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Open File Report 1-2023
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Preface

Oklahoma Geological Survey (OGS) open-file reports (OFRs) are data and/or informational reports to provide freely available, discoverable, and timely updates to the public on activities within the OGS. Starting in 2023, OFRs will have assigned Digital Object Identifiers (DOIs) to enhance discoverability and align OFRs with data-publication policies of scientific societies and libraries. OFRs are internally reviewed and approved by the OGS Director. Additionally, OFRs will be posted to the OGS publication website (currently: https://www.ou.edu/ogs/publications/openfilereports) prior to DOI assignments during which time they may be updated. Should subsequent revisions be made, the DOI will be updated.
Following the uptick in earthquake activity, the OGS was requested by the Oklahoma Corporation Commission, the Petroleum Alliance, and other groups in the Oklahoma energy sector, to study the subsurface pressures in the Arbuckle Group, the target for salt-water disposal that was correlated with the seismicity. The following OFR is a stand-alone document to report on that effort in a simple, freely available manner. The effort was spearheaded by then-OGS staff hydrogeologist Dr. Kyle Murray (now at Murray GeoConsultanting, LLC).
The following report describes the 2017-2020 Oklahoma Geological Survey (OGS) well-pressure monitoring data. A full analysis of the data is presented in the manuscript "Pressure monitoring of disposal reservoirs in North-Central Oklahoma: implications for induced seismicity and storage" by Allen et al., submitted on July 31, 2023 to the Journal of Geophysical Research.
All data and instructions for data download and use accompanying this report can be found at https://www.ou.edu/ogs/data/well-pressure.

Introduction

During operations of extracting oil and gas, large quantities of water are used and recovered from underground, also called *produced water* (Scanlon 2017). Produced water often has trace minerals and elements, and unconventional oil and gas recovery will often use water floods with additives to enhance the lubricating effects (EPA 2020). Therefore, produced water should not be introduced to groundwater aquifers either accidentally or intentionally, due to radioactivity and toxicity. Yet, produced water is also costly to purify. Therefore, produced water is often disposed of deep in geological basins, well below the fresh-water aquifers and drinking water, referred to by the Environmental Protection Agency as *underground sources of drinking water (*USDWs). The practice of produced water injection is also referred to as *salt-water disposal* (SWD).
The deep geological layers, or stratigraphy, of Oklahoma, below the oil and gas producing reservoirs, are generally under-pressured for reasons that are not entirely understood (Al-Shaieb 1994). Rather than expel fluids, these geological units will pull fluids in. The Arbuckle Group carbonates of Oklahoma have long been targeted for SWD partly because of these sub-normal pressures (Puckette 1996, Lemons 2019). Injection of waste fluids started in the early 20th century. However, around 2010 SWD became correlated with an increase in earthquake activity, also known as *induced seismicity* (Keranan 2016, Rottman 2018, Anasari 2019). The following

report describes one of several activities conducted by the Oklahoma Geological Survey (OGS) in response to the uptick in induced seismicity.

Project Background

In order to explore solutions for induced-seismicity mitigation, the Oklahoma Independent Producers Association (OIPA) and Oklahoma Oil and Gas Association (OKOGA) — which are now merged as the Petroleum Alliance of Oklahoma — joined together with oil-field operators and the OGS to commission a study of the fluid pressure in the Arbuckle Group of Oklahoma. These groups provided the OGS with funding to deploy instrumentation and worked with operators to get access to inoperative wells completed into the Arbuckle. It is therefore important to note that many of the initial decisions regarding deployment of instruments, use of data loggers, recording rates, and other logistics were a byproduct of the history of the project. That is, funding levels, well access, and speed of deployment were a function of the urgency and limited available resources at the time of the project's inception. Moreover, the project's inception was tied to then Governor Fallon's Emergency Orders in response to the increased earthquake activity, leading to heightened regulatory actions from the Oklahoma Corporation Commission (OCC).

Instrument Deployment

During the month of August 2016 eight wells were instrumented for monitoring the well pressure, and seven more wells were added over the next year (Figure 1; Table 1). Solinst® Model 3001 LT Levelogger Edge M100:F300 pressure transducers were lowered by the direct read cable about 50-75 feet below the fluid surface, and the fluid height was found using the 8-10 fluid density column measurements performed by L.R. McBride, Inc. before instrumentation by a Calscan Badger+ gauge (Figure 2). The internal data loggers were set to record the pressure and temperature every 30 seconds and data was gathered monthly from the sites while checking for problems and resetting the memory in the data loggers. The data logging and retrieval was continued until early 2020, when monitoring became impractical because of travel restrictions during 2020, ownership changes of the monitoring wells, fluid level decreases, or instrument failure.

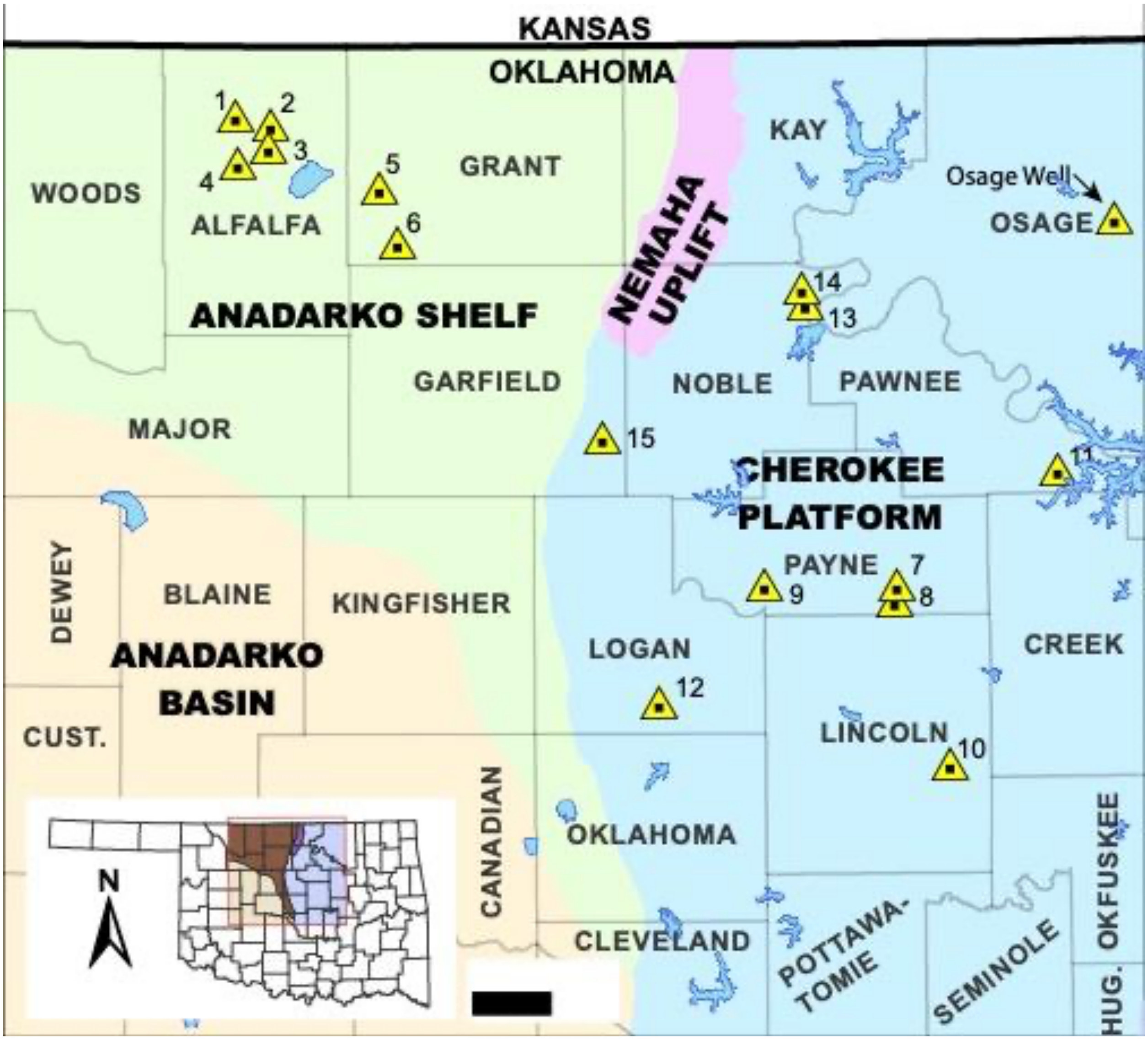

Figure 1. Map of instrumentation of all 15 wells, with the Osage DD1 Burbank well in North-Central Oklahoma as well as the main geological province.

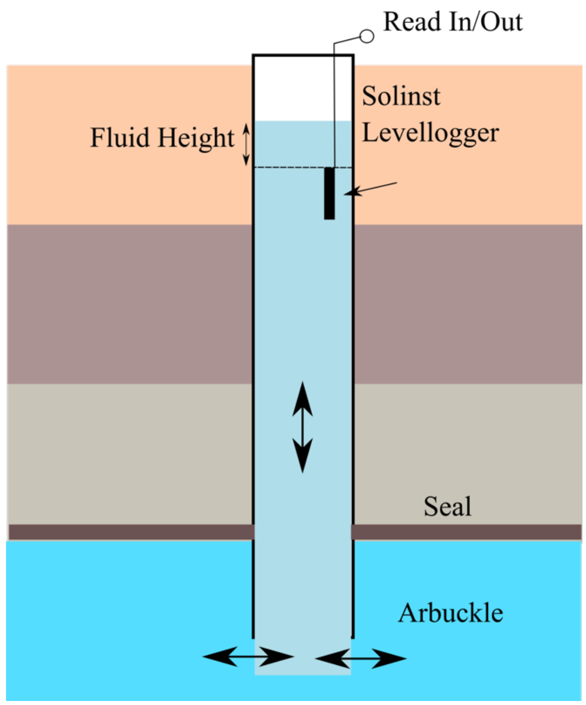

Figure 2. Schematic showing the monitoring set-up with the pressure monitor below the surface measuring the fluid column change. *Width has greatly been exaggerated.*

Table 1. A list of the wells implemented, along with the date implemented and the orientation of the wells in the open section. Further information can be found via OCC reports 1002A (and Survey for the non-vertical wells).

Well	API	County	Well Name	Date Instrumented	Latitude	Longitude	Orientation	Lateral (ft)
1	3500323106	Alfalfa	Clark W SWD 2811 2-27	8/1/2016	36.871139	-98.3715	Lateral	2330
2	3500322737	Alfalfa	Diamondback SWD 2710 2-5	8/1/2016	36.853908	-98.289931	Lateral	2303
3	3500323033	Alfalfa	Tatum Rose SWD 2710 1-5	8/1/2016	36.812417	-98.295472	Lateral	2542
4	3500322247	Alfalfa	Presley 2-27 SWD	8/1/2016	36.783944	-98.367306	Vertical	
5	3505322987	Grant	Harley SWD 2-11	8/2/2016	36.739417	-98.036444	Vertical	
6	3505322487	Grant	K9 SWDW1	8/2/2016	36.637667	-97.99175	Vertical	
7	3511923946	Payne	Ethridge 25-3 SWD	8/12/2016	36.000713	-96.8334643	Vertical	
8	3511923926	Payne	Wilson 11-1 SWD	8/12/2016	35.9702401	-96.8385227	Vertical	
9	3511923642	Payne	Bostian 1-25 SWD	9/28/2016	36.000738	-97.141083	Lateral	4076
10	3508123802	Lincoln	Many Drinks 1 SWD	12/9/2016	35.66551261	-96.71520259	Lateral	3834
11	3511723617	Pawnee	School Land 2-16	12/9/2016	36.20645708	-96.45562696	Vertical	
12	3508324032	Logan	Harvey 1-11 SWD	9/28/2016	35.78589	-97.386869	Vertical	
13	3510324285	Noble	Mat SWD 1-36	2/8/2017	36.5211111	-97.0395555	Vertical	
14	3510324350	Noble	Superman 1-13 SWD	2/8/2017	36.550848	-97.047617	Vertical	
15	3504724818	Garfield	Olmstead 21-21N-3W 1 SWD	6/22/2017	36.2756923	-97.5153323	Vertical	

Data Management

Data can be found at https://www.ou.edu/ogs/data/well-pressure and consists of **Fluid Density Borehole.pdf**, **welldata.h5.**

This study produced some early data sets which have been examined in Kroll et al. (2017) and several Master's Theses (Perilla-Castillo, 2017; Williams, 2017; and McConville, 2018) supervised by Dr. Kyle Murray to examine flow parameters and material properties of the Arbuckle Group.

Additional background data are from OCC forms 1002A which gives basic data such as well locations and depths (Table 1), and OCC form 1012D which provides daily Arbuckle injection data. Forms 1012D were used in the analyses of Allen et al. (submitted) but are not used here.

Fluid Density Borehole.pdf contains the measurements of the fluid density column on instrumentation by L.R. McBride, Inc. for this project.

Appendix A: Sample scripts for accessing data

The well data are stored in a compressed file of the Solinst Levellogger data.
The included well data has been compressed into an hdf5 data format (The HDF5 Group n.d.) with a file structure:
`welldata.h5/data/w#`
For each individual (#) being the number of the well derived from the table above, including the USGS monitored Osage well. The data can be decompressed individually with a python code:

```
import pandas as pd
h5File = "welldata.h5";
# Pick which well number (1-15)
wellnum=15
welldat = pd.read_hdf(h5File,'data/w'+str(wellnum))
#Write to csv 'txt' file
welldat.to_csv('W_'+str(wellnum)+'.txt',index=False)
```

There are 5 columns:
Date | PSI | Temperature| FluidHeight | Fluid Elevation
The **Date** is in Central Daylight Time with the format: mm/dd/yyyy hh:MM:SS
The **PSI** (Pressure) is the weight of the fluid above the sensor and is recorded in PSI with an uncertainty of ±7.25e-6 PSI.
The **Temperature** is the temperature of the fluid recorded in Farenheit with an uncertainty of 0.1 degrees Fahrenheit.
The **Fluid Height** is then calculated as the fluid pressure gradient, calculated from the initial borehole measurements reported in the accompanying "Fluid Denisty Borehole.pdf", with a sensitivity of 0.0001 inches. This sensitivity does not include the uncertainty from the fluid density gradient, but rather the amount of change recorded by the instrument.
Finally, the **Fluid Elevation** is the height of the fluid above sea-level calculated from the elevation of the pressure sensor and the fluid height above it.
Included are **readh5.py**, for reading **welldat.h5**

The fluid levels from **USGS 364337096315401 26N-07E-15 DDD 1 Burbank** are stored in **welldata.h5/data/Osage** and recovered as above with:

```
welldat = pd.read_hdf('welldata.h5','/data/Osage')
```

Additionally, reported injection into the Arbuckle reported to the Oklahoma Corporation Commission can be found in the file **welldata.h5/injdat.** This data is collated from Report 1012D of the daily fluid injection into the Arbuckle. The data is accessed as above with

```
injdat = pd.read_hdf('welldata.h5','/injdat')
```

This data has 6 columns:

API | Report_Date | Volume_BPD | Pressure_PSI | Latitude | Longitude

Table 2. Maintenance Report of operational issues.

Well	Date	Description
1	January 24, 2023	lowered Levellogger because of decreasing fluid level
3	March 9, 2018	Levellogger replaced in w03 with TatumRose2
5	January 23, 2019	lowered Levellogger as as possible into w05 with cable zipped to wellhead
6	February 7, 2017	MIT test conducted on w06 caused increase in fluid elevation and change in fluid density
6	January 22, 2020	data cable damaged by rodents, Levellogger and cable removed from w06
7	December 1, 2017	lowered Levellogger because of decreasing fluid level
7	August 29, 2018	lowered Levellogger because of decreasing fluid level
7	December 4, 2019	when arrived at w07 on 12/18/2019 there was oil around the wellhead, after reviewing pressure data it is apparent that there was an increase in pressure on 12/4/2019 and likely a change in the fluid density in the well
8	December 22, 2017	lowered Levellogger because of decreasing fluid level
8	May 22, 2018	lowered Levellogger because of decreasing fluid level
8	May 24, 2018	deleted data for may 14-May 2018 because pressure was less than atmospheric
8	January 23, 2019	lowered Levellogger because of decreasing fluid level
9	January 22, 2020	removed barologger from w09 because it failed on Decemeber 19, 2019
11	August 29, 2018	when arrived at w11 the Levellogger and cable were no longer deployed, was removed by the operator in previous month because injection plug was ineffective
12	March 5, 2020	lowered Levellogger because of decreasing fluid level
13	June 26, 2020	lowered Levellogger from w13 at operator's request, asset sold to another operator
14	June 26, 2020	lowered Levellogger from w13 at operator's request, asset sold to another operator
15	July 20, 2017	redeployed Levellogger because new 600 ft direct read cable arrived

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