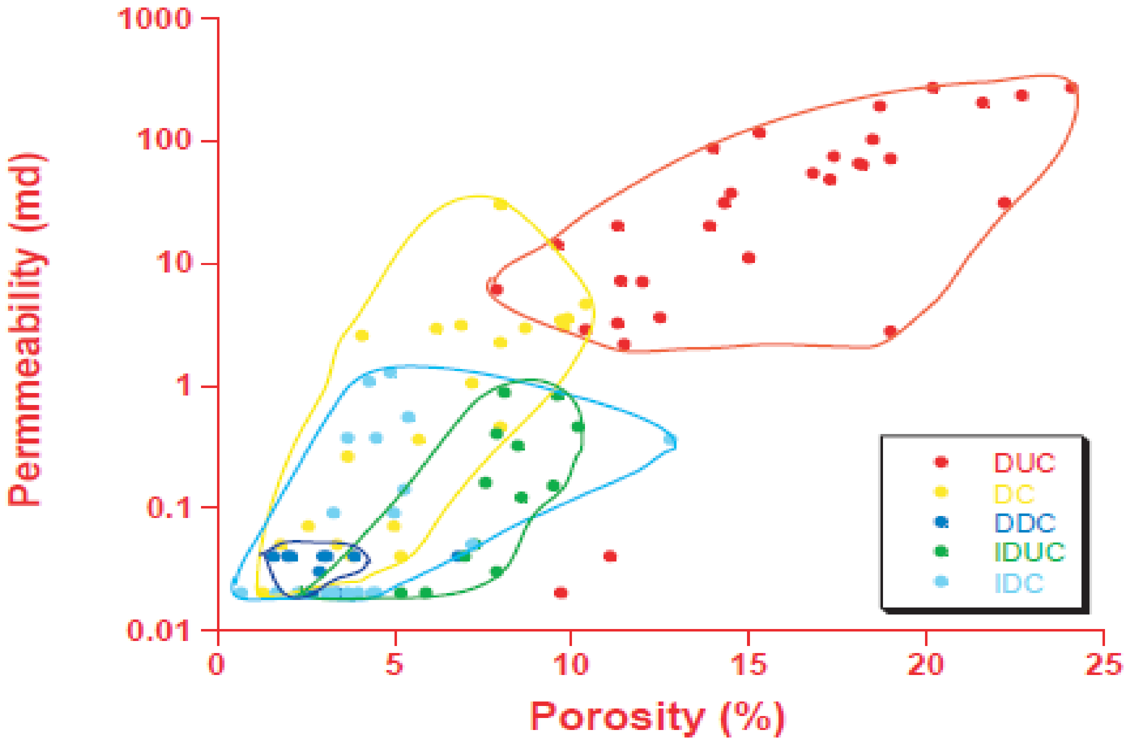


Figure 10 – Display of the permeability and porosity of different cores taken from the Tensleep formation.

Financial/Environmental Consideration

Considerations we used throughout our projects are financial constraints, safety of any individuals potentially involved, and environmental regulations. As well as doing literature research, we also looked into all aspects of our project to ensure it was done correctly and optimizes potential production. We also conducted risk analysis on major decisions throughout the project. We wanted to be able to give a report that minimizes any potential risks and possible disasters in our designs and recommendations. With the Tensleep formation being in the State of Wyoming, the team reviewed and followed all laws and regulations put in place by the State of Wyoming and Natrona County.

The Wyoming Oil and Gas Conservation Commission (WOGCC) issues state-wide rules and regulations to govern the development of oil and gas in Wyoming. Oil and gas development in Wyoming is governed primarily by statutory provisions in Title 30, Chapter 5 Oil and Gas of the Wyoming Code (Wyo. Stat. Ann. § 30-5-100, et seq.) and rules promulgated by the Wyoming Oil and Gas Conservation Commission (WOGCC). The WOGCC also handles the drilling permit process and ensures industry compliance with statewide oil and gas laws and regulations. Air quality and water quality provisions of Wyoming’s Environmental Quality Act (§ 35-11-100, et seq.) play important roles in regulating the environmental impacts of oil and gas development throughout the state as well. Additionally, the WOGCC and other state agencies, like the Wyoming Air Quality Division, issue various guidelines and policy statements to guide the future of oil and gas development in Wyoming and to assist regulated industries understand and comply with Wyoming’s statutes and regulations.

Engineering Ethics:

Throughout the designing and implementation of this project all team members were expected to maintain high ethical standards. We reviewed every major decision on the project and made sure, those decisions were up to high ethical standards. The entire team held and maintained the same ethical practices as outlined by the Society of Petroleum Engineers.

Static Reservoir Model

The first thing the team did was create the static reservoir model. The static reservoir model was built in two separate parts. First the correct wells were selected and then uploaded into Petrel along with their log information and deviation surveys.

Below is a figure of the uploaded wells, well logs, and deviations.

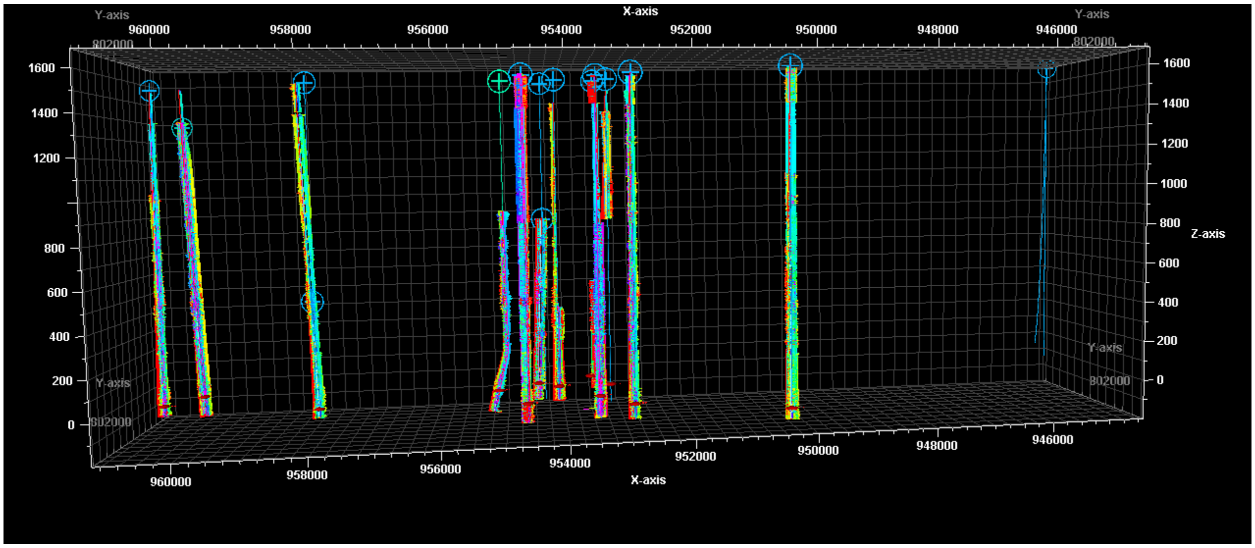


Figure 11 – Wells, well logs, and deviation surveys of the wells used in the static model.

After the wells were uploaded, the 2-D and 3-D seismic were then added to the model. There were difficulties in aligning the seismic data in the z-direction. The team felt that it was not completely necessary to completely align the seismic data so the team then moved on due to time constraints.

Below is a figure of just the seismic data for the Teapot Dome basin.

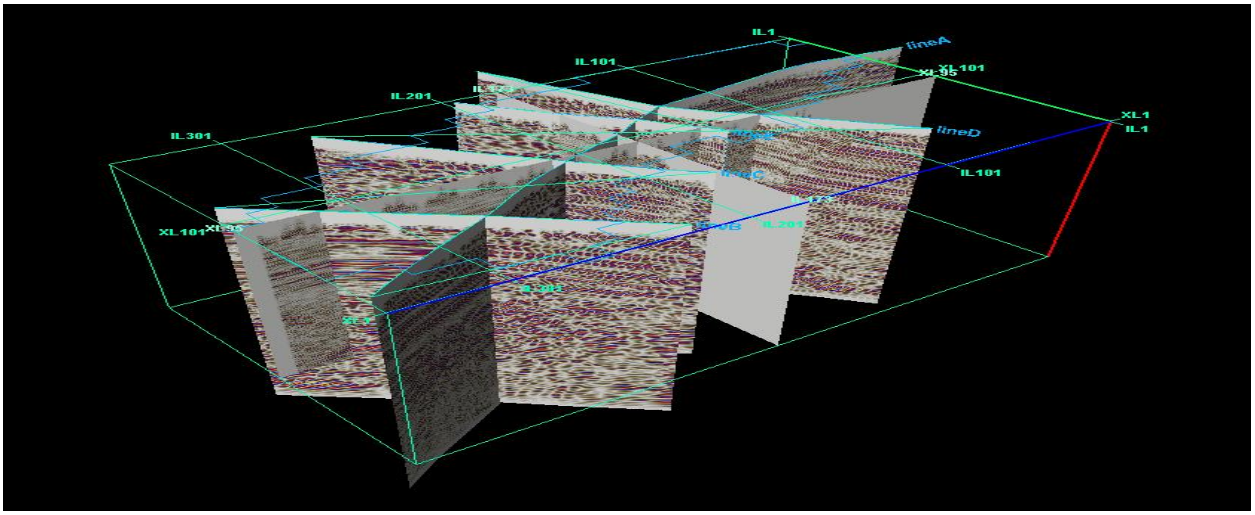


Figure 12 – The seismic data of the seismic model.

Below are two images of the well data and seismic data merged together.

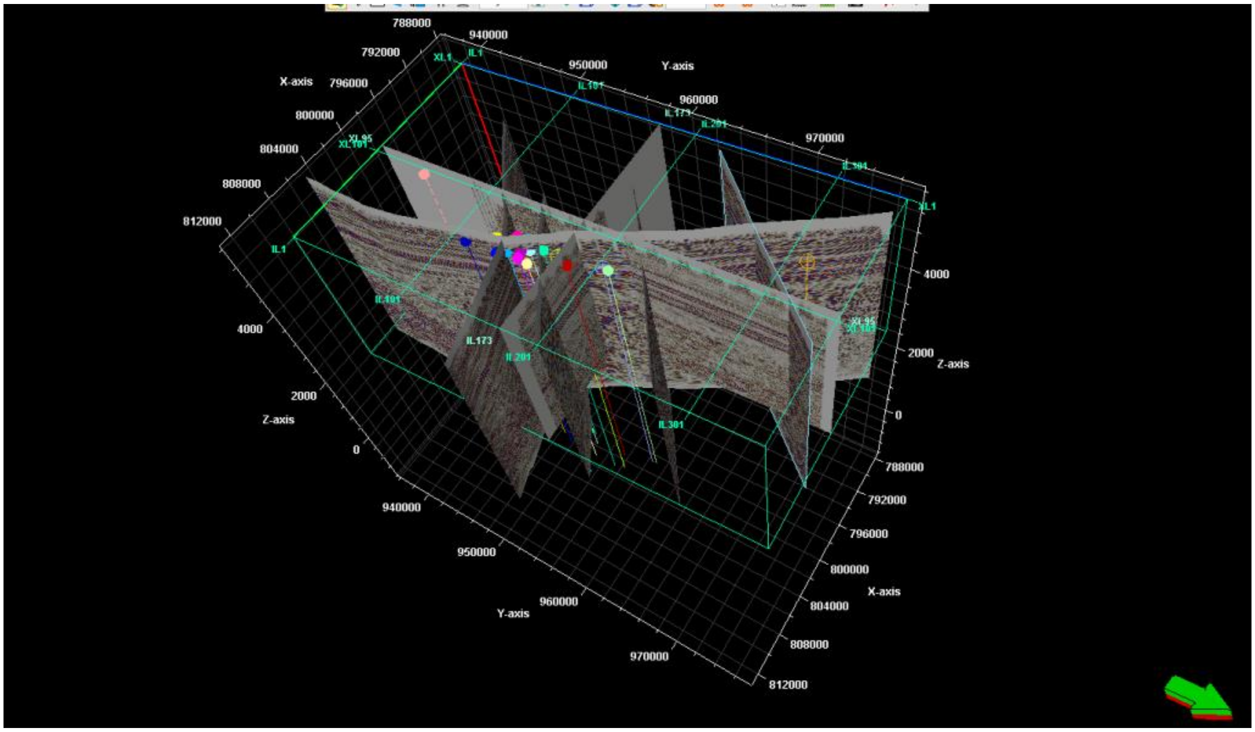


Figure 13 – The static model after the wells and seismic data are merged.

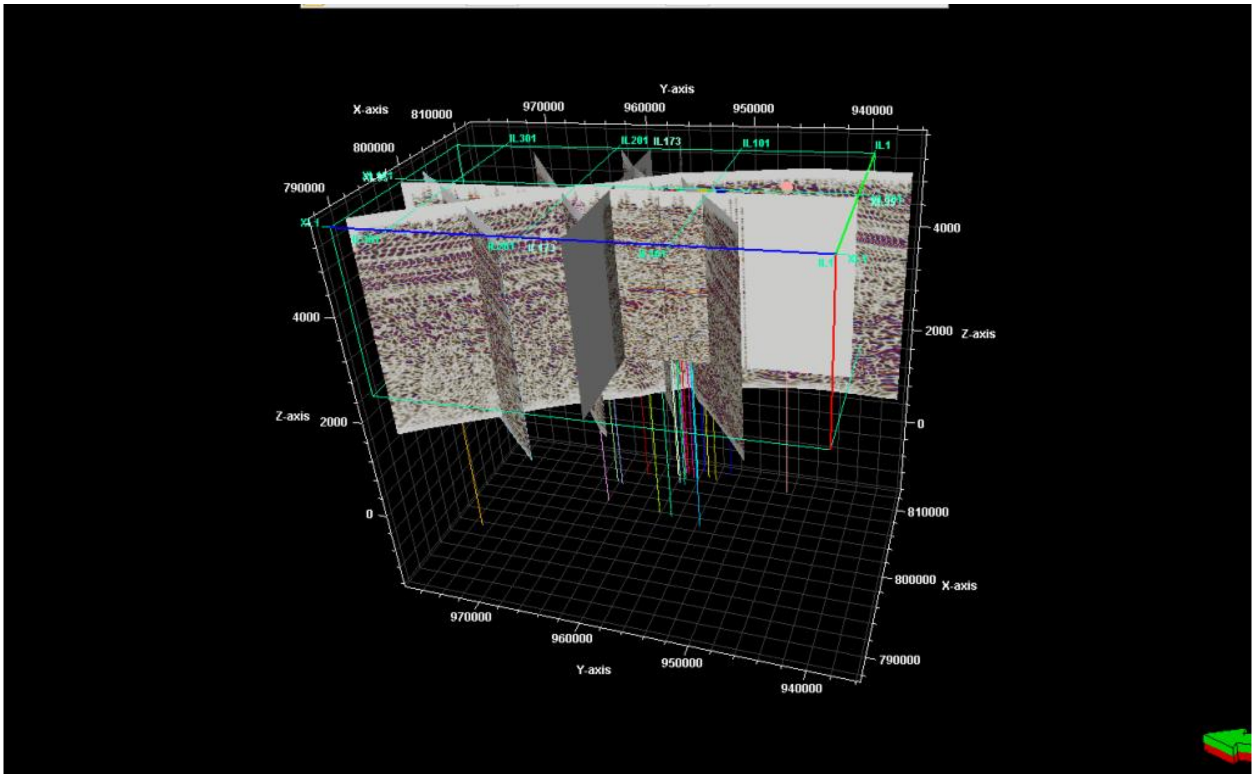


Figure 14 – The static model after the wells and seismic data are merged.

The logging data was also used to merge the entire formations properties to give the team a rough idea of what the formation properties would look like. Below is the merged Gamma Ray Log of the Tensleep formation.

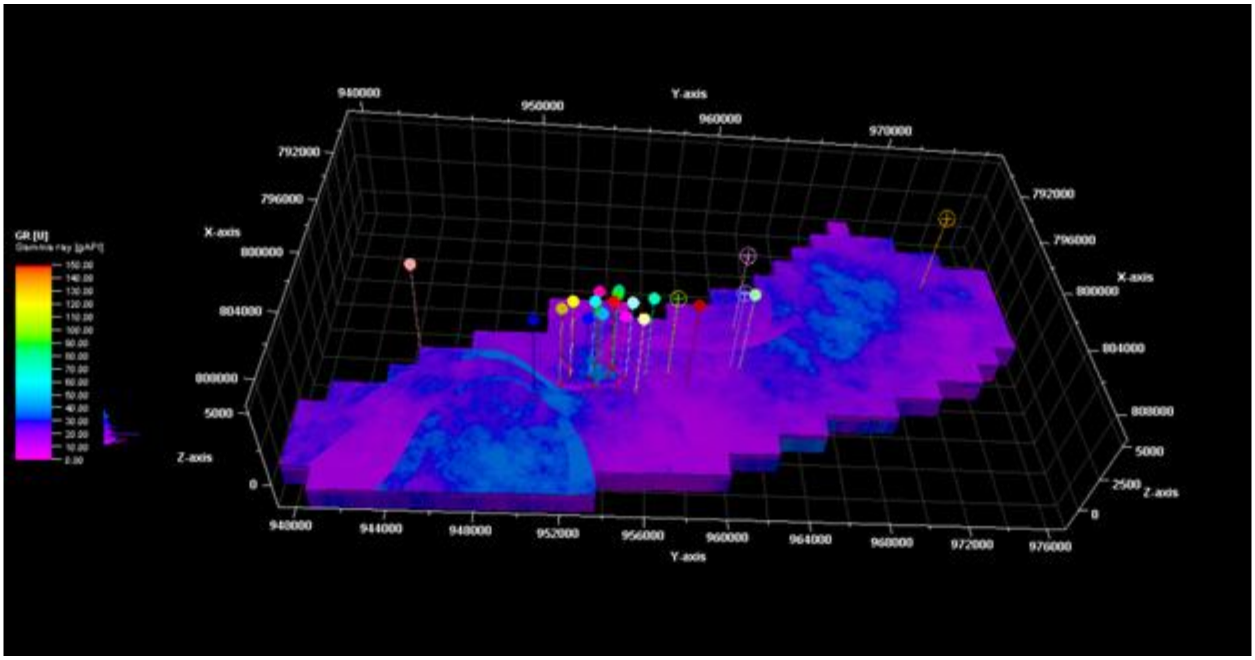


Figure 15 – Gamma Ray Log of the Tensleep formation.

The static reservoir was an important aspect of the project to build because it was used as the basis for the dynamic reservoir model built. The construction of the static reservoir is definitely where the reservoir property neglecting took the most noticeable effect. The major properties not added to the static reservoir model were the faults and fracture systems. Again the reason for not adding the faults and fracture systems where due to man power and time constraints. The team decided that these properties were the right properties to overlook because of the overall scope of the project. The project being designed to determine the best possible CO_2 injection EOR plan, the faults and fracture systems have the potential to greatly increase the production due to an increase of system permeability. Neglecting the faults and fracture systems would lower the production associated with each future simulation which would cause a result of a pessimistic profit margin in the recommendation.

Dynamic Reservoir Model

The dynamic model was started by using the static model developed in Petrel to create the surface of the dynamic model. Below is a figure displaying the initial surface in CMG of the dynamic reservoir.

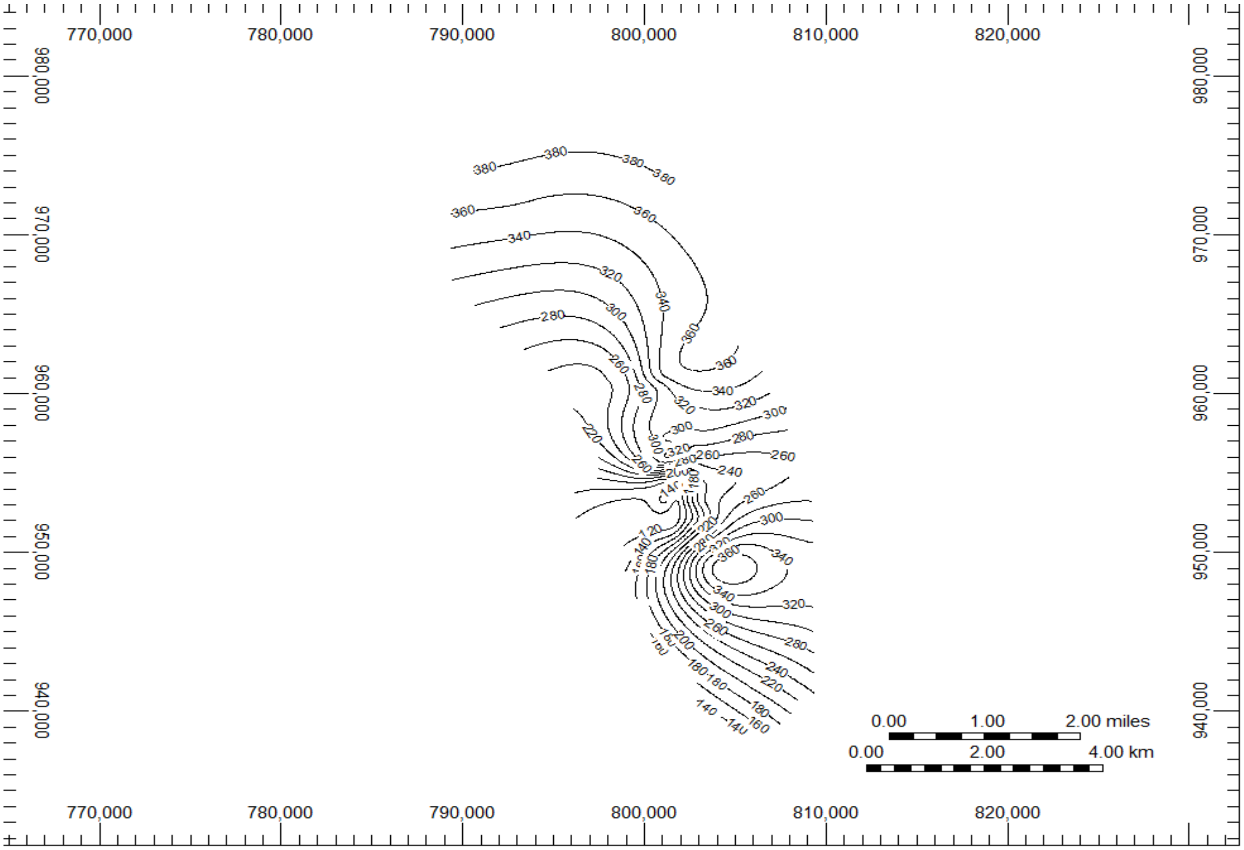


Figure 16 – Surface developed in CMG from the static model made in Petrel.

Next, the entire Tensleep formation was created in CMG with the help of the well data from Petrel. Below is a figure of the entire Tensleep formation in CMG where the color scheme is only related to depth.

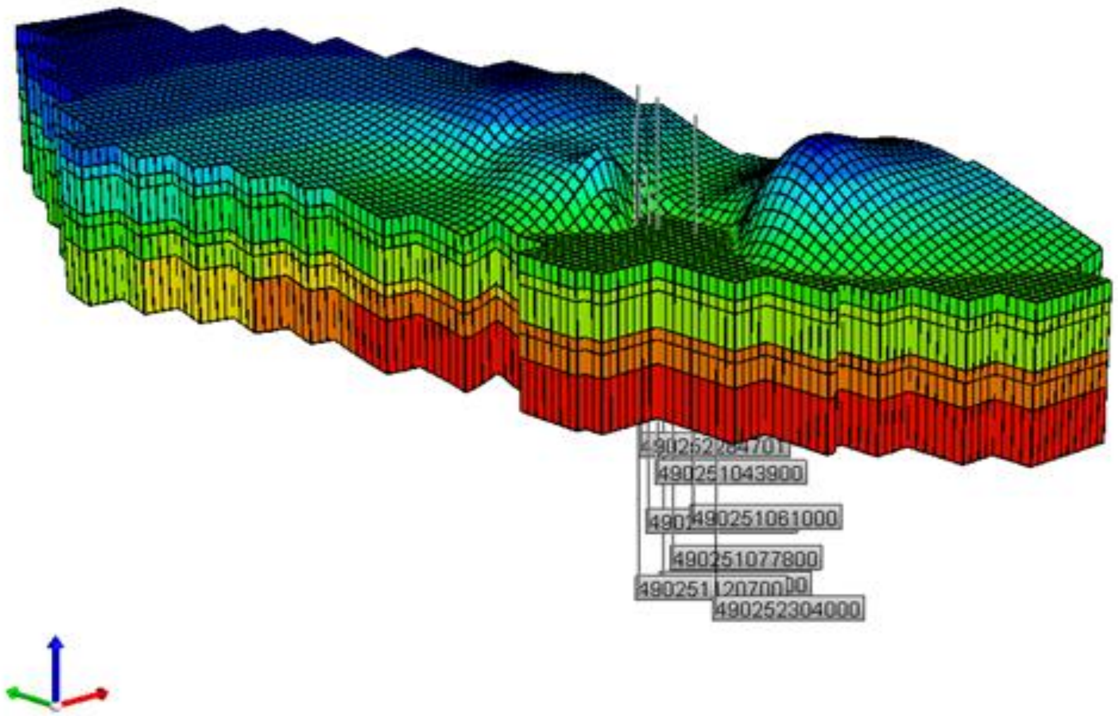


Figure 17 – Tensleep formation developed in CMG from the static model made in Petrel.

The biggest issue with dealing with CMG was cutting down the scope of the entire formation into just the area of interest being the producing zone. As you can see in figure 17, there are a lot of wells that are not very well spaced out. The scope needed to be cut back to allow a smaller area of interest as well as a small amount of wells to work with in the production zone.

Below is a figure that trims the scope of the project.

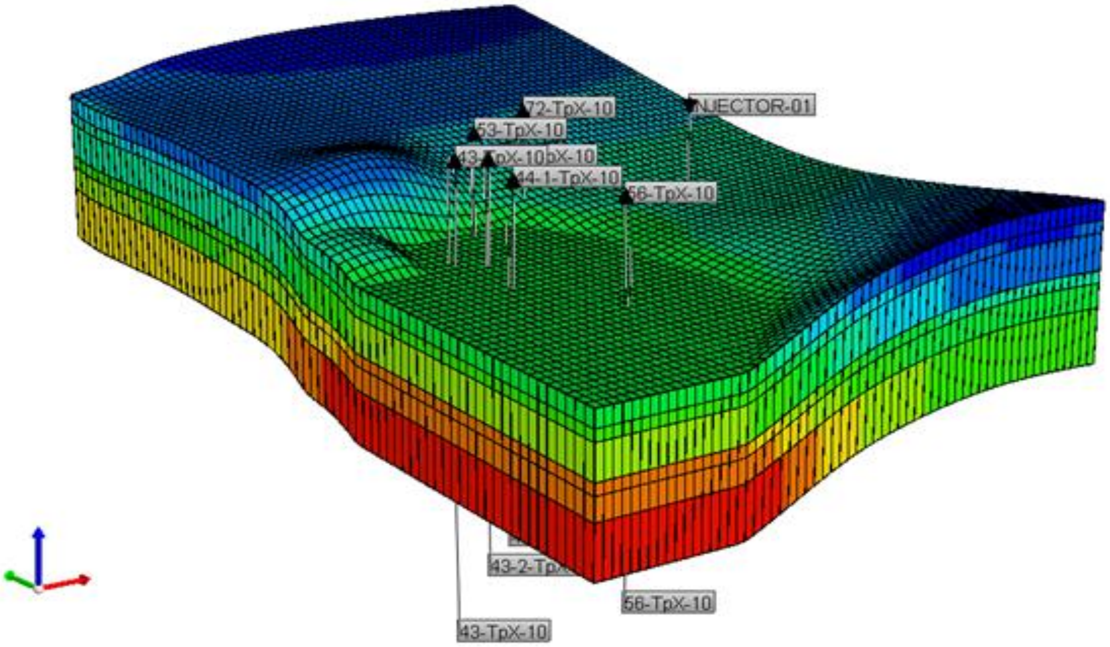


Figure 18 –Trimming the scope geologically of the Tensleep formation developed in CMG from the static model made in Petrel.

The scope of the dynamic model had to be cut down because of the specific license used from CMG. The team only had access to a license that allowed only 10,000 grid blocks for simulations. As well as building the static model in Petrel, with the dynamic model in CMG assumptions needed to be made.

Below is a figure that clearly shows how the assumptions of the properties do not completely match what would be true in the field. The color scheme in the image is a gradient of porosity.

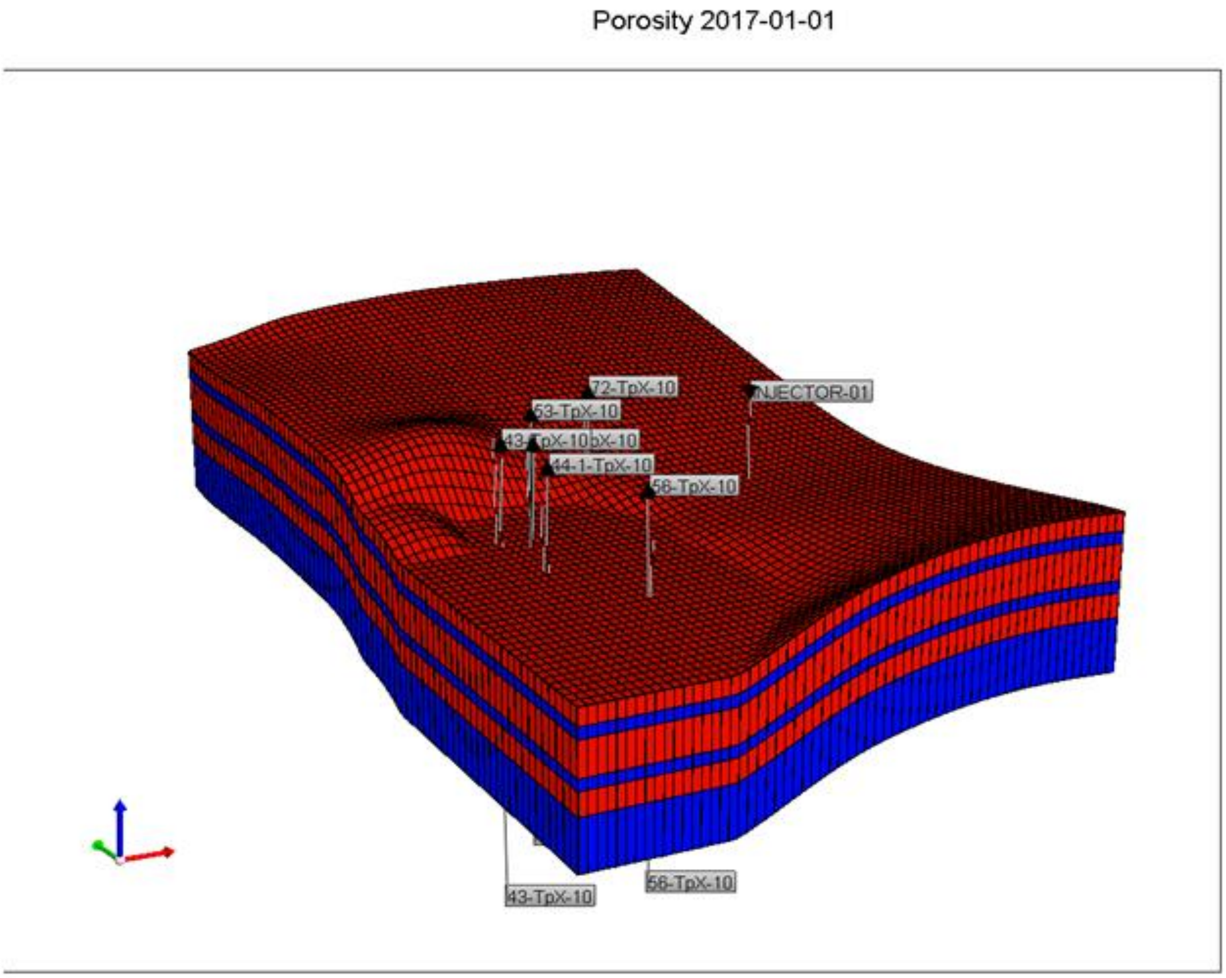


Figure 19 –The porosity of the Tensleep formation developed in CMG from the static model made in Petrel. Displaying how assumptions do not act the way properties do in the field.

Similar to the static reservoir model, the assumptions made on the properties were apparent. The formation has several geologic layers that all are vastly inconsistent with their properties. With the homogenous assumptions made it made it very difficult to have a true representation of the properties throughout the formation. The permeability representation is similar to the porosity field which is not the true representation of the formation.

Simulations

After completion of the dynamic model in CMG, the CO_2 injection simulations were ran. Each injection plan only varied in the amount of CO_2 injected. Each plan used two injection wells and five producing wells. The different injection simulations done were injecting 100, 200, and 300 MCF/D in each of the injection wells for three different simulation plans.

Below is an image of the dynamic model after the 300 mcf/d simulation was done. The color scheme is related to the oil saturation of the area of interest in the formation.

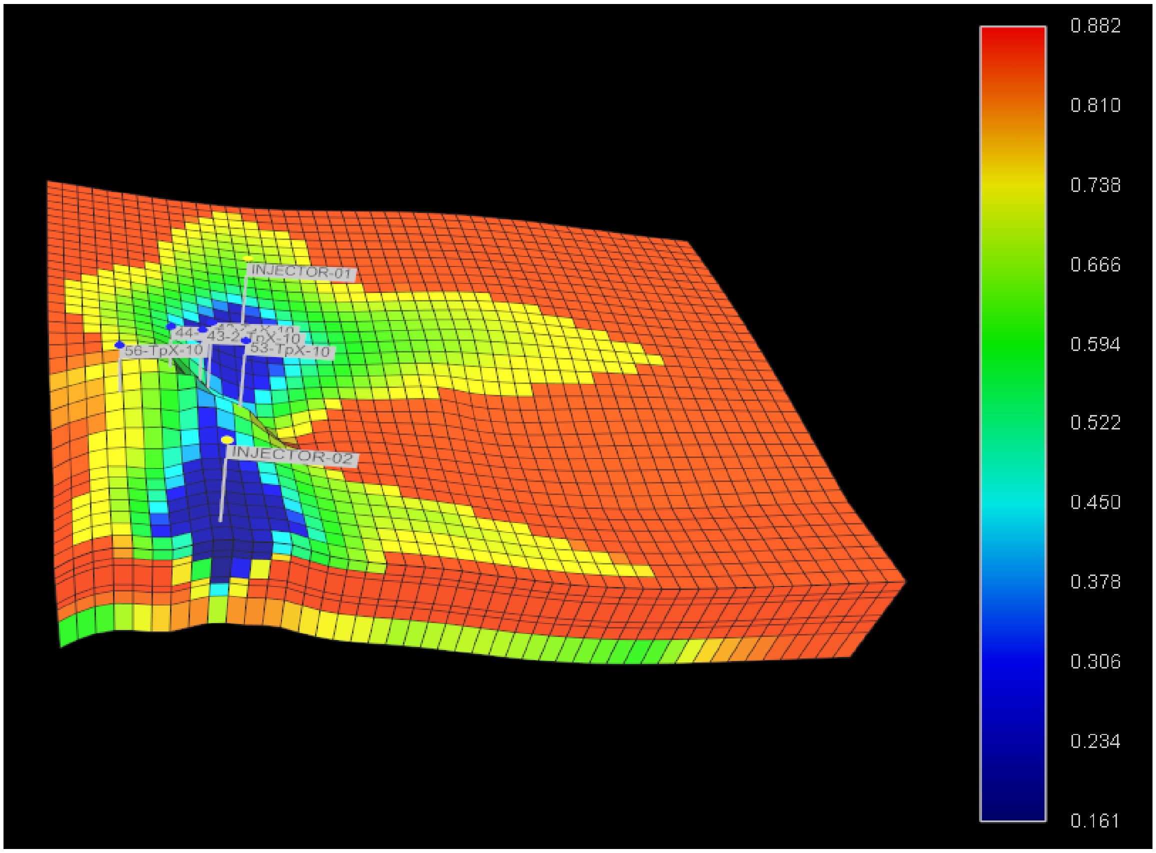


Figure 20 –The dynamic reservoir after three years of injecting 300 mcf of CO_2 per injection well per day into the formation related to the oil saturation.

There was a total of four simulations ran. One was done not using any type of EOR plan and the three others were done in the way described above. The reason for the first simulation not using any type of EOR plan was to determine if the other injection plans were more economic than just allowing the well to flow naturally. Each simulation was done for three years after the injections started.

Below are four graphs of the flow rates of the different simulations done on the formation. Note that the flow rates are the daily flow rates for each date throughout the three-year period.

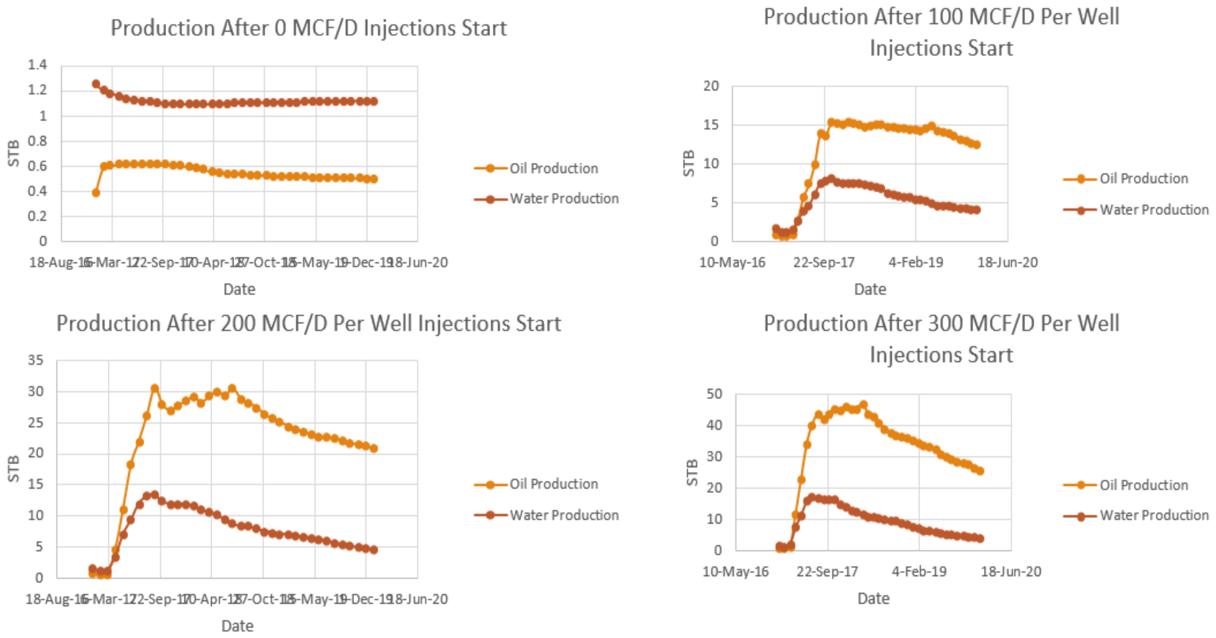


Figure 21 –The daily production graph of each of the simulations done.

An interesting trend that was noticed is that only for the simulation ran without the CO_2 injection was the water production rate consistently higher than oil production rate. For the other three simulations the oil production quickly surpassed the water production rate within the first few months.

Below are charts that correspond to the production numbers of the formation from 1956 to 2017 then each of the four simulations ran with 0, 100, 200, and 300 mcf/d in each well, respectively.

Production Totals (1956-2017)		
Oil (MSTB)	Gas (MMSCF)	Water (MSTB)
27.573	2.5774	27.824

Table 2 – Production data before any EOR plan simulations have taken place.

Production Totals (1956-2020)		
Oil (MSTB)	Gas (MMSCF)	Water (MSTB)
28.182	2.6281	29.047

Table 3 – Total production data without any EOR plan used.

100 MCF Production Totals (1956-2020)		
Oil (MSTB)	Gas (MMSCF)	Water (MSTB)
40.93	125.25	33.724

Table 4 – Total production data with 100 MCF/D of CO_2 *injected into both injection wells.*

200 MCF Production Totals (1956-2020)		
Oil (MSTB)	Gas (MMSCF)	Water (MSTB)
52.81	289.26	36.57

Table 5 – Total production data with 200 MCF/D of CO_2 *injected into both injection wells.*

300 MCF Production Totals (1956-2020)		
Oil (MSTB)	Gas (MMSCF)	Water (MSTB)
64.458	469.53	38.151

Table 6 – Total production data with 300 MCF/D of CO_2 injected into both injection wells.

The results of the simulation showed that the higher the injection rate the higher the production of oil, gas, and water. An important parameter to take into consideration is that through the CMG simulation system, it does not take into account what type of gas is being produced. The programs simulation cannot determine the difference between a hydrocarbon gas and the CO_2 that was initially injected.

Recommendation of EOR Plan

After the simulations are ran in CMG, a recommendation of an EOR plan was determined. The results of the simulations and the pricing model set are what the recommendation was based on. The price for the outcomes of the simulations were set at \$50/STB of oil, \$4.50/MCF of natural gas, \$1.50/STB of production water, and \$20/ton of CO_2 gas. The oil and the gas are products that can be sold and that are what the revenue will be based off of. The production water needs to be disposed of in disposal wells which will cost money as well as purchasing the CO_2 to inject into the wells. With the CO_2 being the estimated largest cost to the project, below is a table displaying the prices of each EOR injection plan.

CO2 Costs	100 MCF/D	200 MCF/D	300 MCF/D
Per Day	\$ 228.76	\$ 457.53	\$ 686.29
Per Month	\$ 6,862.92	\$ 13,725.84	\$ 20,588.76
Per Year	\$ 83,498.86	\$ 166,997.72	\$ 250,496.58

Table 7 – Pricing of the CO_2 for each of the EOR Injection plans.

Additionally, the results of the simulations can be found below in a table stating the differences and price ranges between the production from 1956 to 2017 and from 2017 to 2020 for each of the simulations.

Production Differences	Oil Production (STB)	Water Production(STB)	Gas Production (MSCF)	Oil Production Revenue (USD)	Water Production Cost (USD)
0 MCF/D	609	1223	50.7	$ 30,450.00	$ 1,834.50
100 MCF/D	13357	5900	122672.6	$ 667,850.00	$ 8,850.00
200 MCF/D	25237	8746	286682.6	$ 1,261,850.00	$ 13,119.00
300 MCF/D	36885	10327	466952.6	$ 1,844,250.00	$ 15,490.50

Table 8 – Breakdown of the differences of each other EOR plans once the plans would start in 2017 until 2020.

From tables seven and eight, it can be seen that the CO_2 is by far the greatest cost to the project. Table seven only shows the cost of the CO_2 up to a year which is only a third of the overall cost of the project because the simulations lasted three years. Below are the profits from the different EOR plans.

Profit After 3 Years	
0 MCF Plan	$ 28,615.50
100 MCF Plan	$ 408,503.42
200 MCF Plan	$ 747,737.84
300 MCF Plan	**$ 1,077,269.76**

Table 9 – Profit from each EOR plan after the simulated three years.

From the results of the profit analysis the 300 MCF/D per injection well, 600 MCF/D total injected, was selected as the recommended EOR CO_2 injection plan. The profit figures were determined but taking the total revenue from the oil production and deducting the cost of the water production as well as the price for the total amount of CO_2 needed for the duration of the three years of the simulation. The gas produced was actually not taken into account for the revenue of the simulations because of the lack of knowledge of what gas exactly is being produced. The formation in general does not produce a large amount of hydrocarbon gas so the extremely high gas production numbers from the injection plan simulations were assumed to be predominately CO_2. Additionally, the profit numbers are even more pessimistic because they do not take into account that the CO_2 that is thought to be produced throughout the production life of the simulations can be reused. With the CO_2 being reinjected into the well it will help in cutting down the greatest cost of the projects which is the CO_2 itself. It was found that the higher the injection rate, the higher the percentage of return of the CO_2 injected. So, theoretically, the recommended 300 MCF/D injection rate is the most pessimistic profit figure. The recommendation of the 300 MCF/D of CO_2 injected per well was decided by three major factors: initial profitability, legality, and future profits. Table 9 shows the initial estimated profit margins where the 300 MCF/D was the most profitable. All of the simulations were within the legal amount to inject in the State of Wyoming and Natrona County. Finally, with the highest percentage of CO_2 returning being from the 300 MCF/D injection plan it suggests that the plan will also be able to save the highest percentage of money going forward because it will not have to buy as much additional CO_2. With the ability to save on buying the CO_2 the 300 MCF/D injection plan is also thought to be bringing the highest amount of profit into the future as well.

Ideal Considerations

The project unfortunately suffered from time and manpower constraints. There were several considerations that were completely assumed or overlooked. If there was an unlimited amount of time for the project, several steps could have been implemented. Faults and fracture systems could have been implemented to both the static and dynamic reservoir model to get a more accurate representation of the formation. More time would have allowed for the heterogeneity of the lithology of the formation to be properly implemented so an average of the property did not need to be used for the entire layer in the formation. Additionally, the quality of the static reservoir would have dramatically increased if the seismic data could have been tied into the well data completely. There was an issue incorporating the z-direction of the seismic data to the wells, which left more uncertainty regarding the lithology of the formation. Finally, if all of the wells from every producing layer in the Teapot Dome Basin could have been uploaded and used, it would have given a better understanding of the geometric dimensions of the Tensleep formation.

Similarly, there are things that could be done in the future to help with the accuracy and success of the project. Looking throughout the formation instead of just the area of interest within the smaller scope for production “sweet spots” to isolate the best location to start production. Along with determining the ideal locations for production, looking into different locations to drill could improve productivity of the entire field. Additional or re-stimulating the production zone could also have a positive effect of the production throughout the life of the producing wells. Lastly, the group did not have time to look into the possible corrosive effect that CO_2 could have on the injection wells and the production equipment. The injection plan recommendation involves the most CO_2 which could have an extremely destructive effect on the equipment leading the frequently replacing the equipment which could affect the profitability of each proposed injection plan.

Summary

The project was planned to take just under 80 days and was completed within the estimated period. The project will cost EKO Oil Company no money to achieve the objective, just time and man power. The scope of the project involved no collateral needed to start the project so those considerations where not taken into account. With the use of Petrel and CMG, a static and dynamic model of the Tensleep formation was built. After the models were constructed, EOR simulations were done to determine the best CO_2 injection plan within the CMG program. The most profitable plan for the Tensleep formation is injecting 300 MCF/D into each injection well for a total of 600 MCF of CO_2 injected daily.

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ABET-Required Learning Outcomes

Outcomes:

(**c**) an ability to design a system, component, or process to meet desired needs

Location: Page 18	Section: Project Workflow
Location: Page 16	Section: Project Work Breakdown Structure
Location: Page 20	Section: Project Gantt Chart

These examples show that the team has the ability to identify a problem, or desired outcome, create a plan, and then follow that plan to completion in order to succeed at the initial goal.

(**d**) an ability to function on multi-disciplinary teams

Location: Page 14	Section: Team Dynamics
Location: Page 8	Section: Acknowledgments

While the team is compiled of only Petroleum Engineering students, each member "specialized" in a certain discipline in order to move through the project quickly and productively. All the members on the team are also interested in pursuing different fields within Petroleum Engineering which brings forward different initial views and considerations.

(**f**) an understanding of professional and ethical responsibility

Location: Page 24	Section: Engineering Ethics
Location: Page 36	Section: Recommendation of EOR Plan

Throughout the project the entire team kept ethic in mind when coming up and executing plans. The code of ethics of the Society of Petroleum Engineers was used throughout the project as well as a firm understanding and compliance with the laws and regulations of the State of Wyoming.

(**g**) an ability to communicate effectively

Location: Pages-All	Section: Entire Report

The entire report is an example of how the group can efficiently communicate a goal, steps to achieving the goal, and the end result of the goal. The report was written for an audience with a similar education background as the group and that is illustrated throughout the report.

(**h**) broad education necessary to understand the impact of engineering solutions in a global and societal context

Location: Page 22 Section: Data Review

The explanation of using assumptions was described and how that can hurt the accuracy of a project. Just because a project yields an answer does not mean that answer is truly viable if corners were cut in order to quickly produce results.

(**i**) a recognition of the need for, and an ability to engage in life-long learning

Location: Page 9 Section: Literature Search and Review

Before the project was even underway the group knew it was necessary to do a literature search to fully understand the formation. In the middle of the project, after the static reservoir model was built, an additional literature search was done. This is a practice that proved extremely beneficial and something every team member will continue to do throughout their professional careers.

(**j**) a knowledge of contemporary issues

Location: Page 36 Section: Recommendation for EOR Plan

Environmental issues are becoming a more and more pressing issue in the media surrounding the oil field. The group was very concerned about limiting our environmental impact and took measures to do so.