AASG
Association of American State Geologists

INDUCED SEISMICITY

The Association of American State Geologists (AASG) represents the State Geologists of the 50 United States and Puerto Rico. Founded in 1908, AASG seeks to advance the science and practical application of geology and related earth sciences in the United States and its territories, commonwealths, and possessions.

Introduction

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Earthquake activity has increased recently in parts of the U.S. midcontinent. Some of that increase has been associated with human activity, rather than occurring naturally. Earthquakes associated with human activities are referred to as induced or triggered (as opposed to natural) seismicity. They include both small events that cannot be felt, but are measureable by sensitive instruments, and larger events that may be felt and that can cause damage[1]. Disposal of fluids from oil and gas production, geothermal energy production, mining, construction, disposal of waste fluids, and impoundment of large reservoirs can cause induced seismicity. Determining whether a single earthquake is natural or induced can be extremely difficult, in part because fluids may be injected in areas where earthquakes occur naturally. In some situations, however, it is possible to correlate fluid injection with an increase in the frequency and/or magnitude of earthquakes. Efforts are underway to understand and prevent human-caused earthquakes that are strong enough to be felt or cause damage; this includes voluntary efforts by industry and by more comprehensive regulatory arrangements. Both are supported by more thorough information collected and managed on a coordinated basis by industry and both state and federal agencies, including state geological surveys. The following statement discusses seismicity, induced seismicity, causes of induced earthquakes, means to prevent such occurrences, and expresses the position of the Association of American State Geologists (AASG).

Seismicity

Earthquakes, whose pattern is known as seismicity, occur when the strength of a mass of rock, or frictional resistance between adjacent bodies of rock, is exceeded by stresses. A fault is a fracture where rock bodies have moved relative to each other. Earthquakes occur when rock ruptures or if adjacent rock bodies slip relative to each other along a fault. Whether rocks on either side of a fault will be displaced relative to each other depends on the fault's orientation, the natural stresses on the fault, the properties of the faulted rocks, and the nature of fluids in the pore spaces of rocks surrounding the fault. Numerous faults have formed in the geologic past, although many do not continue to slip because the shearing stresses on the fault no longer periodically exceed the frictional strength of the fault.

Induced seismicity

As long as the stress on a fault is less than the frictional strength of the fault, there is no relative motion along the fault. However, where a fault is oriented so as to be susceptible to slipping, and is near a critical state of stress, an increase in pore fluid pressure in the surrounding rock can reduce the friction holding the fault in place, thus potentially triggering an earthquake. Injection of fluid into the subsurface may cause such an increase in pore pressure, reducing friction, allowing fault movement, and potentially inducing earthquakes. Aside from the characteristics of the faults, several factors affect whether injected fluids will induce seismicity, including the distance between a fault and an injection well, permeability of the strata surrounding the fault, and the volume and rate of injection. The potential for induced seismicity following subsurface liquid waste disposal has been recognized for some time. One early, well-known instance occurred when waste from chemical manufacturing was injected at the Rocky Mountain Arsenal near Denver in the early 1960s.

Relationship of hydraulic fracturing to induced seismicity

In recent years, earthquake activity has increased noticeably in several areas of active oil and gas production across the United States. Much public attention has been drawn to hydraulic fracturing (or "fracking"), which involves use of water, sand (or similar material), and chemical additives, under high pressure, to fracture rocks in the subsurface to allow additional oil and gas production. By definition, hydraulic fracturing causes seismic events, and measurement of these micro-seismic events in the subsurface is one method for determining where fractures in the rock have been created. Except in a few cases, however, seismic events related to hydraulic fracturing are too small to be felt at the surface, and thus to cause structural damage.

Relationship of wastewater injection to induced seismicity

In many oil and gas-producing regions, considerable amounts of fluids such as saltwater are produced along with oil and natural gas. Much of that saltwater is injected into oil reservoirs during secondary and enhanced oil recovery operations to force additional oil out of the rocks, and to maintain a pore-pressure balance within the rock formation. In places, however, substantial amounts of saltwater are injected into deep subsurface rock formations via disposal wells. In some locations, wastewater disposal operations correlate with increased seismicity. Though many of these seismic events are too small to be felt by most people, some have been widely felt and have caused damage. In most areas of active oil and gas operations, wastewater injection thus is the focus of induced seismicity prevention, rather than hydraulic fracturing. In the future, due to concerns about greenhouse gases and climate change, increased injection of CO_2 could also require careful management in relation to induced seismicity.

Relationship of geothermal energy production to induced seismicity

Enhanced geothermal systems are engineered reservoirs in which water is injected into hot subsurface rocks that tend to have low fluid content or permeability. The introduced water re-opens existing fractures in the rocks to increase circulation and absorbs heat from the rocks; it is then transported back to the surface to generate electricity. The injection of water into the typically magma-heated hot rocks to produce steam or very hot water to generate electricity induces seismic events because of thermal expansion and contraction of the rocks, as well as dynamic fluid pressure changes that affect minor faults and fractures. This is especially common where the rock is already highly fractured. Many induced micro-seismic events occur daily around these geothermal operations and many felt events have been associated with some operations.

Preventing damaging induced seismicity

Deep injection of contaminated liquids, which would otherwise pose a risk to health and the environment if left at the surface, is a widespread activity across the US. Nearly 2.5 billion gallons of fluids are injected into hundreds of thousands of disposal wells every day. Approximately 180,000 of these fluid-injection wells in the US dispose of wastewater or inject recycled water back into producing oil fields to enhance oil recovery. These wells have been designated Underground Injection Control (UIC) Class II wells by the U.S. Environmental Protection Agency (EPA). The EPA regulates the licensing and operation of Class II disposal wells under the Safe Drinking Water Act or delegates that authority to state agencies. The act is primarily designed to protect freshwater aquifers and other drinking water sources from contamination by injected fluids. Geothermal wastewater is disposed of in Class V wells and CO_2 injection wells are in a newly created Class VI. Class V and Class VI wells are also regulated by the EPA or a state agency under authority from the EPA.

One approach to prevention of induced seismicity is a traffic light protocol that has been developed in association with enhanced geothermal systems. Under this system, operators have a green light to continue injection as long as earthquakes do not occur above a specified level. Under a yellow light, which prevails if seismicity above certain levels occurs, operators must slow injection rates and take additional precautions. They must stop injection under a red light scenario if associated seismicity does not stop or slow adequately after precautions are taken. In some states, this sort of protocol has been applied to induced seismicity caused by wastewater disposal associated with oil and gas production. In addition, states are developing best practices designed to reduce the risk of induced seismicity, including avoiding fluid injection near known faults, and more frequent monitoring of injection pressures, volumes, and duration. Enactment of these and other mitigation protocols requires coordination between industry, government, and the research community. These protocols, best practices, and monitoring, conducted on a well-coordinated basis by public and private groups including state geological surveys, are thus directed at further assessment of the risk of induced seismicity associated with fluid injection, and minimization of that risk in order to prevent felt and, in particular, damaging induced earthquakes.

AASG Statement: State geological surveys are important sources of information and expertise about geology, energy, minerals, water, and hazards. AASG members, who direct state geological surveys, and their staff regularly play active roles in monitoring and investigating topics such as seismicity and energy production. Several state geological surveys, along with federal counterparts, have been actively engaged in investigations of seismicity that may have been caused by subsurface injection, and in the ongoing collection of systematic information needed to support best practices and regulation. In this context, the following points constitute the AASG position on induced seismicity:

- AASG is committed to protecting the nation’s public safety and the natural environment.
- AASG supports the wise and prudent production of energy resources to help fulfill the nation’s needs.
- AASG recognizes the economic and social importance, and the abundance, of energy resources that can only be recovered if associated with needed injection and disposal operations.
- AASG recognizes that the environmental record of secondary recovery, wastewater injection, and geothermal energy production over several decades has been overwhelmingly positive.
- AASG supports assessment of alternatives to subsurface wastewater disposal, including increased reuse of wastewater.
- AASG advocates for better understanding and scientific documentation of our subsurface geology, which will help avoid problems that might occur during injection.
- AASG encourages efforts to ensure adequate assessment of pre-drilling levels of seismicity, to support later clarification of whether seismicity rates have changed in relation to industrial activity.
- AASG advocates increased seismic monitoring, employing both permanent and temporary seismic arrays as needed, in locations where seismic activity has increased or may increase.
- AASG supports enhanced reporting and public availability of injection data, including pressure, volume, duration, and other information related to injection, as an aid to improved prevention of induced seismicity.
- AASG supports additional research into the subsurface mechanics associated with induced seismicity, including better methods of detecting and analyzing faults and stress field orientation.
- AASG advocates that comprehensive public information on injection and seismicity be used in formulating energy and environmental policy, including improved data sharing among research institutions, regulatory agencies, and the energy industry.
- AASG maintains that state regulatory agencies are best equipped, through statutory authority, expertise, experience, and familiarity with regional conditions, to ensure that energy production and waste disposal proceed in a manner that protects public safety and the environment.
- AASG recognizes and supports coordinated national efforts to engage industry, academia, and governmental agencies in an effort to better understand and more effectively prevent induced seismicity.

[1] *National Research Council. Induced Seismicity Potential in Energy Technologies. Washington, DC: The National Academies Press, 2013.*