Online Map Resources and Comments Regarding Geologic Hazards in the December, 2018, BLM Oil & Gas Leasing Area

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This is a two-part memorandum that can be used to frame your own comments about geologic hazards and their considerations or limitations for oil & gas leasing. The first part lists some publically available technical resources that show pertinent landslide and earthquake locations. The second part contains comments of my own regarding the viability of oil & gas development with regard to those hazards.

I am a professional geologist with over 35 years of experience, first in oil & gas and minerals exploration, and later, 25 years in engineering and environmental geology. The focus of my last 10 years with the State of Colorado was mapping the geology of the Uncompahgre and North Fork Gunnison River valleys, from Montrose to Delta to Paonia and Crawford. I currently am semi-retired and live in Paonia.

Technical Resources from Colorado Geological Survey

The following online maps and reports are useful for framing comments about geologic hazards in the greater Muddy Creek drainage basin, a headwaters area for the North Fork of the Gunnison River:

Rogers, W.P., 2005, Critical landslides in Colorado – a year 2002 review and priority list: Denver, Colorado Geological Survey Open-File Report 03-16, 59 p., 1 map plate, scale 1:500,000.

In this report, the State Highway 133 corridor between Hotchkiss and Paonia Reservoir is listed as the #2 most serious landslide threat in the entire state of Colorado. It contains "extremely active landslides along entire corridor, [and] severe rockfall hazard on west side of Paonia Reservoir." At risk is the highway itself, the railroad line, and coal-mining and irrigation facilities. The nearby East Muddy Creek Landslide is listed as the #12 most serious in the state. This report can be downloaded for free from the CGS online bookstore.

Colorado Geological Survey, Colorado landslide inventory map viewer: Denver, Colorado Geological Survey web site, http://coloradogeologicalsurvey.org/geologic-hazards/landslides/colorado-landslide-inventory/

This interactive map contains a statewide inventory of known or inferred landslides, compiled from previously published geologic maps by the CGS and USGS. The landslides are shown as brightly colored polygons upon a topographic base map. The scale of the data sources is indicated by the color of the polygon. The sources range from broad, regional compilations (1:250,000 scale) to locally detailed mapping areas (1:24,000 scale). One can use the interactive map by zooming in or out, as needed, to find areas of interest. The map has its limitations, and should not be used in lieu of site-specific mapping and evaluations of the landslide hazard.

Morgan, M.L., 2017, Colorado earthquake map server: Golden, Colorado Geological Survey web site, http://coloradogeologicalsurvey.org/geologic-hazards/earthquakes/maps/

This interactive map contains a statewide inventory of historic earthquakes in Colorado. They are shown by circles or squares at the quake epicenters, colored as to magnitude. The map also shows faults and folds that are thought to be relatively young, geologically, and thus locations of potential future earthquake hazards. By zooming the slider and panning (with the “glove” cursor), one can find areas of interest. By clicking (ctrl-click) a particular earthquake feature, a separate window is opened that contains data and a narrative describing the earthquake event. If possible, the cause of the earthquake is given. Most are from natural geological processes, but some are ascribed to human-related incidents such as coal-mine room collapses (“coal bumps”) or earthquakes induced by fluid injection.

<u>Comments on Geologic Hazards, by David C. Noe, Ph.D.</u>

Landslide Hazards

My conclusion is that landslide terrain is a poor place upon which to conduct oil & gas drilling, development, and transportation operations. In most cases, the size of the landslide features and the force of their movements are simply too great to be controlled with standard, affordable engineered mitigation methods. The proposed lease area contains serious landslide terrain, which argues for withdrawal of those leases.

The statewide ranking of landslide hazard areas by Rogers (2002) names the State Highway 133 corridor, from Hotchkiss to Paonia Reservoir, as the #2 most serious landslide area in Colorado. It contains “extremely active landslides along entire corridor, [and] severe rockfall hazard on west side of Paonia Reservoir.” At risk is the highway itself, the adjacent Union Pacific railroad line, and coal-mining and irrigation facilities. Rogers only considered main valley of the North Fork River, which contains the highway and railroad corridor. It stands to reason that the surrounding lands, being of similar geology, would contain widespread landslide terrain and potentially severe landslide hazards. This is partially borne out in the same publication, which lists the nearby East Muddy Creek Landslide, along the base of the Raggeds mountain range, as the #12 most serious landslide hazard area in the state.

The abundance of landslides in the greater Grand Mesa/North Fork/McClure Pass area is further underscored in the Colorado Landslide Inventory Map Viewer (Colorado Geological Survey web site). This compilation from previous CGS and USGS projects shows that extensive landslide terrain is present in the area. It does not assess whether the landslide is active or dormant, nor does it assess the overall hazard or movement potential; those assessments are accomplished by site-specific geotechnical studies, augmented by drilling, material testing, and stability modeling.

When I was doing detailed mapping in Colorado, I nearly always found that there were more landslides present than were shown on regional maps. It was a function of scale and detail. For our purposes, the area may be even more landslide-prone than is shown in the online viewer. The whole Muddy Creek/Paonia Reservoir area, which was mapped at a regional scale, may contain more landslides than are shown. From my observations while traveling through this area, the landslide range from small, localized land slips to very large, composite landslide complexes that are composed of up to dozens of amalgamated landslides. In certain places, such as the hillsides across the river from Somerset, along Hubbard Creek, and along the western edge of Thousand Acre Flats, whole mountainsides have failed and peeled off into the adjacent stream valleys. The landslides across the area range from active to inactive, but all of them should be considered to be metastable (that is, they are capable of future movement if their stress fields are altered and destabilized by natural or human causes).

My concern with landslides is their potential effect on oil & gas operations, and the resultant health and safety and water quality issues. Landslide activity can be induced or accelerated by human activities such as road building, fill emplacement, and obstruction or diversion of surface or shallow subsurface water. At risk are those very facilities. Of greater importance is the effect on oil & gas wells. A moving landslide body is subject to differential internal movements, and the basal boundary is a locus of potentially serious shear movements. When I was doing landslide monitoring for the Colorado Geological Survey (including at the East Muddy Creek Landslide), we pinpointed the base of the landslide by lowering a sonde down previously drilled boreholes that originally penetrated to below the slide. Wherever the borehole was sheared and broken off was the depth of the landslide body. The forces generated within a moving landslide are too great for a drill pipe to resist, even with casing and other reinforcement. A sheared borehole pipe becomes a place where an uncontrolled, pressurized leak will occur into the surrounding substrate. Landslides often have complicated shallow ground water systems. Hydrocarbon or waste fluid spills within a landslide would be difficult to trace and remediate. Landslides often contain ground water seeps. Contaminants reaching the seeps could then enter surface waters.

Oil and gas pipelines are also at particular risk in landslide terrain, in part because they are buried in shallow ground and cross between areas having variable ground stabilities. The boundaries between stable and unstable ground, or between sliding ground masses that are moving at different rates, are the sites of pipeline breakage, pressurized leaks, and ground and surface water contamination.

Another affect to consider is the role of natural climate variations upon landslide activity. To wit, the more water in the soil, the greater the chances of landslide activity and reactivation. In western Colorado, landslide activity is influenced strongly by the amount of snow that accumulates during the winter. In 1983 and 1984, there were notably deep snowpacks in Colorado and Utah. The melting of the snows created abundant runoff, and the ground was saturated over a long period of time, resulting in a spate of landslide reactivations and several potential emergency situations. In our area, the East Muddy Creek Landslide became so active that State Highway 133 had to be relocated across the river, at a high public cost. Once landslide reactivation occurs, there is little we can do to stop the earth from sliding. Engineered stabilization treatments, used when building roads, pipelines, or other facilities, may have a local effect, but many landslides are far too massive for those treatments to have any effect. In short, landslide movements driven by natural changes in ground moisture are essentially beyond human control, and in those cases the risk of damage to facilities, and resulting impact to the local ecosystem, is unavoidable.

Earthquakes and Seismic Hazards

The Colorado Earthquake Map Server (Morgan, 2017) is an online, interactive mapping tool that shows the epicenter locations and magnitudes of historical earthquakes in Colorado. In the immediate area around the proposed lease sale, it shows one earthquake at Hotchkiss, a belt of 45 earthquakes near Bowie and Somerset, and three separate earthquakes along the valley of Muddy Creek.

The Hotchkiss quake occurred in 2008, at a shallow depth of 1 km (4,000 feet), with a magnitude of 2.7. No explanation of cause was given. The Bowie /Somerset earthquakes had magnitudes of less than 4.0 and one of 4.4 and occurred at shallow depths of around 1 km. Many of these are attributed to “coal bumps,” or sudden ground movements or collapses within the area’s large, underground coal mines. The largest reported quake, which occurred in 1944 in the upper reaches of Hubbard Creek, had an intensity of VI, and was felt strongly in Grand Junction, Montrose, Aspen and Eagle. The three Muddy Creek earthquakes occurred in 1984, 1988, and 2008, with magnitudes of 2.7 to 3.1, and depths of 1 to 5 km (4,000 to 16,400 feet). The northernmost quake is attributed to a possible coal bump at a coal mine near Redstone.

The map server data show that both natural and human-caused earthquakes have occurred in the proposed lease sale area. It is plausible that both types of earthquakes will continue to occur here, with shallow, low-magnitude “coal bump” quakes far outnumbering the deeper and higher-magnitude natural quakes.

There is much concern from North Fork residents about whether fracking oil & gas operations will induce a new breed of earthquakes if drilling is allowed in the area. To me, the pertinent questions are (1) whether the hydrofracking itself, which occurs several thousand feet below the ground surface in the targeted production zone of the Mancos Shale, will produce felt earthquakes; (2) whether waste fluids pumped under pressure into disposal wells produce felt earthquakes; (3) whether the induced seismicity from these operations will affect the stabilities within the coal mines and cause a chain-reaction effect of more occurrences of "coal bumps;" and (4) whether the induced seismicity will affect the stabilities of landslides in the area and cause more occurrences of reactivation of dormant landslides or greater movement within currently active landslides. All of these effects could increase the overall earthquake hazard, affect mine safety, and cause increased damage to properties and infrastructure within the greater North Fork and Muddy Creek area.

I am not aware of the latest research findings for (1). There is definitely scientific evidence for (2) occurring from injection wells in different circumstances in Colorado (see Colorado Geological Survey newsletter, *RockTalk*, v 5, no.2, April 2002) and elsewhere. The injection appears to produce earthquakes of small to moderate severity, up to about magnitude 5.0. As such, there is a possibility that induced seismicity from fracking operations leads to more frequent and occasionally more powerful earthquakes. I have not seen a discussion about the potential effect of (3) on mine stability and safety, but parts of the underground mines exist in a partially collapsed or locally reinforced condition, both of which are metastable. It seems to me that ground shaking from nearby, induced earthquakes could certainly compromise the delicate stability within the mines. Additionally, I have not seen a discussion about the potential effect of (4) on landslide stability and hazards. It seems intuitive that an increased level and frequency of seismicity could have a destabilizing effect on a landscape where there are already abundant unstable or metastable slopes.

Rockfalls are already a frequent hazard in the North Fork and Muddy Creek areas, where they damage roads (and sometimes close them for days) and threaten the safety of people driving or riding in vehicles. The process occurs because the sandstone bedrock cliffs are cracked and locally unstable. It stands to reason that an increased level and frequency of seismicity could destabilize the rock cliffs even more, thus increasing the overall rockfall hazard.