Induced Seismicity Potential with Depleted Parent Wells

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Summary

Magnitudes of induced seismicity detected from 90 pad developments in Oklahoma were investigated to test if seismicity was reduced over depleted parent wells compared to parent adjacent wells. For cases with anomalous seismicity, larger magnitudes were observed next to the parent wells as hydraulic fractures preferentially grew towards the earlier depleted regions and along regional faults.

Introduction

Hydraulic fracture induced seismicity has been documented in certain reservoirs, most notably in the WCSB, Eagle Ford, Utica and SCOOP and STACK trends in Oklahoma. While most operations are seismically quiet, a small percentage of well completions can lead to anomalous seismic events. Operational regulations and protocols based on traffic light protocols have proven effective in managing seismicity in these cases as part of a management framework that included pre-job risk assessment and mitigation.

The primary mechanism of injection induced seismicity is pore pressure increases resulting in reduced clamping stresses on preferentially oriented pre-existing faults. In regions of earlier well development and associated production, reducing reservoir pressure could therefore result in a reduction of seismicity potential by increasing the pressure change during operations necessary to cause faults to slip. Indeed, such a stabilizing influence of earlier regional pressure depletion has been hypothesized to have contributed to the lack of injection induced seismicity in certain areas (e.g., Dvory and Zoback, 2021).

Hydraulically fracturing of new infill wells next to existing older production wells creates additional development challenges, since fracturing of the newer 'child' wells can significantly interact with the existing 'parent' wells. Reduced reservoir pressure and potentially associated stress levels tends to facilitate fracture growth from the child wells towards the parent wells. Pressure observations in parent wells during offset well completions occasionally show significant pressure increases as the new hydraulic fractures preferentially grow towards the parent wells. Issues have been identified in many reservoirs of the parent-child interaction which can lead to increased water production when the parent wells return to production (see for example, Daneshy and King, 2019). Production from child wells adjacent to the parent wells also typically underperform more offset wells.

Microseismic monitoring of parent adjacent hydraulic fracturing can result in increased activity near shut-in parent wells, associated with the preferential fracture growth towards the inactive depleted wells. However, in certain reservoirs including the SCOOP and STACK plays, small magnitude microseismicity associated with hydraulic fracture growth are typically found to be subdued near depleted parent wells attributed to the geomechanical conditions of reduced reservoir pressure stabilizing pre-existing fractures (e.g., Maxwell and Greig, 2024). Apparently, the competing influences of geomechanical stabilization at lower pressures and preferential fracture growth towards depletion can lead to either increased or decreased microseismicity next to depleted parent wells, depending on which is the dominant factor in each situation.

In this paper, a population of hydraulic fracture completions in the SCOOP and STACK monitored with high resolution seismic arrays are evaluated to compare instances of induced seismicity along existing parent wells relative to parent adjacent child wells.

Seismicity Data

Over the past several years, enhanced seismic arrays have been deployed to monitor hydraulic fracturing operations across the Anadarko Basin of Oklahoma as part of induced seismicity management to prevent anomalous seismicity aligned with regulatory requirements. Temporarily deployed enhanced arrays were able to collect small magnitude microseismic (magnitudes above -0.5 using a local magnitude scale consistent with the public seismic array across Oklahoma). The enhanced arrays are sensitive enough to detect conventional microseismicity during operations as well as larger magnitude seismic events of concern, which would also be detected on the public array. Dense seismic station spacing and high-precision hypocentral locations of these enhanced arrays, allow accurate positioning of events relative to the well spacing. Over 90 examples of fracturing at distances of less than a few thousand feet of existing parent wells were evaluated and using to compare detected seismicity located next to parent wells with events detected next to parent adjacent child wells. In this way, the database can be used to statistically evaluate the seismic potential of these competing mechanisms of stabilization versus preferential growth towards the parent wells. Note the analysis described here focuses exclusively on the parent and parent adjacent wells; in some cases anomalous events were detected associated with other child wells in the development.

Figure 1 shows a comparison of the maximum magnitude detected event over parent wells versus the parent adjacent wells. Relative to a one-to-one line, the majority of cases show only small magnitude events significantly below levels of concern. In these cases, the magnitude of events (along with number of events which is not shown here) next to the parent wells are reduced relative to the parent adjacent wells. This is consistent with what has been observed during several microseismic monitoring campaigns around quiescent parent wells during infill fracturing of child wells (Maxwell and Greig, 2024). For these cases, the geomechanical stabilization of the parent depletion appears to be the dominant factor controlling the seismic response.

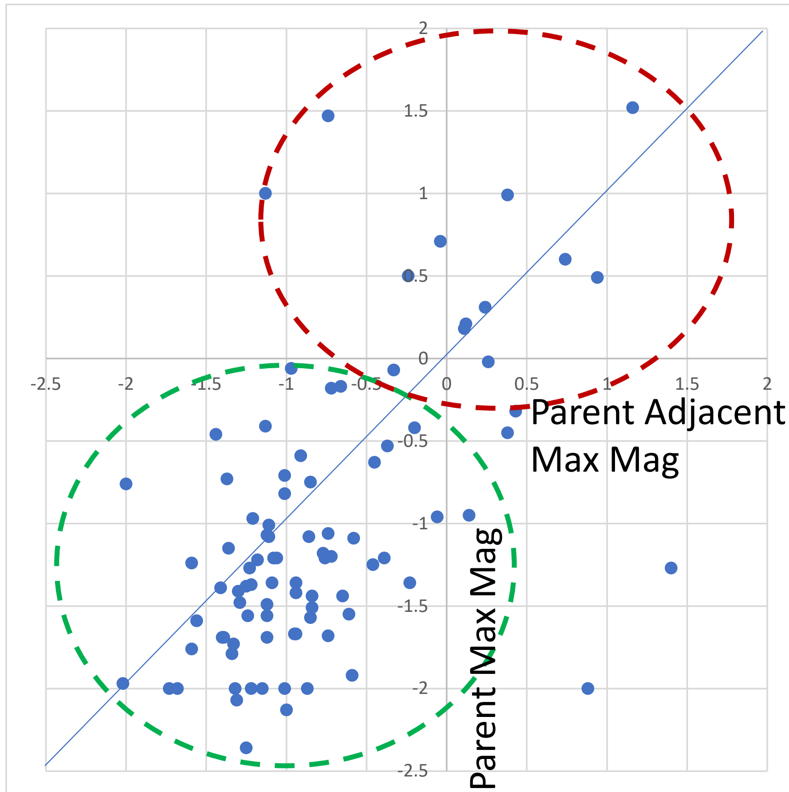

Figure 1. Cross-plot of relative magnitude near parent adjacent wells versus relative magnitude near parent wells. Smaller magnitude have larger events near parent adjacent wells (green circled cluster), while larger magnitude are larger near parent wells (red circle).

However, a smaller subset of operations with larger magnitude events suggests an opposite trend with a tendency for more comparable magnitudes near the depletion and in several cases the largest events are located on the parent well. Notably, many of these cases were associated with regional faults and had seismically active structures between parent and parent adjacent wells. In a substantial number of these cases, seismicity extended significantly further along the regional structure, past the parent well away from the current development. Many of the cases in this subset with similar magnitudes on both wells also showed a general reduction of magnitudes along well slots approaching the parent well, suggesting a regional reduction in seismic potential in the area regardless of the presence of depletion near the parent well. While two of these larger magnitude cases demonstrated significantly larger events on the parent adjacent wells, in both cases these anomalous events were single events not related to detectable seismically active lineation.

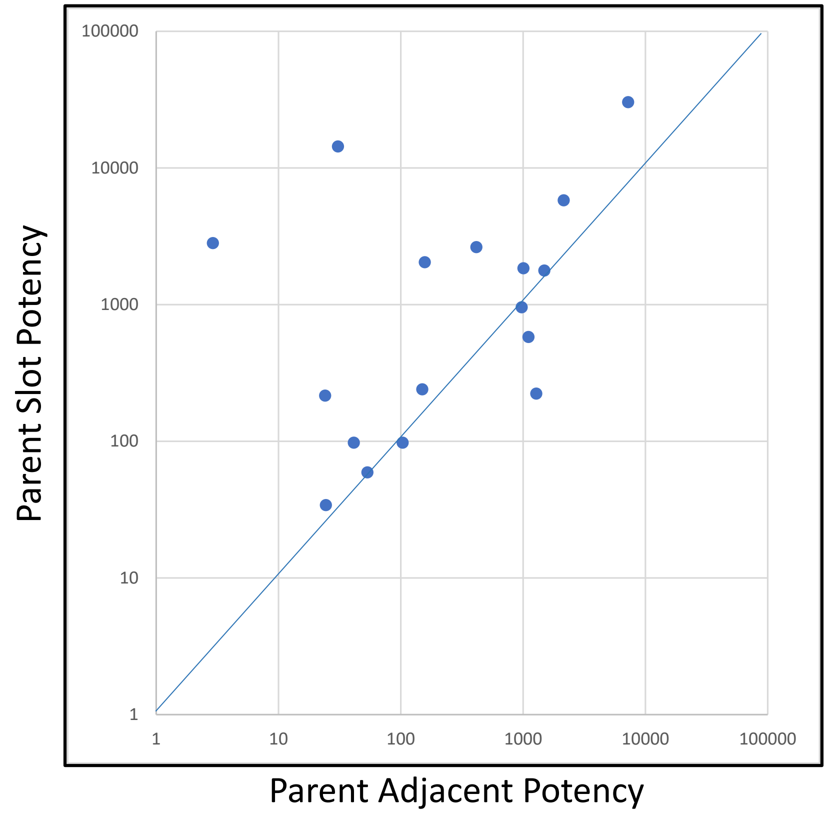

Figure 2. Cross-plot of seismic potency of anomalous larger relative magnitude cases (red circle) shown in Figure 1.

To test if the trend for these larger magnitude cases was related to one-off single events, Figure 2 compares the total moment release of all events on the same two wells slots. Similar trends are observed although there is more offset towards total moment release in the parent slots when compared to the maximum magnitude plot. For these cases, the preferential fracture growth towards the parent well is apparently focusing into the regional faults and increasing the seismic hazard. In none of these examples do we have an indication of significant events during the original parent well completion, although only the public array was functioning during those times and was not particularly sensitive to detect these relatively low magnitudes described here. Typically, these early developments for the parent wells had much lower scope hydraulic fracture treatments, including both the number of stages and amount of fluid being pumped. Therefore, no conclusion can be made if the seismic hazard has changed as might be expected associated with the parent well depletion, but for the current conditions the fracture growth into the depletion appears to overcome any stabilizing effects of reduced pressure.

Conclusions

In conclusion, this study shows in the SCOOP and STACK play for scenarios of small magnitude microseismic response, that parent well depletion reduces seismic potential consistent with geomechanical stabilization with lower pressure near the parent wells. This observation is consistent with reported trends from conventional microseismic monitoring. With scenarios of anomalous induced seismicity associated with regional faults, examples show preferential growth into depleted parent wells increases the seismic potential relative to the parent adjacent wells. These two extreme scenarios appear to represent ‘end member’ cases define opposing mechanisms between depleted pressure stabilization with small magnitudes and preferential fracture growth and increased seismic potential for depleted regional faults.

References

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