Newdigate Seismicity and Link to Horse Hill HH-1 Well Activities

Summary of Proposed Scenario

This brief summary postulates a probable scenario of a direct link of the seismicity at Newdigate, Surrey, UK with activities and petroleum production at the Horse Hill well, HH-1. The timing of seismic events and the activities at HH-1 well are too compellingly time correlated, that a meaningful scenario linking the two should have been explored before now. The conclusions from the OGA workshop[(1)], chaired by the BGS, cite that no casual link between the two could be conceived, and thus concluded that the seismicity was of natural causes. How the seismicity can be labelled as natural[(2)], just because a viable scenario linking the two can't be formulated, is not a scientific approach to the issue.

The seismic events and the HH-1 well are shown in Figure 1. The scenario presented here utilizes data from the Weald and other UK onshore basins under strike slip stress states, where the presence of hyper-stress sensitive bedding planes have acted as fluid conduits over geological time. These bedding planes under normal fluid pressure conditions are virtually impermeable, but under very low fluid over-pressures become highly permeable. The seismic events at Newdigate are located approximately 3kms from the HH-1 well, and ~1km deeper than its current production zones. The hydrocarbon fluids are light crudes 36-40°API, all gas is in solution, and the reservoirs are at or near normal pressured. Data[(1)] from testing of HH-1 in 2016, indicate that the well is very slightly over-pressured by ~15bar.

It is postulated that hydrocarbon fluids are being generated and have been over centuries, at or near the current epicenters of the seismic events. Fluid over-pressure from their generation open the hyper-stress sensitive bedding planes leading to hydrocarbon fluid migration some 3 kms to the reservoirs at HH-1, see Figure 2. The scenario depicted in Figure 2 has been in equilibrium over centuries, with no or minimal induced seismic activity. For this scenario to occur, slight fluid over-pressure must be present at HH-1 and in its surrounding reservoirs, of the order of ~15bar. This fluid over-pressure has been observed at HH-1 as noted earlier. The bedding plane fluid conduits are horizontal hydraulic fractures that contain "beef" [(3)], see Figure 3. The transmissivity of these planes are highly sensitive to fluid over-pressure as shown in Figure 3.

If the fluid over-pressure at HH-1 is removed, by bleeding off excess pressure at the wellhead or by production, then the bedding planes become impermeable at the well and in the surrounding reservoir, and the planes close some distance from the well, see Figure 4. Hydrocarbon fluids can't migrate from the source area, and thus fluid over-pressures rise at the source area to re-open the bedding planes, see Figure 5. To re-open these bedding planes requires considerably greater fluid over-pressure, than the steady state flowing conditions as shown in Figure 2. The excessive fluid over-pressures generated at the source areas, are present over a considerable area, enabling the hydrocarbon fluids to migrate to a nearby critically stressed fault, giving rise to significant induced seismicity at these epicenter locations.

Evidence for/against the Proposed Scenario

The timeline of seismic events and activities at HH-1 are shown in Figure 6. The first events occurred on the 1st April 2018. Surface works were underway at HH-1 in March and early April 2018, denoted as pre-rig arrival activities. Pre-rig arrival activities included bleeding off excess pressures at the wellhead. In 2018, the operator stated that the site was ready for the rig on the 5th April. So presumably any excess

pressures at the wellhead would have been bled off before then, possibly on the 30, 31 March or 1 April 2018. The OGA workshop[(1)], the operator stated that wellhead annuli were measured on the 5th and 6th April 2018 and were normal. This statement is contrary to the early statement in April 2018, that the site was ready for the rig as of 5th April 2018. So, were over-pressures bled off prior to the seismic events of the 1st April 2018?

The rig, in this case a crane, arrived on site on the 25th June 2018. Pre-rig activities were conducted, presumably over the 25, 26 and 27 June 2018. Thus, any over-pressures would have been bled off before the rig entered the well. So, were over-pressures bled off prior to the seismic events of the 27th June 2018?

If the above activities did not involve bleeding off over-pressure at the wellhead, then this weakens the case for this proposed scenario. If over-pressures were bled off at the above timelines, then the Portland bridge plug must have been leaking under up-flow conditions. The Portland bridge plug was pressure tested before removal, but only under down-flow conditions.

On the 4th July 2018, the Portland bridge plug was removed and the largest seismic event to date, 3.0 M_L occurred on the 5th July 2018, see Figure 6. Clear evidence that this proposed scenario may be plausible, as any fluid over-pressure in the Portland was completely lost on the removal of the Portland bridge plug.

Portland production commenced on the 10th July 2018, and seismic activity continued. Production from the Portland ceased in late Aug 2018, and Kimmeridge production began on 10th Oct 2018, see Figure 7. During Kimmeridge production, the Portland is shutin, so fluid over-pressures can develop in the Portland during its shutin. As seen in Figure 7, there is no or minimal seismicity during production from the Kimmeridge, indicating that the fluids from the source area are migrating to the Portland reservoir at the Horse Hill site.

Portland production re-commences on the 10th Feb 2019, and seismicity is significant, with the largest event of 3.1 M_L occurring on 27th Feb 2019. Seismicity continues throughout Portland production. Kimmeridge production re-commenced on the 6th July 2019, with seismicity falling off during its production, because the Portland is shutin. The Kimmeridge was temporally shutin on the 30th Aug 2019. Portland fluid over-pressures developed during its shutin, were presumably bled off at this time, leading to some moderate seismicity. Kimmeridge production restarted on the 11th Sep 2019.

References

1. OGA Newdigate Seismicity Workshop – 3 October 2018. Online workshop summary and presentations are available :- https://www.ogauthority.co.uk/media/5174/2018_11_23-newdigate-workshop-summary-finalv3.pdf
2. Hicks S., Verdon J., Baptie B., Luckett R., Mildon Z. and T. Gernon, 2019. A shallow earthquake swarm close to hydrocarbon activities: discriminating between natural and induced causes for the 2018–19 Surrey, UK earthquake sequence, Seismological Research Letters, ISSN: 0895-0695
3. Cobbold P. R., Zanella A., Rodrigues N. and H. Loseth, 2013. Bedding-parallel fibrous veins (beef and cone-in-cone): Worldwide occurrence and possible significance in terms of fluid overpressure, hydrocarbon generation and mineralization, Marine and Petroleum Geology, 43, 1-20.

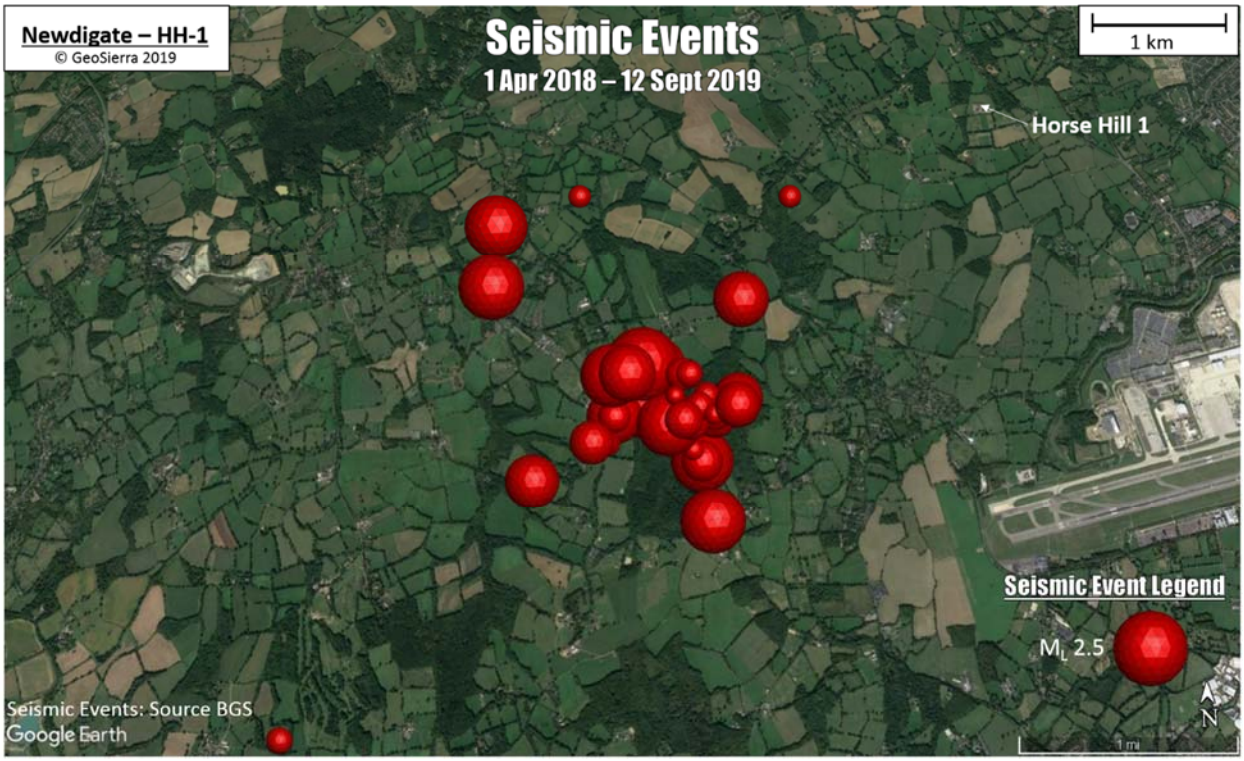

Figure 1. Seismic Events around Newdigate, Surrey, UK and Horse Hill well pad.

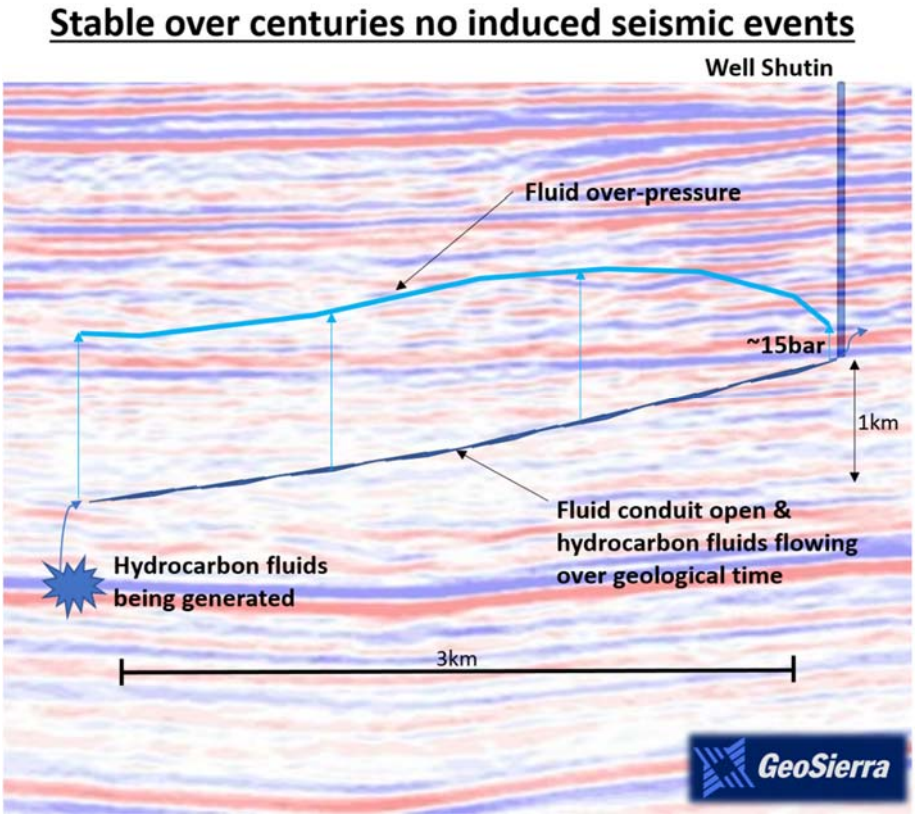

Figure 2. Proposed Scenario of Steady State Fluid Migration over Centuries with no Seismicity

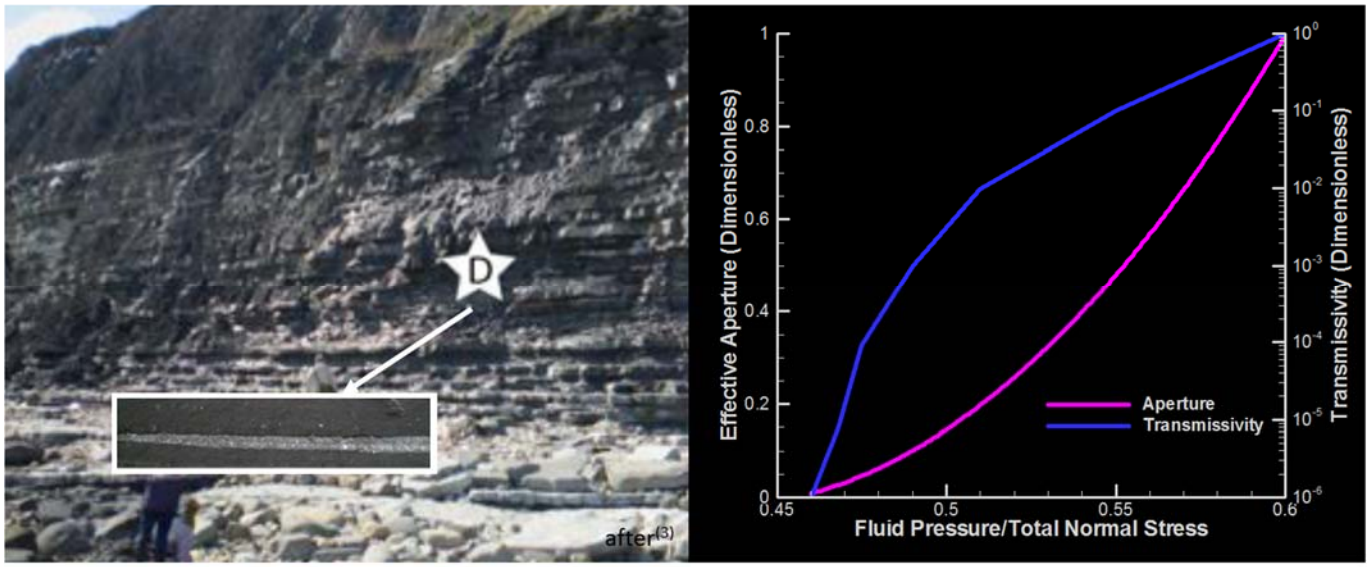

Figure 3. Hyper-stress Sensitive Bedding Planes and their Transmissivity versus Effective Stress.

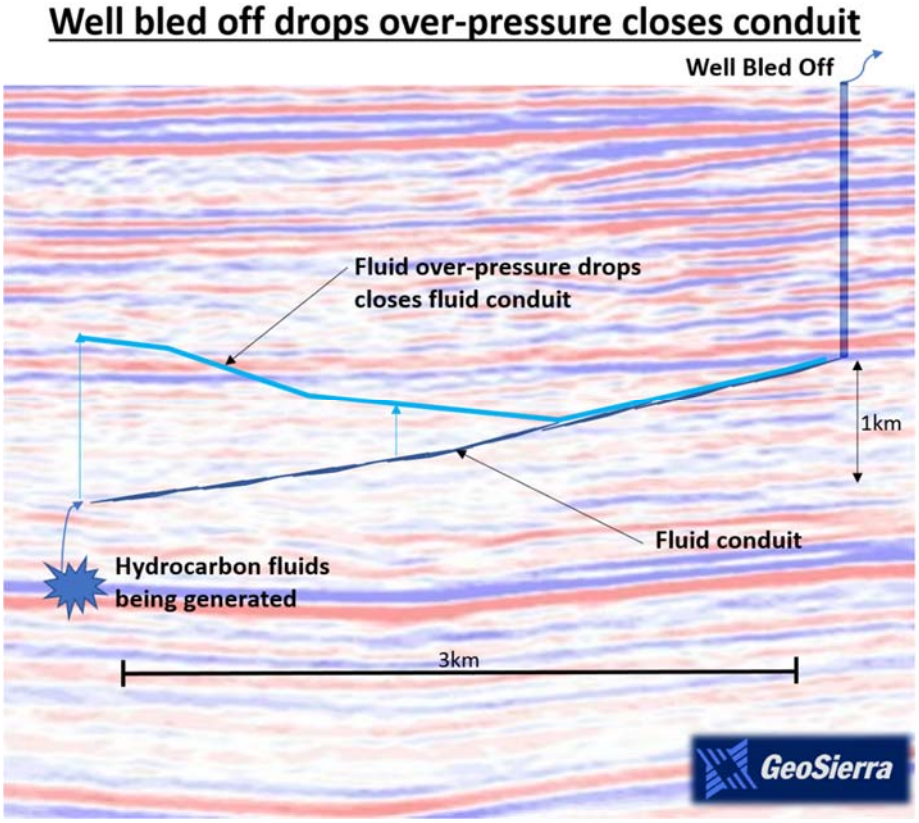

Figure 4. Loss of Over-pressure at HH-1 leads to Closure of Hyper-stress Sensitive Bedding Planes.

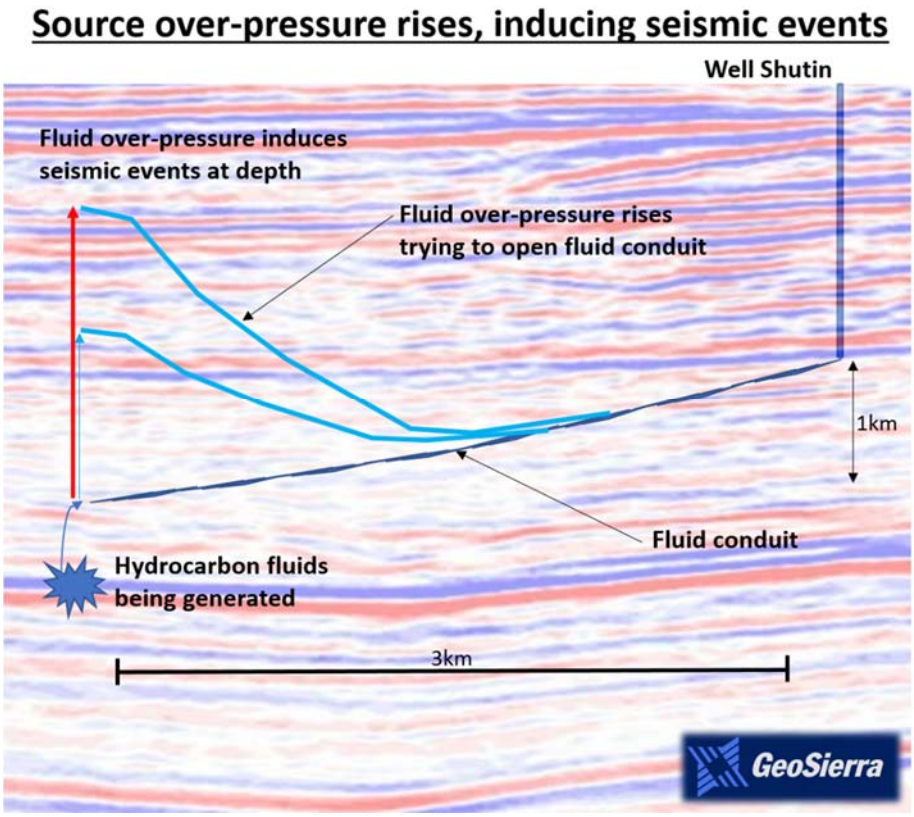

Figure 5. Fluid Generation raises Over-pressure giving rise to Induced Seismicity.

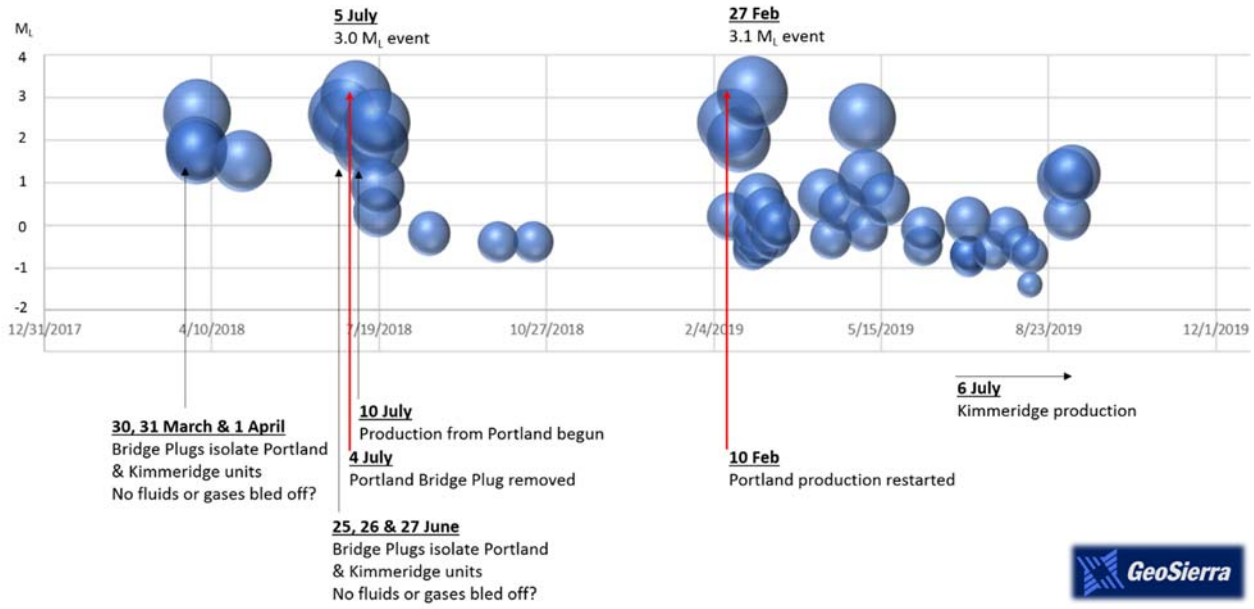

Figure 6. Timeline of Seismic Events and Activities at HH-1.

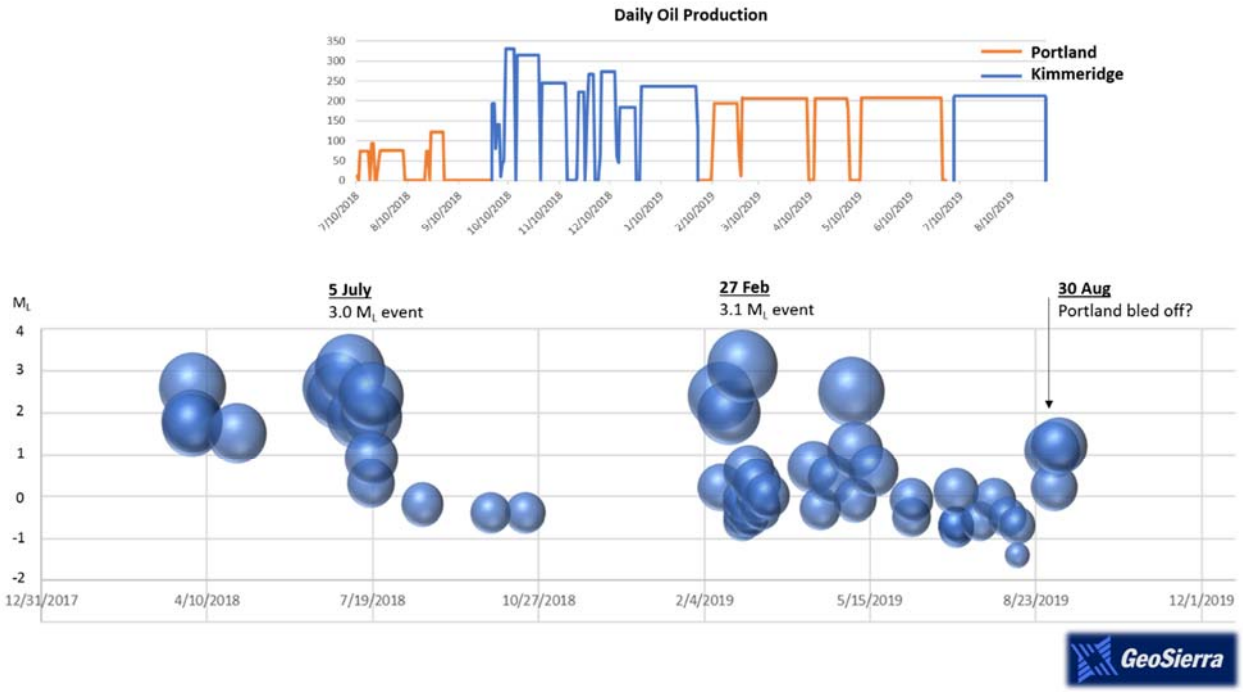

Figure 7. Timeline of Seismic Events and Production from Portland and Kimmeridge Reservoirs.