

From: [Art McGarr](#)
To: [Keller, G. Randy](#)
Cc: [William Ellsworth](#); [Holland, Austin A.](#); [Keranen, Katie M.](#)
Subject: Re: M5.6 Oklahoma earthquake
Date: Friday, November 18, 2011 1:18:49 PM

Hi Randy,

Thanks very much for getting back to us. From the information you provided so far, it looks as though we will have to be patient with regard to resolving the question of whether the recent earthquake sequence, including the M5.6, is induced or natural. Let's definitely discuss this at the AGU meeting. I'll be there all five days, I think, and can meet you almost any time during the meetings. My only conflict is when I have to give a talk at 4:45 on Thursday afternoon. I should probably be there for the entire session (S44B, 4 - 6 pm). Aside from that session, I'll can meet you at a time and place of your choosing. I'll try to digest the report you sent in the meantime. If you manage to find out anything before the AGU, we would be grateful for any information. Best wishes, Art

On Nov 17, 2011, at 9:41 PM, Keller G.Randy wrote:

Hi Art: I of course remember you. I am in Beijing at a meeting about China's megaproject called SinoProbe. Earthquakes (even the Oklahoma ones) are of course a major topic of discussion.

We are trying to find out more about the injection wells in the Lincoln County area ourselves, but we have been covered up by the task of running aftershock studies. Thankfully, we have had some help from the USGS.

The Oklahoma Corporation Commission is the body that permits the injection wells, but they do not make operators report much after they receive their permits. We know that the volumes are large (10,000's of barrels/day) in many wells, but the injection pressure is low because the Cambro-Ordovician Arbuckle limestone/dolomite is incredibly porous. The biggest volume we know about is in 2 wells between Norman and Oklahoma City and is ~100,000 barrels/day. There is virtually no seismicity near these wells. Just east of Oklahoma City near Jones, a swarm of small events has been going on for ~2 years, but there are only a few injectors around, and they spatially correlate poorly with the seismicity and have volumes on the order of 3000 barrels/month. I was at a meeting last week that focused on the Osage Country area, which is just north of Lincoln County. There they are injecting volumes that approach 50,000 barrels/day in a number of wells.

In most cases in central Oklahoma, the Silurian/Devonian Hunton Formation has been very prolific. At current oil prices, producers can extract fluids from it, extract the oil (gas?) that is 10% or less of the volume, and inject the waster water in the deeper Arbuckle Formation. There has been an effort called the Hunton Dewatering Project going on in the Lincoln Country area, but it is not clear to us yet what the geographic limits of this effort are. I have found one DoE report about

this, and it is attached.

In regard to New Dominion, I have to be careful in contacting them. They have been very open with us about the wells between Norman and Oklahoma City (they even gave us money to buy seismic systems to install around their wells). However, this was before my time at OU, so I need to do a little more homework before contacting them. I will do this the week after Thanksgiving.

I hope this information is helpful, and we will do what we can before the AGU meeting. We certainly would like to meet with you there.

Cheers, Randy

<Hunton_dewater.pdf> <ATT00001.html>

From: [Andrews, Richard D.](#)
To: emily.sutton@kfor.com
Subject: fracking
Date: Friday, March 21, 2014 9:00:00 AM
Attachments: [earthquakes fig.pdf](#)
[disposal wells.pdf](#)

Hi Emily:

As you can imagine, the issue concerning well fracking, waste-water (salt water) disposal (SWD), earthquakes, and ground water contamination is a very sensitive issue. At the Survey, we have to be careful in what we say since any conclusions should be backed with data. So in this regard, what I am saying is my own personal opinion but it is shared by virtually all my O&G colleagues. Unfortunately, any conclusive data linking earthquakes, fracking, and SWD is still lacking. There is however, a lot of circumstantial evidence as that portrayed in the attached figures. These illustrations would be quite shocking to the general public though the information is public if one knew how to get it!. Although everything in this email can be retrieved under the “freedom of information act”, it should nevertheless be treated with caution and of course, you did not get it from me!

The general public and media are generally mistaking the cause of recent earthquakes in the “Carnie Triangle” as I call it (the triangle in the first attachment) and more recently, the rash of quakes in northcentral Oklahoma. Most think they are caused from hydraulic fracking in horizontal wells but this is simply not the case. The same fracking is also in no way causing ground water contamination since these wells have redundant casing protocols making it almost impossible to leak injection fluids or produced materials into the shallow subsurface. One must remember that groundwater beneath about 350 feet is highly brackish or saline and therefore unusable for human drinking/irrigation.

However, the recent trend in recovering oil from depleted oil reservoirs, particularly the Hunton carbonates and the Mississippian limestone results in the recovery of unthinkable volumes of salt water. A relatively small percentage of recovered fluid consists of oil and the remainder is simply salt

water. The oil is separated at the surface and the water is then re-injected into a lower formation called the Arbuckle. Many billions of gallons of salt water are disposed of each year in this process! The Arbuckle is highly fractured in places and has enormous porosity in the form of vugs and cavities. The Arbuckle seems capable of “taking” unlimited volumes of waste water with little or reduced injection pressure. Nobody knows for sure where all this water goes; some of it likely works its way into the igneous “basement” rocks whereas much of it is somehow stored in the Arbuckle. The bottom line is that since this practice started several years ago, earthquakes suddenly became common (see the bottom figure in the first attachment). It is the belief of most petroleum geologists that the sudden increase of earthquakes is caused by removing huge volumes of water from a shallower formation and disposing it into a deeper formation. Of course, the argument against this lies in the location of disposal wells and the epi-centers of earthquakes; they are not always the same! To me, this simply indicates that in some instances, the injected waters travelled a considerable distance in the subsurface. Even so, no one knows for sure just how the injected water “pulls the trigger” in causing an earthquake. But it does in my opinion. The areas outlined in the triangle and rectangle are under tremendous stress due to the presence of many small and large fault zones. Like the old saying, “if it smells like a dog, barks like a dog, wags its tail like a dog, it probably is a dog”.

I hope this information helps you.

Sincerely,

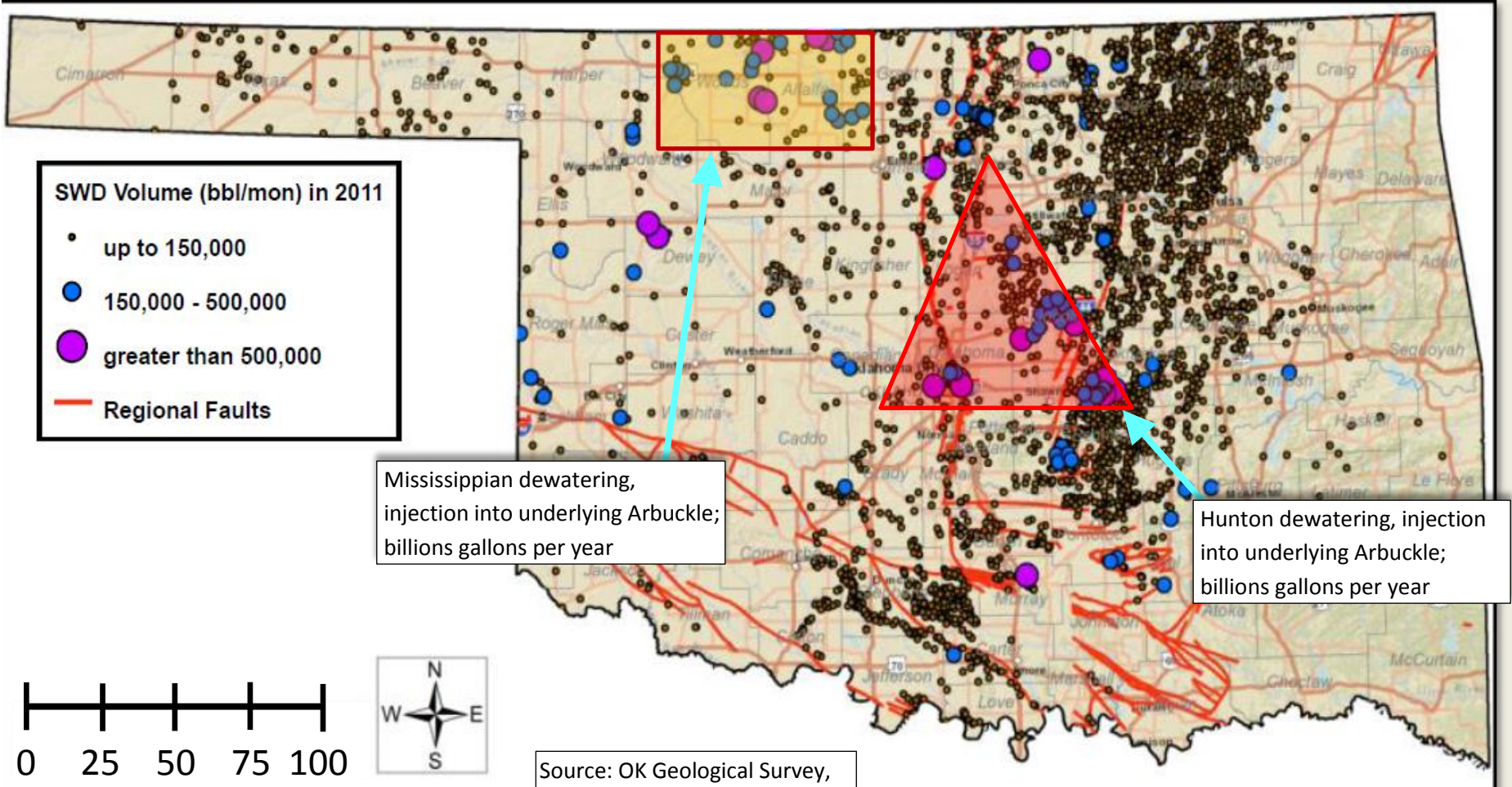
Rick Andrews

Salt-Water Disposal Well (SWD) Injection Volumes (barrels per month/well)

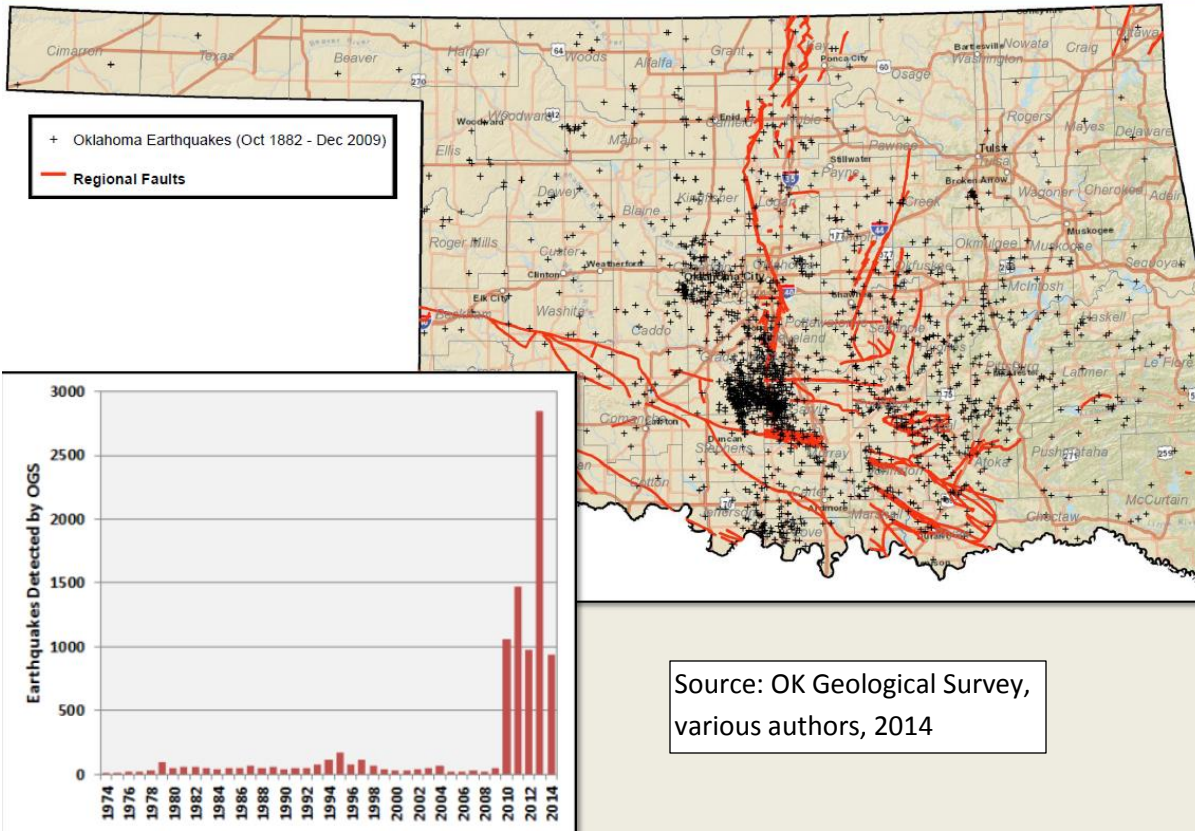
Note: 1 barrel = 42 gallons

676 Osage SWD Wells with > 0bbl

3003 Non-Osage SWD Wells with > 0bbl (~217-350 Commercial)

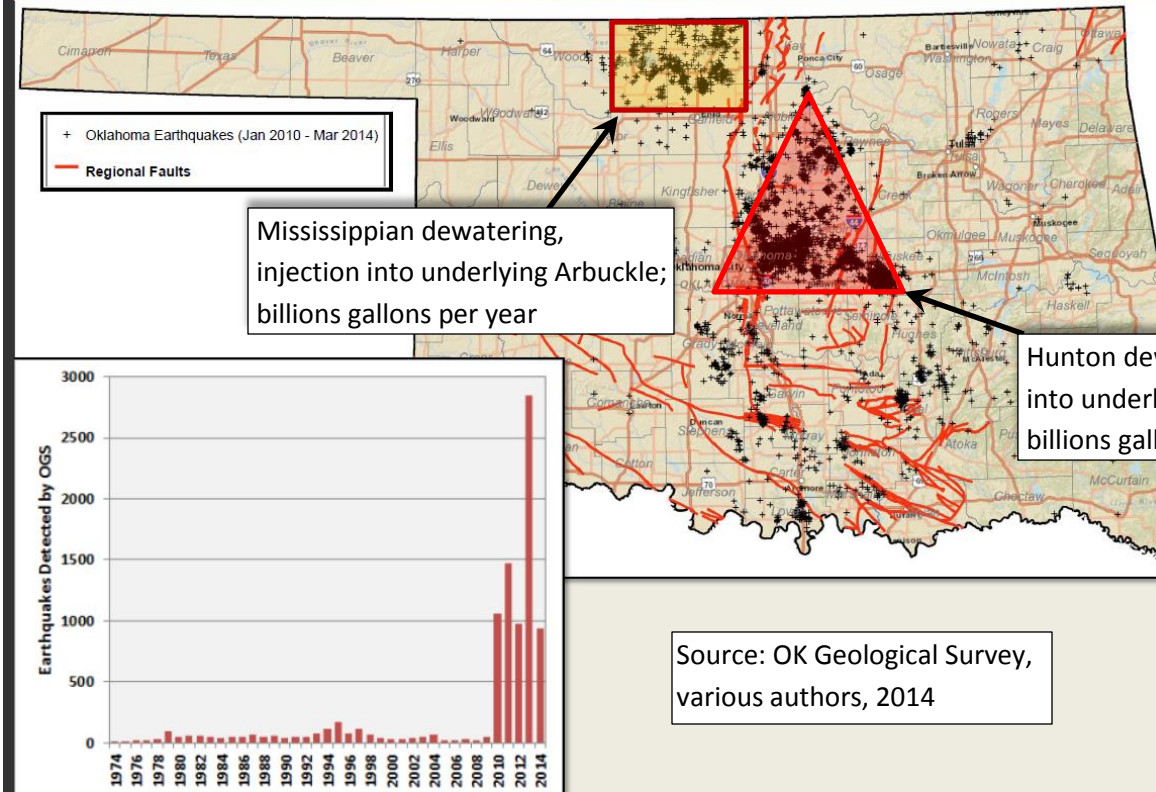


Epicenters of Earthquakes recorded by OGS, Oct 1882 – Dec 2009



Historical earthquake occurrences: pre-disposal era

Epicenters of Earthquakes recorded by OGS, Jan 2010 – Mar 2014



Mississippian dewatering, injection into underlying Arbuckle; billions gallons per year

Hunton dewatering & injection into underlying Arbuckle; billions gallons per year

Earthquake occurrences: post-disposal era

Hi everyone:

Very early this morning around 1:45, I was jolted out of bed by another moderate earthquake. I had thought earlier that the house shook but dismissed it and fell back to sleep. The epicenter was located about 20 miles east of Edmond. A sharp “bang” accompanied the larger quake that was measured at 4.3. Coincidentally, I had discussed quakes with my former colleague Dan Boyd the day earlier as the Survey is currently dismissing such events as being naturally-occurring. Sooner or later, the media will pick up on the real cause and create a genuine ruckus. I am dismayed at our seismic people about this issue and believe they couldn’t track a bunny through fresh snow!

On another issue that few people are not affected – global warming. I was thumbing through a magazine in our main office when I came across a figure depicting atmospheric CO₂ concentrations throughout geologic time. We all know that concentrations of this gas are increasing rapidly since the beginning of industrial times but for comparison, the attached graph shows estimated levels of CO₂ during the past 500 million years of earth’s history. On the horizontal axis, K = Cretaceous and J = Jurassic (the period of dinosaurs). “C” denotes Carboniferous –the age of extensive swamps and forests across much of prehistoric earth. And the youngest period “N” pertains to the Neogene which dates the past 2.5 – 23 million years before present. Of significance, is that the current CO₂ concentrations on earth is 15 – 30 times less than historic periods when life flourished on Earth! Each of you can be the judge whether or not this is bad!

I have to run; hope you have a grand day.

Love, dad/uncle ricky/me

From: Holland, Austin A.
To: Keller, G. Randy
Subject: FW: OK Earthquakes
Date: Monday, September 22, 2014 8:44:33 AM

From: Dan Boyd <scarab71254@gmail.com>
Date: Saturday, September 20, 2014 at 9:13 AM
To: Austin Holland <austin.holland@ou.edu>
Cc: "Suneson, Neil H." <nsuneson@ou.edu>, "Andrews, Richard D." <rdandrews@ou.edu>
Subject: OK Earthquakes

Austin:

I know that you're incredibly busy, but I've been thinking about this for awhile and I had an idea that you or others may want to pursue if you have not already.

We know that the Arbuckle/Precambrian hydrologic system is underpressured because it can receive incredible volumes of water on vacuum. This implies that the Sylvan and/or Woodford, or other intervals above have acted as an effective seal from the rest of the stratigraphic column through time - as shallower zones are mostly normally pressured.

The disposed water must dominantly be taken up by the fracture system that we know extends from the Arbuckle into the pre-Cambrian as any fluid will always take the path of least resistance (the Deep Throat wells drilled by New Dominion show these open fractures in both the Arbuckle and the PC, and we have logs to prove this). If so, then the limited storage capacity of these fractures, although they are extensive, are probably now being brought up to hydrostatic pressure. This may take a long time, but it suggests, at least to me, that with a limited container taking the fluid, that the pressure within these fractures will build in direct proportion to the volumes being injected and that these pressures will not dissipate until the fluid can move perhaps hundreds of kilometers across all areas where the Arbuckle/PC system is underpressured. In other words, spread out. This may explain why the number and more importantly, the magnitude of the earthquakes is increasing.

If we have some idea as to the spacing, average width (openness) and the depth at which these fractures exist, it would be possible to do a 'simple' volumetric calculation to try and predict what the ultimate storage capacity is. This would only apply to the PC interval as because the earthquakes are not within the sedimentary section the porosity of the Arbuckle and what it could store should not be a factor. If you could get pressures within the fractures that would be great, but it would require a lot of cooperation from many companies. However, with enough data I think it might be possible to come up with almost a reservoir simulation that could help predict where we might be going. It may be possible that for some of the high volume disposal wells that the water is not going into the ground as readily due to the increased pressures.

Sorry for the ramble, but this topic is one that I find fascinating. I tried to cc Randy, but my OU e-mail wouldn't pull him up, so please send this on if you think it appropriate. This is my permanent address as OU has cut me off after March.

You've got a tough job, guy.

Cheers:

Dan (Boyd)

From: [Boyd, Daniel T.](#)
To: [Suneson, Neil H.](#); [Andrews, Richard D.](#)
Subject: FW: oil and gas field information
Date: Thursday, February 20, 2014 1:00:57 AM

7 of 7

From: Boyd, Daniel T.
Sent: Friday, May 10, 2013 3:22 PM
To: Keranen, Katie M.
Subject: RE: oil and gas field information

Katie:

I no longer have access to Oklahoma oil and gas data, but if you go through the old annual drilling activity articles I wrote for the Shale Shaker (OCGS Pub) there are updated play maps in all of those.

You are one of the first to get on the correct track as to the origin of the OK earthquakes. The first big ones occurred in about 2007 ? or so when Mankin was still director. New Dominion's massive disposal wells for the dewatering of the Arbuckle in the Oklahoma City Field were clearly responsible - we met with them and they paid for a set of stations to be erected around the injection site. They were really worried about possible bad press. At the time these wells were putting 300,000 barrels per day into two highly inclined wells that went through the entire Arbuckle and into the Precambrian. The FMS logs showed large, open fractures which were definitely how they were able to put those kind of volumes into the ground on vacuum. Matrix permeability alone could never allow for those kind of fluid rates.

I cannot answer for the mechanics of how these earthquakes are generated, but the weight alone of all of the water is massive. In addition, the earthquakes as time went on, migrated in a northeasterly direction - suggesting that that was where the water was going. I'm doing this from memory, but as I recall that is the direction of one of the conjugate fracture sets. The first ones were in the Tinker Airforce base area and they moved from there.

Although there is no direct proof of their being induced (Austin's contention), the timing of when these started, their location near the largest water disposal area in the State (by far), their depth, and the fact that we know there are large open fractures that extend through the Arbuckle into the basement below makes this a no-brainer in my opinion - and I've been connecting dots in the subsurface for a long time. Whether its lubrication of the faults, hydrostatic pressure as the water column grows, or a combination - I have no idea.

I brought this idea up on more than one occasion with Randy and Austin to encourage the Survey to get ahead of this, but they were understandably hesitant. This is potentially huge, given the State's reliance on oil and gas revenues. The only reason that it's been possible to keep a lid on this is because of the relatively small amount of damage and the fact there have not yet been any injuries. I called a reporter from the Tulsa World in 2011 and she said she would ask her editor if she should interview me. I never heard back.

Looking ahead, there are a number of other horizontal plays in the State that are putting ever-increasing amounts of water into the ground - the Mississippi Lime being the largest. It has the advantage of being located on the Anadarko Shelf and Cherokee Platform, where stress levels are probably less than where the Arbuckle and Hunton dewatering is going on now. I believe that a Chesapeake disposal well was suspected of causing an earthquake in Ohio.

I'm beginning to ramble, but as far as earthquakes are concerned the frac jobs have little or no effect, but the water is another story altogether. You can probably make a career out of following up on these.

Hope that all of this helps.

From: [Boyd, Daniel T.](#)
To: [Suneson, Neil H.](#)
Cc: [Andrews, Richard D.](#)
Subject: RE: OK Earthquakes
Date: Thursday, February 20, 2014 11:52:15 AM

Neil, I'll leave that up to you. I don't recall if I said anything too untoward.
Please keep me up on developments. Sounds like things could finally get interesting.

Sent from my Windows Phone

From: Suneson, Neil H.
Sent: 2/20/2014 5:08 PM
To: Boyd, Daniel T.
Cc: Andrews, Richard D.
Subject: RE: OK Earthquakes

Thanks, Dan. I think this is something Austin would be interested in, despite our (and especially your) frequent incredulity that he and Randy kept insisting they were not induced. Do you think I should give Austin hard copies of what you sent me? I ask because I'm sure (I haven't read all of what you sent me) there are comments in some of those emails that are not complimentary of either Austin or Randy. But your history with this is important. I could give him hard copies with "personal comments" redacted.

What do you think?

- Neil

From: Boyd, Daniel T.
Sent: Thursday, February 20, 2014 12:58 AM
To: Suneson, Neil H.; Andrews, Richard D.
Subject: RE: OK Earthquakes

Guys:

Please keep me up on my replacement. I wish her all of the luck in the world.

After I get done with this message I'm going to forward to you all of the correspondence that I kept regarding this. I've kept a work diary since I started working in 1978 with the just the high (or low) points - in other words, no detail.

The issue began in 2007. On 28-March-2007 we had a meeting (Charlie, Jim Lawson, Luza, and myself) in New Dominion's offices in Tulsa with David Chernicky and some of his staff over the earthquake that was so big near Tinker AFB. It created a big boom that people thought might be a terrorist attack. Speaking only for myself, that earthquake hitting right next to twinned disposal wells injecting 300 MBW (Deep Throat-1 and -2) nailed the correlation. I called David on 15-February 2007 to talk to him about it and he I think tacitly agreed, or he wouldn't have held the meeting and given us the logs and paid for the seismic stations. It's a meeting I'll never forget for a number of reasons (Charlie's dimensia and Chernicky coming in in shorts and continuously answering two cell phones he laid on the table).

As you know I wrote some stuff online (I can't remember the forum) outlining my thoughts to various people - I think that I may have cc'ed you on some of these, Neil. I also initiated a telephone interview

with Amanda Bland with the Tulsa World on 8-November 2011 that she couldn't get permission from her editor to print. Neither of you guys were surprised. I also recall that staff meeting we had (16-December 2011) where Randy and Austin kept up the 'natural phenomenon' story and them looking at me like I was crazy.

Your friend Ms. Kernanen - who never replied after I sent her my thoughts, is one of them, Neil.

Here they come.

D

From: Suneson, Neil H.
Sent: Wednesday, February 19, 2014 4:53 PM
To: Boyd, Daniel T.; Andrews, Richard D.
Subject: RE: OK Earthquakes

Dan –

Did Rick tell you that a bunch of us were served with a “freedom of information” request a couple of weeks ago? A guy connected with KGOU, but asking through KOSU, asked about 10 of us at the Survey for any and all emails over the last 3 years that contained the words earthquake, fracking, injection, etc. etc. Rick was included, as was I, Randy, Austin, Julie, and more. OU IT, of course, stashes everyone’s emails in their computers, so they were to scour all our emails. We were allowed to redact any “research” information that might be private, but of course since Rick and I don’t do any research on earthquakes, all our emails were fair game and going to be turned over to KOSU. (There was one email of mine in there that was pretty critical of Randy, but nothing that many people would disagree with.)

The shit has really hit the fan around here re: earthquakes and Austin’s research and the demands of OU’s administration, certain alums, etc. etc. etc. If Austin hasn’t aged 20 years in the past 3 he’s a better man than I. We have a new geophysicist to help Austin out, but it’s not the science, it’s the politics, and she (no one) will be able to help him out on that account.

Meanwhile, the rest of us trudge along trying to keep our heads down.

Rick and I are interviewing a woman today for our long-open petroleum geologist position. My question to her will be, “Why the hell would you want to work in this place?” No raises, no support, we’re the bastard-offspring of the School, the list goes on. Oh well – I’m outahere in a few years, so I don’t care.

And on that cheery note Hi to Starla!!! - Neil

From: Boyd, Daniel T.
Sent: Tuesday, February 18, 2014 10:07 PM
To: Suneson, Neil H.; Andrews, Richard D.
Subject: OK Earthquakes

An Oklahoma Geological Survey [statement Monday said](#), “The OGS has not ruled out that some earthquakes may have a relationship to oil and gas activities.”

Holy shit, on the USGS site there were 7 (>2.5 magnitude) in the last week. The Survey is in danger of