Newdigate earthquakes, Gatwick airport 2018: Natural or causal?

OGA workshop 3 October2018   Prof Stuart Haszeldine, Dr Stuart Gilfillan, Univ of Edinburgh

The problem

During April to July 2018 about 13 earthquakes occurred in the Weald of south-east England. These were clustered around Newdigate, close to active hydrocarbon exploration and production at Brockham and at HorseHill. Regionally, clusters of M1-2 earthquakes were aftershocks after a M4.3 damaging earthquake near Folkestone (April-May 2007), and 12 x M2-3 near Chichester (Jan 2015). The key question is: *Are the 2018 Newdigate earthquakes a natural coincidence of location and timing, or are these earthquakes somehow induced by human activity?*

1) WHERE were the earthquakes? The focal points of all the earthquakes cluster north and west of Gatwick, south and east of Newdigate. However earthquake locations marked on the British Geological Survey (BGS) "Geology of Britain" viewer do not fit with Latitude and Longitude numerical data tabulated in the BGS archive, and can be several kilometres shifted. Consequently it is not yet reliable to try exactly locating earthquake epicentres onto known or conjectured faults. Monitoring of seismicity at onshore hydrocarbon sites could be improved using additional low cost geophones.

2) WHAT is the deformation style? Interpretation by Dr Steve Hicks, suggest that most of these earthquakes are unusually shallow 0.5 to 1.5 km and that normal faulting is most likely. These are both unusual effects; seismic activity in the UK is typically strike slip and at 3 to 7 km depth. Shallow seismicity is known to be associated with injection of pressurised fluid into subsurface reservoirs, which reduces vertical stress. Did that occur in the Weald?

3) WHEN did earthquakes occur? Two clusters of timing are interpreted, the first commencing on April 1 for about four weeks; the second commencing on 27 June for about four weeks. Reconstructing a timeline of activity shows that the Brockham site was dormant at these times. The Horse Hill site had commenced surface ground works in mid-March preparing for an Extended Well Test, with a waste-water tanker leaving the site on 28 March, but no heavy equipment on site. On 26 June, crane lifting equipment was installed onsite, but no pipework was installed until 2 July and pump was connected 10 July. There is thus a strong coincidence of general earthquake timing to human activity, but not a good coincidence of detailed timing to large pumps or energy input.

4) HOW did earthquakes occur? There are four types of driver which could be considered: A) injection of fluid which increases pore pressure and leads to shallow depth reservoir vertical uplift; B) fluid production decreases pore pressure, to compact shallow depth reservoir, leading to vertical subsidence (Segall 1989); C) seismicity triggered by increase of fluid pressure on faults oriented perpendicular to the least compressive stress; D) God: natural seismicity without human activity.

Reservoir conditions, Brockham. This field has produced oil during tests, but requires pumping, with a large co-production of 60% water suggesting a large active hydrostatic pressured aquifer. The OGA data website shows no water injected at Brockham since mid-2012, and a production of about 15 bbl/day water (ie 870m^3 water per year) and 30bbl/day oil during 2014 and during 2015. By contrast. the Environment Agency database for well BRX3 records 2790m^3 waste water and 973m^3 Lidsey water injection during 2015 to end Jan 2016. These two databases do not match, even though the volumes are not large. Pressure connection from Brockham to earthquake sites is about 10km, crossing perpendicular to three east-west fault planes. Consequently, pressure increase is expected to be dispersed into the wider aquifer. Although an ideal mechanism, this water injection is a poor candidate in pressure amount.

Reservoir conditions, Horse Hill. This is classified as an Exploration site, so much less information is publicly available. Reservoirs are being tested in the Portland sand, and three carbonate concretion "micrite" layers in the Kimmeridge Formation. The Portland reservoir flows oil slowly to the surface (popularly portrayed as a "gusher"), which is very unusual in the Weald. The produced oil is very mature low viscosity (API 40) unusually free of water (98%), and has 15,000 ft^3/day methane content to justify flaring during well tests. Horse Hill HH-1 inclined discovery well (2014) is south of Collendean Farm discovery, drilled vertically by Esso in 1964. The Portland sandstone top reservoir is 1791 ft TVDSS, with oil down to 1,901ft TVDSS and an oil saturation of just 36%. During flow tests of 350bbl/day, the bottom hole pressure was about 700psi, recovering quickly to 915psi, suggesting a larger oil pool. The OWC on Collendean (1857ft TVD +SS) and Horse Hill (1903ft TVDSS) are nearly identical, indicating that the intervening east-west fault forms a minimal barrier to fluid transmission. The HH-1 well trends north from surface position, to intersect this fault. Thus the fault could connect deeper gas to shallower well sections. Oil at Kimmeridge Bay is similar in API and gas.

Earthquake method inference: I infer that, since reservoir pressures are hydrostatic, the gusher flow may be driven by low density gas lift. The oil has minimal water (different to Lidsey in the same reservoir), so is not tapping the reservoir, but may be draining permeable fault and fracture planes. Gas exsolves from the oil at reduced pressure. Deeper Kimmeridge reservoirs will be fracture-dominated and potentially overpressured with gas and oil sourced from deeper Lias (as at Kimmeridge Bay). This raises the possibility that variation of gas columns in the HH-1 borehole could alter subsurface pressure and rock stress state. Variations of stress can trigger faulting.

Because UKOG have not released any detailed operational information, the following narrative is speculative. HH-1 was drilled, produced as a short test, and then killed and shut in with 3 deep thick cement plugs in the main annulus; but with 3 retrievable bridge plugs in the Kimmeridge. Maybe deep methane gas seeps into the well during suspension 2014 to 2018. That produces a lower density fluid column within and around the well, with increased vertical stress causing compaction creep along the uncemented fault and damage fracture planes - being much more permeable than the reservoir (OWC similar across fault). At the edges of the field, the fault plane becomes more cemented deeper than the oil zone, so accumulates stress via creep as "asperities" (Pennington 1986). A sudden bleed-off of gas from the outer annulus increases overburden vertical stress, resulting in earthquake failure at asperities. Bleed off of gas is via casing valve, annulus A valve and annulus B valves at the well head, requiring no equipment. This venting is normal practise in many USA jurisdictions, although not in the UK. Was gas bled off around March 28th in preparation for acidisation, and gas bled off again on 26 June, in preparation for Extended Well Test tubing?

Recommendations: 1) If some Weald faults are close to failure, then future earthquakes may be induced across additional faults. Consequently any conversion to fracking operations could increase faulting downwards to produce undesirable much larger seismicity (M 3, 4, 5) focused on faults in deeper rocks. 2) Plotting of earthquake locations by BGS needs re-checked; 3) Improved much more numerous, low-cost geophone arrays around all onshore hydrocarbon sites - to produce more sensitive and accurately positioned measurements; 4) Improved recording of water, or oil and gas, extraction or injection - not just oil production. 5) Public accessibility for a daily report of site industrial activities, fluids volumes and densities; arrival, operation, and departure of equipment; measured pressure data - top hole and bottom hole: on the outside of casing, in the central annulus A at specified depth zones; in the outer Annulus B, at specified depths.

Conclusion: Hypotheses of earthquake causality 1) fluid injection increasing downhole pressures and enticing fault movement is hard to support; 2) gas columns of reduced pressure could occur in the dormant borehole and be drained before operations to cause earthquakes -possible; 3) God caused earthquakes with timing co-incidental to borehole operations - untestable. Public information of wellsite operations is needed, and access by researchers to legacy borehole records and seismic.

Refs: Pennington et al 1986 Bull Seis Soc America, 76, 939-948; Segall 1989 Geology 17, 942-946