

Final Report on CAES Sitting in Northeastern Colorado

University of Colorado-Boulder

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Executive Summary

Bedded salts, saline aquifers and abandoned oil and gas fields in northeastern Colorado were evaluated to determine if there were any suitable geologic conditions for compressed air energy storage (CAES) in that area. Evaluation criteria were taken from Succar (2008) and focused on depth of burial, unit thickness, porosity & permeability, and presence of an overlying seal. Key findings are:

1. Bedded salts, with anywhere from ~140 to ~400 ft of net soluble salt occur in Washington and Morgan counties at depths of 4500 to 6000 feet. Individual salt beds can be >100 ft thick. Anhydrite forms a suitable cap seal. These salts are one possible candidate for a CAES repository
2. Uppermost Dakota Group sands (D-sands) at depths > 3,000 ft occur across ~ 5,750 sq miles in the far eastern portion of the state and have sufficient thickness (~40 ft), porosity (probably >25%), and permeability (probably > 250 md) to form a CAES site. Trapping would probably be by lateral variations in rock types (i.e., a stratigraphic trap), not by structural deformation.
3. The only shallow and abandoned oil and gas field in a geologic unit (the Dakota D-sand) with sufficient porosity and permeability is Chappel Field, which occurs at a depth of 3000 ft in the northeastern corner of Sedgwick County. The field though is small (~0.2 km²), thus unless the trap is vastly under filled with hydrocarbons, it would probably be too small for CAES.
4. Bedded evaporate deposits (Blaine Formation) near the Las Animas arch (Lamar) and the Niobrara chalk (saline aquifer and abandoned oil & gas fields throughout NE

Colorado) occur at appropriate depths for CAES, but are not suitable due to either their composition and thinness (Blaine Fm.), or lack of permeability (Niobrara).

Introduction

This study was conducted to determine the suitability of geologic formations for CAES in northeastern Colorado. The main objective of this study was to take the first step in identifying potential geologic repositories in northeastern Colorado such as: bedded salts, saline aquifers and abandoned oil and gas fields. Criteria for assessing geologic units for compressed air energy storage (CAES) were taken from Succar's (2008) discussion of baseload power production from wind turbine arrays coupled to compressed air energy storage (Table 1). Key parameters considered herein were depth (<3,000 ft), thickness, porosity, permeability, and presence of an overlying seal.

Score	1	2	3	4	5
Score Interpretation	Unusable	Marginal	OK	Good	Excellent
Permeability (md)	< 100	100- 200	200- 300	300-500	> 500
Porosity (%)	< 7	7-10	10-13	13-16	> 16
Total Reservoir Volume (V _R /V _s)	<0.5		0.5 – 0.8 or > 3.0	0.8 – 1.0 or 1.2 – 3.0	1.0 – 1.2
Total Closure Rating (h/H)	< 0.5		0.5-0.75	0.75-0.95	0.95-1.0
Depth to Top of Reservoir (m) ¹⁷	< 137 or >760	140-170	170-260 or 670-760	260-430 or 550-670	430 -550
Reservoir Pressure (bar)	< 13 or > 69	13-15	15-23 or 61-69	23-39 or 50-61	39-50
Type of Reservoir	Highly Discontinuous	Moderately vulgar limestone & dolemite	Reefs, highly vulgar limestone & dolemite	Channel sandstones	Blanket sands
Residual Hydrocarbons (%)	> 5%		1-5%		< 1%
Caprock leakage	Leakage evident	No data available	Pumping test shows no leakage		
Caprock Permeability (md)			> 10 ⁻³	< 10 ⁻³	
Caprock Threshold Pressure (bar)			21-55	> 55	
Caprock Thickness (m)			< 6		> 6

Table 1.-Ranking Criteria for Candidate Sites for Aquifer CAES used to evaluate saline aquifers in northeastern Colorado (Succar, 2008, Page 51)

Methods

Cross sections of the northeastern portion of the state, created by the Rocky Mountain Association of Geologist (RMAG), were examined to determine if there were any bedded salts in the subsurface of northeastern Colorado, and to determine what potentially porous (i.e., non-shale) geologic units were also present at depths < 3,000 ft in the same area. The latter have the potential to be regional saline-water aquifers and locally shallow, abandoned oil or gas fields. Very shallow surficial potable groundwater aquifers at tens to a few hundreds of feet were not pursued on the assumption that these geologically very young, structurally undeformed and sand-rich units would not contain appropriate geological scenarios to allow the localized trapping and containment of any compressed air.

Once salt-bearing and potentially porous rock units were identified, the Colorado Oil and Gas Conservation Committee's (COGCC) online database was exploited to collect data on each unit's depth, gross thickness, and in the case of salts, the net salt thicknesses and lateral extent of the salt formations. The COGCC's online database contains borehole data gathered from all oil and gas drill holes across the state of Colorado. The data collected allowed mapping of each unit's areal extent, subsurface depth, and structural surface (elevation relative to sea level) using the computer mapping programs PETRA and PATREL. The regional structural maps indicate the potential for storage of compressed air in structural traps (i.e., containment of the injected air where the porous units had been deformed).

Select well logs from the COGC data base were also used to assess lithologic heterogeneity of each unit. This was possible because salt, limestone, sandstone, and shale can be readily distinguished from each other by a variety of borehole geophysical tools. Permeability and porosity of the candidate saline aquifer units were assessed using data gathered from the published geological literature on the oil and gas fields of the region.

Results

Bedded Salts

Geologists refer to all minerals evaporated from seawater as "salts" or "evaporites". Of these, the dominant forms are the minerals anhydrite (CaSO_4), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), and halite (NaCl). The later is far more soluble than the former two and is the sole mineral generally referred to when discussing "salt" in the singular. Halite is also the only one of the three common evaporate "salts" that can be dissolution mined to form a CAES cavern.

The others, in fact typically form the top seal for such many types of salt storage caverns (e.g. Chevron’s Windy Hill gas storage facility near Brush).

Shallow (<3,000 ft) Eastern Colorado Evaporite Beds - The only evaporite formation found in Eastern Colorado at subsurface depths less than 3,000 feet is the Blaine Gypsum Formation, which is up to 18m thick but regionally averages less thickness. The unit consists of the mineral anhydrite or gypsum. The unit is shallowest in southeastern Colorado (i.e. the Lamar area) where it occurs at depths of < 2,500 ft. In northeastern Colorado (Sterling, Brush, Wray, etc) it is generally below 5,000 ft.

Huber Corp., Friesen #13-1
 ~24 miles east of Green Colorado Wind Farm
 sec 13, 27S, 43W, Prowers Co., Colorado
 Lat/Long: 37.690845/-102.214042

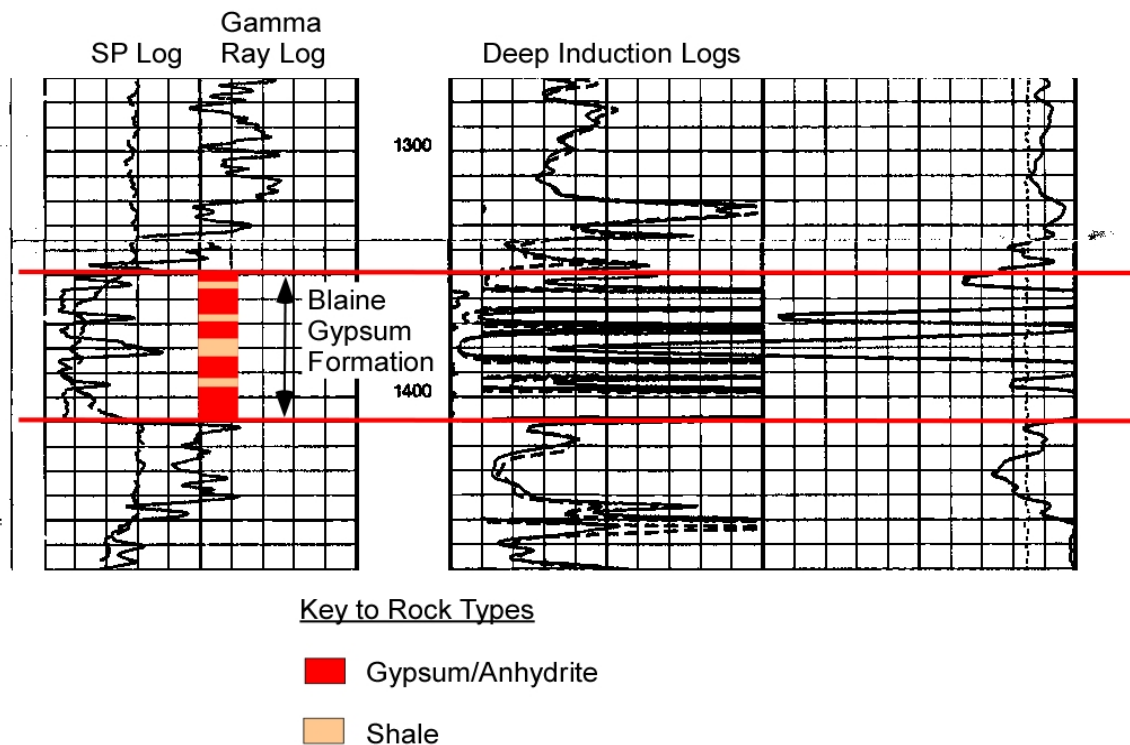


Figure 1.- Induction log from ~1300 to 1400 feet, subsurface depth, showing the different rock types composing the Blaine Gypsum Formation in southeastern Colorado.

Because of its anhydrite/gypsum composition, the Blaine evaporites cannot be recommended as a suitable CAES unit. Also, given that there needs to be a void storage volume of 200,000 m³ in order to generate 1 GWh of CAES capacity, the area covered by a Blaine storage system would be large. An 18m thick unit of Blaine that is 75% evaporite minerals would have to be around 14.8 km² which would seemingly be an unreasonably large area for even a consortium of storage sites.

Deep (>3,000 ft.) Salt Beds in Eastern Colorado - Thick salts of the mineral halite that can be dissolution mined into suitable storage caverns do occur in the northeastern region of the state. The areal extent of these salts are shown in Figure 2. Due to the lack of hydrocarbons below the salts, there are few penetrations into this unit. The seven wells through it indicated that these Permian salts consist of interlayered halite, anhydrite, dolomites, and shales. In the borehole log shown in Figure 3, halite occupies ~75% of the salt-bearing interval. Regionally, individual salt beds are interpreted to be more than 100 ft. thick.

The entire salt-bearing interval is at least 480 ft. at its greatest thickness, but only ~340 ft at its thinnest. Regional variations in gross thickness of the Permian salt unit and percent halite in the entire salt-bearing interval are demonstrated in **Figure 4** and **Figure 5**, respectively. The lateral “pinch-out” of salt is also depicted in the RMAG cross section in Figure 6. The Permian salts in NE Colorado occur at depths of approximately 5,500 ft. to 6,500 ft. in Morgan and Washington Counties and shallow to the east to depths of 4,000 ft. to 4,500 ft. in Yuma and Phillips Counties. The lowest percentages of salt (~40%) occurs at the margins of the salt body, meaning that where the depth to salt is shallowest (i.e., to the east), the net amount of salt will also be the least (<140 ft net salt), and individual salt beds

are no more than 70 ft thick. A CAES repository would still seem feasible, but its height and area would differ from a site in the purer and thicker salt intervals.

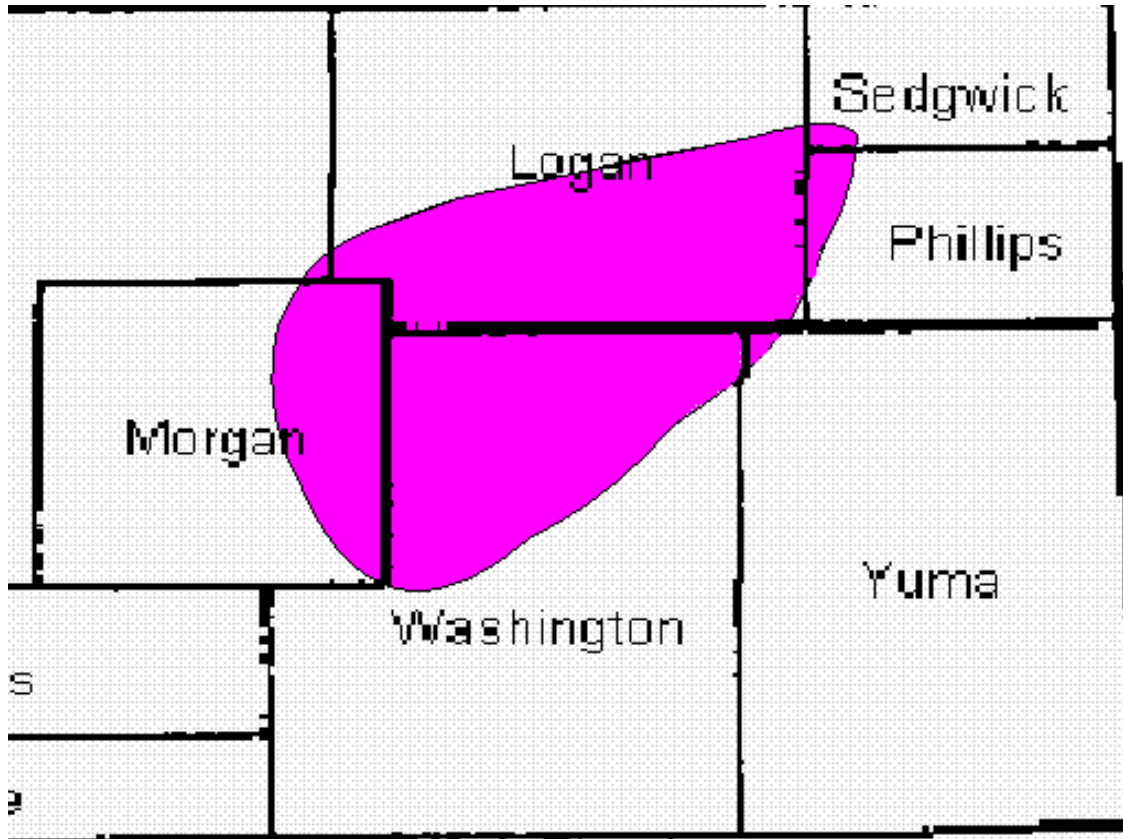


Figure 2- Approximate location of Permian salt beds in Northeastern Colorado. This preliminary map is based solely on two geological cross sections through the area published by RMAG in 1976. The lack of hydrocarbons below the salt interval means that there are few penetrations into the salt; only seven were found in the COGC database, consisting of 4 on the 1976 RMAG cross sections that constrain this map, one well at the Windy Hill Gas Storage facility, and two other wells.

Hunt D. Burnkhardt #1-33
 ~14 miles NE of Brush, CO
 sec 33, 5N 54W, Washington Co., Colorado
 Lat/Long: 40.351231/-103.414709

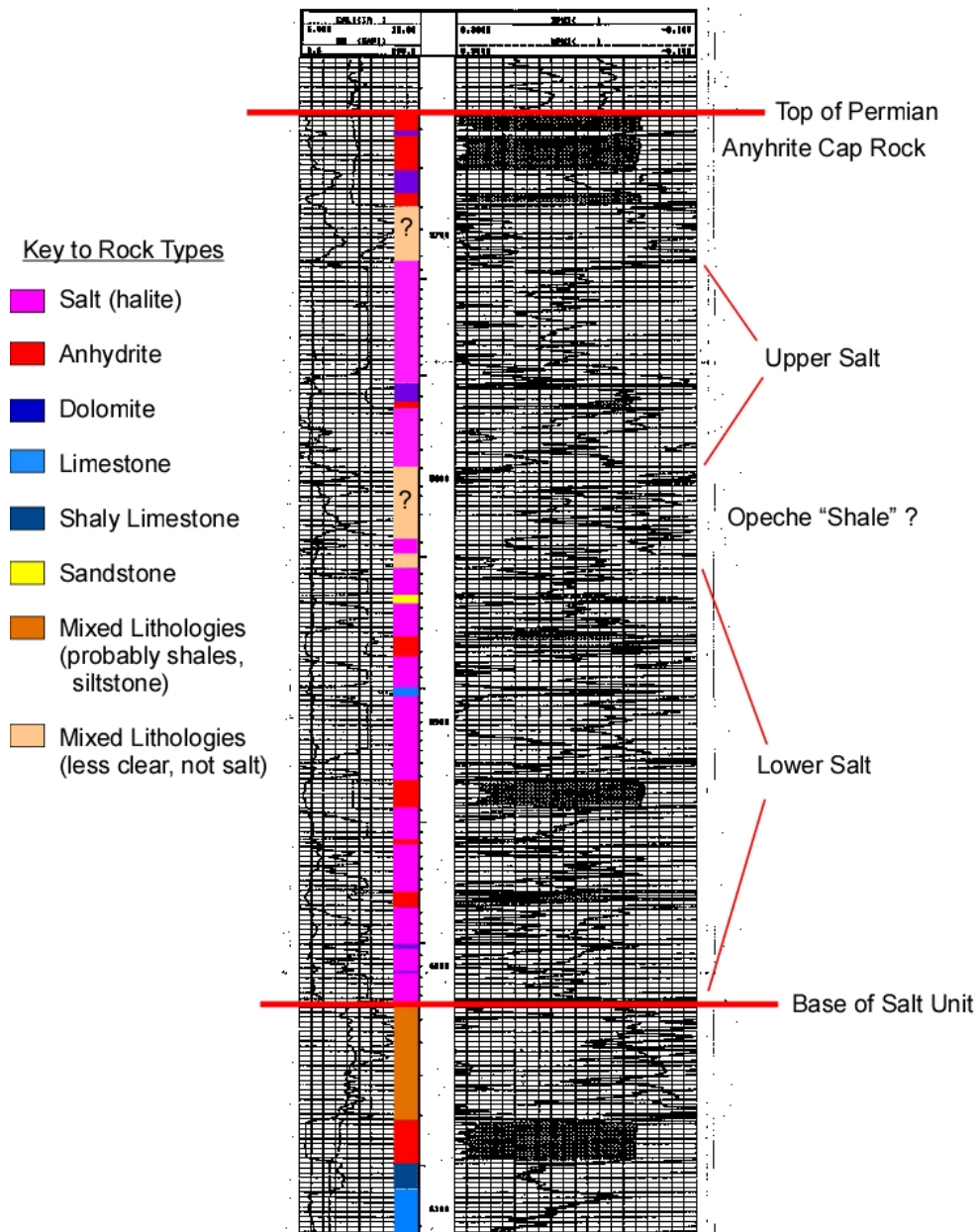


Figure 3– Neutron density log from ~5600 to 6150 feet, subsurface depth, showing the different rock types composing the Permian Salt interval in northeastern Colorado. Note that the salt is not a homogeneous unit, but a heterogeneous interlayering of halite beds with anhydrite, dolomite, and shales.

Well #	API #	County	Township & Range	Depth to Top	Gross Thickness	% Halite
1	087-05899	Morgan	32 3N 55W	5923 ft.	410 ft.	84 %
2	121-09845	Washington	33 5N 54W	5650 ft.	363 ft.	73 %
3	121-10006	Washington	28 4N 53W	5748 ft.	483 ft.	43 %
4	125-05156	Yuma	21 4N 48W	4573 ft.	337 ft.	41 %

Table 2,- Location, gross thickness and % halite of salt-bearing interval used to construct Figure 4 and Figure 5. Figure 3 shows the salt section of Well #2 and is from the Windy Hills gas repository. Three additional wells the penetrate the salt unit are recorded in the COGC database, but do not contain well logs, and thus gross thickness and % halite in those wells could not be determined.

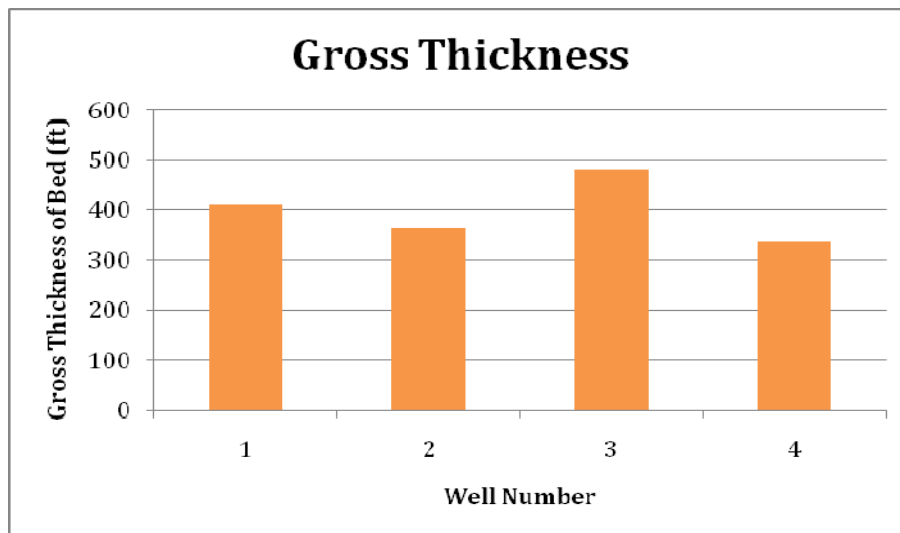


Figure 4.-Gross thickness of the salt-bearing interval shown at different well locations across northeastern Colorado. Wells are the same as Table 2.

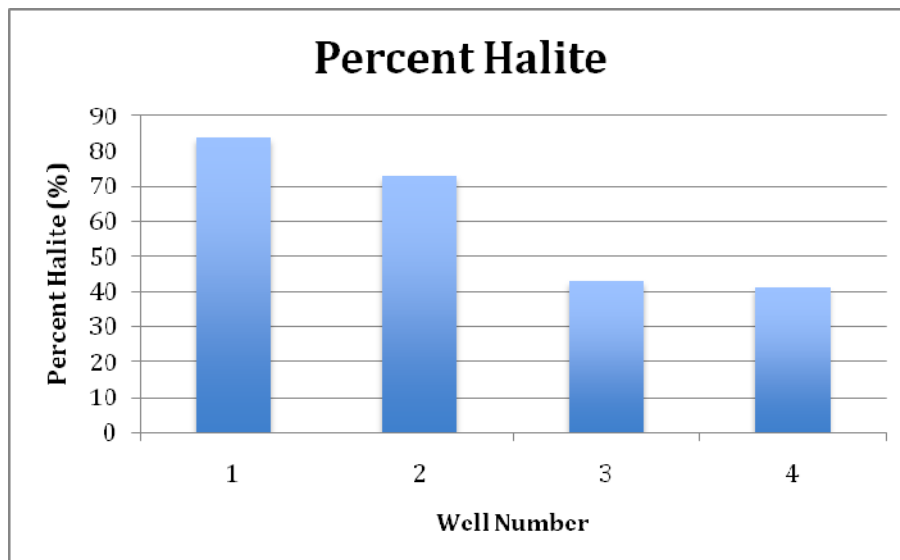


Figure 5.- Percent halite of the salt-bearing interval shown at different well locations across northeastern Colorado. Wells are the same as Table 2.

HERNDON DRLG. HEGARTY #1 14-1N-59W Morgan Co., Colorado	SUPERIOR WEISS #45-32 32-3N-55W Morgan Co., Colorado	AMERADA C.J. HEYEM #1 7-2S-52W Washington Co., Colorado	CALCO MUMM #1 1-3S-48W Yuma Co., Colorado
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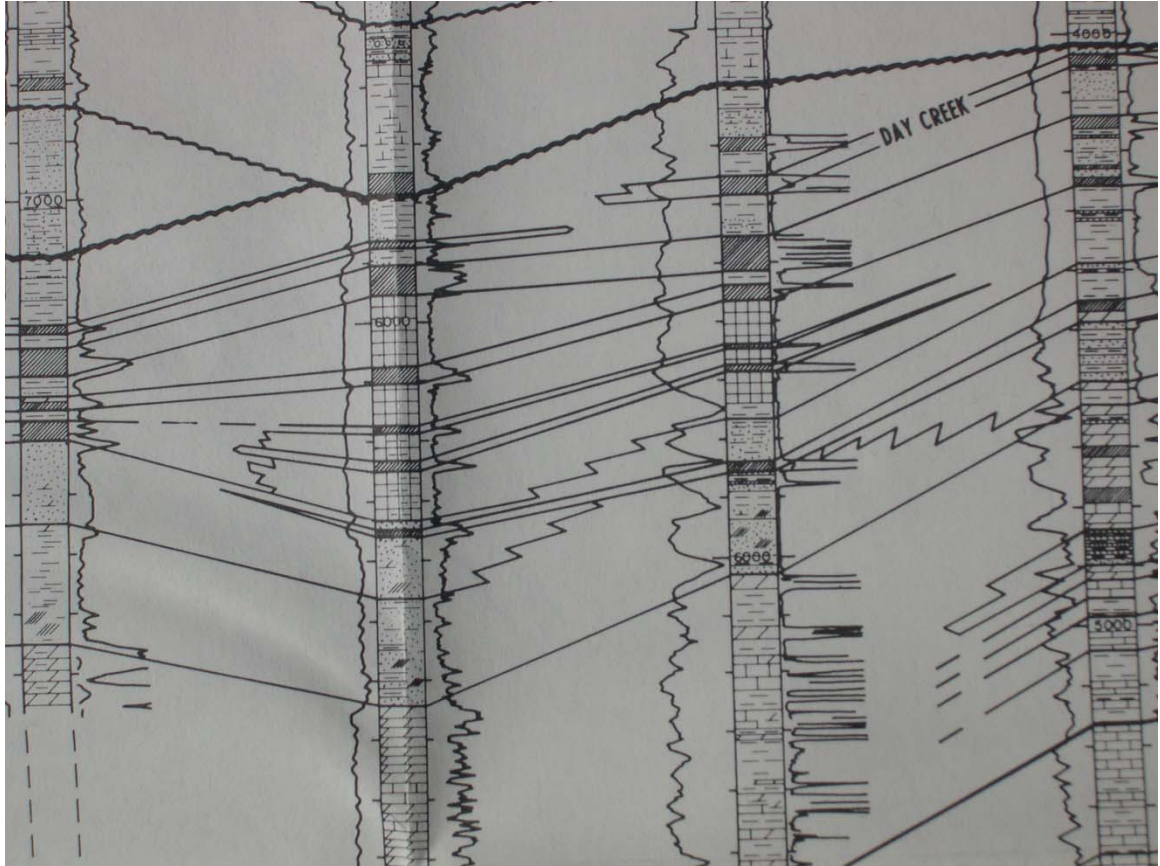


Figure 6. - Cross-section of upper Permian units in eastern Colorado (section D-D', RMAG, 1976). Salt (square pattern for rock type) is present in the two wells in the center of the cross section, but absent in the two wells on the margins of the section, indicating the salt depositional basin terminated laterally.

The Chevron Corporation plans to utilize these thick Permian salts in the Windy Hill Gas Storage facility near Brush, Colorado.(Unocal Windy Hill Gas Storage) The Windy Hill repository is at a depth of ~6,000 ft in a 370-foot interval consisting of inter bedded salt, anhydrite, and shale. The cap rock (upper seal) of the storage interval is ~60 feet of the Chugwater Anhydrite. The underlying caverns will be made in the Permian Salt Unit, which

consists of 143 ft. of the upper salt, 50 feet of the Opeche Shale, and 178 feet of the lower salt. Each cavern will be solution-mined from a single wellbore. Insoluble material is expected to take up approximately 25 percent of the cavern space, and the open space dimensions of the caverns will be approximately 226 by 260 feet. The distance between each cavern ranges from 1,041 feet to 1,320 feet.

Saline Aquifers

Two potential saline aquifers that occur at depths > 3,000 ft in northeastern Colorado were identified as potential CAES candidates --- the Niobrara chalk and the sandstones of the Dakota Group. Shales dominated the rest of the shallow stratigraphic section. COGC database yield data on approximately 120 well sites for the Niobrara and 100 well sites for the upper most Dakota sandstone (known as the "D-sand").

Niobrara Chalk - The Niobrara Chalk, also known as the Smokey Hills Member of the Niobrara Formation, is a Cretaceous deposit whose burial depth shallows from the center of the Denver-Julesberg Basin eastward into Kansas and south onto the Las Animas Arch (Figure 7). It is an interlayered chalk and shale that can be found at subsurface depths of 3,000 ft. and greater in Washington and Logan counties to depths as shallow as ~1,500 ft. in southeast Yuma county near the Kansas boarder. Topography on the top of the unit reflects some type of structural deformation.

The Niobrara chalk is capped by roughly 2,000 ft. of the Pierre Shale, which would form an excellent top seal to any CAES repository. The entire Niobrara unit is up to ~400 ft thick with porosities typically of 25%-30% in the chalk (Figure 8; Byrnes et al., 2005). The

uppermost 30-40 ft can be even more porous and is the gas-bearing interval in Niobrara chalk gas fields of northeastern Colorado, western Kansas, and southwestern Nebraska. Thickness of that uppermost gas reservoir interval varies by field. Data from six Niobrara gas field (**Table 3**) reveal that although the unit is very porous it is not very permeable. Porosity is the volumetric space in the geologic formations where as permeability the connectivity of those spaces. Both volumetric space as well as connection of those spaces is needed to flow in, store, and flow out the high pressure air. The very small size of the calcite crystals in a chalk makes for very small pore spaces (David A. Budd, personal communication). As a result, the permeability of the Niobrara chalk is typically less than 1 md (**Table 3**) and never greater than 3-5 md (Byrnes et al., 2005; Watney, 2005).

<u>Field Name</u>	<u>Depth</u>	<u>Porosity</u>	<u>Permeability</u>
DE NOVA	3000 ft.	32 %	.1md
ROCK CREEK	2800 ft.	33%	0.1-0.5 md
WAGES	2800 ft.	33%	0.1-0.5 md
WAVERLY	2800 ft.	33%	0.1-0.5 md
OLD BALDY	2700 ft.	33%	0.1-0.5 md
ECKLEY	2700 ft.	33%	0.1-0.5 md

Table 3- Porosity and permeability values taken from Colorado and Nebraska oil and gas field volumes by the Rocky Mountain Association of Geologists. These values are similar to those reported by Byrnes et al. (2005) and Watney (2005).

In spite of low permeabilities the chalk is a productive natural gas unit because it is very brittle, which leads to natural fracturing that increases the overall permeability of the 40-ft reservoir interval. That is, storage is in the chalk's high porosity, but delivery to the well bore is through the fracture, not the matrix permeability. These fractures do not extend into the more ductile Pierre Shale, thus maintaining the structural integrity of the overlying Pierre Shale.

A 3D structural map of the formation shows that there are structural traps where there may be enough closure to hold compressed air (**Error! Reference source not found.**). But, while there still may be closure, the permeability of the formation renders it unusable for CAES according to the criteria for candidate sites established by Succar (2008).

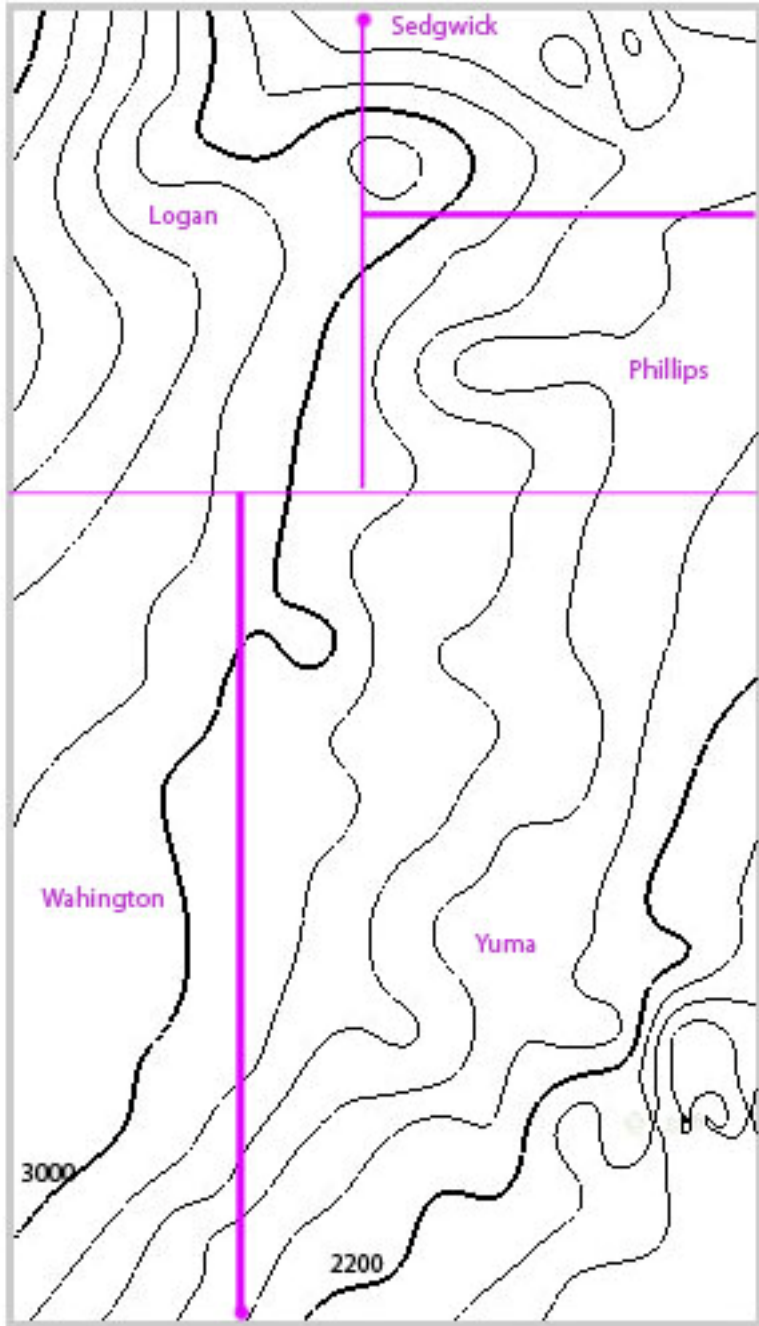


Figure 7- Contour map of the depth to the top of the Niobrara from surface elevation. The map displays the uppermost northeast corner of the state and is bordered by Kansas to the east, Nebraska to the northeast and Wyoming to the north. The bottom of the map is the Yuma county border and the western edge of the map is an arbitrary boundary in Washington and Logan counties chosen past the 3000 ft. contour line. County names and boundaries are drawn in violet. This map was made with approximately 120 data points from the Colorado Oil and Gas Conservation Committee's online data-base (<http://oil-gas.state.co.us/>).

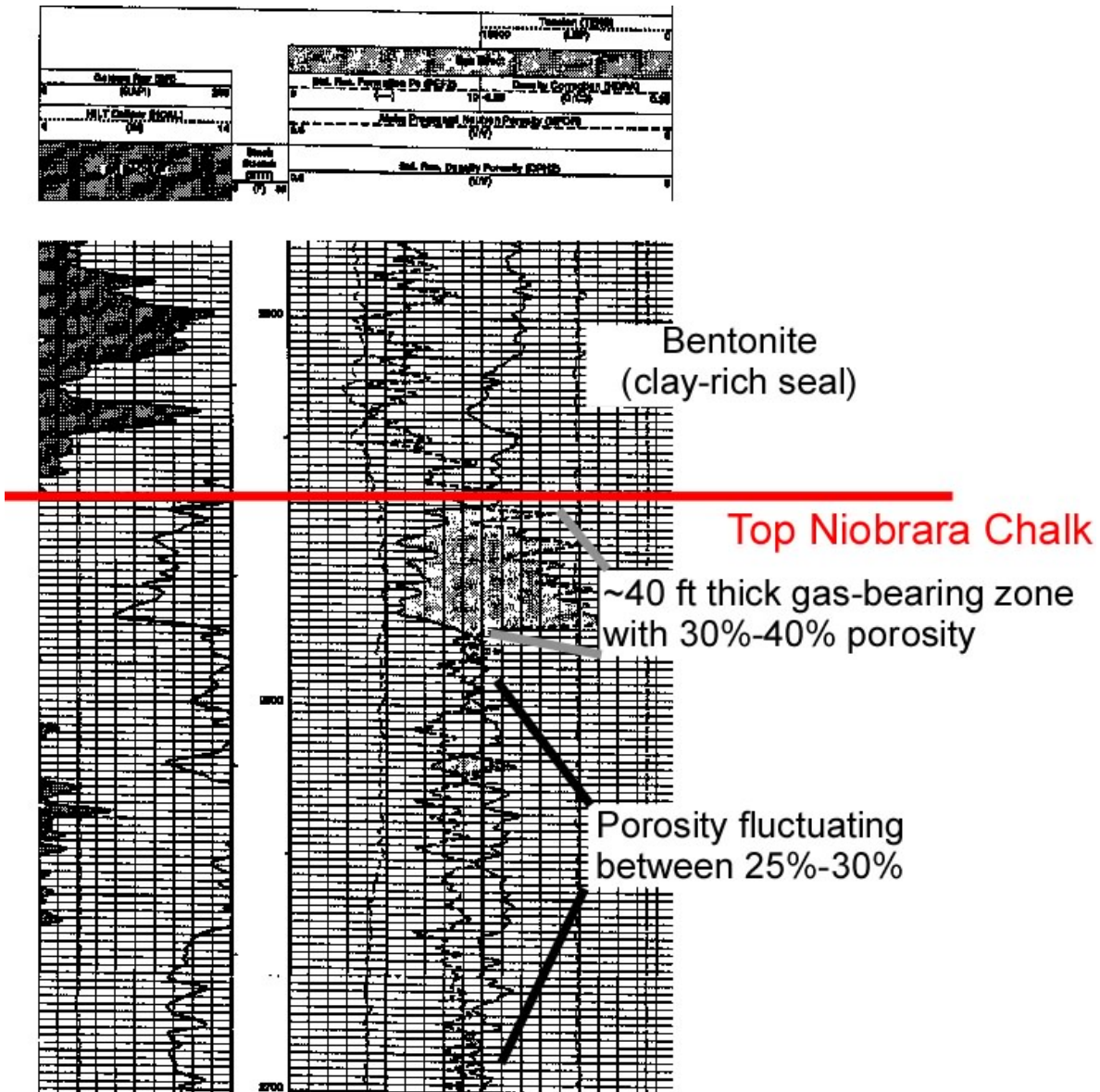


Figure 8. – Neutron porosity log from a gas well in the Old Baldy Field, Yuma county, northeastern Colorado. Top of the Niobrara chalk is at 2550 ft (subsurface elevation). Porosity is high throughout the entire unit, and particularly high in the gas bearing uppermost 40 ft. The bentonite-rich shales of the overlying Pierre Shale form the capping seal.

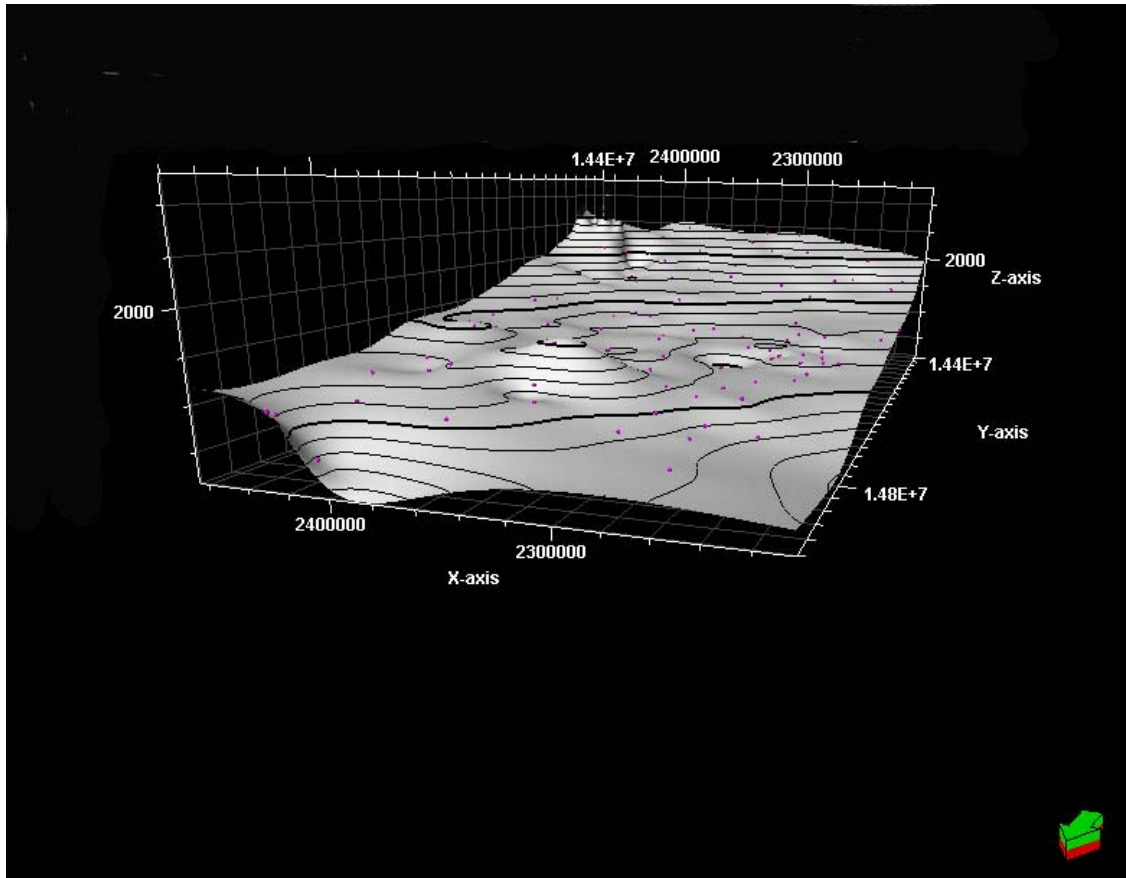


Figure 9. – Three-dimensional structural map of the Niobrara Formation in the northeastern corner of Colorado. View is looking southeast from the Wyoming boarder. Map shows that the Niobrara shallows to the east into Nebraska and Kansas and to the south onto the Las Animas Arch. The purple dots are well locations where data was gathered. Elevation is measured from sea level. Data is from the same map as in Figure 7.

Uppermost Dakota Group D-sands - The lower Cretaceous Dakota Group consists of alternating shale and sandstone (Figure 10), with the uppermost sandstone known as the “D-sand”. The D-sand houses oil and gas fields throughout northeastern Colorado, but where oil or gas is not trapped, the D-sand (and all other Dakota Group sands) is a saline water aquifer.

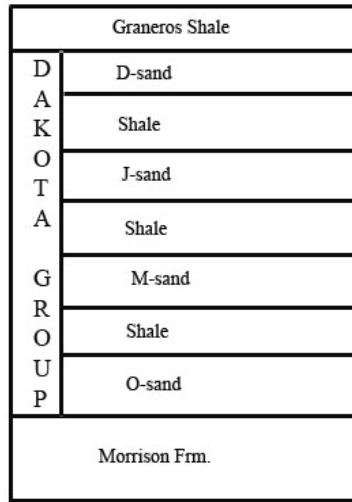


Figure 10. -Simplified stratigraphic column that displays the different subsurface units recognized within the Dakota Group, as well as the formations encasing the Dakota. The stratigraphic column was constructed using well logs found on the COGCC online database.

The D-sand burial depth shallows from the center of the Denver-Julesberg Basin eastward into Kansas and south onto the Las Animas Arch (Figure 11). The D-sand can be found at subsurface depths of more than 6,000 ft. in Logan County but as shallow as 2,000 ft in Kit Carson County in the east-central portion of the state as it begins to rise onto the Las Animas Arch. The top of the D-sand is at >3000 ft over ~5,750 sq miles in Kit Carson and southern Yuma counties.

Topography on the top of the unit also shows structural deformation (Figure 12). Deformation has the potential to provide closure that will trap compressed air, however, most of that deformation on the D-sand occurs at depths greater than 1600 ft and in the northeastern portion of the map area. In the absence of structural trapping, sands of the

Dakota are known to still have closure due to stratigraphic trapping (Table 4). Stratigraphic traps are ones in which lateral variations in rock type (which formed when the sediments were originally deposited on the land surface in Cretaceous time) provide the closure.

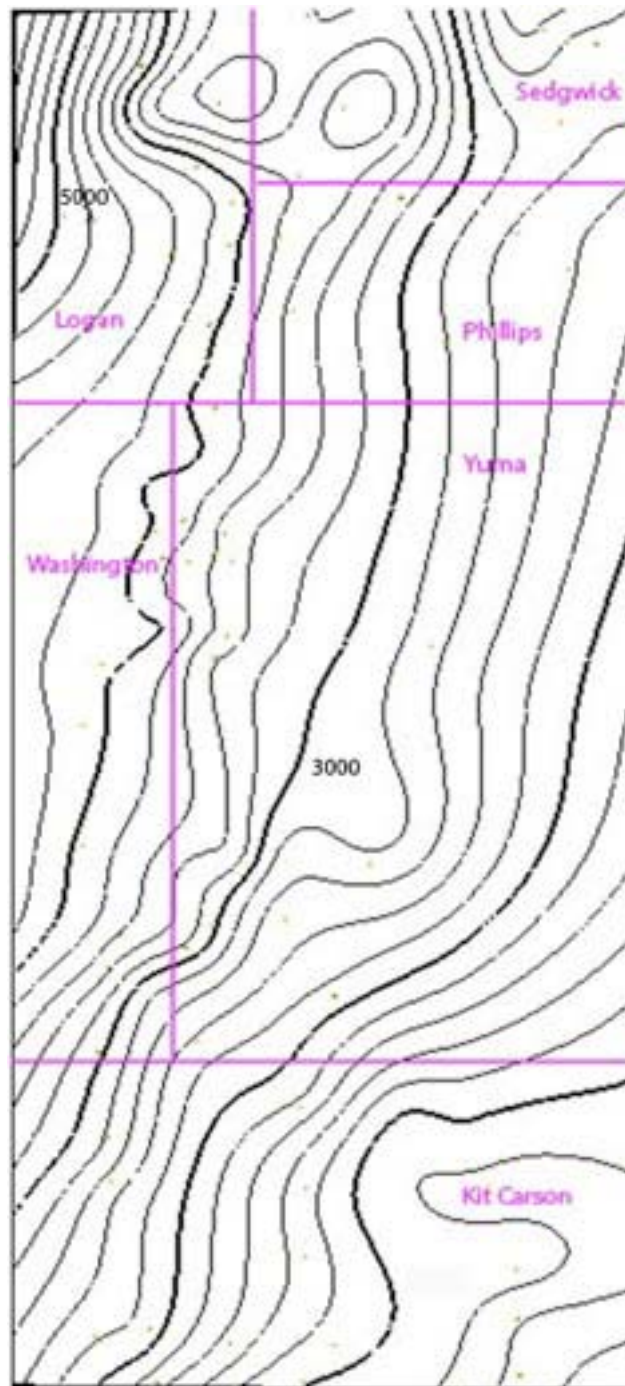


Figure 11.- Contour map of the depth to the top of the D-sand from surface elevation. The map displays the upper most northeast corner of the state with Wyoming to the north, Kansas to the east and Nebraska to the northeast. The bottom of the map is near the southern border of Kit Carson County and the western edge is an arbitrary boundary in Washington, Logan and Kit Carson counties chosen to demonstrate the depths the formation is found at in this portion of the state. This map was constructed using approximately 100 data points from the Colorado Oil and Gas Conservation Committee's online data-base (<http://oil-gas.state.co.us/>). As shown above the formation shallows to the east into Kansas and to the south onto the Las Animas Arch.

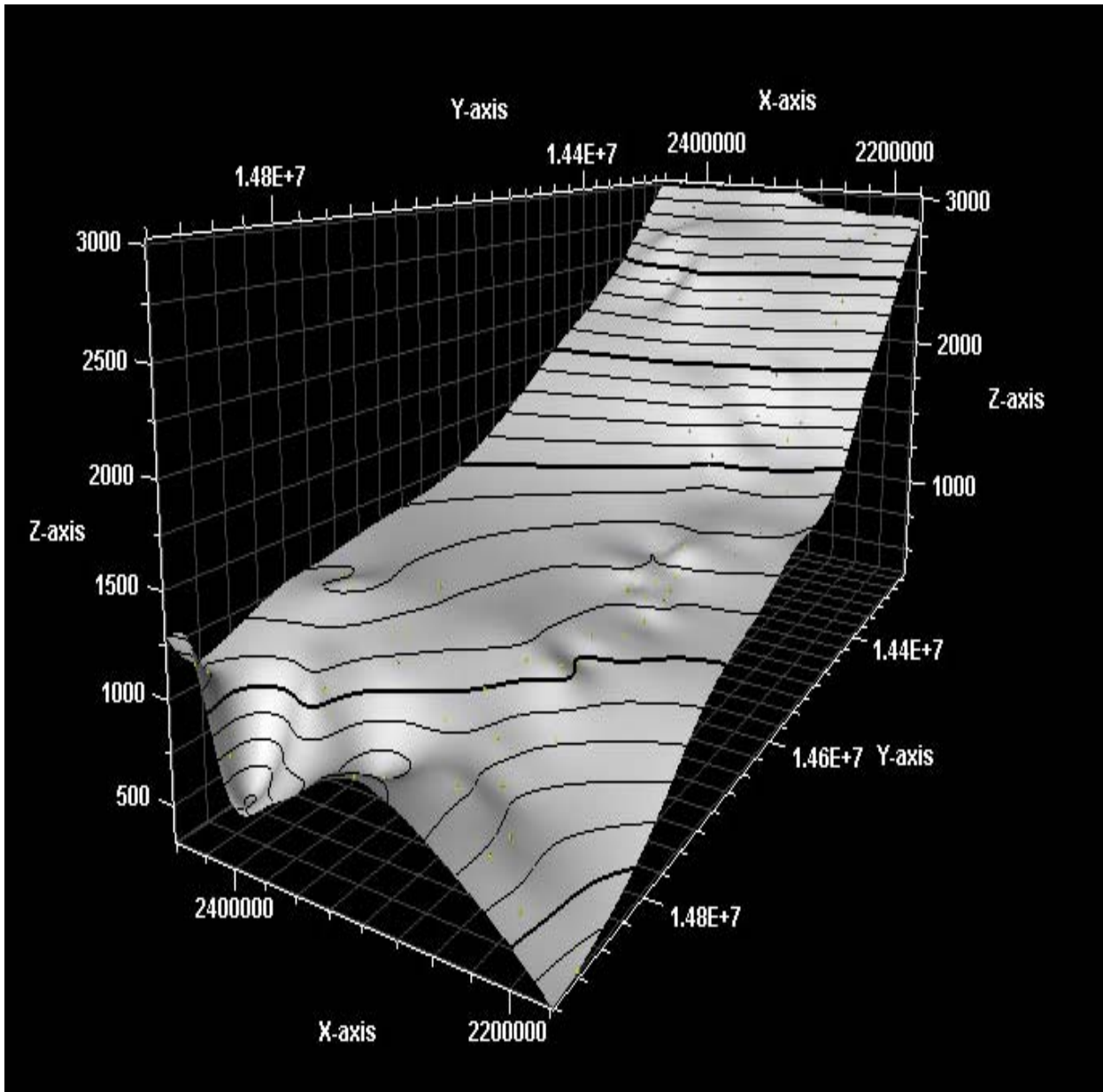


Figure 12.-Three dimensional structural map of the d-sand in the northeast corner of Colorado. The view is looking southeast from the Wyoming border. Map shows that the D-sand shallows as it goes east into Kansas and south onto the Las Animas Arch. Elevation is measured from sea level. The yellow dots are well locations where data was collected. Data is from the same map as in Figure 11.

Field Name	Depth (ft.)	Porosity (%)	Permeability (md)	Type of Trap
AKRON EAST	4500	22	375	Structural/Stratigraphic
ATWOOD EAST	4400	23	80	Structural/Stratigraphic
BASE LINE	7500	8.5	0.79	Stratigraphic
BEACON	5800	19.3	175	Stratigraphic
BUGLE	8200	10	100	Stratigraphic
BUSY BEE	6400	15	135	Stratigraphic
CHAPPEL	3000	24	N/A	Stratigraphic
COMANCHE CREEK	7500	14	20	Stratigraphic
DARBY CREEK	4900	16	N/A	Stratigraphic
DIVIDE	4700	23	250	Stratigraphic
ELM GROVE	4500	20	N/A	Stratigraphic
FENCE POST	7600	8.5	N/A	Stratigraphic
FRASCO	5500	17	199	Stratigraphic
HORSE CREEK	7500	8.6	N/A	Stratigraphic
IRONDALE	7900	9	15	Stratigraphic
JACKPOT	6400	15.8	60	Stratigraphic
JAMBOREE	7900	5	0.1	Stratigraphic
KRAUTHEAD	7700	9.6	10.7	Stratigraphic
LANYARD	6800	15.2	48.7	Stratigraphic
LITTLE HOOT	5100	15	20	Stratigraphic
LITTLE HOOT SO	5100	15	16	Stratigraphic
NUGGET	5300	19	157	Stratigraphic
RED LION	3800	29	N/A	Stratigraphic
RUNNING CREEK	8300	12	N/A	Stratigraphic
SAND RIVER	5100	20	150	Stratigraphic
YOUNG	5800	20.2	500	Stratigraphic

Table 4-List of oil and gas field names that were used to construct the projection charts for permeability and porosity in the D-sand above a subsurface depth of 3,000 ft. These values were taken from the R.M.A.G. oil and gas field anthologies (Crouch,1983).

The D-sand ranges in thickness from approximately 15-60 ft. thick. However, the entire D-sand is not entirely sandstone. Borehole logs (Figure 13) indicate that the D-sand is a heterogeneous unit with at least 2 thin shaly zones (3494 ft and 3500 ft in Figure 13), and a

thicker, 14 ft shaly interval (3520 to 3534 ft. in Figure 13). This means that porous and permeable sand might occupy only ~2/3rds of the interval. The unit is capped by the much thicker Graneros Shale, which form a suitable top seal for CAES

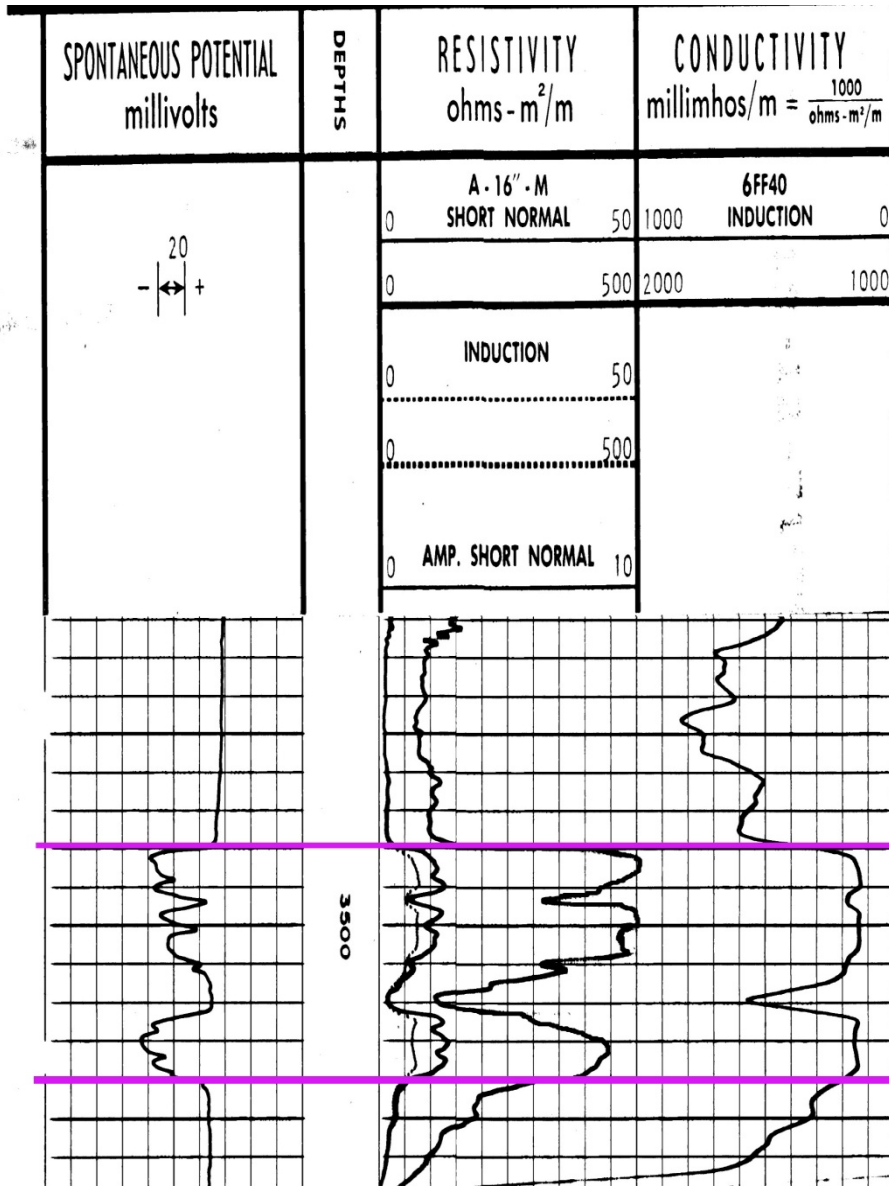


Figure 13.- An induction log from the Colorado Oil and Gas web site. The violet lines encase the D-sand member. The entire unit extends from 3,480 ft. to 3,540 ft. roughly a 60 ft interval. However, it is not pure sand throughout. Shaly zones ranging from 2-14 ft in thickness are indicated by fluctuations in the SP curve in the left column This log was taken from a well site in Phillips County.

The D-sand also has a suitable permeability and porosity ranges for CAES (

Table 4). Permeability of the unit ranges from 80md at greater depths to as high as 250md at shallower depths. The porosity of the unit also varies in the same depth dependent way; 16% at greater depths to 24% at shallower depths. No data was found for depths shallower than 3,000 ft., but extrapolation of porosity vs. depth (Figure 14) and permeability vs. depth (Figure 15) suggest porosities $\geq 25\%$ and permeabilities ≥ 250 md will prevail at $<3,000$ ft. This renders the D-sand unit usable for CAES according to the criteria for candidate sites established by Succar (2008). These porosity and permeability projections would be applicable regardless of whether a candidate site was a shallow, abandoned gas field or where the D-sand is water-saturated (i.e., a saline aquifer). It is not unreasonable to assume the underlying sandstones of the Dakota Group (Figure 10) would also be suitably porous and permeable for CAES at shallow depths.

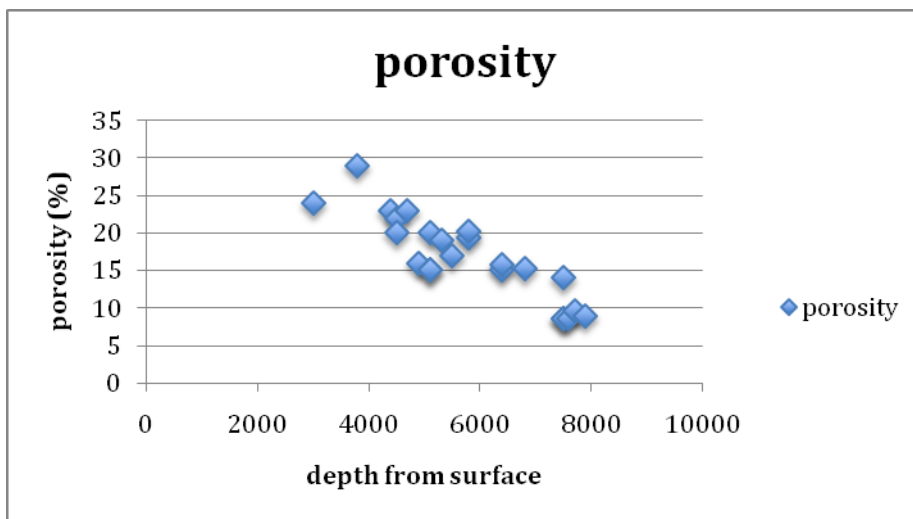


Figure 14.- Projection of estimated porosity of the D-sand. Data points are the same as in Table 3. At depths < 3000 ft. estimated porosity is projected to be approximately 25-30 %.

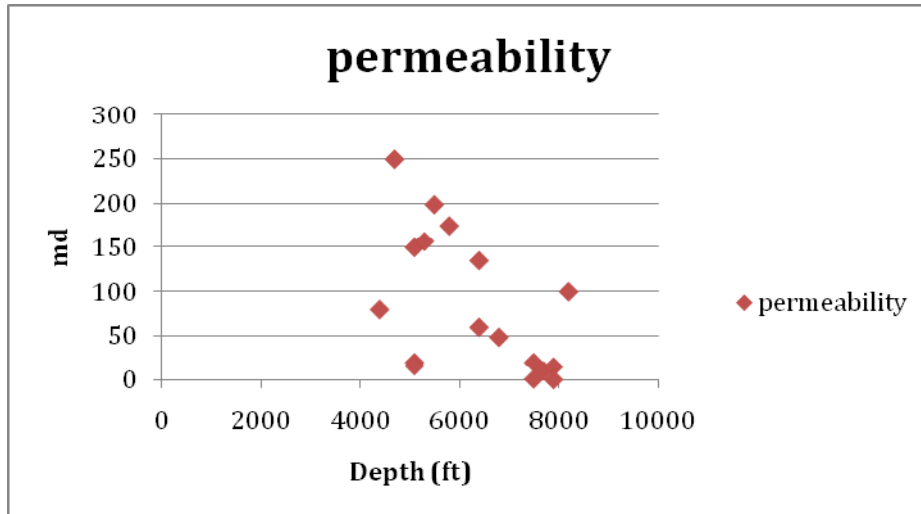


Figure 15.- Projection of estimated permeability of the D-sand. Data points are same as in Table 3 (but with the highest and lowest values dropped). At depths < 3000 ft. permeability is estimated to be roughly 250-300 md.

Using a projected porosity of 30% and an average net porous D-sand thickness of 40 ft., a D-sand CAES reservoir would have to cover an area of approximately 52 square kilometers in order to achieve a pore volume of 200,000 m³ and thus 1Gwh of CAES capacity. However, the average area of an oil or gas field in the D-sand is between only 5-10 km² (Parker, 1962; Crouch, 1983). The 5 to 10-fold difference in needed trapping capacity and proven trapping capacity requires further evaluation of specific D-sand fields. The critical question would be whether the typical D-sand stratigraphic oil reservoir is underfilled with respect to its maximum trapping capacity.

Abandoned Oil and Gas Fields

A list of all oil and gas fields in the state of Colorado was provided by Jason Deardorff, a graduate student at Colorado School of Mines. This list included data on field size, geographic location, reservoir formation, status (abandoned or active), minimum depth, the ambient pressure, the pressure the reservoir can sustain before fracturing and the pressure difference between the two. This list was sorted to identify abandoned oil and gas fields in northeastern Colorado at minimum depths of 3,000 ft or less (**Table 5**). Thirty-six fields were identified, 35 in the Niobrara chalk and one in the D-sand of the Dakota Group.

Table 2 already establishes that Niobrara fields have permeability far too low for CAES, but **Table 3** and **Figure 14** and **Figure 15** show that shallow D-sand fields would have suitable porosity and permeability. Thus, the single abandoned Dakota field (Chappel Field at 3000 ft in Sedgwick County (Figure 16), would appear to be the only possible CAES candidate in the area. The Chappel field is a stratigraphic trap in the D-sands with a known pay zone (hydrocarbon-saturated porous sandstone) of 18 ft. The field covers an area of approximately 193,536 m²(0.2 km²), which means the known field is too small for a suitable CAES site. A more detailed study of the field (i.e., using all well data in the field and immediately surrounding it) would be needed to determine if this stratigraphic trap could hold sufficient volume of compressed air.

Field Name	Formation	County	Depth (ft)
ABARR	NIOBRARA	WASHINGTON	2900
ARMEL	NIOBRARA	YUMA	1700
BEECHER ISLAND	NIOBRARA	YUMA	1600
BLIZZARD	NIOBRARA	YUMA	2400
BONNY	NIOBRARA	YUMA	1600
BUCKBOARD	NIOBRARA	YUMA	2800
BUFFALO GRASS	NIOBRARA	YUMA	2900
CHAPPEL	D SAND	SEDGWICK	3000
COUNCIL	NIOBRARA	YUMA	1700
DAPPER	NIOBRARA	WASHINGTON	3000
DE NOVA	NIOBRARA	WASHINGTON	3000
DUKE	NIOBRARA	YUMA	2300
ECKLEY	NIOBRARA	YUMA	2700
FERAL	NIOBRARA	WASHINGTON	2900
MILDRED	NIOBRARA	YUMA	2400
OLD BALDY	NIOBRARA	YUMA	2700
PHUMA	NIOBRARA	YUMA, PHILLIPS	2700
PONY EXPRESS	NIOBRARA	YUMA	2700
PRICE RANCH	NIOBRARA	YUMA	2900
RED WILLOW	NIOBRARA	YUMA	-99
REPUBLICAN	NIOBRARA	YUMA	2100
ROCK CREEK	NIOBRARA	YUMA	2800
SCHRAMM	NIOBRARA	YUMA	2600
SCOTTIE	NIOBRARA	WASHINGTON	2900
SHOUT	NIOBRARA	YUMA	2800
SOMBRERO	NIOBRARA	WASHINGTON	3000
SPEAR	NIOBRARA	WASHINGTON	3000
STONES THROW	NIOBRARA	YUMA	1700
TIERRA PLANO	NIOBRARA	YUMA	2200
VERNON	NIOBRARA	YUMA	2300
WAGES	NIOBRARA	YUMA	2800
WAVERLY	NIOBRARA	YUMA	2800
WHISPER	NIOBRARA	YUMA	2900
WHITE EAGLE	NIOBRARA	WASHINGTON	3000
YODEL	NIOBRARA	YUMA	2500
YODEL NORTH	NIOBRARA	YUMA	2500

Table 5 – Abandoned oil and gas fields in northeastern Colorado that occur at depths < 3000 ft.

Fields with CAES Potential in the D-J Basin

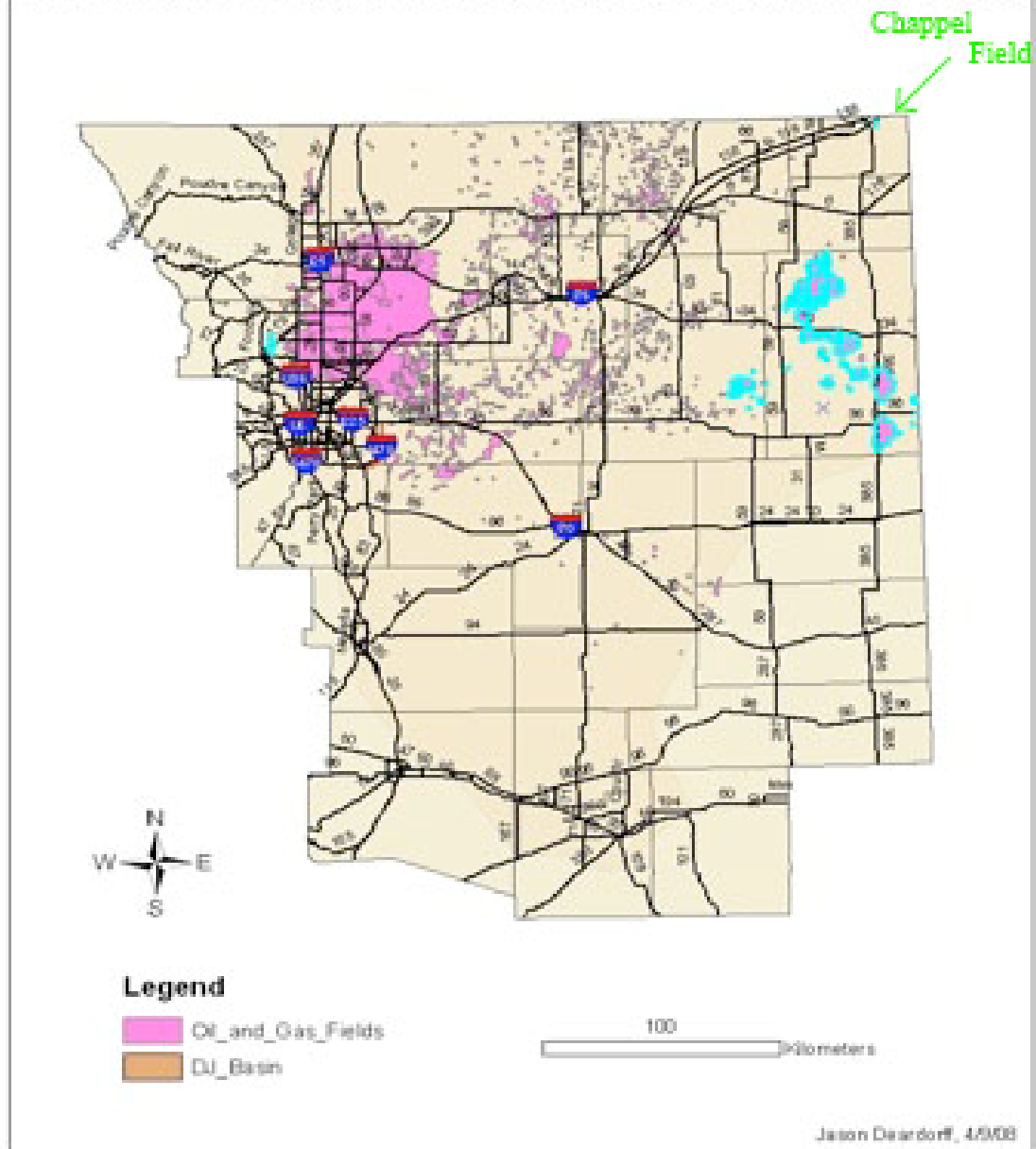


Figure 16- Map of oil and gas fields in northeastern Colorado, with abandoned fields (Table 4) outlined in blue. The only field that might be a suitable for CAES is Chappel Field (arrow) because it is the only abandoned field in the D-sand.

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