Wellington KS CO2 EOR Project
Monitoring CO2

• August 5, 2016

• Dana G. Wreath

• Vice President Engineering

• Berexco LLC – a private oil and gas company based in Wichita KS

• Operator of Wellington Field in southern KS
DANA G. WREATH

PRESENT POSITION:

Vice President  
BEREXCO, LLC  
Wichita, Kansas

EDUCATION AND TRAINING:

B.S. - University of Kansas, Petroleum Engineering – 1987  
M.S. - University of Texas, Petroleum Engineering – 1989  
Many Petroleum Engineering Continuing Education Courses

PROFESSIONAL EXPERIENCE:

2010 - Present  Vice President, BEREXCO, LLC., Wichita, Ks.  
1996 - 2010  Division Engineer, BEREXCO, INC., Wichita, Ks.  
1992 - 1996  Reservoir Engineer, BEREXCO, INC., Wichita, Ks.  
1989 - 1992  Reservoir Engineer, Mobil E&P US, Houston, TX
DOE Funded CO2 Research

QUARTERLY PROGRESS REPORT

To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

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EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO₂ are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both in situ and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO₂ using lab and field testing and comprehensive characterization and modeling techniques.

CO₂ will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO₂ plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO₂ plume and estimate tonnage of CO₂ stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO₂ leakage. A rapid-response mitigation plan will be developed to minimize CO₂ leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO₂ shall be supplied from a reliable facility and have an adequate delivery and quality of CO₂.
DOE-NETL Contract #FE0006821

L. Watney (Joint PI), J. Rush (Joint PI), T. Bidgoli, J. Doveton, E. Holubnyak, M. Fazelalavi, R. Miller, D. Newell, J. Hollenbach
(static & dynamic modeling, well test analysis, high-resolution seismic, passive seismic, accelerometers, geomechanical analysis, project management)

Tom Daley, Barry Freifeld (CASSM, U-Tube, cross well seismic)

Jennifer Roberts, Leigh Stearns (cGPS), Mike Taylor (InSAR), George Tsoflias (passive and active seismic)

T. Birdie (Class VI permitting, monitoring, synthesis, reporting, closure)

Brian Dressel, DOE Project Manager

Dana Wreath & Adam Beren (field operator and operations, repeat 3D multicomponent seismic)

CO₂ supply

seismometers

T. Birdie Consulting, Inc.

Department of Geology
Wellington Field
Site of Small Scale Field Test

Top Mississippian Structure, 10 ft C.I.

20 Million Barrel Oil Field above Arbuckle Group
South-central Kansas CO₂ Project
Kansas Geological Survey

Updates

<table>
<thead>
<tr>
<th>June 2016</th>
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<tr>
<td>New presentations from Carbon Capture, Utilization &amp; Storage Conference, June 2016.</td>
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<table>
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<td>Eighteenth Quarterly Report for Small Scale Field Test.</td>
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<td>New photos from a recent tour of the CO₂ injection site.</td>
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<td>New presentation from Kansas NextStep Conference in Hays, April 2016.</td>
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About...

South-central Kansas CO₂ Project is a DOE-funded project of the Kansas Geological Survey. More...

Topics...

- Home
- Small Scale Field Test
- Presentations
- Reports
- Well Data
- Well 1-32
- Well 2-32
- Well 1-28
- Interactive Map
CO$_2$-EOR Technology & Carbon Management Research in Kansas

- Utilize oil and gas field Infrastructure
- Utilize comparable approaches to characterization and simulation of oil and reservoirs
- Evaluated sites for commercial scale carbon storage sites in aquifers beneath existing oil fields
- Conduct small scale CO2-EOR injection at Wellington Field, Sumner County Kansas
- KU & partners have performed extensive research on:  
  - monitoring  
  - verification  
  - accounting of the CO$_2$ over the long term
Geologic Carbon Utilization & Storage

DOE-NETL
Wellington Project Current Status

• CO2 EOR Project is the first phase at 3600’ depth, then deep saline injection to follow (USEPA Class 6) at 5100’ depth.

• CO2 EOR injection began Jan 2016 and was completed June 22, 2016.

• EOR recovery, monitoring and CO2 mass balance measurement currently ongoing.

• USEPA Class 6 Injection Permit pending for saline injection phase. Timing?
CO$_2$ Utilization in Enhanced Oil Recovery (EOR)

CO$_2$ mixes with oil and CO$_2$ is recycled.
Mississippian Reservoir

- Java web app (freeware);
- archive well data as LAS 3.0

http://www.kgs.ku.edu/software/PfEFFER-java/
Pilot CO$_2$-EOR well drilled in 2015 and injection began in January 2016
Mississippian dolomite reservoir in Wellington Field
Sumner County, Kansas

Berexco LLC
Wellington KGS #2-32
2680'FSL & 709'FEL, Sec 32, T 31S, R 1W
Sumner County, Kansas

**Drilled in March 2015**
Wellington CO2 Project
Wellington CO2 Monitoring

• CO2 Flowmeter at injector wellhead.
• Temperature sensor at injector wellhead
• Water Flowmeter at wellhead
• CO2 Flowmeters at producing wells
• CO2 Flowmeter at tank battery
Wellington Automation System

Summary Page
Alarm Roster
Main Page

KGS 2-32

Data Age
Demand Poll
Continuous Fast Poll

261.0 PSI

INJECTION PUMP
1494 RPM
33 AMPS
384 VOLTS

CHARGE PUMP
1310 RPM
5 AMPS
460 Volts

WELL
239.0 PSI

MC-III
Rate  1204.7 Bbls/Day
CDay Vol 1058.5 Bbls
PDay Vol 0.0 Bbls
Total Vol 81774 Bbls

Operations Notebook

MC II Meter repaired and calibrated 19:30
Comment

MC III Meter not working correctly since 10:27 on 3/14/15. Parts are ordered. Rate is between 1500 and 1600 BPD
Comment + 1 comment

MC III Meter and noise located and fixed 14:02 3/14/15

MC III Meter not working correctly since 10:27 on 3/14/15. Parts are ordered. Rate is between 1500 and 1600 BPD
Comment + 1 comment

MC III Meter and noise located and fixed 14:02 3/14/15

Start
Stop
Reset

EMERGENCY SHUTDOWN
Liquid CO2 Injection Meter Display
# CO2 Properties

**Linde LLC Data**

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<th>Volume of Gas @ 60 F, 1 ATM</th>
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CO2 Injection

5/23/16  1269 BBL CO2 injected @ 174# TP. Current rate 1327 BPD. E. Nelson 26 BO.
5/24/16  1081 BBL CO2 injected. Had to switch to water while repairing CO2 pump. E. Nelson 23 BO.
5/25/16  Injected 886 BBL water @ 0# TP. Current rate 1213 BPD. Switched back to CO2. E. Nelson 28 BO.
5/26/16  1668 BBL CO2 injected @ 173# TP. Current rate 1230 BPD. E. Nelson 22 BO.
5/27/16  1383 BBL CO2 injected @ 163# TP. Current rate 1367 BPD. E. Nelson 45 BO.
5/28/16  1515 BBL CO2 injected @ 175# TP. Current rate 1499 BPD. E. Nelson 43 BO.
5/29/16  1331 BBL CO2 injected @ 160# TP. Current rate 1412 BPD. E. Nelson 37 BO.
5/30/16  1502 BBL CO2 injected @ 166# TP. Current rate 1588 BPD. E. Nelson 27 BO.
5/31/16  1480 BBL CO2 injected @ 154# TP. Current rate 1428 BPD. E. Nelson 28 BO.
6/1/16   1472 BBL CO2 injected @ 180# TP. Current rate 1453 BPD. E. Nelson 28 BO.
6/2/16   1758 BBL CO2 injected @ 180# TP. Current rate 1543 BPD. E. Nelson 28 BO.
6/3/16   1186 BBL CO2 injected @ 160# TP. Current rate 1373 BPD. E. Nelson 4 BO- cleaned stock tank.
6/4/16   1236 BBL CO2 injected @ 171# TP. Current rate 1473 BPD. E. Nelson 33 BO.
6/5/16   1433 BBL CO2 injected @ 152# TP. Current rate 1322 BPD. E. Nelson 35 BO.
6/6/16   1722 BBL CO2 injected @ 184# TP. Current rate 1575 BPD. E. Nelson 32 BO.
6/7/16   1176 BBL CO2 injected @ 200# TP. Current rate 1405 BPD. E. Nelson 33 BO.
6/8/16   1514 BBL CO2 injected @ 177# TP. Current rate 1508 BPD. E. Nelson 45 BO.
6/9/16   1514 BBL CO2 injected @ 178# TP. Current rate 1453 BPD. E. Nelson 42 BO.
Lessons Learned Measuring Liquid CO2 Injection Volume

• Temperature Matters!!
• Daily volume of liquid CO2 trucked in averaged 900 bbl, but wellhead flowmeter was reading 1400 bbl per day.
• CO2 density at -14F is different than -5F.
• Berexco installed temperature sensors tied to SPOC controller to record temp continuously.
• Recommendation: Measure gas volume at low pressure in gas phase. Its more reliable.
CO2 Produced Gas Measurement

• Cameron MC-III EXP Flow Measurement
• Installed at wellhead vent, or 2 phase separator at well.
• Separators needed to stop liquids flowing up annulus making a mess as gas volumes increase.
• CO2 Content Sensors for low volume gas venting.
Overview

NUFLO GT gas turbine flowmeters feature a transducer that utilizes a lightweight, low-inertia rotor to sense gas velocity. It offers an output frequency that has a linear relationship to gas velocity over a wide flow range.

The meter tracks the flow rate continuously, offers little resistance to flow, and has a unique cartridge design that allows removal of all internal parts as one assembly. The meter also exhibits little sensitivity to gas density above two atmospheres pressure. The low inertia of the rotor and vee bearings allows overranging of the meter to twice its rated capacity without damage for intermittent flow variations.
NUFLO™
MC-III™ EXP Flow Analyzer
User Manual
Wellington Oil Well Configuration
2 Phase Separator
CO2 Vent Measurement
CO2 Content Sensor
# CO2 Monitoring Data at Oil Wells

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<th>% CO2</th>
<th>Date</th>
<th>MCF</th>
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Well #53 – CO2 and oil produced
Well #61 – CO2 and oil produced

- Very steady CO2 produced after breakthrough with slow, recent increase in CO2
- CO2 production did not drop off midway as result of pause of the CO2
- Good, consistent oil recovery
CO2 Measurement at Tank Battery
CO2 Meter at Tank Battery
CO2 Measurement, Verification and Accounting

• Accurately measure ALL CO2 injected – volume or mass.
• Must know relationship between volume and mass if using liquid CO2!
• Accurately measure ALL CO2 at producing wells and tank batteries. Any place CO2 leaves the reservoir.
• Choose injection site carefully to avoid underground leakage.
Wellington Results

• CO2 Accounting
• Total 374,461 MCF Injected (21,784 US tons)
• Required 1,101 Truckloads, each about 20 US tons.
• Incremental Oil Production about 4,200 bbls to date.
• Approximately 11% of CO2 injected has been produced (vented)
CO₂ Injection Begins 1-09-16

Pause in CO₂ Injection

Oil Recovery Starts 2-26-16

CO₂ Injection Ends

Sustained High Volume Water Injection Begins 7-14-16

Legend
- CO₂ Purchased Daily (MCF)
- CO₂ Produced Daily (MCF)
- Cumulative CO₂ Produced (MCF)
- Incremental Oil Daily (bbls)
- Cumulative Incremental Oil (bbls)
- Cum. Ratio Produced/Purchased CO₂
- Daily Ratio Produced/Purchased CO₂
- Daily Water Injection (bbls)

CO₂ Injected and Recovered; Oil Produced Through 7/31/16
Daily Purchased MCF CO$_2$ (red) -- MCF CO$_2$ recovered (gold) ---- Daily Ratio recovered vs purchased CO$_2$ (blue)
Wellington Unit Oil Production
Summary and Future Work

• No substantial deviations due to unforeseen circumstances (carbonate fracturing, temperature, pressure, etc.)
• Successful oil recovery
• Low CO$_2$ losses due to venting or reservoir properties
• Manage CO$_2$ plume and finalize CO$_2$ injection
• 2D seismic to confirm CO$_2$ plume
Phase 2 CO2 Disposal

• Phase 2: Deep CO2 Disposal in Arbuckle Formation at 5100’ depth.
• Phase 2 goals: demonstrate CO2 can be safely disposed (sequestered) in the Arbuckle Formation.
• Phase 2 will start in 2017 (?) but waiting on disposal permit from USEPA. Getting close.
• Previously Berexco drilled two deep wells to the basement to characterize the Arbuckle reservoir, one of which will be the CO2 disposal well.
Conclusions

• Measure CO2 accurately in and out.
• Use good measurement equipment.
• Maintain good records.

• Thanks and Credits to DOE/NELT, Kansas Geological Survey, Berexco LLC.
KGS 2-32 Drilling Phase

3/20/15  Spud well 7.00 am, 3/20/2015. TD 17-1/2” conductor hole @ 140’ KB, 3/20/2015. Survey 1° @ 140’. Ran 3 jts 13-3/8” 48# conductor casing- set @ 137’ KB. Cemented with 145 sx Class A cement with 1/4# flakes and 3% CC. Finished cementing 1:15 pm, 3/20/2015. Cement circulated to surface.

3/21/15  Drilling @ 465’. TD 12-1/4” surface hole @ 650’ KB, 3/21/15. Survey 1° @ 650’. Ran open hole logs in surface hole: LTD @ 653’ KB. Log showed base of conductor @ 142’ KB. Ran 15 jts 8-5/8” 24# surface casing. Set @ 647’ KB. Cemented with 175 sx 60/40 POZ 6% gel 1/4# flakes 3% CC tailed with 150 sx Class A with 1/4# flakes and 3% CC. Plug landed 8:15 pm, 3/21/15. Cement circulated to surface.

3/22/15  Drilling out of surface casing.

3/23/15  Drilling @ 1470’. Survey 3/4° @ 1164’.

3/24/15  Drilling @ 2325’. Surveys 1/2° @ 1670, 3/4° @ 2179’.

3/25/15  Drilling @ 3135’. Surveys 3/4° @ 2624’, 1/4° @ 3134’. Displaced mud system at 2815’.

3/26/15  Conditioning hole for coring. Reached core point @ 3654’ KB 6:15 am, 3/26/2015. Survey 1/2° @ 3654’. TIH w/coring tools. Cored from 3654’ to 3669’ and core barrel jammed. TOH w/ Core #1. Recovered 15’ of core. TIH and resumed coring. core barrel jammed @ 3691’. TOH w/ Core #2. Recovered 22’ of core.

3/27/15  Coring @ 3691’. Recovered 60’ of core. Ran DST #1:
            DST #1, 3671’-3751’, Mississippi
            Times: 30-60-60-120
            IFP: 51-235#  FFP: 231-392#
            ISIP: 95#  FSIP: 950#
            Recovery: 300’ VSOSMW (Tr O, 95% W), 120’ VSOSWM (Tr O, 35% W), 120’ M;
            Chlorides 95,000 ppm

3/28/15  Drilling @ 3765’. TD well @ 3860’ 2:00 pm, 3/28/15. Survey 1/4° @ 3860’.

3/29/15  Running open hole logs- LTD @ 3860’ KB. Lay down drill pipe and drill collars. Ran 95 jts 5-1/2” 15.5# casing. Tag TD @ 3860’ KB and set casing @ 3858’ KB. Circulated half way into hole and on bottom. DV @ 2515’ KB. Baskets @ 3732’, 3608’, on jet below DV tool and at 1000’. Ran centralizers every other collars up to 3000’ and on joints above and below DV tool.

3/30/15  Cemented bottom stage with 95 sx A-Con w/ 1/4# flakes and 2% CC mixed at 2.01 cu ft/sx  with 105 sx AA-2 thixotropic cement with 5% Calseal, 1% C-44 Gas Blok CO2 resistant additive, 10% salt, 1/4# defoamer, 1/2% fluid loss, 0.3% CFR-2, and 6# gilsonite. Plug landed 2:10 am, 3/30/15. Opened DV tool and circulated 4 hours. Saw cement from bottom stage circulate to surface. Cemented top stage with 465 sx A-Con w/ 1/4# flakes 2% CC at 2.01 cu ft/sx and 50 sx AA-2. Plug landed 7:20 am, 3/30/15. Cement circulated to surface. Plugged mouse and rat holes with 50 sx A-Con. Rig released 3/30/15

3/31/15  Waiting on completion.
KGS 2-32 Completion

4/22/15  MIRU BX Rig #13. TIH w/ 4-7/8” bit, 3-  3-1/8” drill collars and 2-7/8” workstring. Tag DV @ 2515’ KB. Drill out DV tool. Tag PBTD @ 3820’ KB. Circulated hole clean with fresh water. SOH w/ tubing, drill collars and bit. Shut down.

4/23/15  FOH w/ tubing and bit. Ran CBL- PBTD @ 3815’ KB. Good bond from TD to surface. Pressured casing to 2500#- held. TIH w/ 4-7/8” bit, 5-1/2” casing scraper and 2-7/8” workstring to 3780’ KB. Shut down.

4/24/15  Swab casing fluid level down to 3150’ from surface. TOH w/ bit, scraper and tubing. Perforate Mississippi Chert from 3664’-3706’ KB, 4 SPF. Shut down.

4/25-26/15  Shut down.

4/27/15  Ran 5-1/2” X 2-7/8” Arrowset PKR. Set @ 3638’ KB. Ran swab- fluid level 1800’ from surface, 100’ free oil on top. Recovered 10.8 BW on swab down. Had 700’ fill up after 1 hour. Acidized Mississippi perfs with 2500 gallons 10% NEFE-HCI and 250 ball sealers. Treated 3 BPM @ 1300# initially, increased to 5.7 BPM @ 700# towards end. ISIP 50#, 30 seconds to vacuum. TLTR 90 BTF. Ran swab- fluid level 1100’ from surface. Recovered 44.7 BW on swab down. Next hour recovered 20.8 BTF with trace oil. Shut down.

4/28/15  Ran swab- fluid level 2000’ from surface, 50’ oil on top. Swabbed 26.7 BTF. Release PKR and run across perfs to remove any remaining ball sealers. Reset PKR @ 3638’ KB. Ran swab. Recovered 16.8 BTF on swab down.

1st Hour  19.1 BTF, fluid level 2800’ from surface
2nd Hour  23.4 BTF
3rd Hour  16.7 BTF
4th Hour  13.4 BTF
5th Hour  13.4 BTF
6th Hour  20 BTF. Fluid level stayed 2800’ from surface. Caught fluid samples.

Shut down.

4/29/15  Ran swab- fluid level 2000’ from surface, 75’ free oil on top. Injected 2 BPM for 10 minutes- took fluid on vacuum. Injected 4 BPM for 10 minutes- stabilized pressure 150#. TOH w/ tubing and PKR. RDMO BX Rig #13.
KGS 2-32 Start of Injection

6/8/15  MIRU Contract WS Rig. TH w/ nickel coated Arrowset-1X PKR with Viton rubber and 1.875” stainless steel profile nipple for X-style blanking plugs, nickel coated on-off tool and 110 gs TK-70XT coated tubing. Pump packer fluid and set PKR @ 3500’ KB. Annulus held 150#. RDMO Contract WS Rig. Will MIT well 6/10/15.

6/10/15  MLI well to 350#. Held. Witnessed by Jonathan Hill of KCC District #2 office.

6/23/15  Permit for carbon dioxide injection approved by KCC.

7/7/15  Installed 2” 2250# fiberglass water injection line from Wellington Unit #521 injection well to Wellington KGS #2-32 well.

7/27/15  Waiting on high pressure stainless steel fittings to finish hooking up wellhead.

8/3/15  Finished hooking up wellhead and began injecting water. Instantaneous rate 300 BWIPD @ 0# tubing pressure. Backed rate off to 115 BWIPD.

8/27/15  Injecting 115 BWPD on vacuum.

9/2/15  Injecting 111 BWPD on vacuum.

10/1/15  Shut in Wellington Unit producing wells #53, #61 and #62 to raise reservoir pressure around KGS #2-32.

10/5/15  Injecting 115 BWPD average on vacuum. BHP on offset wells: #53 at 1056 psi, #61 at 732 psi, #62 at 961 psi.

10/12/15  Injecting 115 BWPD average on vacuum. BHP on offset wells: #53 at 1222 psi, #61 at 910 psi, #62 at 1100 psi.

10/19/15  Injecting 115 BWPD average on vacuum. BHP on offset wells: #53 at 1254 psi, #61 at 1007 psi, #62 at 1163 psi.

10/26/15  Injecting 115 BWPD average on vacuum. BHP on offset wells: #53 at 1301 psi, #61 at 1072 psi, #62 at 1209 psi.

11/1/15  Increased injection to 250 BWPD- well still on vacuum.

11/2/15  BHP on offset wells: #53 at 1316 psi, #61 at 1120 psi, #62 at 1240 psi.

11/23/15  Finishing pad for injection skid and working on electric hookup.

12/1/15  Injecting 250 BWPD on a vacuum. #53 at 1394 psi, #61 at 1234 psi, #62 at 1333 psi.

12/8/15  Injecting 250 BWPD on a vacuum. #53 at 1394 psi, #61 at 1250 psi, #62 at 1348 psi.

12/18/15  Increase injection to 300 bwpd. Move in first CO2 storage tank.

12/23/15  Move in one transport truckload of CO2. Hook up truck to suction side of Berexco CO2 injection pump. Pump 17 US tons of CO2 down the KGS 2-32 CO2 injection well using the CO2 injection pump over 2.5 hours total. Starting pressure 500 psi, final injection pressure 300 psi. Resume water injection. Total CO2 pumped down well 34,135 lbs. Max rate 1750 bbl per day rate at 300 psi, which is approx 310 tons per day. Resume injection at 500 bwpd. Cumulative water injection to date: 21,894 bbl water.

12/24/15  500 bwpd

12/29/15  Begin filling CO2 storage tanks. Four 70 ton storage tanks on location.
18 seismic seismometer array operating at Wellington Field to monitor CO$_2$ pilot tests

G. Tsoflias
Alex Nolte
KU Geology
J. Hollenbach &
J. Victorine, KGS

Resolutions of Hypocenters from IRIS Seismometer Array at Wellington

- Earthworm software for automated detection of earthquakes
- Reporting 2.5+ magnitude per USGS convention

IRIS Seismometer Installation

Housing setup for Sercel (Mark Products) L-22D-3D sensors, 5 ft below surface to minimize surface noise; installed below frost line in bedrock

Shelby Patele, KGS Exploration Services, checking installation in July 2014

KGS #1-32 — Synthetic seismogram integrated with well logs and stratigraphy — Java app (asynvis, KGS)