# Geothermal potential at Grangemouth and eastern Midland Valley of Scotland

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# Geothermal potential at Grangemouth, Midland Valley of Scotland

**There are numerous locations onshore Scotland where groundwater in the temperature range 70-100 degrees Centigrade can be brought to surface in significant quantities by producer wells drilled to 2000-2500 metres, and if it were run through a modern ORC heat exchanger (we explain what this is, below) the resulting vapour can spin a twin turbine set for commercial electricity generation. This ORC technology wasn't available in previous decades: but it is now.**
**The old "hot rocks only" deep-drilling approach for geothermal projects is history. The low-temperature variant hasn't been applied yet in UK but geothermal ORC is working commercially in the USA (Alaska), Mexico (Cerro Prieto), Germany (Bruchsal), Caribbean (Nevis). Some major international projects are in advanced planning stage: India's Cambay Basin for example, huge potential.**

**The aim of this note is to demonstrate the low-temperature option for Scotland's Midland Valley. We show not just the technical basis for low-temperature geothermal projects there. Just as important is the profitability. It's a route to low-cost electricity. Grangemouth is a suitable place to establish a pilot project which confirms geothermal is commercially viable onshore Scotland. With favourable geology and imminent closure of the refinery, Grangemouth creates options to develop a heavy industry site constructively.**

**Ultimately it's not technical issues that determine whether energy projects can attract investment: it's profitability. We are seeing this fact in the declining appetite for major offshore wind projects: returns are too low. Our assessment is that we have a game changing option with geothermal in UK. The cost of electricity generated in this way onshore is substantially less than the cost of onshore wind turbine power. The economics of low-temperature geothermal producers wells drilled to around 2500 metres are perfectly feasible provided they deliver warm water at reasonably high rates. If we choose to take the opportunity, ORC bi-turbines can revitalise manufacturing industry, it can be done by 2030 without the massive costs of building and operating dozens of additional wind farms, which are only operable because of government subsidy paid for by the consumer.**

**There is plenty of onshore acreage which is not licensed for oil and gas exploration (and thus is much less likely to automatically attract objections and serious delays in getting permissions), and can be studied at minimal cost using the available seismic data held in the UK Onshore Geophysical Library. Highland Geology has been researching potential projects, with a particular approach. We are specialists in mapping fractured rock systems, and it is deep fracture zones storing warm water which are our high-grade targets for the latest bi-turbines. If we allow that some warm water will flow from the rocks themselves, too, that's a bonus and allows a wider range of areas to explore: but fracture zones are our main interest to exploit. From a geological point of view, it's straightforward to identify onshore locations and assemble a portfolio of quality targets for drilling geothermal wells. The principal minus factor presently is the lack of a dedicated regulatory system which defines the rules and earned rewards for investment in geothermal projects, but a clear and encouraging regulation and licensing system is readily constructed. Simply adapt one from Europe.**

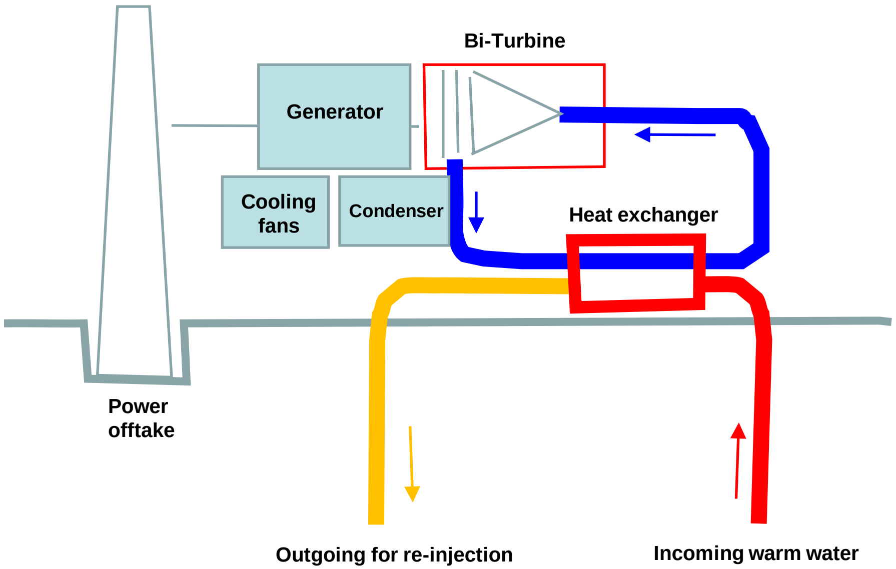
**Drilling depths and drilling design and efficiency are vital to the economics. Regarding capital required, a twin-well pair where the producer is completed at about 2.5 km and the injector to dispose of cooled brine goes to about 1 km, can be done back-to-back for around £4 million. Two wells, a heat exchanger and a modern dual turbine, along with the team overheads, might deliver a small-project at no more than £10 million. Better, is a five or six well pad, as we show below. Groups of pads exploiting proven fracture trends could show spectacular reduction in the cost of power for industrial and private uses.**

# Binary-Turbine and Power Plant

There's huge literature on these units, which are now very important in a wide range of industrial applications. Binary-cycle ORC (Organic Rankine Cycle) power plants are commercial for low-temperature source geothermal fluids. Buy them built, and the connection for output to the national grid should be straightforward. These systems are flexible, modular, and can operate effectively where high-temperature dependent steam turbines cannot operate. Presently the efficiency of ORC turbines is lower than that of conventional steam turbines but designs are steadily improving performance for low-temperature applications.

The geothermal fluids never come into contact with the power plant's turbine unit. This means high-salinity ground water, any hydrocarbons traces, or corrosive/poisonous gas in solution in the fluid stream go back downhole to safe depth. Low-temperature geothermal fluids pass through a heat exchanger which contains a secondary, "binary" fluid. This binary fluid is freeze resistant, it's an organic compound, has a much lower boiling point than water, and modest heat from the geothermal fluid causes it to flash to vapour, which then drives the turbines, spins the generator, and creates electricity. The condenser returns the heat exchanger vapour as liquid.

ORC plants can be highly automated. For low-temperature geothermal, efficiency of the heat exchanger is critical as the temperature differential is small. Cooling efficiency is crucial too, and is optimised.




Small turbines cost roughly a million pounds apiece. Cost of a commercial project setup depends mainly on the depth and number of wells, each producer is assumed here to have a dedicated turbine and support plant but some common header may be possible to give a higher specification configuration. Much of a project outlay can be covered by a large forward sales contract.

## So what do the costs of a bigger geothermal project look like?

**Drilling say 5 producer wells from one pad gives big savings on site prep, well and turbine maintenance, we might need only 3 injectors to get cooled brine back to formation, and those wells are cheaper as they only need go to say 1000 metres. The wells should be separated to minimise interference with the thermal capacity around each other, that means some element of deviation is necessary, maybe spudding at least some of them inclined: a couple could go to different formations.**

**Lets consider the case for one large pad, and drill wells in sequence, skidding the rig, 1 producer well vertical to 2500m, 4 producers radially inclined to 2500m; 3 injectors to 1000m (cover any intermittent build-ups of cooled water for re-injection by building a large holding tank).**

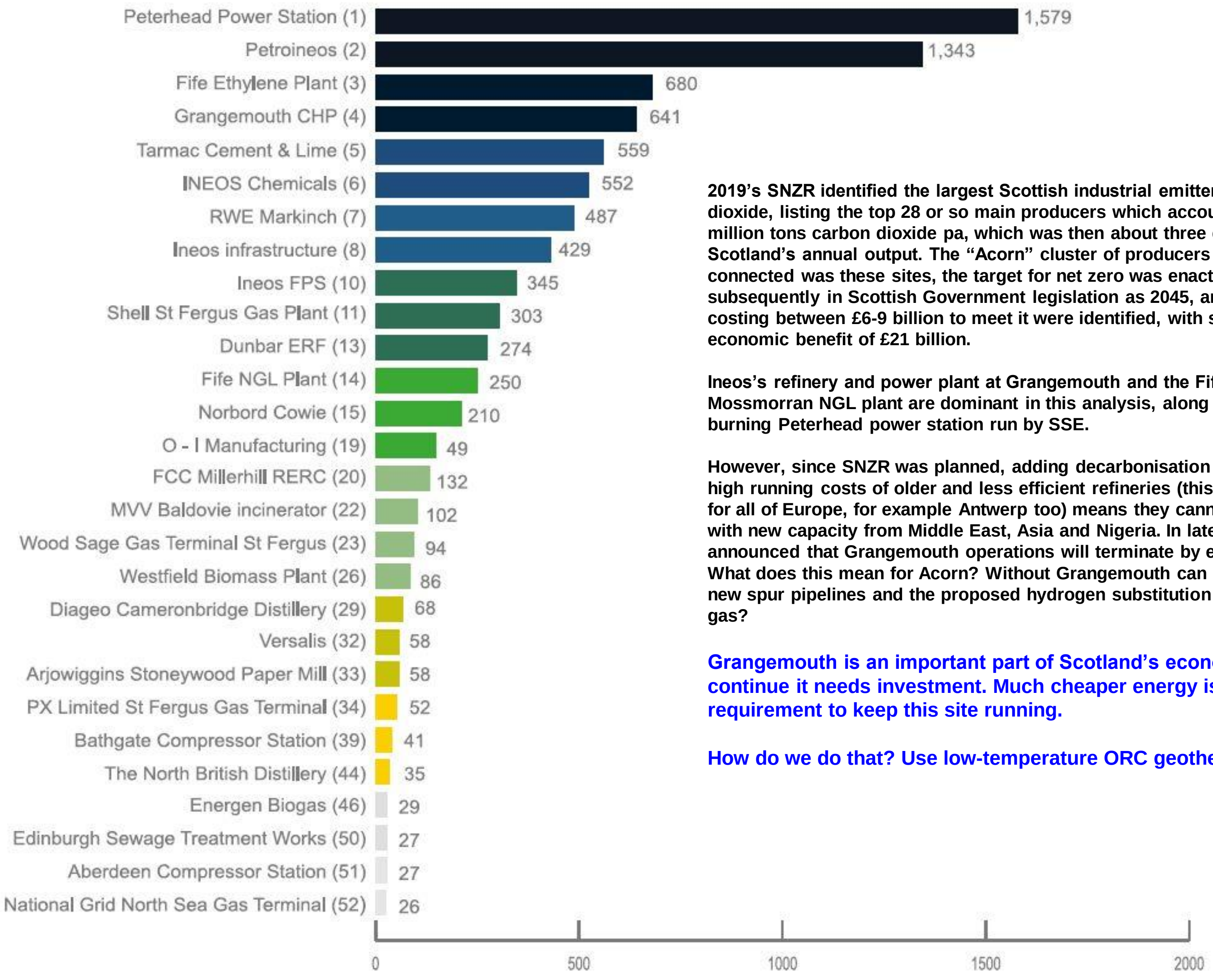
**How many heat exchangers and turbines do we need, if the production is all off one site? Here we presume each well needs its own turbine to produce 2MW, but we might find higher input water temperatures are possible with exchanger boosters.**

| | |
|---|---|
| **Drilling/completions** | **£14 million** |
| **Turbines/generators** | **£5 million** |
| **Exchangers** | **£2 million** |
| **Condensers** | **£1 million** |
| **Installation** | **£1 million** |
| **Pumps, systems** | **£1 million** |
| **Connect to grid** | **?£1 million** |
| **Sundry** | **£1 million** |

**With these uncertain and approximated figures, Capex is £26mm for 5 producer wells, 3 injectors, and 5 turbines. A rig is only on site for the drilling. For operating cost say £7.5 million for 25-year life, the single-site allows major overhead savings compared to cost of separate twin-well pads. For Levelised Cost Of Electricity we exclude off-site manpower costs and eventual site clearance/restoration. Given the amount of power produced over 25 years (2 MW x 5 wells x 0.85 capacity factor x 8750 hrs per well per year x 25 years = 1,859,375 MWh), the LCOE = (26,000,000 + 7,500,000/ 1,859,375) which is levelised at £18 per MWh. That is about 65 percent of the present cost of onshore wind turbine power.**

**Unlike wind power generation, we don't need to turn off the plant when there's no wind, or too much wind. Geothermal is reliable, is environmentally preferable as pads are small and can be made inconspicuous, and the plant has longer life than wind turbines. Like wind, geothermal will see reduced costs as the technology advances.**

# Scottish Net Zero Road Map




**2019's SNZR identified the largest Scottish industrial emitters of carbon dioxide, listing the top 28 or so main producers which accounted for 8.6 million tons carbon dioxide pa, which was then about three quarters of Scotland's annual output. The "Acorn" cluster of producers needed to be connected was these sites, the target for net zero was enacted subsequently in Scottish Government legislation as 2045, and actions costing between £6-9 billion to meet it were identified, with supposed economic benefit of £21 billion.**

**Ineos's refinery and power plant at Grangemouth and the Fife Mossmorran NGL plant are dominant in this analysis, along with the gas-burning Peterhead power station run by SSE.**

**However, since SNZR was planned, adding decarbonisation to already high running costs of older and less efficient refineries (this holds true for all of Europe, for example Antwerp too) means they cannot compete with new capacity from Middle East, Asia and Nigeria. In late 2023 Ineos announced that Grangemouth operations will terminate by end-2025. What does this mean for Acorn? Without Grangemouth can it support new spur pipelines and the proposed hydrogen substitution for natural gas?**

**Grangemouth is an important part of Scotland's economy and to continue it needs investment. Much cheaper energy is a principal requirement to keep this site running.**

**How do we do that? Use low-temperature ORC geothermal.**

## Is Grangemouth area of wider commercial interest for geothermal in Scotland?

**With bi-turbine ORC technology and encouraging practicality, how does this relate to Grangemouth and the sedimentary basins around it?**

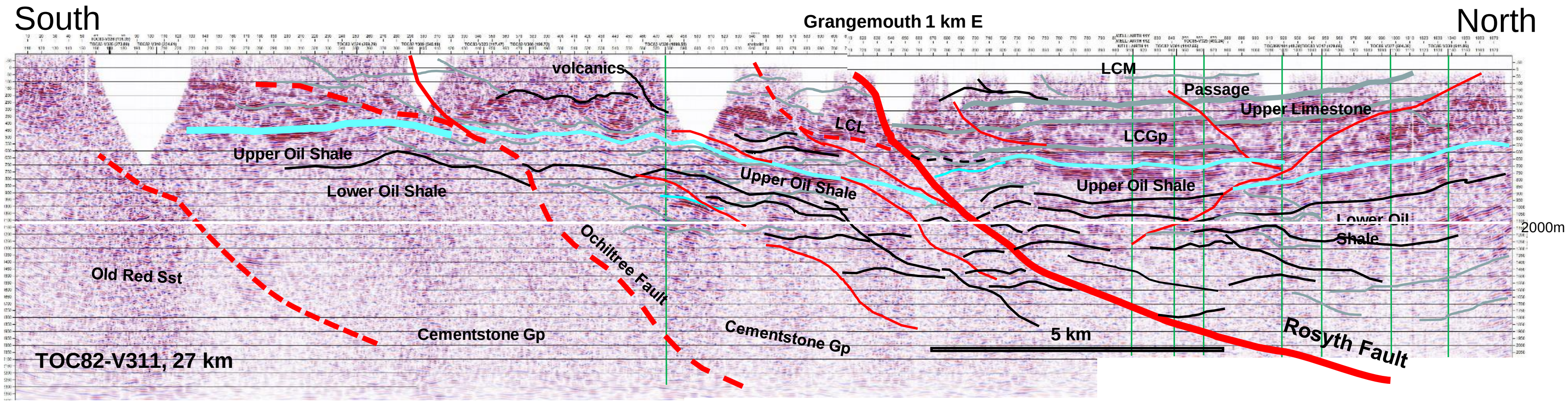
**All Scottish companies running manufacturing processes on a range of scales want lower cost energy. They want to be competitive, domestically and internationally. Right now, UK has the most expensive electricity in Europe and the effect on investment is destructive.**

**Grangemouth refinery closure takes with it the basis for the Acorn collection system for conveying carbon dioxide to Peterhead, where the gas will be pipelined to the central North Sea; and the remaining life of the Forties pipeline in turn comes under threat. Ongoing oil and gas production from numerous small fields is presently looking far less secure than was the case until recently.**

**Suppose we could more or less halve the cost of electricity. What we want for geothermal with ORC is favourable geology, with very extensive and numerous major fracture zones. In the Carboniferous sub-basins at Grangemouth we have them. Industrial parks, likewise, there are several there. A skilled worker base, capital resource, and Aberdeen is close by with all the drilling know-how one could want for geothermal project support.**

**Its clear, Grangemouth is a logical location for the first geothermal project using ORC, in UK. The follow-up potential is very large. A regional centre for further development could be set up at Grangemouth to service Midland Valley energy users, including the Mossmorran LNG plant. The refinery can run on, jobs are preserved and new ones created.**

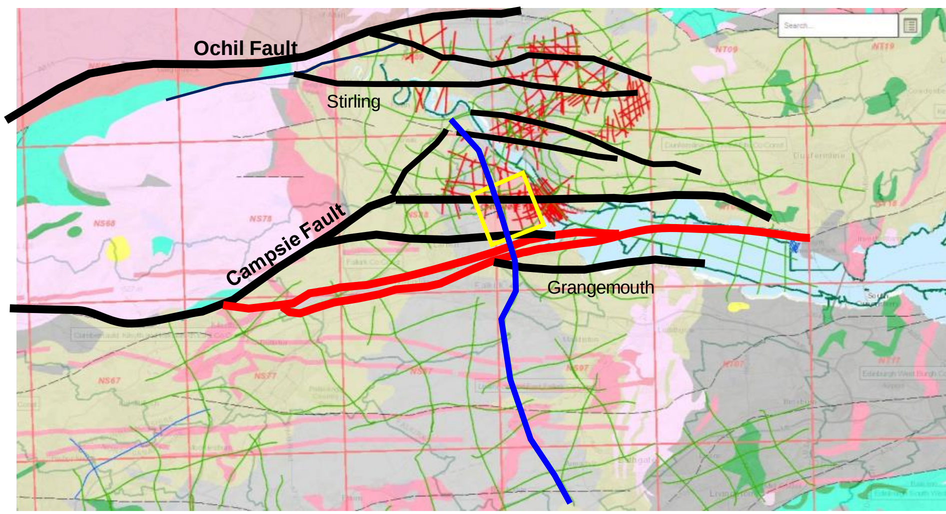
# A geothermal project at Grangemouth



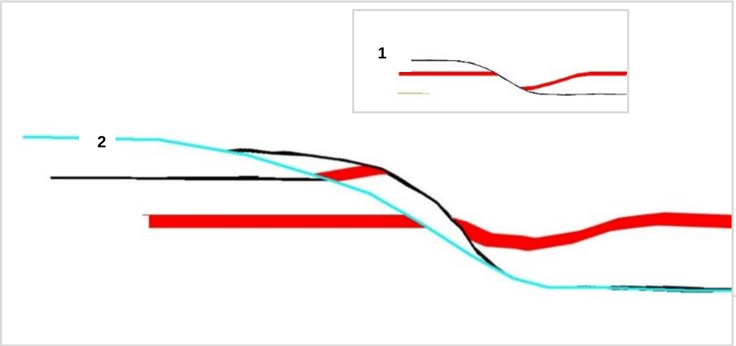

This north-south profile across the central basin of the Midland Valley is based on seismic shot by Tricentrol in 1982, the line is 27 km long and passes close to the Grangemouth site. Green lines are released 2D seismic profiles, the line illustrated is marked in blue on the index map. Note there is a local 3D seismic grid (yellow outline) which will be of value in further work to define fracture patterns near Grangemouth.

It's a sketch, to show structure style: the positions of faults and formation boundaries are only approximations at this stage. We interpret classic strike-slip (wrench) faulting with the gigantic Ochil Fault (4 km vertical displacement) driving Devonian opening and subsequently active again as an oblique frontal ramp for late Carboniferous contraction of the basin. The faults on all scales are inter-linked, distributing cross-basin deformation and dividing the infill sequence into discrete tectonic slices.

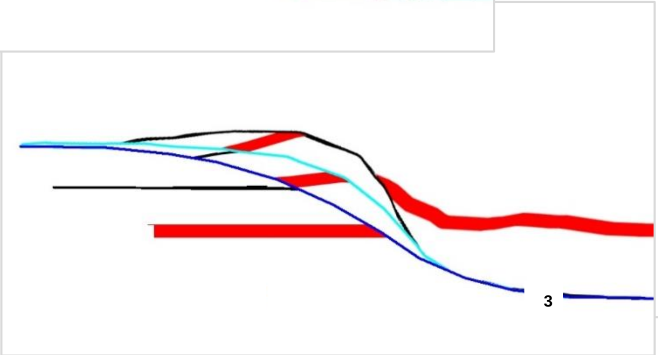
Immediately north of Grangemouth in the hangingwall of the Rosyth Fault (red) there is a series of closely-spaced west-east faults, they root westwards onto the Campsie Fault. These represent fracture targets for geothermal. A zone of duplexes (fault-bounded slices) adjoining the Grangemouth plant, formed in the tightening of the Rosyth Anticline rollover, defines a clear target for geothermal investment. See the next slide for an explanation of what a duplex is.



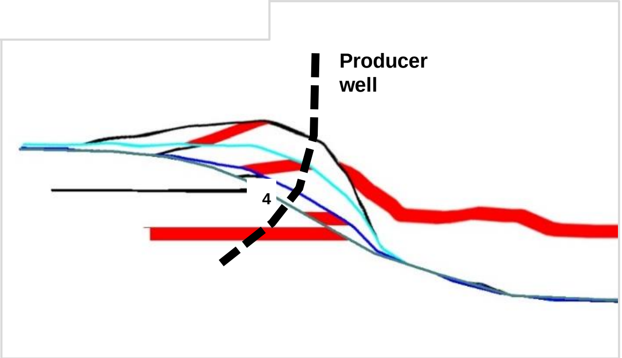
# Passive Roof Duplexing creates structural highs which are excellent targets for geothermal wells




**Inversion fault 2, pale blue, breaks into the footwall of extensional fault 1, and now the only part of fault 1 which is still hydraulically pressured and moving is the shared flat at lower right, in some shale-dominant unit.**




**Pale blue 2 now stops moving and is replaced by new dark blue fault 3, and with movement on this fault whilst 1 and 2 are inactive we have some stacked duplexes appearing. Fault 1 is net-extensional, the other faults are wholly reverse.**




**Fault 4 in dark green propagates off the floor fault of the stack next, it has less heave. There are lots of examples of small steep faults like this, in the seismic imagery.**

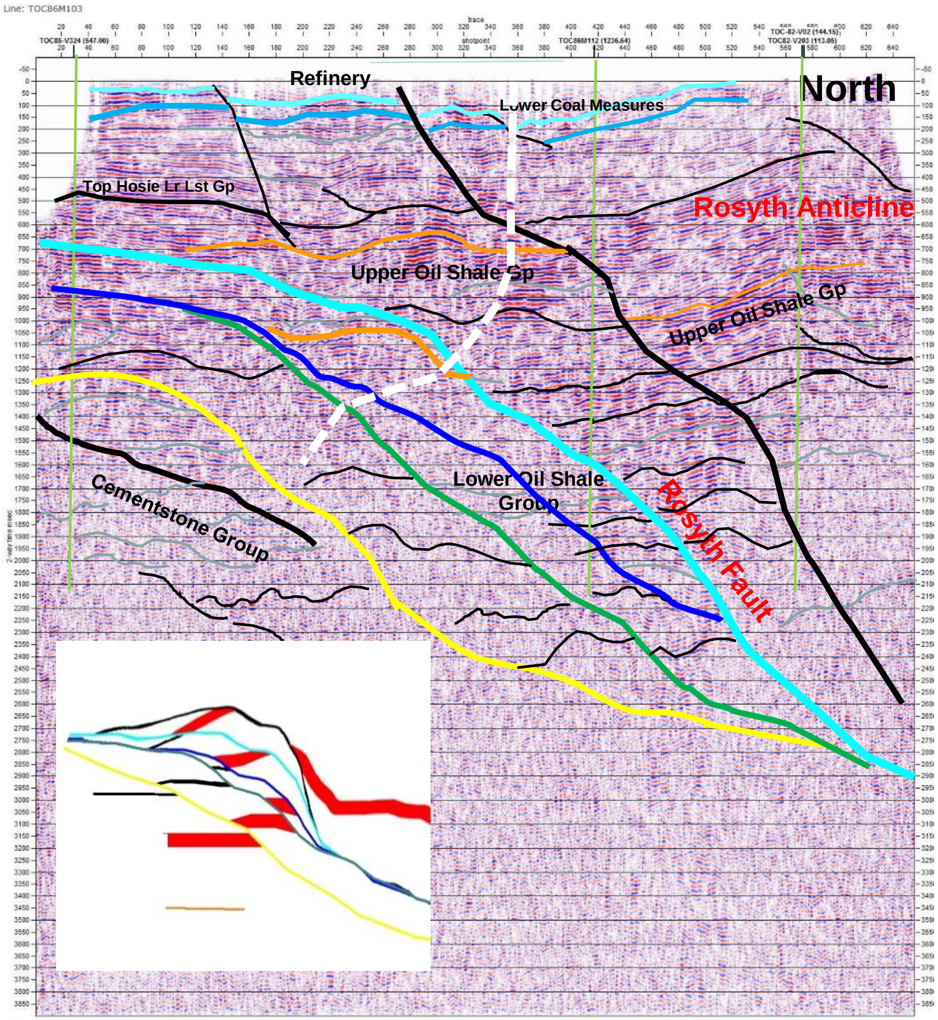
**Models here are made with section balance software written by John Nicholson.**

**Repeated close-spaced footwall faulting in shortening of earlier extensional structure, forces a stack of thrust slices (duplexes) to develop and progressively climb, each slice stretches as it travels over an upward-convex new fault. The evolving hangingwall will fracture continuously as all previous slices of rock are passively flexed in the inversion. The new faults propagate downwards, each new one's curvature imposes more stretching of the evolving stack above it, because the stack has to stay in contact: hence "passive". Each new footwall collapse fault inflicts its own phase of stretching, and renewed axial fracturing on all of the overlying rock travelling across it. Brittle limestones and dolomites will be particularly likely to fracture.**

**So we can expect significant opening fractures to develop and thoroughly penetrate the hangingwall. A deviated well drilled through the stack will find a high concentration of interconnected faults.**

**The drilling method for the wells is pressure-pulse. A competent drilling crew can use mud pressure variation to break rock immediately around the well bore, interlinking the producer and injection wells with natural fractures. This is standard drilling practice (not to be confused with shale gas fracking!), has been so for a quarter of a century, and is accepted onshore UK by environmental agencies.**

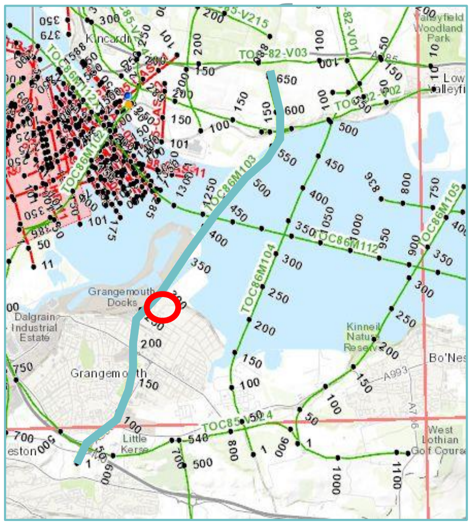
# Possible producer well track at Grangemouth



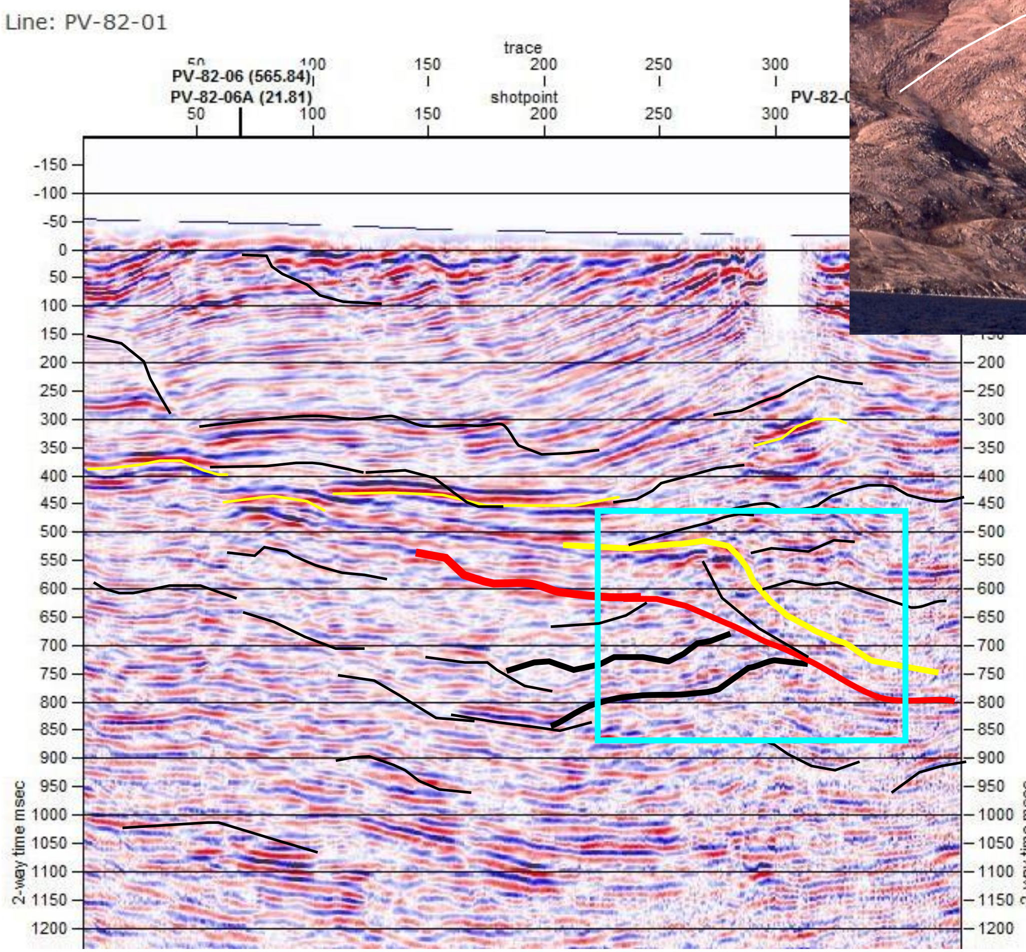

Section TOC86M103 through the refinery location (red circle) is a dip profile across the Rosyth Fault: it images a complex array of folds and discordant bedding contacts which is not easy to interpret! Which surface is the Fault?

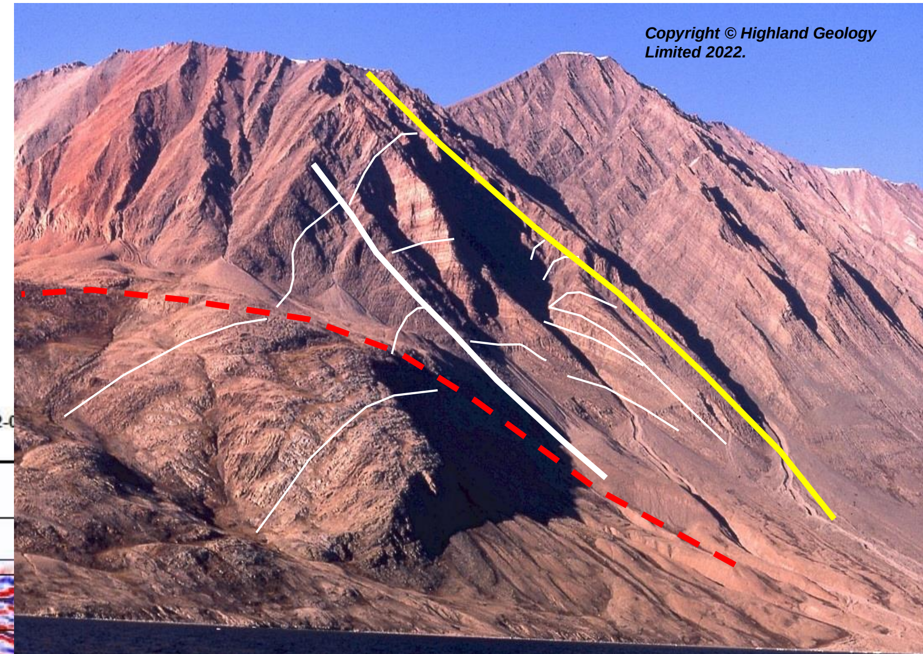
The inset model is a guide to what's a reasonable representation of likely structure style. The duplex stack is made by moving on overlapping faults successively, so that the structure grows progressively higher: it matches Rosyth Anticline geometries reasonably closely.

We can be confident that folded fault-bounded duplexes will be strongly fractured. It is straightforward to position a rig within a kilometre or so of the plant and drill inclined to a target area at about 2500 metres. In two-way time which is the vertical scale of the seismic, a thousand metres would be roughly 550-600 milliseconds, so we'd aim get to around 1.4-1.5 msecs with the producers.



## Anstruther in Fife is another Scottish location with promise for low-temperature geothermal.




**The writer worked on central East Greenland Old Red Sandstone footwall collapse structures, in the late 1960s. This photo shows Rodebjerg, on Ymer O. It's an instructive example of the structure style we have in the Midland Valley of Scotland.**

**The seismic line across Anstruther Anticline shares the same duplex pattern and high degree of fracturing we are interpreting: compare it with Rodebjerg. The Anstruther fold is undrilled, it's a geothermal candidate, it could power the whole of the town and adjoining areas. With lower-cost energy Anstruther town could grow new businesses, and keep its young people.**

**It is straightforward to identify more instances like this, in the central and eastern Midland Valley.**

# What next? FEED using AI

**Our aim in this presentation is simply to outline a plausible efficient and environmentally acceptable way to generate electricity commercially, using now-proven technology onshore, at a major discount to wind.**

**We think a multi-skilled group should work together with government representation (GB Energy?) to look at this option in detail, and run a Front-End Engineering Design for a first project. Following definition of initial objectives, and with expert knowledge of how to drill wells and what it costs, using artificial intelligence a good-enough FEED will take only a few weeks.**

**With a FEED completed one then has the costs and timetable for a trial project, and can put a consortium together to organise location and funding for it. To contract a rig, one has to buy materials and items like well heads and tubulars up-front that need manufacturing and storage. Several million pounds covers the project onset orders.**

**To get to spud-in day for the first well, will take about 1 year because permissions are needed from dozens of interested parties, and whilst that process is happening the consortium becomes a private company and can raise the remaining project capital, along with the team who will provide the technical skills and logistic support.**

**Speed is a key factor. Let’s remember that with too-high energy costs, important UK industrial capability is on the verge of being lost, pointlessly, eliminating economy growth and causing deeply-upsetting consequences for a lot of valuable people.**

## Next step

We have a complete game-changer in low-temperature geothermal. This approach applies also to other basins, world-wide. It has radical implications for future energy development policy – it becomes feasible to control and even reverse the rise of carbon levels, if enough onshore drilling resource became available, and with that the transition to zero carbon need not entail any material decline in UK manufacturing output as we presently know it. It would have the opposite effect!

The risk is small. The reward is off the clock. In the case of Scotland, there is a unique concentration of all the skills which would make onshore geothermal work, an initial site at Grangemouth which is ideal, and the know-how to drive the project forward internationally.

See our website for more information on pulse drilling, and on fracture systems (including a blog visit to a well-exposed outcropping one, at Troup Head in Aberdeenshire).

We should be delighted to discuss this analysis, on request.

Dr John Nicholson

www.highlandgeology.com

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