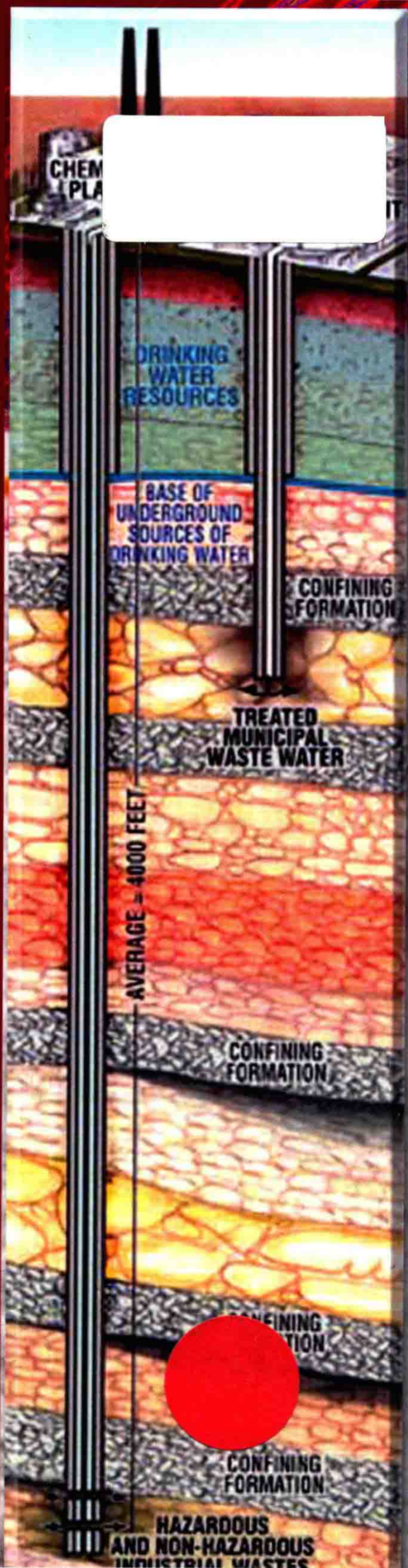

NATURAL DISASTER RESEARCH,
PREDICTION AND MITIGATION

Deep-Well Injections and Induced Seismicity

Understanding the Relationship

(with accompanying CD-ROM)

James B. Fernandez
Editor

NOVA

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DEEP-WELL INJECTIONS AND INDUCED SEISMICITY

UNDERSTANDING THE RELATIONSHIP (WITH ACCOMPANYING CD-ROM)

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nova publishers
New York

Library of Congress Cataloging-in-Publication Data

ISBN: 978-1-63482-557-3

Published by Nova Science Publishers, Inc. † New York

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PREFACE

This purpose of this book is to discuss the relationship between deep-well injections and induced seismicity.

Chapter 1 - The development of unconventional oil and natural gas resources using horizontal drilling and hydraulic fracturing (fracking) has created new demand for wastewater disposal wells that inject waste fluids into deep geologic strata. An increasing concern in the United States is that injection of these fluids may be responsible for increasing rates of seismic activity. The number of earthquakes of magnitude 3.0 or greater in the central and eastern United States has increased dramatically since about 2009, from an average of approximately 20 per year between 1970 and 2000 to over 100 per year in the period 2010-2013. Some of these earthquakes may be felt at the surface. For example, 20 earthquakes of magnitudes 4.0 to 4.8 have struck central Oklahoma since 2009. The largest earthquake in Oklahoma history (magnitude 5.6) occurred on November 5, 2011, near Prague, causing damage to several structures nearby. Central and northern Oklahoma were seismically active regions before the recent increase in the volume of waste fluid injection through deep wells. However, the recent earthquake swarm does not seem to be due to typical, random, changes in the rate of seismicity, according to the U.S. Geological Survey.

The relationship between earthquake activity and the timing of injection, the amount and rate of fluid injected, and other factors are still uncertain and are current research topics. Despite increasing evidence linking some deep-well disposal activities with human-induced earthquakes, only a small fraction of the more than 30,000 U.S. wastewater disposal wells appears to be associated with damaging earthquakes.

The potential for damaging earthquakes caused by hydraulic fracturing itself, as opposed to deep-well injection of wastewater from oil and gas activities, appears to be much smaller. Hydraulic fracturing intentionally creates fractures in rocks, and induces microseismicity, mostly of less than magnitude 1.0, too small to feel or cause damage. In a few cases, however, fracking has led directly to earthquakes larger than magnitude 2.0, including at sites in Oklahoma, Ohio, England, and Canada.

The Environmental Protection Agency's (EPA's) Underground Injection Control (UIC) program under the Safe Drinking Water Act (SDWA) regulates the subsurface injection of fluids to prevent endangerment of drinking water sources. EPA has established regulations for six classes of injection wells, including Class II wells used for the injection of fluids for enhanced oil and gas recovery and wastewater disposal. Most oil and gas states administer the UIC Class II program. The SDWA does not address seismicity, although EPA regulations for certain classes of injection wells require some evaluation of seismic risk. Such requirements do not apply to Class II wells; however, EPA has developed a framework for evaluating seismic risk when reviewing Class II permit applications in states where EPA administers this program. How Congress shapes EPA or other agency efforts to address and possibly mitigate human-caused earthquakes may be an issue in the 114th Congress.

In 2011, in response to seismic events in Arkansas and Texas thought to be associated with wastewater disposal wells, EPA authorized a national UIC technical work group to develop recommendations to address the risk of Class II disposal-induced seismicity. EPA plans to issue a document outlining technical recommendations and best practices in early 2015. At the state level, several states have increased oversight of Class II wells in response to induced seismicity concerns. In 2014, state oil and gas and groundwater protection agencies established a work group to discuss Class II disposal wells and recent seismic events occurring in multiple states.

Chapter 2 - The U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) program regulates injection of fluids related to oil and gas production as Class II injection wells for the protection of underground sources of drinking water (USDWs). Because seismic events from injection have the potential to cause endangerment of underground sources of drinking water, the UIC program director should be aware of that potential and be prepared with response options should seismic events become a concern. Unconventional resources and new technologies, such as horizontal drilling and advanced completion techniques, have expanded the geographic area for oil and gas production activities, resulting in a need for Class II disposal wells in some areas previously considered unproductive.

Recently, a number of small to moderate magnitude (M<5.0) earthquakes have been recorded in areas with Class II disposal wells related to shale hydrocarbon production. To address the concern that induced seismicity could interfere with containment of injected fluids and endanger drinking water sources, EPA's Drinking Water Protection Division requested that the UIC National Technical Workgroup (NTW) develop a report with practical tools to help UIC regulators address injection-induced seismicity. The Induced Seismicity Working Group (WG) of the NTW developed this report in response, using the existing Class II regulatory framework to provide possible strategies for managing and minimizing the potential for significant injection-induced seismic events. The report focuses on Class II disposal operations and not enhanced recovery wells or hydraulically fractured wells. In formulating the strategies in this report, the NTW conducted a technical literature search and review. Additionally, the NTW evaluated four case examples (in Arkansas, Ohio, Texas, and West Virginia) and considered data availability and variations in geology and reservoir characteristics.

Chapter 3 - Portions of all 50 states and the District of Columbia are vulnerable to earthquake hazards, although risks vary greatly across the country and within individual states. Seismic hazards are greatest in the western United States, particularly in California, Washington, Oregon, and Alaska and Hawaii. California has more citizens and infrastructure at risk than any other state because of the state's frequent seismic activity combined with its large population and developed infrastructure.

The United States faces the possibility of large economic losses from earthquake-damaged buildings and infrastructure. The Federal Emergency Management Agency has estimated that earthquakes cost the United States, on average, over $5 billion per year. California, Oregon, and Washington account for nearly $4.1 billion (77%) of the U.S. total estimated average annualized loss. California alone accounts for most of the estimated annualized earthquake losses for the nation.

A single large earthquake, however, can cause far more damage than the average annual estimate. The 1994 Northridge (CA) earthquake caused as much as $26 billion (in 2005 dollars) in damage and was one of the costliest natural disasters to strike the United States. One study of the damage caused by a hypothetical magnitude 7.8 earthquake along the San Andreas Fault in southern California projected as many as 1,800 fatalities and more than $200 billion in economic losses.

Unlike other natural hazards, such as hurricanes, where predicting the location and timing of landfall is becoming increasingly accurate, the scientific understanding of earthquakes does not yet allow for precise earthquake prediction. Instead, notification and warning typically involve communicating the location and magnitude of an earthquake as soon as possible after the event to emergency response providers and others who need the information.

A precise relationship between earthquake mitigation measures, federal earthquake-related activities such as earthquake research, and reduced losses from an actual earthquake may never be possible. However, as more accurate seismic hazard maps evolve, and as understanding of the relationship between ground motion and building safety improves, trends denoting the effectiveness of mitigation strategies and earthquake research and other activities may emerge more clearly. Without an ability to precisely predict earthquakes, Congress is likely to face an ongoing challenge in determining the most effective federal approach to increasing the nation's resilience to low-probability but high-impact major earthquakes.

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In: Deep-Well Injections and Induced Seismicity ISBN: 978-1-63482-557-3
Editor: James B. Fernandez

Chapter 1

HUMAN-INDUCED EARTHQUAKES FROM DEEP-WELL INJECTION: A BRIEF OVERVIEW*

Peter Folger and Mary Tiemann

SUMMARY

The development of unconventional oil and natural gas resources using horizontal drilling and hydraulic fracturing (fracking) has created new demand for wastewater disposal wells that inject waste fluids into deep geologic strata. An increasing concern in the United States is that injection of these fluids may be responsible for increasing rates of seismic activity. The number of earthquakes of magnitude 3.0 or greater in the central and eastern United States has increased dramatically since about 2009, from an average of approximately 20 per year between 1970 and 2000 to over 100 per year in the period 2010-2013. Some of these earthquakes may be felt at the surface. For example, 20 earthquakes of magnitudes 4.0 to 4.8 have struck central Oklahoma since 2009. The largest earthquake in Oklahoma history (magnitude 5.6) occurred on November 5, 2011, near Prague, causing damage to several structures nearby. Central and northern Oklahoma were seismically active regions before the recent increase in the volume of waste fluid injection through

* This is an edited, reformatted and augmented version of a Congressional Research Service publication R43836, prepared for Members and Committees of Congress dated January 8, 2015.

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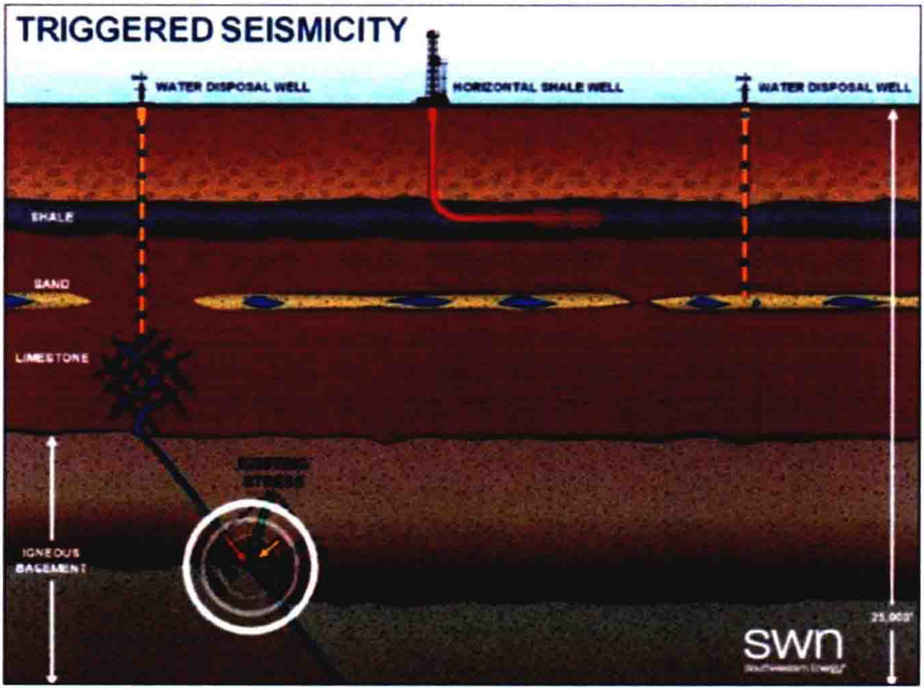
INTRODUCTION

Human-induced earthquakes, also known as induced seismicity, are an increasing concern in regions of the United States where the produced fluids and wastewaters from oil and natural gas activities are being injected into the subsurface through deep disposal wells. The immediate concern is that injection of these fluids into underground formations may be responsible for damaging earthquakes in regions that typically do not experience much seismic activity. Induced seismicity has garnered increased attention because of the rapid development of unconventional oil and gas resources, in part due to the use of hydraulic fracturing (often referred to as fracking). It is important to distinguish between seismic activity possibly related to hydraulic fracturing itself and the possibility of human-induced earthquakes related to injecting fluids down disposal wells, which may not be located near where wells were fracked.

Human activities have long been known to have induced earthquakes in some instances: impoundment of reservoirs, surface and underground mining, withdrawal of fluids such as oil and gas, and injection of fluids into subsurface formations. With the increase in the use of horizontal drilling and hydraulic fracturing to extract oil and gas from shale, and the concomitant increase in the amount of fluids that are injected for high-volume hydraulic fracturing and for disposal, there are several indications of a link between the injected fluids and unusual seismic activity. *Figure 1* illustrates conceptually the processes of deep-well injection and the linkage to triggering earthquakes.

The principal seismic hazard that has emerged from the increased amount of oil and gas activity in the United States appears to be related to disposal of wastewater using deep-well injection in some regions of the country. For example, in a May 2, 2014, joint statement between the Oklahoma Geological Survey and the U.S. Geological Survey (USGS), researchers reported a 50% increase in the rate of earthquakes in Oklahoma since 2013.[1] A USGS analysis of the rising trend suggested that a likely contributing factor was deep-well injection of oil-and-gas-related wastewater.[2] But the relationship between earthquake activity and the timing of injection, the amount and rate of fluid injected, and other factors are still uncertain and are current research topics. A 2013 article that reviewed the current understanding of human-caused earthquakes noted that, of the more than 30,000 wastewater disposal wells classified by the Environmental Protection Agency (EPA) as Class II,[3] only a small fraction appears to be associated with damaging earthquakes.[4]

The potential for damaging earthquakes caused by hydraulic fracturing itself, as opposed to deep-well injection of wastewater from fracking and other oil and natural gas production, appears to be much smaller. The 2013 review article indicated that the vast majority of wells used for hydraulic fracturing itself cause microearthquakes—the results of fracturing the rock to extract natural gas—which are typically too small to be felt or cause damage at the surface. The 2013 review documented a few cases where fracking itself caused detectable earthquakes felt at the surface, but these were too small to cause damage.



Source: North Carolina General Assembly, presentation by the Arkansas Oil and Gas Commission, *Fayetteville Shale Overview, for the North Carolina Delegation*, slide 33 prepared by Southwestern Energy, November 21, 2013, http://www.ncleg.net/documentsites/committees/BCCI-6576/2013-2014/5%20-%20 Feb.%204.%202014/Presentations%20and%20Handouts/Arkansas%20Site%20Visit%20Attachments/Att.%205%20-%20AOGC%20Presentation%2011-21-13%20%283%29.pdf.

Notes: The figure is for illustrative purposes only, and does not depict any specific location or geological formation.

Figure 1. Illustration of the Possible Relationship Between Deep-Well Injection and Induced Seismicity.

This report reviews the current scientific understanding of induced seismicity, primarily in the context of Class II oil and gas wastewater disposal wells. The report also outlines the regulatory framework for these injection wells, and identifies several federal and state initiatives responding to recent events of induced seismicity associated with Class II disposal.

Congressional Interest

How deep-well injection is linked to induced seismicity, and state and federal efforts to address that linkage, are of interest to Congress because of the implications to continued development of unconventional oil and gas resources in the United States. If the current boom in onshore oil and gas production continues, then deep-well injection of waste fluids is likely to also continue and may increase in volume. Also, what Congress, the federal government, and the states do to address and mitigate possible human-caused earthquakes from deep-well injection of oil and gas-related fluids may provide some guidance for the injection and sequestration of carbon dioxide. Carbon dioxide sequestration would involve ongoing, long-term, high-volume, high-pressure injection via deep wells. Several large-scale injection experiments are currently underway; however, the relationship between long-term and high-volume carbon dioxide injection and induced earthquakes is not known.

Current Scientific Understanding of Induced Seismicity in the United States

Since about the 1920s, it has been known that pumping fluids in and out of the Earth's subsurface has the potential to cause earthquakes.[5] In addition, a wide range of other human activities have been known to cause earthquakes, including the filling of large reservoirs, mining, geothermal energy extraction, and others.[6] The mechanics of how human industrial activities may cause earthquakes are fairly well known: the human perturbation changes the amount of stress in the earth's crust, and the forces that prevent faults from slipping become unequal. Once those forces are out of equilibrium, the fault ceases to be locked, and the fault slips, sending shock waves out from the fault that potentially reach the surface and are strong enough to be felt or cause damage.

Even knowing that human activities can cause earthquakes, and the mechanics of the process, it is currently nearly impossible to discriminate between man-made earthquakes and those caused by natural tectonic forces through the use of modern seismological methods.[7] Other lines of evidence are required to positively link human activities to earthquakes. That linkage is becoming increasingly well understood in parts of the United States where activities related to oil and gas extraction—deep-well injection of oil and gas wastewater, and hydraulic fracturing—have increased significantly in the last few years, particularly in Oklahoma, Texas, Arkansas, Ohio, Colorado, and several other states.[8] Nevertheless, the majority of these activities are not known to cause earthquakes; most are termed aseismic (i.e., not causing any appreciable seismic activity, at least for earthquakes greater than magnitude 3).[9] (See text box below for a brief description of earthquake magnitude and intensity.)

Earthquake Magnitude and Intensity[11]

Earthquake magnitude is a number that characterizes the relative size of an earthquake. It was historically reported using the Richter scale. Richter magnitude is calculated from the strongest seismic wave recorded from the earthquake, and is based on a logarithmic (base 10) scale: for each whole number increase in the Richter scale, the ground motion increases by 10 times. The amount of energy released per whole number increase, however, goes up by a factor of 32. The moment magnitude (M) scale is another expression of earthquake size, or energy released during an earthquake, that roughly corresponds to the Richter magnitude and is used by most seismologists because it more accurately describes the size of very large earthquakes. Sometimes earthquakes will be reported using qualitative terms, such as Great or Moderate. Generally, these terms refer to magnitudes as follows: Great (M>8); Major (M>7); Strong (M>6); Moderate (M>5); Light (M>4); Minor (M>3); and Micro (M<3). This report uses the moment magnitude scale, which is generally consistent with the Richter scale.[12]

Scientists currently have limited capability to predict human-caused earthquakes for a number of reasons, including uncertainty in knowing the state of stress in the Earth; rudimentary knowledge of how injected fluids flow underground after injection; poor knowledge of faults that could potentially slip and cause earthquakes; limited networks of seismometers (instruments