UNDERGROUND INJECTION CONTROL
(UIC) SEISMICITY

Colorado School of Mines
Technical Engagement Program

July 10, 2014

COLORADO
Oil & Gas Conservation Commission
Department of Natural Resources

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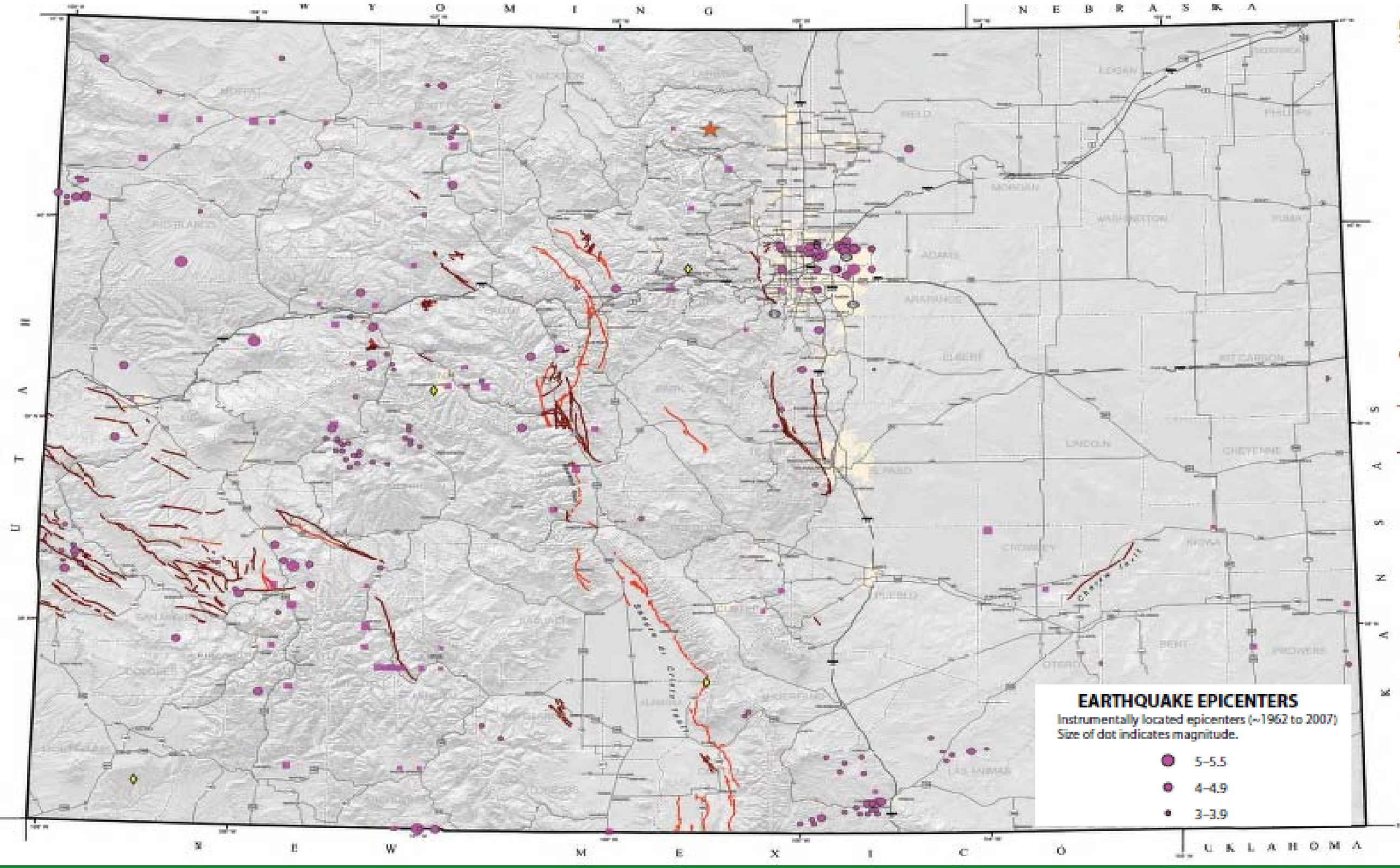
Engineering Manager

GOAL

1. *History on induced seismicity in Colorado*
2. *Colorado's Underground Injection Program*
3. *Safeguard for underground injection*

Colorado's Earthquake and Fault Map



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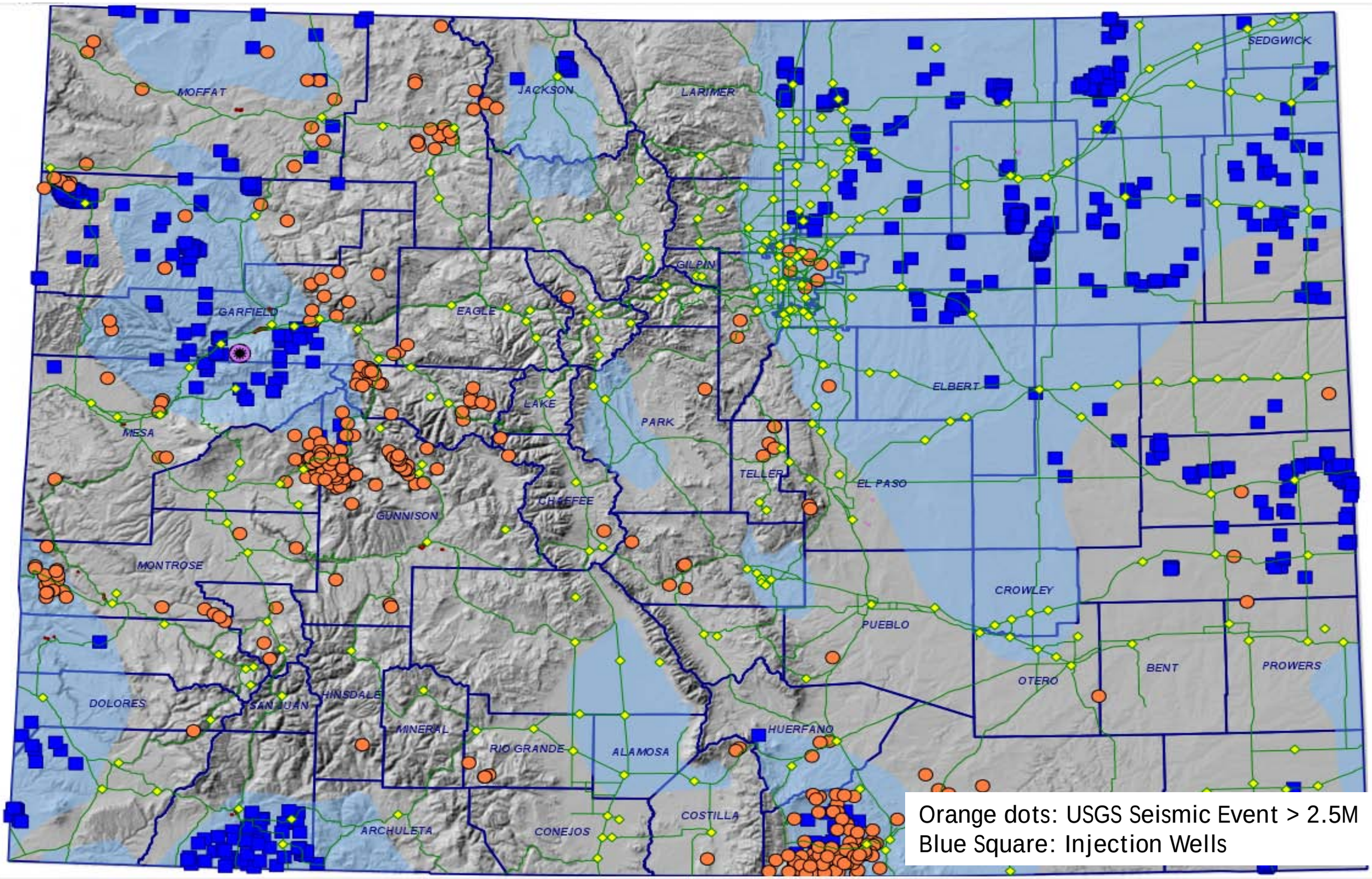
USGS Seismic Events > 2.5M

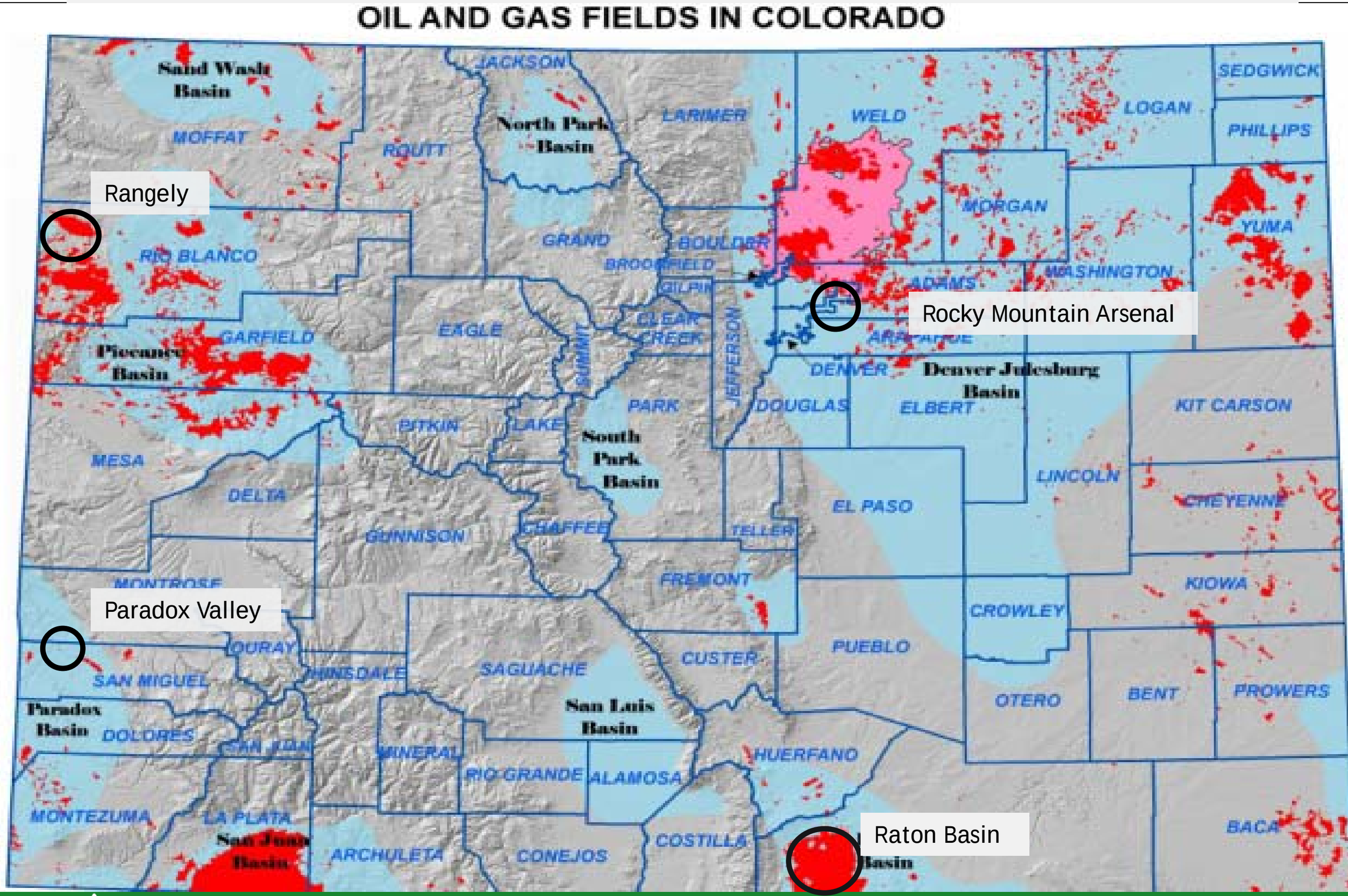


Orange dots: USGS Seismic Event > 2.5M
Blue Square: Injection Wells

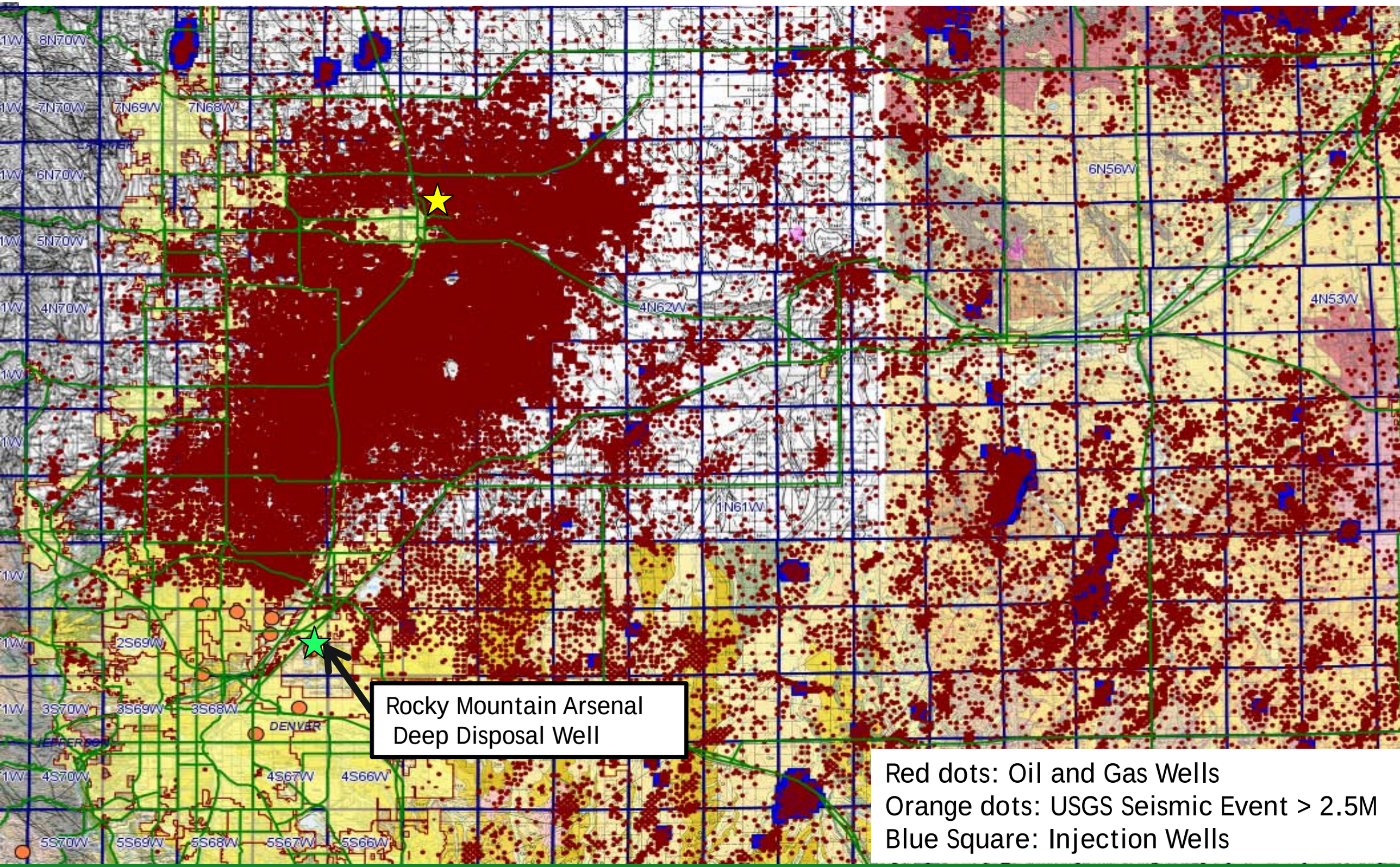
Three History Examples of Induced Seismicity in Colorado

- Rocky Mountain Arsenal, Adams County, Colorado
- Rangely Oil Field, Rio Blanco County, Colorado
- Paradox Valley, Dolores County, Colorado

Three History Examples of Induced Seismicity in Colorado



Rocky Mountain Arsenal Deep Disposal Well



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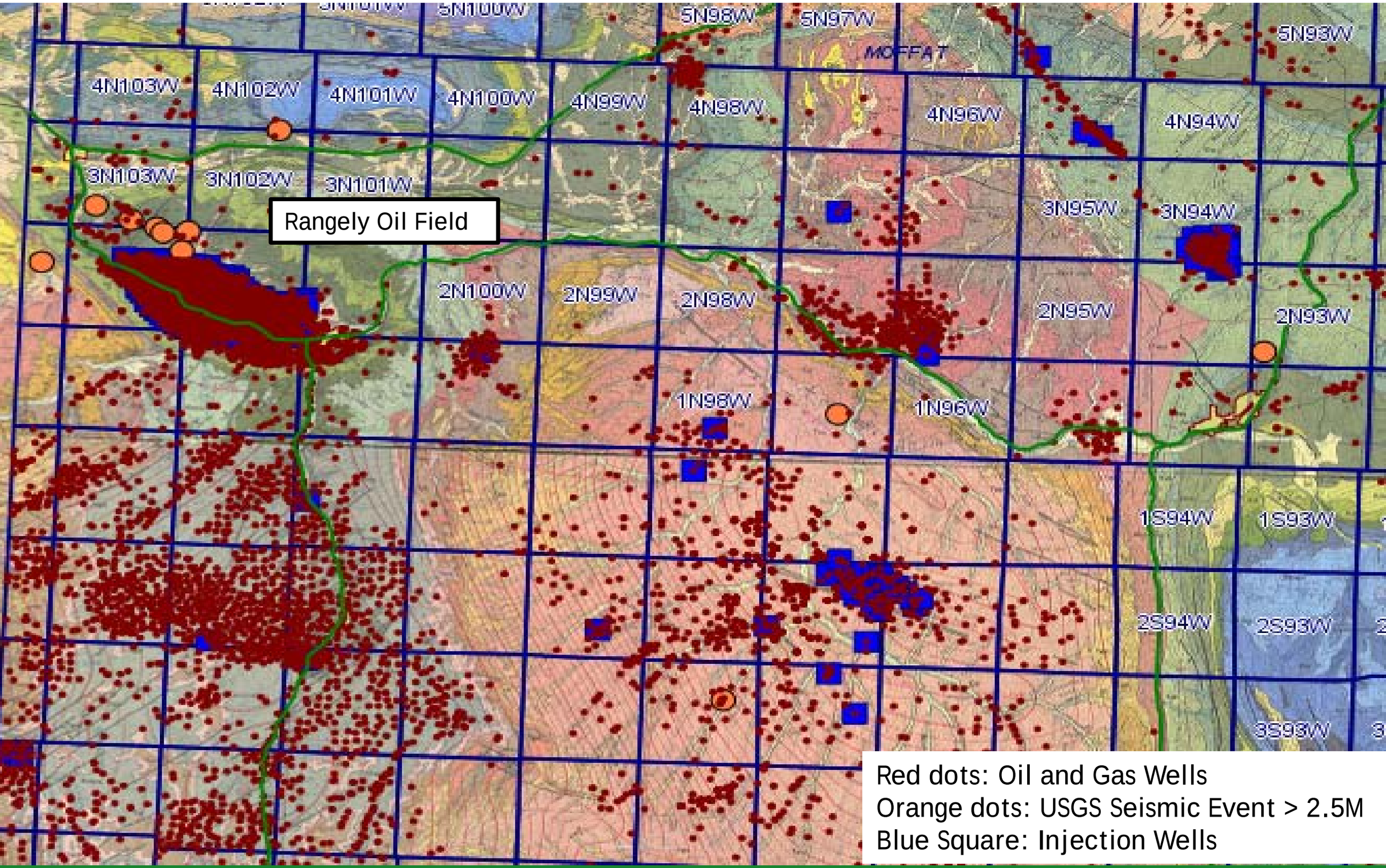
Rangely Oil Field



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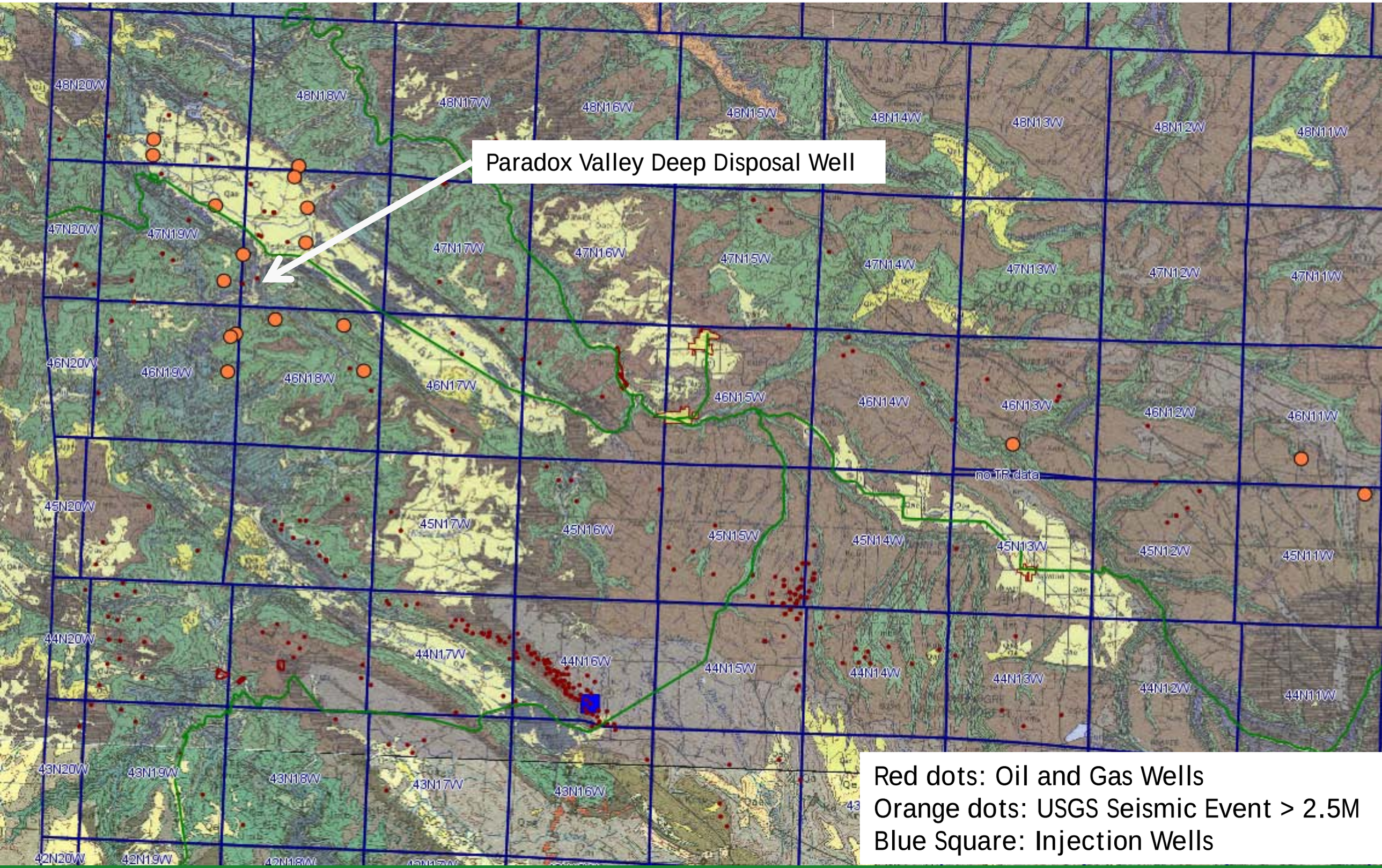
Paradox Valley Deep Disposal Well



Possible Causes of the Historic Induced Seismicity

- Rocky Mountain Arsenal,
  - Large injection volumes,
  - High injection rate
  - Low porosity reservoir
  - Low permeability reservoir

- Rangely Oil Field,
  - Large injection volumes,
  - High injection rate

- Paradox Valley, Dolores County, Colorado
  - Large injection volumes,
  - High injection rate

Colorado's Underground Injection Program

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COLORADO STATISTICS

As of April 1ST 2014, There are 920 UIC wells

350 DISPOSAL WELLS (34 are Tribal)

570 ENHANCED RECOVERY WELLS (2 are EPS)

COLORADO's
UNDERGROUND INJECTION REGULATIONS

- RULE 325 ADDRESSES UNDERGROUND DISPOSAL OF WATER
- RULES REQUIRE WRITTEN NOTICE TO SURFACE OWNER AND MINERAL OWNER WITHIN ¼ MI.
- PUBLICATION OF DISPOSAL WELL NOTICE IN LOCAL NEWSPAPER FOR 30 DAY COMMENT PERIOD
- VARIOUS WELL BORE CONSTRUCTION INFORMATION
- TESTING FOR WATER QUALITY OF DISPOSAL FORMATION. IF TDS IS < 10,000 PPM TDS AN AQUIFER EXEMPTION IS REQUIRED.
- FOR ENHANCED RECOVERY OPERATIONS THESE STEPS ARE DONE OVER THE ENTIRE UNIT AREA

Well construction for fluid isolation

WELL BORE DIAGRAM

PLACE & CEMENT PRODUCTION CASING

Fluid inflow prevented by cement

Per COGCC Rules 317.i, j, & k and verified per Rule 308A

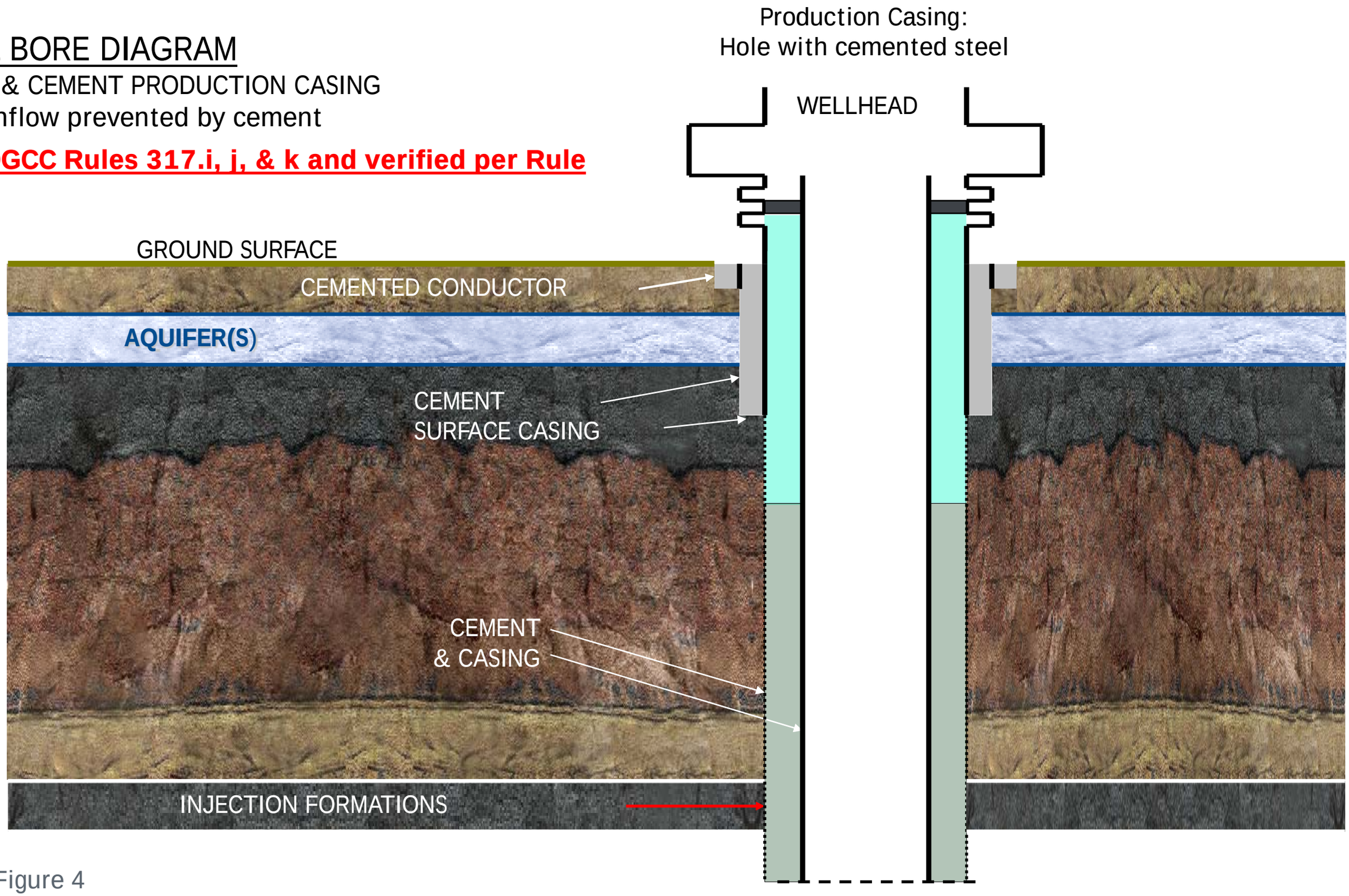


Figure 4

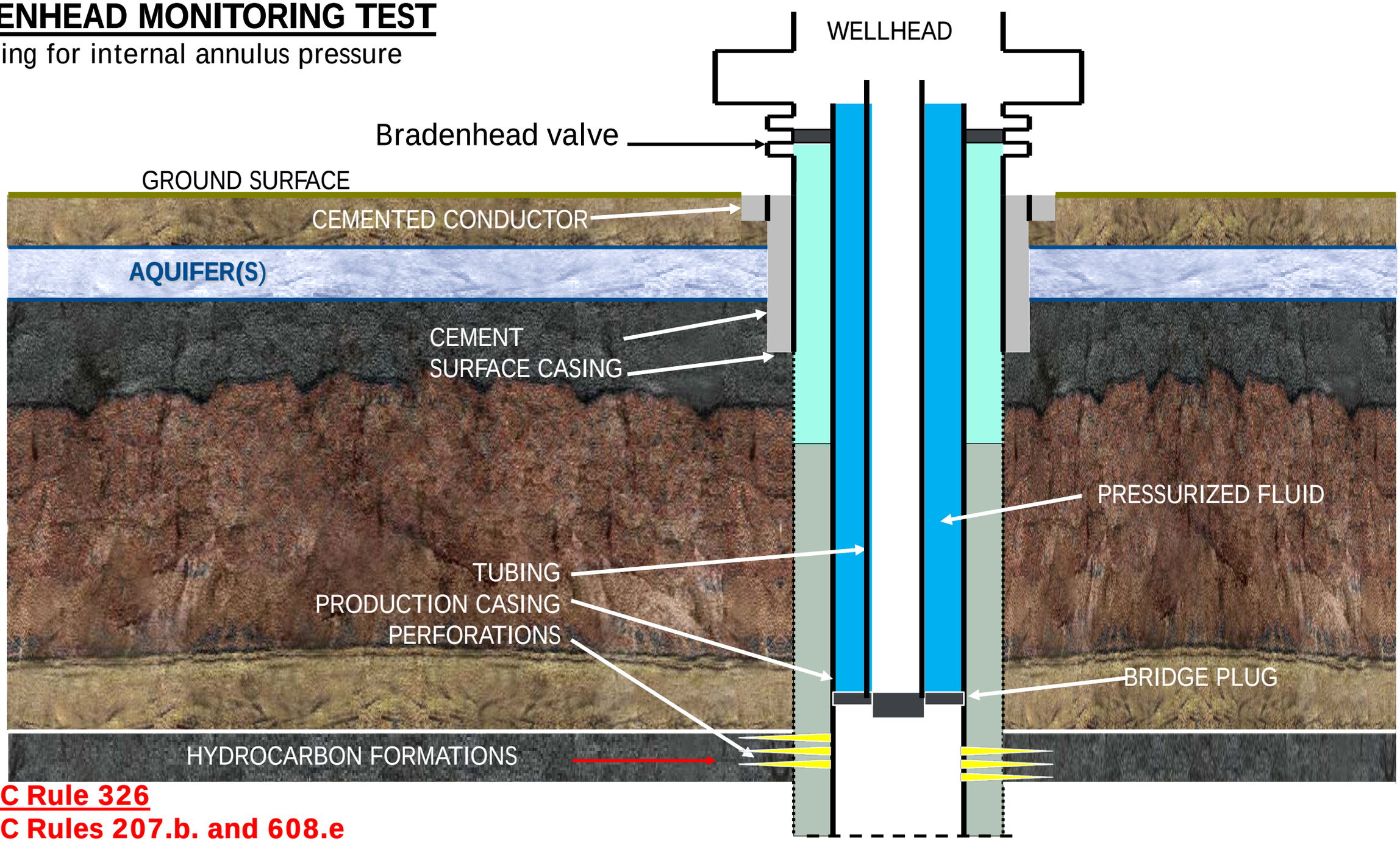
Wellbore Integrity

MECHANICAL INTEGRITY TEST

Applied pressure monitoring of internal casing pressure

BRADENHEAD MONITORING TEST

Monitoring for internal annulus pressure



Per COGCC Rule 326

Per COGCC Rules 207.b. and 608.e

Safeguard for underground injection.

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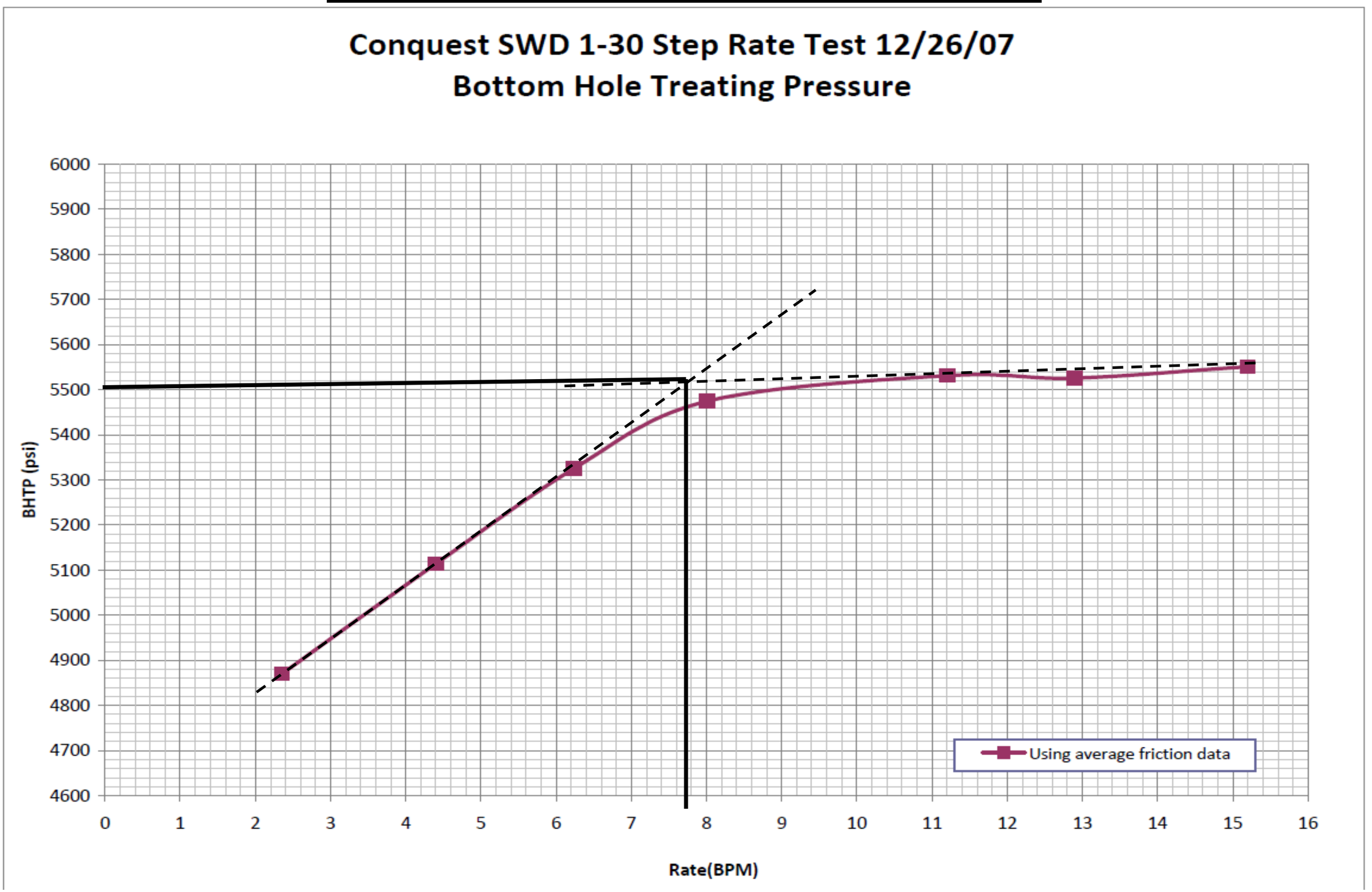
Safeguards

- Injection volume limits
- Injection Pressure less than fracture gradient
- Injection Rate
- Review for seismic activity: USGS
- Review for geologic maps
- DWR review for of injection zone

Step Rate Test for Fracture Gradient



Colorado Geology Survey Review

Colorado Geological Survey

Providing service and science to the people of Colorado

About CGS | Avalanche Info Center | Colorado Geology | Education | Energy Resources | Geologic Hazards | Geologic Mapping | Geological Research | Land Use Regulations | Miner Resourc

Home > Geologic Hazards > **Earthquakes**

Earthquakes

- Origin of Earthquakes
- Colorado's Largest Earthquakes
- What To Do In An Earthquake
- Faults
- Risks, Hazards & Loss
- Colorado Earthquake Hazard Mitigation Council (CEHMC)
- Western States Seismic Policy Council
- Earthquake Reference Collection
- Seismometer Networks
- Triggered (Induced) Earthquakes
- Trinidad Earthquakes

Earthquakes in Colorado

Most people are surprised to learn that natural earthquakes occur in Colorado!

They are even more surprised to learn that we experienced a magnitude 6.6 earthquake in the late 19th Century.

Colorado is most famous in the earthquake literature for the swarm of earthquakes during the 1960s that were triggered by pumping waste fluids down a well at the Rocky Mountain Arsenal. All of this contributes to a false sense of security concerning the possibility of a damaging earthquake(s) hitting Colorado.

To learn more, read our **Earthquake RockTalk** and watch the **Colorado Earthquakes** video.

The map pictured above shows the historic earthquakes we've recorded since 1867. The CGS maintains an **Interactive Earthquake and Fault Mapserver** which contains information on all cataloged earthquakes in Colorado. In addition to earthquakes, the mapserver also has the information on, fault lines that were determined to have ruptured within the last 23 million years.

CGS also has an **Earthquake Reference Collection** (ERC) which contains more than 500 references to ear within the state, some rather hard to find in most libraries. To access the ERC and those publications that are PDFs, click **here**.

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Earthquakes - 7 days, M2.5+

ANSS | GSN

Quick Start and User Guide

Jump to: World | US | California | Alaska | Hawaii | Puerto Rico

Felt something NOT on this map? Report it here!

Choose Data Feed

Data Feed: 7 days, M2.5+

Auto-update every 1 minute

Summary

Updated 2013-01-12 16:59:30 UTC

327 earthquakes
M2.5+ events in the past 7 days

31 meet criteria
located in map area

31 displayed
based on sort order

Download Earthquakes

Control Panel

Timezone
Used for all times displayed on this page.
UTC

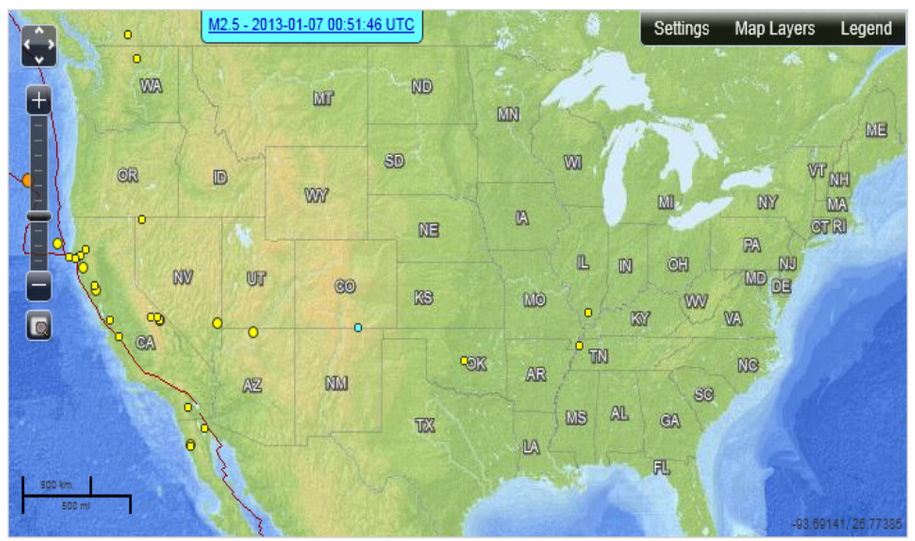
Earthquakes to Display
300

Earthquake Age
Days before present
0.0 — 7.0

Magnitude
2.5 — 10.0

Depth
Kilometers
0 — 1000

Intensity
ShakeMap Maximum MMI
0.0 — 10.0



M	Location (Click event below for details)	Time (UTC)	Lat	Lon	D (km)
2.5	2km SE of Princeton, Canada	2013-01-08 18:18:36	49.446°N	120.488°W	0.0
2.5	17km SW of Trinidad, Colorado	2013-01-07 00:51:46	37.057°N	104.644°W	5.4
2.6	40km SW of Ferndale, California	2013-01-09 23:59:44	40.292°N	124.568°W	18.9
2.6	1km SSE of Spencer, Oklahoma	2013-01-08 23:18:36	35.515°N	97.371°W	5.3
2.6	8km NE of Bishop, California	2013-01-08 18:16:26	37.417°N	118.321°W	8.1
2.6	6km SE of Ridgely, Tennessee	2013-01-07 18:29:13	36.224°N	89.436°W	6.3
2.6	17km SSE of Mammoth Lakes, California	2013-01-07 03:34:32	37.515°N	118.874°W	7.2
2.6	26km WNW of Redway, California	2013-01-07 01:42:34	40.216°N	124.114°W	13.4
2.6	6km NE of East Foothills, California	2013-01-06 16:09:15	37.423°N	121.768°W	6.6
2.6	73km ESE of Lakeview, Oregon	2013-01-05 17:16:46	41.911°N	119.544°W	0.0
2.7	3km ESE of Marion, Illinois	2013-01-11 02:28:46	37.714°N	88.897°W	16.0

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STANDARD CONDITIONS OF APPROVAL

ALL APPROVED INJECTION PERMITS HAVE:

- Maximum Allowable Injection Pressure that is below the injection zone fracture pressure.

- Maximum Allowable Injection Volume: this is calculated to hold the radius of influence of injected fluid to ¼ Mile. The volume may be increased at a later date with additional review and approval by COGCC.

- There may be special data, test or log required periodically.
  - Bradenhead test
  - Temperature, radioactive or noise logs
  - Cased hole integrity logs
  - Transit Analysis.

UIC Inspection and Enforcement

FOR BOTH DISPOSAL AND SECONDARY RECOVERY

- All UIC wells are inspected annually
  - INJECTION PRESSURE IS CHECKED
  - ANNULAR PRESSURE IS CHECKED

- All UIC wells are pressure tested for casing integrity every 5-years.

- All UIC wells are equipped with a packer and tubing annulus are inspected for leaks through by opening the tubing annulus value.

- Any well showing abnormal pressure on the tubing annulus is required to cease injection, be repaired of abandoned.

Planning - Risk Management Plan: Traffic Lights

Green — Continue operations – no seismicity felt at surface (MMI I-II)*

Amber — Modify operations – seismicity felt at surface (MMI II-III+)*

Red — Suspend operations – seismicity felt at surface with distress and/or damage (MMI V+)*

Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	none	none	none	Very Light	Light	Moderate	Moderate Heavy	Heavy	Very Heavy
Peak Acceleration (%g)	<0.17	0.17 to 1.4	1.4 to 3.9	3.9 to 9.2	9.2 to 18	18 to 34	34 to 65	65 to 124	>124
Peak Velocity (cm/s)	<0.1	0.1 to 1.1	1.1 to 3.4	3.4 to 8.1	8.1 to 16	13 to 31	31 to 60	60 to 116	>116
Magnitude	1 – 2.9	3 – 3.9	4 – 4.4	4.5 – 4.9	5 – 5.4	5.5 – 5.9	6 – 6.4	6.5 – 6.9	7.0+
Modified Mercalli	I	II to III	IV	V	VI	VII	VIII	IX	X+
Traffic Lights *									

* *Established based upon local conditions, demographics and codes*

AXPC / Industry induced seismicity SME presentation

Key Points

1. ***Colorado has several case studies on induced seismicity***
2. ***Colorado's Underground Injection Program has evolved***
3. ***There safeguard for underground injection***
   - ✓ Injection volume limits
   - ✓ Injection Pressure less than fracture gradient
   - ✓ Injection Rate
   - ✓ Review for seismic activity: USGS
   - ✓ Review for geologic maps
   - ✓ DWR review for of injection zone

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Oil & Gas Conservation Commission

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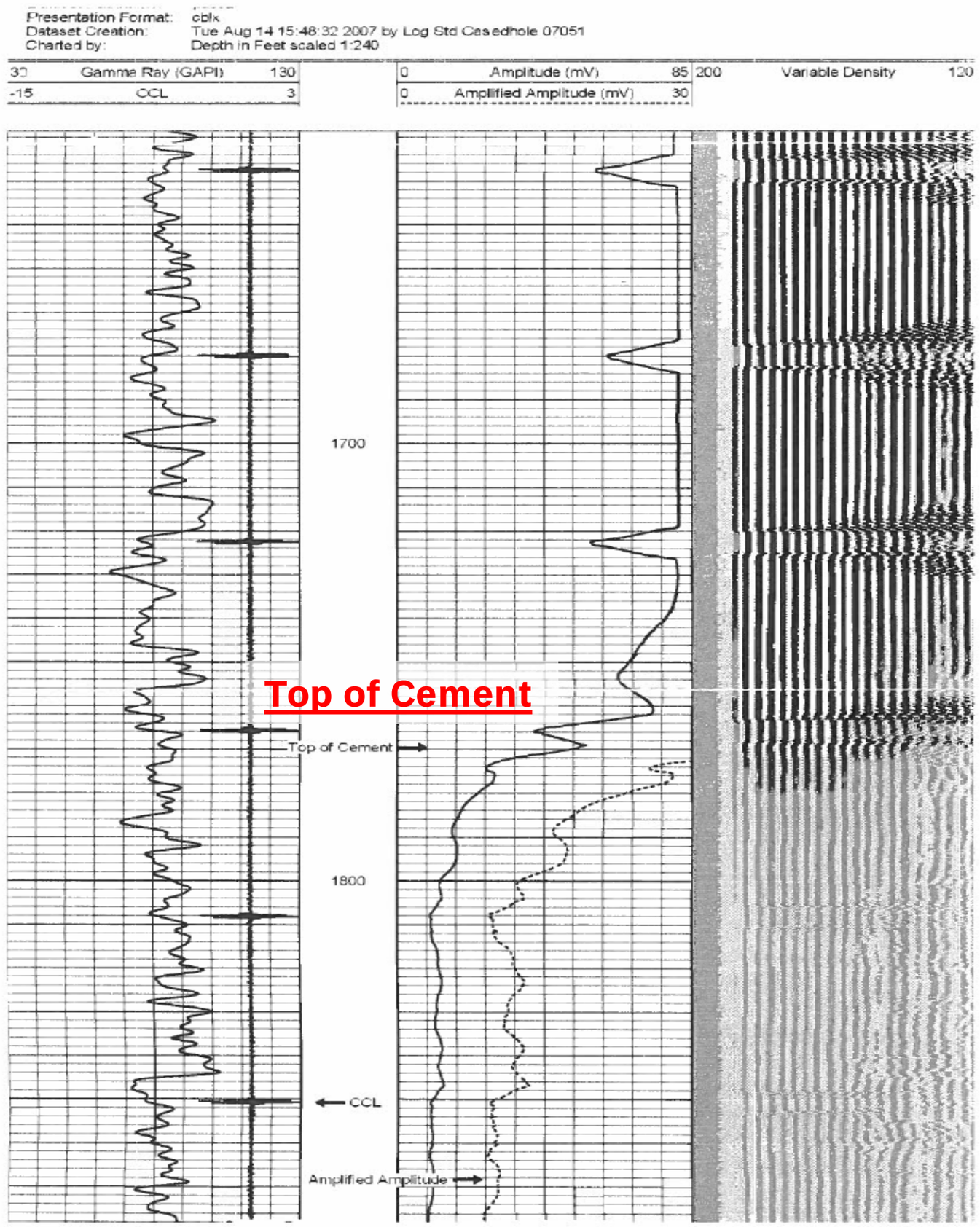
EXTRA SLIDES

CEMENT BOND LOG

317.o. Requirement to log well. For all new drilling operations, the operator shall be required to run a minimum of a resistivity log with gamma-ray or other petrophysical log(s) approved by the Director that adequately describe the stratigraphy of the wellbore. *A cement bond log shall be run on all production casing or, in the case of a production liner, the intermediate casing, when these casing strings are run.* These logs and all other logs run shall be submitted with the Well Completion or Recompletion Report and Log, Form 5. Open hole logs shall be run at depths that adequately verify the setting depth of surface casing and any aquifer coverage. These requirements shall not apply to the unlogged open hole completion intervals, or to wells in which no open hole logs are run.

Cement Bond Logs to verify placement of cement

Per COGCC Rule 317.o requires cement bond logs for all wells.



Calculation of Maximum Injection Volume

$$MIV = \phi\ h\ \pi\ (1/4\ mile)^2$$

ϕ = Porosity

h = Reservoir height

π = PI

Calculation of Maximum Injection Pressure

1. Calculate the fracture gradient (FG):

FG = [ISIP* + (.433XSGXD)] / D

*Or whatever pressure is determined to be used

2. Calculate the maximum injection pressure (Pmax):

Pmax = [FG - (.433XSG)] X D

Figure 1 – Comparison of Richter Magnitude Scale and MMI Values

Richter Magnitude	Description	MMI	Earthquake effect observations	World-wide occurrence
< 2.0	Micro		Micro earthquakes not felt by people and detected by sensitive instruments only.	Continual >8,000 per day
2.0 – 2.9	Minor	1	Imperceptible: Not felt except by a very few people under exceptionally favorable circumstances.	1,300,000 per year (est.)
3.0 – 3.9		2	Scarcely felt: Felt by only a few people at rest in houses or on upper floors buildings.	130,000 per year (est.)
		3	Weak: Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognized as an earthquake.	
4.0 – 4.9	Light	4	Largely observed: Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic. Walls may creak; doors, windows, glassware and crockery rattle.	13,000 per year (est.)
		5	Strong: Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed. Small objects are shifted or overturned, and pictures knock against the wall. Some glassware and crockery may break, and loosely secured doors may swing open and shut.	
5.0 – 5.9	Moderate	6	Slightly damaging: Felt by all. People and animals alarmed. Many run outside. Walking steadily is difficult. Objects fall from shelves. Pictures fall from walls. Furniture may move on smooth floors. Glassware and crockery break. Slight non-structural damage to buildings may occur.	1,319 per year
		7	Damaging: General alarm. Difficulty experienced in standing. Furniture and appliances shift. Substantial damage to fragile or unsecured objects. A few weak buildings damaged.	
6.0 – 6.9	Strong	8	Heavily damaging: Alarm may approach panic. A few buildings are damaged and some weak buildings are destroyed.	134 per year
7.0 – 7.9	Major	9	Destructive: Some buildings are damages and many weak buildings are destroyed.	15 per year
8.0 – 8.9	Great	10	Very destructive: Many buildings are damaged and most weak buildings are destroyed.	1 per year
		11	Devastating: Most buildings are damaged and many buildings are destroyed.	
9.0 – 9.9		12	Completely devastating: All buildings are damaged and most buildings are destroyed.	1 per 10 years (est.)
10.0+	Massive	>12	Never recorded, widespread devastation across very large areas.	Unknown

Figure 1 – Comparison of MMI Values and Magnitude Scale

Potential Damage	MMI	Perceived Shaking	Approximate Magnitude*	Description of Intensity Level
None	I	Not Felt	1.0 - 3.0	Not felt except by a very few under especially favorable conditions.
	II	Weak	3.0-3.9	Felt only by a few persons at rest, especially on upper floors of buildings.
	III			Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
	IV	Light	4.0-4.9	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
Very Light	V	Moderate	4.0-4.9	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
Light	VI	Strong	5.0-5.9	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
Moderate	VII	Very Strong	5.0-6.9	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
Moderate/ Heavy	VIII	Severe	6.0-6.9	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
Heavy	IX	Violent	6.0-6.9	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
Very Heavy	X	Extreme	>7.0	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
	XI			Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
	XII			Damage total. Lines of sight and level are distorted. Objects thrown into the air.