Value of UKOGL Seismic Lines in major engineering projects: The HS2 High-Speed Rail Project

Robin Grayson MSc

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Value of UKOGL Seismic Lines in major engineering projects: The HS2 High-Speed Rail Project

Robin Grayson

Author: Robin Grayson MSC: washplant@rocketmail.com Independent Geologist and Ecologist.
Mobile: 07840 780932.  2 Haughton Drive, Manchester M22 4EQ, United Kingdom.

Robin holds degrees in geology and zoology from the University of Manchester, and as an undergraduate co-authored papers on the Mississippian reefs in the Bowland Basin, and helped create the Salthill Quarry Geology Trail which today is a nature reserve. While a postgraduate he mapped the concealed network of deep channels in the bedrock between Manchester and Liverpool. At the same time he discovered the freshwater Eccles Mudstone as a new formation resting on the marine Manchester Marl.

On leaving university Robin was a geological consultant for the Holme Chapel exploration well near Burnley, then appointed Lecturer in Geology at Wigan Mining College, a post he held for a decade. During this time gained expertise in protecting urban heritage such as Wigan Pier and later joined Lancashire Enterprises as Small Firms Adviser. Serving as an elected councillor on Greater Manchester and later on Wigan Metro he played a role in designating Sites of Biological Importance (SBIs) and Regionally Important Geodiversity Sites (RIGS). When assisting Cheshire and Lancashire Wildlife Trusts to prepare for the Inquiry into the Second Runway of Manchester Airport, he presented evidence for the Mobberley Salfield being under the path of the runway, and that the creation of the Bollin Valley was due to collapse breccia along the edge of the saltfield. He then spent many years as SME business adviser, ecologist and geologist in Mongolia, Kyrgyzstan, Kazakhstan and lately Afghanistan gaining expertise in fluorspar, travertine, talc, lapis lazuli, spodumene, shungite and coal, stratiform copper and alluvial gold. He discovered the North Afghan Orogeny and found evidence for the Kabul Block being a microcontinent broken free of the Katanga Cu-Co Block of Central Africa.

ABSTRACT

Using vintage seismic data is a novel approach in railway construction which has potential to contribute significantly in route optioneering and ground hazard mitigation. The HS2 high speed railway project is a major transport project, well advanced in its planning. Using seismic and other sources, a number of timely comments are made on aspects of Manchester’s geology, which warrant consideration in routing the tunnel to central Manchester and may have a substantial impact on project cost estimates. The main purpose of this report is to draw attention to the existence of the vast UK Onshore Geophysical Library (UKOGL) of more than 50,000 kilometres of seismic lines, enough to twice encircle the Earth. The seismic lines were shot mainly by oil and gas exploration companies in the 1970s to 1990s but many were shot by British Coal. The UKOGL seismic lines are very helpful in mapping the large faults through which the tunnel will pass, and acquisition and interpretation of the seismic data is advisable to reduce risk and control costs. Examination of the UKOGL grid of seismic lines of the 1980s confirm that the 1:50,000 scale BGS geology maps for Manchester (sheet 85) and Stockport (sheet 78) are very useful indeed, but are 30 years out-of-date for much of the HS2 route. Examples of seismic sections are presented, and suggest the UKOGL seismic lines along the M56 are crucial for HS2 route selection to avoid the wet Triassic saltfields between Rostherne Mere and Manchester Airport, where collapse breccias floor the Bollin valley (Grayson et al. 1996, 1997; Wilson 2003). UKOGL seismic lines along the M56 show faulting close to the proposed HS2 station for Manchester International Airport, and close to the south portal of the Manchester Tunnel. UKOGL seismic lines also reveal the geology of the tunnel is inadequately shown on outdated BGS maps, with risk from gas, roof falls, rock bursts, slurrification and rapid influx of groundwater from breaching of Triassic aquifers compartmentalised by not only by large faults but also by wedges of Manchester Marl and Eccles Mudstone (Grayson 2017). Troublesome variations in the rockhead surface are expected, notably the concealed Didsbury Bedrock Channel (Grayson 1972, 1984b) where the rock surface descends below sea level. This concealed topography includes very large erratic boulders in glacial till, liable to incapacitate even the most robust boring machines. Often the tunnel depth is so shallow that the tunnel will interface with the normal base of problematic ‘drift’ cover of running sands and seals of glacial tills. UKOGL Seismic Lines reveal the potential for major deep geothermal energy under Manchester, enabling the HS2 terminus to spearhead a sustainable Green Gateway development to the city centre, taking advantage of the HS2 footprint beneath the elevated section for deep drilling, heat exchangers, closed loop, and to house the primary pipework of a world-class district heating scheme.

Of concern, the final elevated section of the HS2 is shown to be close to the Manchester Earthquake Swarm. Comments are made on the swarm and its location in respect to the HS2 Project. A novel cost-effective method of monitoring any resumption of the Swarm while monitoring the ground vibrations above the HS2 tunnel is presented, using a local network of mobile phones installed with the free MyShake app.

The UKOGL Seismic Lines indicate an alternative route to the city centre further away from the Earthquake Swarm; a route which would be shorter, less expensive and enable passengers, luggage and parcels to swiftly change between the HS2 and east-west express trains to all northern cities in England and Scotland.

NOTE: The reader’s attention is drawn to proposed changes to the HS2 route, out for public consultation: https://www.gov.uk/government/consultations/hs2-phase-2b-design-refinement-consultation
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1  PREFACE

This valuable report demonstrates the importance of access to the large seismic database held by the UK Onshore Geophysical Library in planning large engineering projects. Although these seismic data were acquired mainly in the search for oil and gas, they are available for use by all interested parties, not just educational and commercial organisations but also the general public. In this case, the seismic lines show elements of the underlying deep geological structure that can have a large influence on the stability of major construction work and it is very encouraging to see our data utilised in this manner. We congratulate Robin Grayson on this study and we hope it will set a precedent for best practice in future projects.

Dr. Malcolm Butler
Chairman
UK Onshore Geophysical Library

2  ACKNOWLEDGEMENTS

The author is deeply grateful to the UK Onshore Geophysical Library (UKOGL) for permission to publish seismic lines shown in this report. UKOGL was established in 1994 to manage the archive and official release of onshore UK seismic data. At the time the Library was set up the data were scattered, deteriorating and in real danger of being lost to the nation. The Library was founded to ensure that this resource was located, recovered, reconciled and saved for the national archive, and is very effectively run by Lynx Information Services.

Special thanks are due to Iain Williamson the Senior Lecturer in Geology of Wigan Mining College and Dr. Michael Eagar the Curator of Geology at Manchester Museum for sharing their knowledge of local geology and coalfields, and also to Rodney J. Ireland FGS the Geologist of North-West Water Authority for sharing his knowledge of the Permo-Triassic rocks of Greater Manchester, especially of groundwater and our discovery of the enigmatic Eccles Mudstone under Manchester and Stockport. Linda Gregory, Jill Smethurst and Tony Browne assisted Robin in mapping the Mobberley Saltfield and recognising its linear dissolution and the Bollin Breccia were the main cause of the Bollin valley rather than river erosion alone. Rick Parker and Linda Gregory assisted in unravelling the geological and ecological importance of dynamic meanders and ox-bow lakes along the Bollin at Manchester Airport, and Albert Wilson of the BGS who completed detailed mapping of the Triassic at the airport and Mobberley Saltfield. Ecologist Dave Bentley gave expert advice on the Great Crested Newt.

More than a hundred geologists, mostly professionals of the conventional onshore oil and gas industry accompanied Robin on fieldwork in Greater Manchester, and special thanks are due to Tony France and Gerald Price, both coal geologists of the National Coal Board for fieldwork above and below ground. This Report has benefited from contributions by the members of the Manchester Geological Association, the Wigan and District Geological Society, the Greater Manchester RIGS Group, and the Friends of Fallowfield Loop.

Dr. Bernd Braetigam reviewed the entire document, and made many valuable comments on improving the layout and clarity based on his substantial experience with planning and construction of high-speed railways in Germany.

Thanks to Martin Browne for alerting the author to examine seismic lines of geothermal value in Manchester.

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SECTION ONE
UKOGL
Seismic Lines

Thumper Trucks passing quietly along a rural road.

photo: courtesy of Mark Abbott
3 INTRODUCTION

3.1 Fifty thousand miles of Seismic Lines

An astonishing fifty thousand miles of seismic lines crisscross the United Kingdom, funded by many hundreds of millions of pounds by onshore oil and gas exploration companies. Most of the seismic lines are in the public domain, viewable by the public free of charge. They are accessible on-line via a user-friendly zoomable database, the UK Onshore Geophysical Library UKOGL https://ukogl.org.uk managed by Lynx Information Systems http://www.lynxinfo.co.uk on behalf of the UK Oil and Gas Authority (OGA) https://www.ogauthority.co.uk/. UKOGL is the official archive and release mechanism for all UK public domain onshore seismic data. UKOGL’s vast holdings are vital for oil and gas, geothermal energy and minerals such as potash.

3.2 UKOGL Seismic Lines – How the seismic data is collected

Most of the seismic data is collected by a string of geophones trailing behind a recording truck, moving slowly ahead of vibroseis trucks often known as thumper trucks. These send vibrations of energy into the ground, some of which is reflected back to the surface and recorded by the string of listening geophones.

The cartoon shows only the general idea, the convoy moving slowly from right to left. The cartoon is extremely simplified, and the interested reader is referred to Wikipedia for proper accurate information: https://en.wikipedia.org/wiki/Reflection_seismology.

The following account is also simplified, intended only as a primer for engineers and scientists familiar with other disciplines. The goal is to alert them to the value of UKOGL Seismic Lines in gaining valuable insight into the hidden world beneath our feet, as part and parcel of a construction project long before finalising a route. Before opening a door, it is best first to knock, for it may be a very costly mistake not to knock first.
WHERE ARE THE 50,000 MILES OF SEISMIC LINES?

4.1 Distribution of UKOGL Seismic Lines

UKOGL Seismic Lines are most closely packed in lowland areas, for these have always been deemed to hold the most potential for discovery of onshore oil, gas, coal and potash resources.

Figure 3: UKOGL MAP OF SEISMIC LINES

As can be seen from the map, Greater Manchester has an unusually dense network of UKOGL Seismic Lines. This is due to being inside the northern rim of the Cheshire Basin, prospective for oil, gas and coal.
4.2 UKOGL Regional Seismic Lines

UKOGL includes Regional Seismic Lines of exceptional length and quality, produced by cooperation between geophysicists from the ranks of academia, government agencies and onshore oil and gas companies. Over hundreds of person-years, they have pieced together hundreds of miles of seismic lines and chosen ‘picks’ of the best seismic reflectors and tied each reflector to not only exploration and production wells, but also to classic exposures visible in quarries, railway cuttings and sea cliffs, often famous as Sites of Special Scientific Interest (SSSIs), Regionally Important Geodiversity Sites (RIGS), geology trails and tourist attractions.

It took the arrival of Railway Lines to best correlate the town hall clock.
It takes the arrival of the UKOGL Regional Lines to best correlate the town’s rocks.
4.3 Where are the UKOGL Seismic Lines around Manchester?

Figure 6: MAP OF UKOGL SEISMIC EXPLORATION LINES IN AND AROUND MANCHESTER
GREEN LINES: UKOGL seismic exploration lines for oil and gas.
RED LINES: UKOGL seismic exploration lines for coal.
4.4 Hundreds of miles of Seismic Lines crisscross the HS2

This report offers to planners, geologists and engineers a ‘keyhole example’ of the potential value of UKOGL in major engineering projects, by illustrating the merit of using UKOGL to assess the final stretch of the proposed HS2 high-speed railway between the M6 motorway and the terminus at Manchester Piccadilly.

Figure 7: UKOGL SEISMIC EXPLORATION LINES PRESENTED IN SECTION THREE – brown lines

Exercise 1 Eastward on the M56 from Rostherne to Manchester Airport – AUK87A-135
Exercise 2 Northward on the M56 past Manchester Airport on Princess Parkway over HS2 Tunnel – SOV88-XL060-G
Exercise 3 Northward on Princess Road from Princess Parkway to Mancunian Way at city centre – UK-86-431
Exercise 4 Eastward on the northern perimeter of Manchester Airport – SOV87-X60-05
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Exercise 11 Eastward from Salford then under Mancunian Way to Ashton Old Road to near Tameside – UK-86-421
Exercise 12 Large-scale geothermal energy potential for HS2 Piccadilly Station development – again UK-86-421
Exercise 13 Northeastward from city centre up Oldham Road to cross the Oldham border – UK-86-429
Exercise 14 Shortest HS2 route from Airport to city centre – AUK87A-135 then SOV88-XL060-G finally UK-86-431
Convoy of Thumper Trucks passing along a trunk road in Redcar.

photo: courtesy of Mark Abbott
5  APPROVED HS2 ROUTE TO MANCHESTER

5.1  Final stage from Manchester Airport to Piccadilly Station

5.2  HS2 should follow a seismic line

Strange but often true

The reader is first introduced to the general rule that seismic lines are shot in the straightest line offering the least obstacles to the passage of a slow-moving convoy of giant vibroseis trucks and their miles of cables and geophones. This is of critical importance in urban areas where straight wide roads may be scarce. Similarly the HS2 route should be along the straightest line offering the fewest obstacles during operation and construction, both for surface and tunnel sections. If this holds true, the HS2 route between the airport and city centre should coincide with a seismic line. However this is not so, as shown by the UKOGL map.

5.3  HS2 route optioneering

The route optioneering failed to use free-of-charge UKOGL seismic lines.

HS2 staff recently authored a paper explaining the methodology for selecting the final route for HS2 (McNaughton and Banks, November 2018). The methodology was robust except marred by failing to use the freely available UKOGL Seismic Lines, leading inevitably to major cost overruns and valid safety concerns.

5.4  Land assembly now substantially complete

The approved HS2 route has much of its footprint secured.

“Plans for Phases 2a and 2b aren’t confirmed but are unlikely to change significantly”

https://www.gov.uk/check-hs2-route. In essence, the route has been fixed before serious investigation of the ground conditions has even commenced.

5.5  Engineering design now largely complete

The approved HS2 route has the basics of its engineering design completed.

However, the detailed design cannot be completed until after ground conditions have been investigated.
5.6 Mitigation/landscaping plans only partly complete

**HS2 mitigation and landscaping plans prepared, at least to conceptual stage.**

The approved HS2 route has sought to avoid many potential impacts. The scheme fails to enact Government policy of attempting net wildlife gain, or even 100% wildlife compensation and instead almost invariably proposes less than 100% (aka ‘mitigation’).

Ecological surveys have not been completed, but the final route has been fixed in all but name. For example, surveys for the Great Crested Newt (GCN) *Triturus cristatus*, a strictly protected species under the Berne Convention, the EU Species and Habitat Species Directive, and the equivalent UK species legislation.

Ecological surveys have not been completed, but the final route has been fixed in all but name. For example, surveys for the Great Crested Newt (GCN) *Triturus cristatus*, a strictly protected species under the Berne Convention, the EU Species and Habitat Species Directive, and the equivalent UK species legislation. GCN fieldwork is now underway; too late, as several years of repeated surveying is essential for all GCN ponds have been detected, including evidence of breeding such as eggs, tadpoles and immature adults. Additional work is required to determine the terrestrial habitats used by mature GCN for nighttime feeding of the earthworms and other prey species. To translocate GCN populations out of the path of HS2, requires several years. This lengthy process has barely commenced, and the HS2 would breach UK and EU laws and the Berne Convention if it were shortcut in the absence of any extenuating circumstances. HS2 has had time to identify and monitor the GCN breeding ponds and terrestrial habitat (Grayson 1994), but has failed to do so.

5.7 Public consultation now largely complete

**HS2 cycles of public consultation completed, and a major consultation exercise concluded earlier in 2019.**

The approved HS2 route consultations have yet to be released. Ecological surveys are not complete, but “The route for Phase 1 has been confirmed. Plans for Phases 2a and 2b aren’t confirmed but are unlikely to change significantly” [https://www.gov.uk/check-hs2-route](https://www.gov.uk/check-hs2-route). (UK Government 2019a).

Yet the HS2 fails to enact Government policy of attempting net wildlife gain, or even full wildlife compensation and instead proposes less than 100% (aka ‘mitigation’).

Likewise, some the HS2 documentation has unresolved serious impacts, notably the towering *Palatine Road Ventilation Shaft* on the active Mersey Floodplain, confronting the open view of quality homes. The Mersey Floodplain is occupied by a golf course where storage of floodwaters is par for the course. Due to climate change unpredictability of peak flood heights, the towering Ventilation Shaft may need to be even higher than proposed. Siting a Ventilation Shaft in the Mersey Flood Storage Area introduces an anthropogenic risk by this being an engineering-led project. It is not just the risk of a severe flood overtopping the Ventilation Shaft, but also the risk of subsoils around the shaft collapsing due to “unexpected adverse geological conditions”.

5.8 Public consultation now resumed on certain issues

**HS2 consultation now resumed on siting of ventilation shafts, major facilities at Ashley, and east-west links**

The complications could have been minimised or avoided altogether by better route optioneering

Public consultation has commenced on certain issues, notably:

a) **Repositioning two Ventilation Shafts** (Palatine Road and Birchfield Road) to mitigate severe impacts, albeit triggering other impacts. The severe impact of the Christie Ventilation Shaft remains unaddressed.

b) **New impacts around Ashley village to provide flat HS2 operational land**. No attention has been made of UKOGL Seismic Lines or M52 site investigations, which show collapse breccia of solution of rock salt.

c) **New impacts on Rostherne Mere SSSI National Nature Reserve** by adding spurs for future HS2 lines to Liverpool and Warrington. Again the area has collapse breccia of solution of rock salt.
5.9 **HS2 Railway - Why the Country needs it**

**HS2 will be backbone of the UK rail network, connecting eight of the ten largest cities.**

*Case made by High Speed Two (HS2) Limited*

Alison Munro, Managing Director - Development, High Speed Two (HS2 Limited, presented a paper in 2018 to the Institution of Civil Engineers, entitled ‘**HS2 railway, UK - why the country needs it**’. “High Speed Two (HS2) will be the new backbone of the UK rail network, connecting eight out of ten of the largest cities. Cities are drivers of economic growth, but those in the Midlands and the North are held back by poor connectivity. HS2 will help to rebalance the economy. Demand for rail travel has more than doubled over the past 20 years, and continues to grow. Rail lines serving London, Birmingham and Manchester are under particular pressure, with overcrowding and unreliability. The government is investing £40 billion in the existing network, but capacity shortages remain. HS2 will take pressure off the existing network and add capacity where it is needed most, providing connectivity to support a twenty-first century economy. HS2 will create 30,000 jobs during construction and 3000 jobs in operation. By bringing new investment, employment and regeneration to cities, HS2 can support hundreds of thousands of jobs. The new National Colleges for High Speed Rail will deliver the skills for HS2 and a skills legacy. HS2 is being designed to minimise environmental impacts. It will set new standards in passenger experience and reliability in the UK. It will deliver value for money for taxpayers, with benefits more than double the costs.” [https://doi.org/10.1680/jtran.18.00040](https://doi.org/10.1680/jtran.18.00040)

Roger Vickerman presents a more downbeat assessment in his 2018 paper: “...transport infrastructure by itself is not likely to be transformative, but coupled with other policy interventions it can contribute to such an effect”.

You can read his full paper here: [http://kar.kent.ac.uk/61272/](http://kar.kent.ac.uk/61272/)

Andrew Pendleton, Paul Salveston and Emma Kiberd in their March 2019 for the New Economics Foundation ‘**A Rail Network for Everyone: Probing HS2 and its Alternatives**’ is essential in-depth reading and comprehensive.

You can download a PDF of their full report here: [www.neweconomics.org](http://www.neweconomics.org)

A robust case for HS2 was that high speed rail is ‘good’ for the environment being fast and efficient with a low carbon footprint. The case is weakened due to later recognition that the carbon emissions are destined to be much larger from HS2 construction (Cornet et al. 2018) for instance the vast amount of concrete needed to construct tunnels such as the Manchester Tunnel; and for the switch to concrete slab for New Ballastless Track. The present report attempts to steer clear of the intense debate in which the HS2 project is currently embroiled. To follow the narrative of the debate, the reader is recommended to view the following: articles in the New Civil Engineer (June 2019a,b,c,d,e,f,g); the UK Government (June 2019b) overview of the case for HS2 Phase 2a and its environmental impacts, and the incisive Commons Briefing Paper by Haylen and Bennett (June 2019).

5.10 **Piccadilly Station major development planned**

**HS2 terminus presents major development opportunity led by Manchester City Council.**

*The approved HS2 route unlocks major private sector development at the Manchester Terminus.*

The approved route terminates at Manchester Piccadilly Station around which Manchester City Council has assembled land to create a major investment site for offices and hotels next to the station in anticipation of this station being the HS2 terminus (Williams 2013, Cox 2018a).
5.11  HS2 terminus fails to connect properly with east-west train services

*The approved HS2 route is fourteen platforms away from east-west trains in Manchester.*

The HS2 Manchester terminus will have new platforms on the edge of Piccadilly Station, remote from platforms 13 & 14 which cater for E-W through trains. Passengers changing between E-W trains and N-S HS2 trains face a daunting time penalty especially when humping luggage. The needs of the elderly and disabled have not been taken properly into account.

![Google Earth image, modified by Robin Grayson MSc.](image)

**Figure 11:** THE HS2 TERMINUS IS FAR FROM THE EAST-WEST THROUGH TRAINS

- **YELLOW BOX:** approximate area allocated for the HS2 Manchester Terminus.
- **RED LINE:** route of east-west through trains catered for by Platforms 13 and 14.

The pair of platforms for east-west through trains are already insufficient to meet current demand, leading to Hobson’s choice between longer trains or fewer trains, but still resulting in dangerously overcrowded platforms at peak times. Plans exist for adding Platforms 15 and 16 by doubling the 2-track to 4-track requiring widening of the Piccadilly-Oxford Road-Deansgate multi-arched viaduct, but funding for this project is still under review.

5.12  Length of the proposed Manchester Tunnel

*The approved HS2 route has the shortest feasible route between Manchester Airport and Piccadilly Station.*

But savings are illusory, eroded by unfavourable ground conditions and elevated sections at Piccadilly Station.

5.13  Cost of Manchester Tunnel has been seriously underestimated

*The approved HS2 route is finalised, and requires the boring of the Manchester Tunnel.*

The Manchester Tunnel is expensive, like all modern rail tunnels. The indicative cost of tunnelling a seven kilometre length of HS2 in a hilly rural area was calculated by High Speed Two (HS2) Ltd as £491 million at 2010 prices, inclusive of ventilation shafts and portals but exclusive of track, electrics, signaling, maintenance etc. [https://www.gov.uk/government/publications/hs2-guide-to-tunnelling-costs](https://www.gov.uk/government/publications/hs2-guide-to-tunnelling-costs)

Therefore the indicative cost per km of tunnelling “in a hilly rural area” would be about £70 million. Accordingly the indicative cost of tunnelling a 13-kilometre length of HS2 “in a hilly rural area” would be in the order of **£910 million** at 2010 prices. At today’s prices it would comfortably exceed a billion pounds.

These indicative estimates are for a rural area, and it is reasonable to expect that the tunnelling cost under Manchester will be substantially higher by virtue of it being a major urban area.

Furthermore, assessment of the 30-year old grid of seismic lines archived in the UK Onshore Geophysical Library indicates that the HS2 Manchester Tunnel will face “unexpected geological difficulties” liable to make the tunnel substantially more expensive, more dangerous to build and operate and much longer to complete.
5.14 Risk of encountering natural gas in the Manchester Tunnel

HS2 Tunnel has risk of encountering natural gas fields during and after tunnelling.

The approved HS2 Manchester Tunnel faces the risk of encountering gas pockets in its path.

None of the HS2 reports mention the possibility of gas being encountered in the Manchester Tunnel. This is questionable in the wake of the Abbeystead disaster at a portal to the Lune-Wyre water transfer tunnel (Health and Safety Executive 1985, 2017; Orr et al. 1991).

Potential pockets of natural gas, albeit small, may occur on the planned route of the Manchester Tunnel, associated with occasional movement on these faults:

i) Bradford Fault

ii) Irwell Valley Fault

iii) Ardwick Fault

iv) Heaton Chapel Fault

v) East Manchester Fault

vi) Cheadle Bridge Fault (suspected)

vii) West Manchester Fault

viii) Faults trending across the M56

Potential fault traps involve fault closure to the east and dip closure to the west. Some are shown on the 1:50,000 BGS maps of Manchester and Stockport, and on the UKOGL map of Seismic Lines that crisscross the HS2 route. The UKOGL Seismic Lines are especially important as they display more faults than on the BGS 1:50,000 scale maps of Manchester and Stockport. In truth the latest BGS maps are 30 years out of date.

Source rocks for gas are abundant in the region, (Thomas Shirley 1666, Grayson and Robinson 1990a, 1990b, notably coal seams and gassy shales of the Coal Measures, e.g. Manchester and South Lancashire Coalfields. Firedamp from Upper Carboniferous shales should be anticipated when boring the Manchester Tunnel.

Source rocks for oil are much less common in the region, notably thin oil shales and ‘cannel’ coals of the Lower and Middle Coal Measures, for example, the Manchester, Poynton and South Lancashire Coalfields.

Rocks capable of storing gas and oil lie directly in the path of the Manchester Tunnel intermittently for most of its length, and are good to excellent in terms of effective porosity and effective permeability. These include:

i) Lenses of fluvio-glacial and post-glacial sands;

ii) Persistent Triassic Tarporley Siltstone (= Keuper Waterstones) that are the reservoir rock for the onshore Formby Oilfield and the onshore Elswick Gasfield in the Fylde;

iii) Thick Triassic Chester Pebble Beds (= Bunter Pebble Beds);

iv) Thick Triassic Wilmslow Sandstone, and

v) Impersistent basal Permian Collyhurst Sandstone that are the main reservoir rocks of the Southern North Sea gas fields and the giant onshore Groningen Gasfield of the Netherlands.

vi) In addition, sandstones in the Lower, Middle and Upper Coal Measures have less, but still attractive effective, gas and reservoir potential, such as the Worsley Delf Rock and many others.

Seals for oil and gas pockets lie in the path of the Manchester Tunnel for most of its length. These include:

i) Superficial mantle of Quaternary glacial till (= Boulder Clays).

ii) Plastic mantle of generally tight Triassic Bollin Mudstone (= Lower Keuper Marl).

iii) Plastic tight Permo-Triassic Eccles Mudstone (Grayson 2017) traced between Eccles and Stockport.

iv) Tight Permian Manchester Marl (BGS Manchester (Tonks et al. 1931) and BGS Stockport (Taylor et al. 1963).

Leakage of methane is not unusual (Boothroyd et al. 2016, 2018), e.g. associated with degassing along faults near Wigan Power Station and Heysham Nuclear Power Station. Fugitive escapes are common from gas wells (Davies 2014), high pressure gas mains (Boothroyd et al. 2016) and local gas mains (e.g. Palatine Road 2019). Tunnel boring through gassy rocks is a challenge and demands special procedures, special training and special equipment, for instance modifications to Earth Pressure Balance Tunnel Boring Machine (EPB-TBM) Qi et al. 2018, Bandi et al. 2017, Copur et al. 2012 and Labagnara et al. 2015.

5.15 Risk of encountering methane gas in ventilation shafts

HS2 Tunnel has risk of encountering natural gas in ventilation shafts.

The approved HS2 ventilation shafts face the risk of influxes of methane gas.

The HS2 reports do not discuss the possibility of gas in the ventilation shafts near Altrincham Road, Palatine Road, Wilmslow Road and Lytham Road. This is lamentable in the wake of the Abbeystead disaster at a portal to the Lune-Wyre water transfer tunnel (Health and Safety Executive 1985, 2017; Orr et al. 1991). Methane is present in many Permo-Triassic groundwaters of the UK, albeit at low levels (Darling and Gooddy 2015).

5.16 Risk of liberating radon gas during and after tunnelling

HS2 Tunnel has risk of liberating radon gas – a hazard to tunnellers and householders

The HS2 reports fail to mention the possibility of radon gas being liberated due to the Manchester Tunnel.
5.17 Airport Station remote from Manchester Airport

HS2 steers clear of Manchester International Airport, to avoid engineering complications.

The approved HS2 Airport Station is far from the Airport, symptomatic of an engineering-driven project.

The approved route of HS2 is shown below on the Google Earth image as a red line on its final approach to the approved portal (PIC) of the Manchester Tunnel immediately north of Manchester International Airport. As can be seen, the intended HS2 portal of the Manchester Tunnel is located on the western side of the M56 motorway. To be on the western side, the HS2 has first to gain access to the western side of the M56 by means of a cutting and a rail bridge oblique over the motorway; a substantial piece of engineering.

An alternative route for HS2 is shown below as a yellow line on its final approach to the Manchester Tunnel. The yellow route has no requirement to cross the M56 as its portal (VIC) is positioned on the eastern side of the M56. The alternative route takes advantage of a few of the many hectares of long-term ground level car parks of the airport, for essential operational elbow room during construction of the Manchester Tunnel.

Figure 12: ALTERNATIVE ROUTE FOR HIGH SPEED RAILWAY AT MANCHESTER AIRPORT
APPROVED ROUTE: red solid line & PIC Portal to the HS2 Manchester Tunnel.
ALTERNATIVE ROUTE: orange solid line & alternative VIC Portal to the HS2 Manchester Tunnel,
SUN DOTS: ponds with Great Crested Newt.
BLUE DOTS: other ponds, some with Great Crested Newt.

Figure 13: VIEW OF A SMALL PORTION OF LONG-STAY CARPARKS AT MANCHESTER AIRPORT

Drawing by Robin Grayson MSc. on Google Earth image.

Photograph by Robin Grayson MSc.
5.18 Some consequences of Station being too far from the Airport

**HS2 loss of synergy with international airport**

The approved HS2 route positions the station in a field on the wrong side of the M56.

The location and layout of the station gives the impression of being solely a mandatory halt for high-speed trains before entering and leaving the Manchester Rail Tunnel, rather than also being a major station serving Manchester International Airport (MIA). The station is far from the airport, and would require a bridge across the M56 for air passengers and air freight by people mover, shuttle bus, taxi or tram (see Cox 2018b). This would escalate construction and operational costs, and incur a time penalty of about twelve minutes, degrading the high-speed and comfort of the traveler. Extending the MIA rail link to terminate at the HS2 station would be difficult to justify due to prohibitive costs.

5.19 Database of boreholes prior to selecting the HS2 final route

**HS2 has insufficient borehole evidence to justify the route being essentially fixed.**

*The route for Phase 1 has been confirmed. Plans for Phases 2a and 2b aren’t confirmed but are unlikely to change significantly* https://www.gov.uk/check-hs2-route. Fortunately thousands of boreholes records are archived in the priceless national borehole records centre by the British Geological Survey (BGS) and available on-line, it is important to integrate what is available and useful with the UKOGL seismic.

Unfortunately, only a handful of borehole records exist for the rural *Timperley Wedge* on the west side of the M56; too few for HS2 engineers to predict the ground conditions for the HS2 route or the Tunnel Portal.

In contrast abundant borehole records exist for exist for Manchester International Airport. Even so, most of the airport borehole records are confidential: unacceptable for a public body. In Greater Manchester roughly half of the boreholes logs were never submitted to the BGS and, of those that were, half remain confidential.

An alternative HS2 route is proposed that exploits the long-term car parks inside the perimeter of Manchester International Airport, a municipal success story by a consortium of Greater Manchester local authorities.
5.20 Risk to tunnelling machines posed by giant erratics

HS2 risk of crippling tunnelling machines by large glacial erratics.

The approved HS2 route is liable to delays and damage to tunnelling machines due to exceptionally hard erratic boulders of granite, adamellite, diorite, rhyolite, schist, chert, etc., some of immense size.

Examples are displayed in public places, such as Ardwick Green, but the most impressive is the 20-tonne Borrowdale Volcanic erratic in the quadrangle of the University of Manchester. In the 1970s a larger erratic blocked tunnelling under the Manchester Ship Canal and forced a halt as the tunnel was pressurised and blasting ruled out due to the risk of breaching the canal bed. Today the remedy is to crack boulders asunder by expansive cements but the risk to damage to tunnelling machines remains very high.

FIGURE 15: 20-tonne ERRATIC BOULDER FROM GLACIAL BOULDER CLAY UNDER MANCHESTER
5.21 Risk of natural gas escaping from salt seals

HS2 risk of encountering natural gas seepages bypassing seals of Cheshire Salt.

The approved HS2 route between Rostherne Mere and Manchester Airport is underlain by Cheshire Salt and the Bollin Breccia is a product of collapsed ground caused by salt dissolution.

Dissolution fronts of thick beds of Cheshire Salt are exemplified by the BGS Stockport and Knutsford memoir by Taylor et al. 1963, and the BGS Chester and Winsford memoir by Earp and Taylor 1986. The revised name for the thick rocksalt at Lymm and Mobberley is the Northwich Halite Member, see: http://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=NWHF Key references updating the nomenclature include Howard et al. 2008. Although fieldwork by Grayson, Smethurst and Browne 1995, 1997 on the collapse breccia in the Bollin valley failed to find clear evidence for a dissolution rollover, it did suggest the Bollin Valley was created en masse as a rollover in the distant past. The fieldwork proved the river channel to be meandering on top of collapse breccia. Detailed mapping of exposures and boreholes by Albert Wilson 2003 during the construction of the Second Runway for Manchester International Airport showed this to be at least partially correct. To the west, some collapse breccia were misinterpreted as fills of bedrock channels by Howell 1973 in the vicinity of the Lymm Saltfield.

5.22 Risk of bedrock channels in the path of the Manchester Tunnel

HS2 risk of encountering tunnelling difficulties in the Didsbury Bedrock Channel.

The approved HS2 route bores the Manchester Tunnel through the fill of the Didsbury Bedrock Channel.

The Didsbury Bedrock Channel is carved below sea level in solid rock for at least 40 miles from Didsbury to the Parbold Gap north-west of Wigan (Grayson 1972). The Didsbury Bedrock Channel has been infilled with glacial and recent materials which the HS2 Manchester Tunnel will unavoidably bore through. As admitted by a professor of geology 84 years ago in reference to similar bedrock channels between Liverpool and Birkenhead, “...nobody, least of all a geologist, would care to predict the exact course, changes in depth, or lithological variation from clay to sand or gravel in a buried channel of glacial drift.” - Boswell 1925. Indeed, the Didsbury Bedrock Channel caused problems in constructing the Manchester Ship Canal necessitating repositioning locks downriver to solid rock at Irlam, and in recent times plastic laminated clays were a challenge for foundation engineers of the Barton High Level Bridge. Attention is drawn to the construction of one of the world’s first undersea railway tunnels, the 26 feet wide Mersey Rail Tunnel between Birkenhead and Liverpool in 1881 by the Mersey Railway Company. The vital work of geologist Mellard-Reade in mapping the buried bedrock topography (see Boswell 1925) enabled tunnel engineers to anticipate a concealed bedrock channel, duly encountered incised at 95 feet below sea level. By good fortune the channel was plugged by a stiff seal of impervious glacial clay. The HS2 Manchester Tunnel requires advance drilling of the channel fill which may include running sands and voluminous slurries of plastic silty clays. The challenge is compounded by the modern River Mersey seemingly occupying a different bedrock channel.

Image by Robin Grayson MSc.

Figure 16: BURIED BEDROCK TOPOGRAPHY BETWEEN MANCHESTER AND THE MERSEY ESTUARY

SOURCE: Grayson 1972 in Grayson & Oldham 1984; and see Forster et al. 2001.

NOTE: The above map is more detailed and accurate than the latest BGS map by Kearsey et al. 2019.
5.23 Risk of encountering small earthquakes

**HS2 in close proximity to the Manchester Earthquakes Swarm.**

The approved HS2 route is remarkably close to the Manchester Earthquake Swarm. Upon emerging from the twin tunnels, the elevated HS2 will pass close to the cluster of epicentres of more than a hundred discrete earthquakes, known as the Manchester Earthquake Swarm (Baptie and Ottemoeller 2003). The Earthquake Swarm commenced in Manchester on 19th October 2002. Three temporary seismograph stations were installed to supplement existing permanent stations and to better understand the relationship between the seismicity and local geology. The British Geological Survey (BGS) received more than 3,000 reports from people who felt the Manchester earthquakes. Reports of minor damage, such as small cracks, falling tiles, shattered windows, falling rubble and plaster were also received. The BGS website reported “a maximum intensity of 5+ on the European Macroseismic Scale (EMS) was determined for the earthquake on October 21 at 11:42.” According to the BGS website, “The activity appears to be an earthquake swarm, since there is no clear distinction between a main shock and aftershocks. However, most of the energy during the sequence was actually released in two earthquakes separated by a few seconds in time, on October 21 at 11:42.” The cause of the Manchester Earthquake Swarm remains uncertain even in close proximity to abandoned deep coal mining for “the earthquakes occurred at a depth of 6-7 km, which places them far below even the deepest mine workings”. Numerous smaller earthquakes occurred later.

http://www.earthquakes.bgs.ac.uk/research/events/manchester_sequence.html

![Epicentres transcribed manually from BGS Geology of Britain viewer](http://mapapps.bgs.ac.uk/geologyofbritain/home.html?mode=earthquakes)

**Figure 17: EPICENTRES OF THE MANCHESTER EARTHQUAKE SWARM**

**ORANGE SYMBOLS:** BGS initial estimation of locations of seismic epicentres.

BGS analysis of the events in the sequence showed that many of the seismic events were very similar. Such similarity only occurs if the earthquakes are closely located and have a similar fault mechanism. The BGS were then able to determine relative locations for the earthquakes by measuring small differences in the travel times of seismic waves between different events. The revised locations of epicentres show a strong alignment along a NW-SE trend (see map). Source mechanisms determined for the largest of the earthquakes suggest either NE-SW or NW-SE striking fault planes. The NW-SE plane agrees with the observed trend of the epicentres, suggesting this is probably the orientation of the fault plane. Numerous faults have been mapped at the surface, which mostly strike N-S or NW-SE. Again, a NW-SE strike agrees with the strike of the epicentres and the calculated focal mechanisms. The coal measures in and around Manchester were worked extensively up to the 1970s. But according to BGS seismologists “the earthquakes occurred at a depth of 6-7 km, which places them far below even the deepest mine workings”.

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21
HS2 plans for encountering earthquakes during tunnelling or operation have not been released

The approved HS2 route may encounter seismic events but no contingency plans released.

Every laptop and every mobile phone contains a tiny component - the accelerometer - to detect shaking in order to trigger automatic shut-down of shake-vulnerable electronics. Otherwise your laptop and mobile would soon be junked! A fierce technology race is fuelling mass-production of the cheapest, tiniest, most sensitive accelerometers. Within the current decade, this has produced three-axis accelerometers that are good enough for high-street laptops and mobiles to detect shaking by strong earthquakes (D’Alessandro et al. 2013, Xudong et al. 2014). Bearing in mind that on-line laptops and mobiles use atomic time, have in-built GPS and shake-detection from the inbuilt accelerometer, means your laptop or mobile is indeed a powerful seismometer after adding a suitable application (Nof et al. 2019) such as the MyShake app (Kong et al. 2016) which is free, easy to use and easily installed (MyShake tutorial 2019). MyShake uses artificial intelligence to discriminate between seismic shakes and everyday shakes such as suffered by mobiles in traffic or by a laptop knocked off a table. It also recognises stability of your device is likely to be during the middle of the night for ‘best results.’

With improvements to artificial intelligence and sensitivity of accelerometers, Asaf Inbal et al. 2019 claimed “…having 0.5% of Los Angeles population download the MyShake app would be sufficient to accurately locate M>1 events recorded during nighttime by stationary phones located at epicentral distances <5 km”.

Taking advantage of the astonishingly rapid improvement in the accuracy of laptops and mobiles as seismometers, the HS2 engineers should contemplate funding the installation of a permanent local network of smartphones bolted to the ground along the HS2 route, in a grid 4 km wide at one km spacing of about a hundred fixed smartphone-stations each with the MyShake app, and operated 24-7 by solar powered batteries. Doing so, would take advantage of the relentless improvements to the MyShake artificial intelligence and likewise of accelerometers inside the latest smartphones. The smartphones would need replacing every few years to take advantage of the latest accelerometers capable of detecting M>1 events. Citizen science additions could supplement the HS2 seismometer grid to give coverage for the whole of Manchester.

A priority area is the HS2 stretch between Manchester Airport and the HS2 terminus at Manchester Piccadilly Station, due to the need to better understand the Manchester Earthquake Swarm and the risk of its resumption during HS2 construction, especially regarding the Manchester Tunnel and the elevated section close to the previous swarm. Important here is the ongoing construction boom in Manchester/Salford city centre with one of the top ten crane counts in the western world (Deloitte 2019). At the time of the Manchester Earthquake Swarm, high rise blocks were much fewer and it is a matter of legitimate concern that some blocks may suffer damage if the swarm resumes. The installation of intelligent monitoring networks (Foti et al. 2017) is warranted to control Manchester and Salford’s high-rise framed structures including the HS2 infrastructure.

5.24 Risk of Manchester Tunnel creating excessive noise and vibration

HS2 may encounter problematic noise and vibrations from the Manchester Tunnel.

The approved HS2 Manchester Tunnel may generate too much noise and vibration from unknown geology.

Railways are associated with noise and vibration, especially in a tunnel and especially in single track tunnels (Mostafa Ranjbar 2019). The HS2 Manchester Tunnel has two single track tunnels plus central service tunnel. Sound and seismic waves will propagate through the surrounding rocks causing micro-seismic vibrations in rocks, soils and ground surface, including foundations, sewers and gas pipes. HS2 engineers should switch attention from Chalk and London Clay of other rail tunnels (Summers et al. 2018a, 2018b; Parry et al. 2014, 2015a, 2015b and Crossrail 2016) to the seismic and acoustic properties of rocks of the Manchester Tunnel, via state-of-the-art Pipe-in-Pipe freeware designed to address surface vibrations from underground trains (Simon Jones and Hugh Hunt 2010, and the PowerPoint by Hugh Hunt http://www2.eng.cam.ac.uk/~hemh1/PiP.htm)

UKOGL Seismic Lines confirm the Manchester Tunnel has varied rock types with diverse seismic/acoustic properties requiring investigation. In particular the highly porous Triassic sandstones both as water-charged aquifers and as air-charged dry rocks, along with the very different seismic/acoustic properties of dense claystone such as the Eccles Mudstone and the variable Manchester Marl. The Tunnel may encounter Permo-Triassic sandstone cemented by minerals such as barite and anhydrite enabling the rock to resonate like a bell; while some large erratic boulders may be rock xylophones brought by ice from the Lake District; and propagation of energy to the surface is possible via faults known only from UKOGL Seismic Lines.
5.25 Risk of Manchester Tunnel encountering expansive smectite clays

HS2 likely to encounter problematic expansive smectite clays.

The approved HS2 route for the Manchester Tunnel has a high risk of encountering “unexpected geological difficulties” from expansive smectite clays in the Mercia Mudstone Group.

From boring the Manchester Tunnel portal at Manchester Airport to the River Mersey, the boring machines may encounter expansive smectite clays. This risk to the performance of full-face tunnelling machines caused major problems in boring the Abbey Sewer Tunnel in Triassic Mercia Mudstone near Leicester, as reported by Atkinson, Fookes, Milgano and Pettifer 2003. During full-face tunnelling, a full-face tunnel boring machine “did not behave as expected on the basis of the pre-construction ground investigation”. “When the machine was operated in open mode the spoil often reduced to a slurry as anticipated. However, when it was operated in closed mode the spoil changed to a plastic clay which clogged the machine.”

Later investigations “revealed that the Mercia Mudstone formation through which the tunnel was driven contained highly plastic swelling smectite clays which had not been identified in the pre-construction ground investigations” and “demonstrated that under the influence of the tunnel boring machine in closed mode the spoil could have disaggregated releasing swelling smectite-rich clay.” “This important case has implications for construction processes in certain formations within the Mercia Mudstone Group. It is particularly relevant to processes such as operation of earth pressure balance tunnelling machines and deep drilling in which there is significant mechanical working in enclosed environments. In these cases there is need to establish the true clay content, mineralogy and aggregation ratios during preconstruction site investigations and to assess whether the water content is close to the plastic limit and whether there is access to free water in the ground. Access to free water underground is therefore important for this problem to arise. Based on knowledge of Robin Grayson of the geology of the M56 during its construction, the Mercia Mudstone Group north of Manchester Airport includes the ‘waterstones’ with layers of thin silty sandstones alternating with thin mudstones: “free water in the ground” is copiously available at Sharston close to the Manchester Tunnel.

Sharston is notable for the discovery of Triassic trace fossils by Rod Ireland assisted by Robin Grayson, and documented in great detail by Dr. John Pollard of the University of Manchester in his 1981 research paper: A comparison between the Triassic fossils of Cheshire and South Germany. Five fossiliferous localities in or near the M56 motorway excavations were recorded, and the HS2 excavations are expected to be similar over tens of miles including the Airport Portal to Sharston section of the Manchester Tunnel:

Loc. 7. Warburton Cross (walling slabs), Lymm (SJ 699895) Waterstones: Chirotherium.

More details of the Waterstones trace fossils are given by Rod Ireland, John Pollard, Ron Steel and David Thompson 1978, and more information on the geological and engineering geological characteristics of the Mercia Mudstone Group can be found in publications by Anon 1977; Atkinson, Pettifer and Fookes 2000; Chandler and Foster 2001; Davis 1967 and Warrington 1970.

5.26 Risk of Manchester Tunnel having inrushes of groundwater

HS2 likely to encounter serious inrushes of compartmentalised groundwater when breaching faults.

The approved HS2 route for the Manchester Tunnel has a high risk of serious flooding underground when tunnelling through major faults and breaching dammed compartmentalised aquifers.

Manchester is underlain by Permo-Triassic aquifers of excellent thickness, porosity and permeability (Griffiths et al. 2003, Crook and Howell 1970, Crook et al., 1971, 1973) of regional extent (Worthington 1977), compartmentalised by fault seals similar to under Liverpool (Mohamed and Worden 2006, Lewis et al. 1989).

5.27 Risk of Manchester Tunnel encountering 40-metre deep fissures

HS2 Tunnel may encounter 40-metre deep fissures, affecting tunnel integrity, safety and surface stability.

The approved HS2 route for the Manchester Tunnel may encounter deep sediment-filled fissures affecting surface stability and allowing pollutants to enter the tunnel.

Deep fissures in Triassic sandstones of North Cheshire can be 40 metres deep (Gary Wealthall et al. 2001).
SECTION THREE
UKOGL EXERCISES
HS2 High Speed Rail

Convoy of Thumper Trucks passing along a rural road.  
photo: courtesy of Mark Abbott
6 UKOGL SEISMIC LINES – EXERCISE ONE

Your FIRST exercise is on a vibroseis UKOGL Seismic Line along the M56 from Rostherne to Manchester Airport.

6.1 HS2 follows the M56 motorway: UKOGL Seismic Line AUK87A-135

**STEP 1:** Open the UKOGL website [https://ukogl.org.uk](https://ukogl.org.uk)

**STEP 2:** Open the UKOGL zoomable map [https://ukogl.org.uk/map](https://ukogl.org.uk/map)

**STEP 3:** Type ‘Rostherne Mere’ in the search box.

**STEP 4:** Enjoy the zoom to Rostherne National Nature Reserve!

**STEP 5:** Note the green lines, these are UKOGL Seismic Lines

**STEP 6:** Eyeball the green line labelled **AUK87A-135** and click on it.

**STEP 7:** **AUK87A-135** will change from green to turquoise blue.

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL]

**Figure 18:** UKOGL SEISMIC LINE AUK87A-135 FROM M6 TO MANCHESTER AIRPORT ALONG THE M56

The M56 skirts obstacles, so the hard shoulder of this motorway has been followed by UKOGL Seismic Lines. HS2 is in open cut but has to parallel the M56 and therefore follows these UKOGL Seismic Lines. The UKOGL Seismic Lines are ideally placed for inspecting the M56 for salt subsidence issues. Likewise for ensuring the HS2 route can be fine-tuned to avoid saltfields visible on UKOGL Seismic Lines.

**PUZZLE:** Typical of ‘vintage lines’, this line **does not quite follow** the road on the UKOGL map. In reality it **does follow** the road! The discrepancy is due to the UKOGL line consists of a string of **smoothed CDP** (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The **original raw data** is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL]

**Figure 19:** ZOOMING IN ON THE ROUTE OF UKOGL SEISMIC LINE AUK87A-135

**STEP 8:** Zoom out to see the length of AUK87A-135 from Rostherne to Manchester Airport.

**STEP 9:** Click on IMAGES in the pop-up box for AUK87A-135.

**STEP 10:** This takes you to a choice of COLOUR or GREYSSCALE > Click COLOUR.

**STEP 11:** Copy the image, open it in MS PAINT and delete the lower half of the image.

**STEP 12:** Now turn to the next page to see if your image is correct!
Your trimmed UKOGL Seismic Line should now look like this…

Figure 20: UKOGL SEISMIC LINE AUK87A-135, AFTER DISCARDING THE DEEPEST PART

Congratulations on getting this far! Having admired your work of art for a while, you may then be gripped by deep nagging thoughts such as “great but what does it all mean?”

Your next task is to make your UKOGL Seismic Line more user friendly, like this…

Firstly by removing clutter and then by adding names of surface locations along the surface path of the convoy of thumper trucks that created the seismic line.

STEP 13: Examine your TURQUOISE Seismic Line AUK87A-135 on the UKOGL map. Notice there are tiny black numbered ticks along the line, which are consecutive numbers of the ‘shots fired’. You can, indeed must, use the shot numbers to mark places of your choice along the Seismic Line. Because the Seismic Line was ‘shot’ along the M56, explosives were not used! Instead the energy to get a seismic ‘echo’ to ‘bounce back’ a reflection from a rock layer was by a convoy of thumper trucks crawling along the hard shoulder.

PUZZLE: Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the road! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

Figure 21: UKOGL SEISMIC LINE AUK87A-135 WITH SURFACE LOCATIONS ADDED

6.2 This UKOGL Seismic Line is important to the M56 and HS2 rail project.

PRELIMINARY INTERPRETATION: The rock layers should be continuous but vanish in parts of the Seismic Line for no immediately obvious reason. The Lymm Salfield and Mobberley Salfield being nearby, this can be attributed to subsidence due to dissolving of rock salt to create Rotherne Mere and triggering the general collapse of the Bollin Mudstone to form the Bollin Valley. Rock salt is a low density mineral known as halite (NaCl) and famously in September 1947 a gravitational survey by Professor William Bullerwell 1954 using Eötvös’ Torsion Balances confirmed the Warburton Fault near Lymm.

Risks to the M56 and HS2 include not only subsidence due to dissolution of rock salt but also powerful upheaval and collapse due to expansion and dissolution of gypsum crystals from sulphate waters. The resultant Bollin Breccia has been mapped at Manchester Airport by Robin Grayson et al. 1995, 1997, and later in much greater detail by Albert Wilson 2003. While attention to re-routing HS2 to avoid salt subsidence areas has been made in central Cheshire (Chris Eccles and Simon Fearnley 2018), insufficient attention has been paid to the gypsum hazard spelt out in BGS UK reports (Cooper 1986, 1995, Cooper et al. 1998, 2011), a hazard currently active in the Bollin Mudstones, Bollin Breccia and Bollin Valley.
7 UKOGL SEISMIC LINES – EXERCISE TWO

7.1 HS2 follows the M56 motorway: UKOGL Seismic Line SOV88-XL060-G

Your SECOND exercise is on a vibroseis UKOGL Seismic Line along the M56 Motorway past Manchester Airport and northwards past the HS2 Tunnel Portal to under the Mersey.

STEPS 1 to 13: Repeat steps 1 to 13 and your Seismic Line should now look like this:

PUZZLE: Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the road! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

7.2 This UKOGL Seismic Line is important to the M56, HS2 and Airport

This vibroseis line is especially important as it closely parallels the HS2 route from Manchester Airport HS2 Station, into the portal of the Manchester Tunnel and along the first section as far north as the Mersey.

PRELIMINARY INTERPRETATION: A quick glance shows the seismic reflectors are not horizontal but tilted down to the left (south). The tilted reflectors are best interpreted as being tilted layers of Triassic sedimentary rocks originally deposited more-or-less horizontally. Eyeballing reveals the tilted rock layers are no longer continuous but in several broken steps.

The most likely explanation is that each step is a breakage due to a fault. Closer eyeballing shows the plane of each fault to be inclined down to the right (north).

Further eyeballing shows each seismic reflector has been pulled apart laterally, showing it to be a normal fault rather than a vertical fault or reverse fault. To be a reverse fault, a rock layer would not only have needed to have been broken in two pieces; but also for one piece to be shunted on top of the other piece.

So, is UKOGL Seismic Line SOV88-XL060-G helpful to HS2 engineers and planners?

Indeed yes! One of the inclined fault planes can be seen to break surface close to the Tunnel Portal.
8.1 Princess Road to the City Centre: UKOGL Seismic Line UK-86-431

Your THIRD exercise is on a vibroseis UKOGL Seismic Line northwards along Princess Road (A5103) to its junction with the Mancunian Way (A635M) on the very edge of Manchester city centre.

**STEPS 1 to 13:** Repeat steps 1 to 13 and your Seismic Line should now look like this:

**PUZZLE:** Typical of ‘vintage lines’, this line does *not quite follow* the road on the UKOGL map. In reality it *does follow* the road! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The *original raw data* is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

![Image of UKOGL SEISMIC LINE UK-86-431 WITH SURFACE LOCATIONS ADDED](figure23)

8.2 This UKOGL Seismic Line is important to the M56, HS2 and City Centre

**PRELIMINARY INTERPRETATION:** The seismic reflectors are sedimentary rocks of Triassic age, formerly horizontal but now tilted downwards to the south (left). However, it seems likely that to the north (right), the tilted seismic reflectors are so closely spaced that they may be coal-bearing cycles (‘cyclothems’) typical of the ‘Lower Coal Measures’ deposited in late Namurian to early Westphalian times.

**MORE DETAILED INTERPRETATION:** At first glance this Seismic Line may appear straightforward, but not so. Close inspection indicates the presence of faulting and a possible unconformity. The abundance of reflectors suggests that detailed analysis and preparation of a *balanced section* is likely to yield a considerable amount of information.

**So, is UKOGL Seismic Line UK-86-431 helpful to HS2 engineers and planners?**

Not at first glance. However, the good clarity of the reflectors suggests detailed analysis will produce valuable predictions for tunnels regarding the presence of faults and source rocks for natural gas.
9 UKOGL SEISMIC LINES – EXERCISE FOUR

9.1 HS2 Airport Station and HS2 Tunnel: UKOGL Seismic Line SOV87-X60-05

Your FOURTH exercise is on a vibroseis UKOGL Seismic Line is a vibroseis line from Ringway Golf Course in the west (left) across the Manchester Tunnel under the M56 and eastwards across the northern edge of Manchester International Airport to the A34 Handforth By-pass further east (right). [Note: deleted from this UKOGL Seismic Line is its continuation for many miles further east (right) via Poynton to near Lyme Park].

STEPS 1 to 13: Repeat steps 1 to 13 and your Seismic Line should now look like this:

Puzzle: Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the roads! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

Figure 24: UKOGL SEISMIC LINE SOVEREIGN SOV87-X60-05 WITH SURFACE LOCATIONS ADDED

9.2 This UKOGL Seismic Line is important to the M56, HS2 and the Airport

PRELIMINARY INTERPRETATION: The seismic reflectors are sedimentary rocks of Triassic age, formerly horizontal but now tilted downwards to the west (left).

MORE DETAILED INTERPRETATION: The stronger seismic reflectors are sedimentary rocks of Permo-Triassic age dipping westwards (left), resting unconformably on weaker seismic reflectors dipping eastwards eastward (right) of Carboniferous sedimentary rocks. Faults are present, affecting the HS2 Tunnel Portal.

BALANCED INTERPRETATION: Producing a ‘Balanced Section’ strongly suggests a pair of powerful listric faults are present, downthrowing eastwards (right). Listric faults are typically curved, concave-up and very common under the HS2 route. For description of listric faults, see Hutson et al. 2003, Erickson et al. 2001.

So, is UKOGL Seismic Line SOVEREIGN 87-X60-05 helpful to HS2 engineers and planners?

Again yes! For instance, One of the inclined faults can be seen to break surface close to the Tunnel Portal. The powerful faulting is also of concern regarding the potential for gas pockets in the path of the HS2 Tunnel due to the potential alignment of gas source rocks, pathways, reservoir rocks, gas seals and gas traps.
10 UKOGL SEISMIC LINES – EXERCISE FIVE

Your FIFTH exercise is again on UKOGL Seismic Line SOV87-X60-05.

10.1 Reflector broken by faulting: UKOGL Seismic Line SOV87-X60-05

STEPS 1 to 13: First repeat steps 1 to 13 on UKOGL Seismic Line SOV87-X60-05.

STEP 14: Now study your Seismic Line, to ‘pick your picks’ for fragments of the same reflector, broken by faults or waxing and waning for other reasons. Use a plain pencil to pick out the fragments. You will need an eraser! Use a coloured pencil or pen to pick out the broken fragments. Dark Blue, Turquoise, Red or Yellow are good, but use one colour for picks of the same broken reflector.

STEP 15: Repeat the procedure for picking out the fragments of a different reflector.

STEP 16: Repeat again until you have identified a maximum of three different reflectors.

STEP 17: Stop when you reach three! (Best to do just three to begin with).

STEP 18: After plotting picks of three broken reflectors, your UKOGL Seismic Line should now look like this:

![Image of UKOGL Seismic Line SOV87-X60-05 with reflectors picked out in different colors]

---

Figure 25: ‘PICKS’ added to UKOGL SEISMIC LINE SOV87-X60-05

<table>
<thead>
<tr>
<th>OUR PICKS</th>
<th>REFLECTOR</th>
<th>GEOLOGICAL UNIT</th>
<th>ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>Chester Pebble Beds</td>
<td>TRIASSIC (Bunter)</td>
<td>Pebbly rivers into hot deserts</td>
</tr>
<tr>
<td>TURQUOISE</td>
<td>Eccles Mudstone</td>
<td>PERMO-TRIASSIC</td>
<td>Shallow freshwater temporary playa lakes</td>
</tr>
<tr>
<td></td>
<td>Manchester Marl</td>
<td>PERMIAN (Zechstein)</td>
<td>Shallow marine seas flooding deserts</td>
</tr>
<tr>
<td>YELLOW</td>
<td>Collyhurst Sandstone</td>
<td>Base of PERMIAN (Rotliegendes)</td>
<td>Vast hot deserts</td>
</tr>
<tr>
<td>Deeper</td>
<td>Coal Measures</td>
<td>PENNSylvanian (Upper Carboniferous)</td>
<td>Humid deltas and coal swamps</td>
</tr>
</tbody>
</table>

Realise the mapped bedrock is the ‘top solid layer’ near the top of the UKOGL Seismic Line. Realise the base of the ‘top solid layer’ is likely to sit on a good reflector - dark blue, turquoise:

<table>
<thead>
<tr>
<th>OUR PICKS</th>
<th>REFLECTOR</th>
<th>GEOLOGICAL UNIT</th>
<th>ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td>Deeper</td>
<td>PENNSylvanian (Upper Carboniferous)</td>
<td>Humid deltas and coal swamps</td>
</tr>
</tbody>
</table>

So, is UKOGL Seismic Line SOV87-X60-05 -helpful to HS2 engineers and planners?

Yes indeed! Engineers must learn the geology to make sense of rocks for foundations and tunnels.
11 UKOGL SEISMIC LINES – EXERCISE SIX

Your SIXTH exercise is again on UKOGL Seismic Line SOV87-X60-05.

11.1 Pencil asterisks for each fault: UKOGL Seismic Line SOV87-X60-05

But are your colour-matching efforts of seismic reflectors correct? To help you find out, draw in some faults.

**STEP 23:** Eyeball the UKOGL Seismic Line once again, this time to look for faults.

A “convincing fault” will have cut a path through two or more of your coloured picks.

**STEP 24:** Having eyeballed a gap, pencil a chain of asterisks to indicate the path of a possible fault.

A “clear fault” will have cut a path through two or more of your coloured picks.

**STEP 25:** Having finalised with stars for faults, your UKOGL Seismic Line should now look like this:

Figure 26: ‘FAULT PICKS’ added to UKOGL SEISMIC LINE SOV87-X60-05

11.2 This UKOGL Seismic Line is important to the HS2 Tunnel

**PRELIMINARY INTERPRETATION:** You should have found a pair of faults: best considered a pair as they slope at much the same angle to the right (east), and parallel one another. Of concern, one string of stars heads to the surface in close proximity to the portal of the HS2 Manchester Tunnel.

**MORE DETAILED INTERPRETATION:** Reflectors of this Seismic Line, along with reflectors of several more lines in Central Manchester and the inner suburbs, appear to show a somewhat different geology to that portrayed on the 1:50,000 BGS geology maps of Manchester and Stockport. Excellent though the BGS maps indeed are, the maps have not incorporated much information from the UKOGL seismic lines that crisscross the region.

So, is UKOGL Seismic Line SOV87-X60-05 helpful to HS2 engineers and planners?

Yes indeed, as it illustrates the need for conducting an assessment of the UKOGL grid of seismic lines as a matter of urgency in order to appreciate the engineering challenges and potential cost overruns for the HS2 Tunnel Portal and the HS2 Manchester Airport Station.
12 UKOGL SEISMIC LINES – EXERCISE SEVEN

12.1 HS2 to Stockport Triassic: UKOGL Seismic Line SOV88-XL060-A

You SEVENTH exercise is on vibroseis UKOGL Seismic Line SOV88-XL060-A having shot holes numbered from east (left) to west (right). To match other seismic lines in the area, copy the image, save in MS Paint, and reverse the image horizontally. Next erase superfluous text as per previous examples. Best is to re-reverse all the text - other than the shot points which, remaining reversed, reminds you that you reversed the Seismic Line. The line is from west (left) to east (right) from Altrincham Road (A560), then via Cheadle to follow the M60 in the Mersey bedrock gorge into the middle of Stockport.

**STEPS 1 to 13:** Repeat steps 1 to 13 and your Seismic Line should now look like this:

![Image 1](image_url1)

**Figure 27: UKOGL SEISMIC LINE SOV88-XL060-A WITH SURFACE LOCATIONS ADDED**

12.2 This UKOGL Seismic Line is important to the HS2 Tunnel

**PRELIMINARY INTERPRETATION:** The seismic reflectors are Permo-Triassic sedimentary rocks deposited horizontally but are now tilted down to the west (left).

![Image 2](image_url2)

**Figure 28: M60 CUTTING IN TRIASSIC ROCK, EASTWARDS OF UKOGL SEISMIC LINE SOV88-XL060-A**

Counteracting this westerly tilting are normal faults that downthrow the reflectors to the east. The most famous is the **Cheadle Heath Fault**, considered to be the continuation of the **Pendleton Fault**.

The UKOGL Seismic Line confirms the **Cheadle Bridge Fault (CB)** as a continuation of the **Kirkleyditch Fault (KD)** of Alderley Edge; as suggested by Grayson (1984 MS) from observation of Chester Pebble Beds in Mickle Brook. **KD-CB** may be a branch of the Cheadle Bridge Fault; all down-to the-east normal faults.

**So, is UKOGL Seismic Line SOV88-XL60-A helpful to HS2 engineers and planners?**

Yes, as it gives confidence UKOGL Seismic Lines can help define Triassic aquifers in the HS2 Tunnel and - controversially - help modelling of surface vibrations using PiP software (see Hugh Hunt 2019).
13 UKOGL SEISMIC LINES – EXERCISE SEVEN ‘B’

13.1 Two seismic lines over steeply dipping Chester Pebble Beds

Your 7b exercise involves two vibroseis UKOGL Seismic Lines, BP-82-44 in 1982 on the M60 in Stockport, repeated by SOV88-XL060 in 1988. Your task is to relate both the seismic lines to the large M60 road cuttings from the spectacular Stockport Railway Viaduct, past the A6 bridge, beyond a footbridge and to the B5167.

**STEP 1:** Open the UKOGL website [https://ukogl.org.uk](https://ukogl.org.uk)

**STEP 2:** Open the UKOGL zoomable map [https://ukogl.org.uk/map](https://ukogl.org.uk/map)

**STEP 3:** Open the 1982 line BP-82-44 and examine from the viaduct to the B5167

**STEP 4:** Open the 1988 line SOV88-XL060 and examine from the viaduct to the B5167

**STEP 5:** Compare the older and younger lines and decide which most resembles the rock outcrops.

**STEP 6:** Visit Stockport and view the rock cuttings from the motorway footbridge (take binoculars).

**STEP 7:** Go on a guided tour of the World War 2 Air Raid Shelter Museum in sandstone rock.

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13.2 These UKOGL Seismic Lines are important to the HS2 Tunnel

The HS2 Tunnel will pass through thick Triassic sandstones which are major UK aquifers, compartmentalised by faults and marl beds. Both these seismic lines enable engineers to to visualise the Chester Pebble Beds (aka ‘Bunter’ Pebble Beds) at depth and also to view it in exceptionally large exposures at the surface.
14 UKOGL SEISMIC LINES – EXERCISE EIGHT

14.1 Trafford to Stockport Pyramid: UKOGL Seismic Line UK-86-423

Your EIGHTH exercise is on vibroseis UKOGL Seismic Line UK-86-423 from the Trafford border in the west along the A5145 all the way to the Pyramid in Stockport, via Chorton, crossing Princess Road A5103, through Didsbury Village to cross Kingsway A34 at East Didsbury then via Heaton Moor to terminate at the Pyramid building on the edge of Stockport. A key point is that, while the seismic line is indeed from west to east, the seismic section is presented from east to west in accordance with the numbering of the shotpoints, starting at zero at the Pyramid and ending at shotpoint 850 on the Trafford border. To make sense of the Seismic Line it is essential you flip your seismic section horizontally to produce a reversed image like this:

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL.]

Figure 35: UKOGL SEISMIC LINE UK-86-423 WITH THE SEISMIC SECTION FLIPPED

You will need to flip one-by-one each of the shot points (50 to 840), and the 2-way travel times (0 to 2,000).

**Steps 1 to 13:** Now repeat Steps 1 to 13 to remove the clutter, and add place names from the UKOGL map. Next add a yellow arrow roughly where the HS2 Manchester Tunnel cuts your Seismic Section, like this:

<table>
<thead>
<tr>
<th>PUZZLE:</th>
<th>Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the roads! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YELLOW ARROW:</strong></td>
<td>HS2 Manchester Tunnel, based on HS2 maps and the UKOGL zoomable map.</td>
</tr>
<tr>
<td><strong>YELLOW STARS:</strong></td>
<td>Fault, detected by eye, downfaulting layers on its east side (right).</td>
</tr>
<tr>
<td><strong>BLUE STARS:</strong></td>
<td>Fault, detected by eye, juxtaposing steep layers (right) with gentle layers (west).</td>
</tr>
</tbody>
</table>

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL.]

Figure 36: UKOGL SEISMIC LINE UK-86-423 WITH SEISMIC SECTION CLEANED & LABELLED

14.2 This UKOGL Seismic Line is important to the HS2 Tunnel

At first glance, the HS2 Tunnel narrowly escapes from being in a smash zone of a fault. But there is no escape as the HS2 Tunnel is trapped inside a faulted block for in 3-D the tunnel bores through the smash zone of the ‘yellow fault’ to the south and exits by boring through the smash zone of the ‘blue fault’ to the north.

**So, is UKOGL Seismic Line UK-86-423 helpful to HS2 engineers and planners?**

Yes, powerful faulting is evident, and could have been avoided if the “HS2 route optioneering” described by McNaughton and Banks (November 2018) had paid attention to freely available UKOGL Seismic Lines.
15 UKOGL SEISMIC LINES – EXERCISE NINE

15.1 HS2 Tunnel under Fallowfield Loop: UKOGL Seismic Line UK-86-422

Your NINTH exercise is on BRITOIL UK-86-422; a UKOGL Seismic Line eastwards from Stretford through Chrolton village across Princess Road (A5103) along Wibraham Road (A6010) to cross Wilmslow Road at Fallowfield to become Moseley Road (B5093), past the Owens Park campus eastwards to Kingsway (A34) and onwards to Stockport Road (A6) in Levenshulme, finally reaching the Secret Lake in Reddish.

Below is UKOGL Seismic Line BRITOIL UK-86-422 in the Black & White option offered by UKOGL.

Figure 37: UKOGL SEISMIC LINE BRITOIL UK-86-422, BLACK & WHITE OPTION

STEPS 1 to 13: Repeat steps 1 to 13 on the colour version, and your Seismic Line should now look like this:

PUZZLE: Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the roads! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

Image strictly copyright of the UK Onshore Geophysical Library UKOGL.

The UKOGL Seismic Line is along Wilbraham-Moseley Roads closely parallels the disused Fallowfield Loop Railway Line which from west to east displays semi-continuous rock cuttings of a downward succession of Triassic rocks at Ladybarn Lane Bridge, through basal Triassic Eccles Mudstone (freshwater playa lake) on Upper Permian Manchester Marl (marine Zechstein marls and dolomitic limestones) at Lindleywood Road Bridge resting on thin basal Permian Collyhurst Sandstone (barren desert sands) which display spectacular thickness variations in Manchester (Poole and Whitman 1955). The Collyhurst Sandstone rests unconformably on a thick sequence of late Carboniferous sediments of clays, sandstones, thin coals towards Kingsway Bridge A34, and the Ardwick Limestone which the Romans mined under Manchester to produce hydraulic cement.

15.2 This UKOGL Seismic Line is important to HS2 and History of Geology

This UKOGL Seismic Line is of great importance to HS2 because it shadows the Fallowfield Loop which gives easy bulk sampling of all critical formations to be tunnelled north of the River Mersey to the city centre: Triassic, Permian and Pennsylvanian; and their strongly contrasting engineering properties presenting a challenge to the tunnelling machine but also to the waste removal: sometimes as piped slurry, sometimes as solids on conveyors. Together, UKOGL and the Fallowfield Loop offer unique potential for education and the history of science: the Loop is where leading Victorian geologists fiercely debated rival theories about the ‘Drift’ and the Permian System, and today is a place where tying UKOGL seismic sections to surface rocks can be demonstrated.
The Fallowfield Loop can claim to be the most important sequence exposed in Greater Manchester of the Permo-Triassic and Upper Carboniferous rocks and earlier this year was approved as a Regionally Important Geodiversity Site (RIGS). The status of the cutting is strengthened by being parallel to the UKOGL Seismic Line UK-86-422 which is freely accessible for download by the public. Likewise the Fallowfield Loop Line is fully accessible with caution on foot, as part of the busy long-distance NCN 60 route of the National Cycle Network. The Fallowfield Loop is managed by Sustrans (www.sustrans.org.uk/map-ncn) with the assistance of the FLOOP - Friends of the Fallowfield Loop (https://fallowfieldloop.org). The Fallowfield Loop is one of the best locations in the region where the UKOGL network of seismic lines can be so readily interpreted with the help of linear surface outcrops displaying such a thick sequence. Access for the disabled is excellent, with care.

The HS2 Manchester Tunnel will not only cut across the UKOGL Seismic Line but will also pass beneath the Fallowfield Loop at depth below the rock cutting, as illustrated below.

Note: Ongoing public consultation about ventilation shafts may shift the tunnel a little further east.
Figure 42: SECTION OF “UPPER PERMIAN SERIES” EXPOSED BY FALLOWFIELD LOOP
BROWN – Boulder Clay, now recognised as basal till of Ice Sheet from the north-west.
RED – Trias, now recognised as Triassic Chester Pebble Beds (with few pebbles of quartzite).
LILAC – Marl, Manchester Marl of marine Permian Zechstein age.
CONTORTED LILAC – Marl, tectonic sheared material, probably non-marine Eccles Mudstone.

Figure 43: “LOWER PERMIAN SANDSTONE” RESTING ON “PURPLE MARLS”, FALLOWFIELD LOOP
BROWN – Boulder Clay, now recognised as basal till of Ice Sheet from the north-west.
RED – Lower Permian Sandstone, today mapped as the Lower Permian Collyhurst Sandstone.
PURPLE – Purple Marls, recognised as Upper Carboniferous.
Sections further east (left) include the Ardwick Limestone with abundant Spirobis fossils.

Figure 44: DIAGRAMMATIC SKETCH OF A BLOCK THE ECCLES MUDSTONE
LOCATION: Western end of M602 motorway road cutting, Eccles, Salford.
Smooth laminated red mudstone, with dessication cracks, and extensive galleried burrows backfilled by angular chips of the mudstone. Salt pseudomorphs are completely absent suggesting a semi-terrestrial playa lake backwater with burrowing crustaceans such as crabs (Grayson 1984). Reptile footprints were found in the Eccles Mudstone in Stockport by Rodney Ireland 1972a,b.
16 UKOGL SEISMIC LINES – EXERCISE TEN

16.1 Alan Turing Way to Didsbury Road: UKOGL Seismic Line UK-86-433

Your TENTH exercise is on UKOGL Seismic Line UK-86-433, a little unusual in being curved. This vibroseis line curves gently anticlockwise from Alan Turing Way (A6010) to cross Hyde Road (A57) in Gorton to then cross the A6 in Heaton Moor to eventually terminate in Didsbury Road. It is important to appreciate the arcuate shape, from SSE > S > SW > SSW > WSW by examining its trace here: https://ukogl.org.uk/map

**STEPS 1 to 13:** Repeat steps 1 to 13 and your Seismic Line should now look like this:

**PUZZLE:** Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the M56! The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

![UKOGL SEISMIC LINE: UK-86-433 WITH SURFACE LOCATIONS ADDED](image)

Figure 45: UKOGL SEISMIC LINE UK-86-433 WITH SURFACE LOCATIONS ADDED

16.2 This UKOGL Seismic Line is important to the HS2 Tunnel

**PRELIMINARY INTERPRETATION:** The seismic reflectors are sedimentary rocks deposited horizontally but now tilted. Two faults are especially clear, the most remarkable causing an abrupt change in geology at the A6 in Heaton Moor and is expected to be the powerful Heaton Chapel Fault. This juxtaposes boldly bedded Pennsylvanian Coal Measures on the left with less clearly bedded Permo-Triassic sediments on the right. Rather than being a normal fault as expected, the Heaton Chapel Fault might possibly be a steep reverse fault, whereby the gassy Coal Measures side “leans upon” the downthrown Permo-Triassic side of the fault. The second fault may also be a reverse fault.

**MORE DETAILED INTERPRETATION:** Reflectors of this Seismic Line, along with reflectors of several more lines in Central Manchester and the inner suburbs, appear to show a somewhat different geology to that portrayed on the 1:50,000 BGS geology maps of Manchester and Stockport. Excellent though the BGS maps indeed are, the BGS has yet to incorporate much information from the network of UKOGL seismic lines that crisscross the region.

**So, is UKOGL Seismic Line UK-86-433 helpful to HS2 engineers and planners?**

Yes indeed, for it illustrates the necessity of conducting an assessment of the UKOGL grid of seismic lines as a matter of urgency in order to better understand the powerful faults the HS2 Tunnel will encounter.
Your ELEVENTH exercise is on UKOGL Seismic Line UK-86-421, unusual in being at ground level below the elevated Mancunian Way (A57M), crossing the city from Eccles New Road (A57) to Ashton Old Road (A635) ending close to the border of Tameside district. Examine its trace here: https://ukogl.org.uk/map.

**STEPS 1 to 13:** Repeat steps 1 to 13 and your Seismic Line should now look like this:

**PUZZLE:** Typical of ‘vintage lines’, this line does not quite follow the road on the UKOGL map. In reality it does follow the roads. The discrepancy is due to the UKOGL line consists of a string of smoothed CDP (Common Depth Points) which has the effect of shifting laterally the actual route. In particular lines shot with vibroseis would normally follow roads. The original raw data is available for purchase from UKOGL at a minimal cost and, with modern processing techniques, can provide enhanced images of the subsurface.

![Image of UKOGL Seismic Line UK-86-421 with Surface Locations Added](image)

**Figure 46:** UKOGL SEISMIC LINE UK-86-421 WITH SURFACE LOCATIONS ADDED

**BLUE LINE:** deep geothermal wells proposal by GT Energy for Manchester District Heating

The sedimentary layers revealed by this line appear are often tilted and broken by many faults. To help interpret this line, open the UKOGL map to display the legend on the left. Click OFF all the tick boxes. Then open only four boxes:

**Seismic**, then **UKOGL 2D Seismic Contexts**, then **BGS Surface Geology**

Click on the ‘BGS Surface Geology’ toggle to fade the geology to render visible the street map beneath it:

![Image of UKOGL Seismic Line UK-86-421 on Top of Transparent BGS ‘Solid’ Geology](image)

**Figure 47:** MAP OF UKOGL SEISMIC LINE UK-86-421 ON TOP OF TRANSPARENT BGS ‘SOLID’ GEOLOGY

**YELLOW DIAMONDS:** narrow strip of probable Eccles Mudstone alongside fault.

The strip of probable Eccles Mudstone is remarkably narrow and persistent, suggesting it is a diapiric-like fault smear. The Eccles Mudstone is a freshwater deposit (Ireland 1972a, 1972b; Grayson 1972, 1984, 2017), easily confused with the marine Manchester Marl upon which it rests. The yellow diamonds are based on casual observations by the author and revisions to the BGS 1:50,000 map of Manchester (sheet 85).

**So, is UKOGL Seismic Line UK-86-433 helpful to HS2 engineers and planners?**

Very much so. The possibility of the Eccles Mudstone being an over-consolidated compressed shear clay sealing faults in the HS2 Tunnel warrants investigation. The delinquency of Manchester Council and developers in submitting borehole records to the BGS archives is a great and growing concern (Grayson 2017) depriving HS2 and the building boom of accurate geological maps.
18 UKOGL SEISMIC LINES – EXERCISE TWELVE


Your TWELFTH exercise is again on UKOGL Seismic Line UK-86-421. This time to recognise the value of UKOGL Seismic Lines in highlighting the potential of deep geothermal basins in close proximity to major urban areas as large target markets for district heating making use of warm water for space heating.

Figure 48: ROUTE OF UKOGL SEISMIC LINE UK-86-421 ACROSS MANCHESTER
BLUE SOLID CIRCLE: deep geothermal wells proposed by GT Energy for district heating.
RED SOLID CIRCLE: revised location for deep geothermal wells proposed by Robin Grayson.

18.2 Deep geothermal energy potential revealed by this Seismic Line

This Britoil seismic line in the UKOGL archives, gave confidence for GT Energy of Dublin to conduct a feasibility study into drilling a pair of geothermal wells in Ardwick at the junction of Stockport Road (A6), Devonshire Street and Coverdale Crescent. The wells would drilled vertically to a depth of 3.2 km for testing, then inclined to achieve a 2 km separation at a depth of 4 km in fractured Carboniferous Limestone. Warm groundwater pumped to the surface up one hole would be the heat source for heat exchangers for a district heating scheme, before pumping the cooled water back underground down the other hole. This major project is presented on-line by Mark Hillsdon 2013: http://ontheplatform.org.uk/article/geothermal-renewable-energy-plan-ardwick. The feasibility study is good (GT-E 2013a,b,c,d) but the proposed drill site became urbanised.

According to detailed calculations for GT-E (2013b) by SLR Consultants using Seismic Line UK-86-421: “Based on an average geothermal gradient of 32.28°C/km below Manchester and consequently a potential heat flow of 75 mWkm-1 (BGS 2008) a temperature of between 96°C and 99°C can be expected at a depth of 3 km” GT-E 2013a, chapter 5, page 15.

Due diligence by the author on UKOGL Seismic Line UK-86-421 confirm these estimates are reasonable, albeit with a very different model for the deep geology.

So, is UKOGL Seismic Line UK-86-421 helpful to HS2 engineers and planners?

Yes indeed, for the HS2 project has a substantial requirement to enhance its green credentials, and coincidentally the HS2 terminus at Manchester Piccadilly is to be the stimulus for a massive commercial development scheme as the HS2 Gateway to Manchester. Here then is a unique opportunity for HS2 engineers to encourage the development plan to use geothermal energy from 3 to 4 km depth for district heating of not only the HS2 terminus but also for the plexus of new shops, offices and high-rise apartments, to contribute towards creating a world-class HS2 Green Gateway to a sustainable Manchester. Review by the author indicates that the geothermal wells, pumps and heat exchangers can be advantageously installed within the HS2 footprint on viaducted final approach to Picaddilly Station together with all the primary pipework of the district heating system. The author therefore proposes a revised location for the deep geothermal drilling under the elevated HS2 footprint in cleared land at Crane Street off Chapelfield Street, with the added advantage of drilling less than a hundred yards of UKOGL Seismic Line UK-86-421. Deep drilling as close as possible to a seismic line offers many advantages including being able to accurately correlate the rock cores, rock cuttings and geophysical logs of the deep borehole with the the seismic line at depth. In turn this increase the confidence of investors, and prepares the way for several more deep geothermal wells along the same seismic line across the city.
19 UKOGL SEISMIC LINES – EXERCISE THIRTEEN

19.1 City Centre and up Oldham Road: UKOGL Seismic Line UK-86-429

Your TWELFTH exercise is on vibroseis UKOGL Seismic Line UK-86-429 along Oldham Road (A62) from the city centre to the Oldham border. Examine its trace here: https://ukogl.org.uk/map

This vibroseis line was shot by Britoil plc over the tantalising Bradford Block which was, and to this day remains, the most obvious target for conventional drilling for oil and gas in Greater Manchester. The Bradford Block was large enough to sustain the deep Bradford Colliery which closed due to subsidence damage to homes, in spite of efforts to backfill the voids with pit waste imported from other pits in the area.

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL.](https://ukogl.org.uk/map)

Figure 49: UKOGL SEISMIC LINE UK-86-429 WITH SURFACE LOCATIONS ADDED

19.2 This UKOGL Seismic Line is important for Shallow Geothermal Energy

The voids in abandoned workings of Bradford Colliery and adjacent pits were an obvious target for extracting coal bed methane (CBM) but this did not happen, and with the passage of time the voids became flooded with rising groundwater after cessation of dewatering by powerful pumps. In turn, the hand-warm water in the capacious flooded mine workings and fractured rocks have become a hand-warm underground reservoir for geothermal energy for space heating of city centre buildings via modern heat exchangers, and merits promotion by Manchester City Council. In addition porous sandstones are at very shallow depth (100-200 metres).

![Image strictly copyright of the UK Onshore Geophysical Library UKOGL.](https://ukogl.org.uk/map)

Figure 50: UKOGL ARCHIVES: BP PROPOSED EXPLORATION WELL ON SEISMIC LINE UK-86-429

**COMMENTS:** interpretation by BP Petroleum, with minor amendments by Robin Grayson.

You can download a pdf of the full BP report from the tab: Historic Onshore Licenses on the UKOGL Interactive Map: https://ukogl.org.uk/ukogl-interactive-map/
20 UKOGL SEISMIC LINES – EXERCISE FOURTEEN

20.1 HS2 to City Centre: A chain of three UKOGL Seismic Lines

Your FOURTEENTH exercise is on using UKOGL Seismic Lines to find a better HS2 route to the City Centre. Shown below is the grid of seismic lines available for inspection free-of-charge on the website of the UK Onshore Geophysical Library (UKOGL) https://ukogl.org.uk. This reveals the easiest route for both seismic lines and high speed rail is along the Princess Parkway Corridor, highlighted by a string of yellow stars. Following the stars is a chain of three UKOGL Seismic Lines: AUK87A then SOV88-XL060-G and finally UK-86-431. This is the shortest, least expensive and the easiest to interpret route for seismic lines. Unfortunately the HS2 route deviates markedly from the string of yellow stars rendering the HS2 tunnel very expensive; needing to hunt for tiny urban patches of land for ventilation shafts; shifting its alignment three times to mitigate impacts; and emerging as an expensive elevated section destroying many inner city firms and jobs.

![Image of UKOGL Seismic Lines and HS2 Alternative Route to the City Centre]

Figure 51: UKOGL MAP OF SEISMIC LINES and the HS2 ALTERNATIVE ROUTE TO THE CITY CENTRE

20.2 This UKOGL Seismic Route is important to the HS2 Tunnel

The Princess Parkway option reduces the Manchester Tunnel by a full kilometre, so reducing environmental impacts by ten percent, worker H&S risks by 10 percent and cutting construction costs by about 100 million pounds. In addition, the Princess Parkway option avoids major cost overruns by skirting many of the geological difficulties revealed by UKOGL Seismic Lines if the HS2 terminates at Manchester Piccadilly Station.

Using savings, a more direct HS2 Manchester Tunnel (12km) could terminate underground in an interchange station beneath east-west through trains on a revamped east-west Piccadilly-Oxford Road Viaduct with a pedestrian tunnel directly into Manchester Central conference centre - more central than Piccadilly Station.

![Image of Manchester Central]

Figure 52: MANCHESTER CENTRAL

21 UKOGL SEISMIC LINES – EXERCISE FIFTEEN

Your FIFTEENTH exercise differs from all earlier exercises. It encourages you to examine some of the historical evidence for methane gas being in the vicinity of the HS2 route, by considering the record of serious explosions of firedamp in many coal mines formerly operating across the region; some major gas explosions were close to the finalised route of the HS2 Manchester Tunnel.

21.1 Historical records of methane fires and explosions

Many thousands of explosions of firedamp were small while some serious ones involved no loss of life and so were rarely recorded in detail.

Here is an example from Poynton, only 6 miles east of the route of the HS2 Manchester Tunnel:
“Ashworth's report for 1849 stated that "On the 26th January last we had an awful fire in three of the pits, Lord Pit, Lady Pit and Albert Pit, which I am thankful to say was providentially extinguished without the loss of life". A plaque in the former Methodist Chapel at Hockley records this event”


Now a second example from Hyde, only 5 miles east of the route of the HS2 Manchester Tunnel. The blue plaque in the entrance to a footpath off Manchester Road in Tameside. The footpath runs alongside the canal, on the opposite side to the towpath, where a coal chute was located that was used to load coal boats.

Figure 53: A BLUE PLAQUE OFF MANCHESTER ROAD, HYDE IN TAMESIDE

But this fatal explosion was by no means exceptional; such disasters occurred in many coal mines in the region. The following list is a compilation of well-documented records of 1,987 fatalities from some of the methane explosions in the South Lancashire Coalfield and nearby coalfields. The reader is encouraged to review the list, and especially the engineers who finalise the route of the HS2 Manchester Tunnel.
21.2 Firedamp explosions and fatalities in Greater Manchester and environs

The following incomplete list is of fatal explosions and fires in coal mines in the South Lancashire Coalfield, in each of which five or more people were killed at one time. The list is condensed from: Wikipedia 2019. *List of mining disasters in Lancashire* being updated and added to by volunteer experts, and cites numerous sources to which the reader is referred: https://en.wikipedia.org/wiki/List_of_mining_disasters_in_Lancashire.

Deaths

<table>
<thead>
<tr>
<th>Date</th>
<th>Colliery</th>
<th>Location</th>
<th>TOTAL OF FATALITIES IN GTR MANCHESTER &amp; REGION DUE TO METHANE FIRES &amp; EXPLOSIONS IN COAL MINES</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Apr 1830</td>
<td>Pemberton Colliery</td>
<td>Pemberton</td>
<td>1,987</td>
</tr>
<tr>
<td>May 1831</td>
<td>Haydock Collieries</td>
<td>Haydock</td>
<td>7</td>
</tr>
<tr>
<td>May 1832</td>
<td>Haydock Collieries</td>
<td>Haydock</td>
<td>12</td>
</tr>
<tr>
<td>24 Nov 1846</td>
<td>Coppen Collieries</td>
<td>Coppen</td>
<td>6</td>
</tr>
<tr>
<td>Jun 1847</td>
<td>Kirkless Hall Colliery</td>
<td>Aspull</td>
<td>9</td>
</tr>
<tr>
<td>11 Feb 1850</td>
<td>Gibfield Colliery</td>
<td>Atherton</td>
<td>5</td>
</tr>
<tr>
<td>16 Mar 1850</td>
<td>Haydock Collieries</td>
<td>Great Marsden</td>
<td>13</td>
</tr>
<tr>
<td>12 Apr 1850</td>
<td>Town House Colliery</td>
<td>Great Marsden</td>
<td>6 men were working in the pit when one man went to check for gas with a safety lamp but before he signalled it was safe, another man removed the top from his lamp causing an explosion that killed them all.</td>
</tr>
<tr>
<td>8 Oct 1850</td>
<td>Bent Grange Colliery</td>
<td>Oldham</td>
<td>12</td>
</tr>
<tr>
<td>8 Nov 1850</td>
<td>Haydock Collieries No.13 Pit</td>
<td>Haydock</td>
<td>16</td>
</tr>
<tr>
<td>22 Dec 1851</td>
<td>Ince Hall Colliery Deep Pit</td>
<td>Ince-in-Makerfield</td>
<td>13</td>
</tr>
<tr>
<td>24 April 1852</td>
<td>Norley Hall Colliery</td>
<td>Pemberton</td>
<td>12</td>
</tr>
<tr>
<td>20 May 1852</td>
<td>Coppen Hall Colliery</td>
<td>Coppen</td>
<td>36</td>
</tr>
<tr>
<td>24 Mar 1853</td>
<td>Ince Hall Colliery</td>
<td>Ince-in-Makerfield</td>
<td>50</td>
</tr>
<tr>
<td>1 Jul 1853</td>
<td>Bent Grange Colliery</td>
<td>Oldham</td>
<td>13</td>
</tr>
<tr>
<td>18 Feb 1854</td>
<td>Ince Hall Colliery</td>
<td>Ince-in-Makerfield</td>
<td>89</td>
</tr>
<tr>
<td>2 Feb 1858</td>
<td>Bardsey Colliery Diamond Pit</td>
<td>Bardsey</td>
<td>An explosion of firedamp ignited by shot firing at Diamond Pit between Oldham and Ashton-under-Lyne killed 53 men and boys.</td>
</tr>
<tr>
<td>13 Dec 1858</td>
<td>Yew Tree Colliery</td>
<td>Tyldesley</td>
<td>25</td>
</tr>
<tr>
<td>1 Nov 1861</td>
<td>Shhevinton Colliery Albert Pit</td>
<td>Shhevinton</td>
<td>25</td>
</tr>
<tr>
<td>13 May 1866</td>
<td>Garswood Colliery</td>
<td>Garswood</td>
<td>13</td>
</tr>
<tr>
<td>30 May 1867</td>
<td>Mesne Lea Colliery</td>
<td>Worsley</td>
<td>7</td>
</tr>
<tr>
<td>26 Nov 1868</td>
<td>Hindley Green Colliery Springs Pit</td>
<td>Hindley Green</td>
<td>13</td>
</tr>
<tr>
<td>21 Dec 1868</td>
<td>Norley Colliery</td>
<td>Pemberton</td>
<td>7</td>
</tr>
<tr>
<td>30 Dec 1868</td>
<td>Haydock Collieries Queen Pit</td>
<td>Haydock</td>
<td>26</td>
</tr>
<tr>
<td>21 Jul 1869</td>
<td>Haydock Collieries Queen Pit</td>
<td>Haydock</td>
<td>93</td>
</tr>
<tr>
<td>7 Jan 1869</td>
<td>Rainford Collieries</td>
<td>Rainford</td>
<td>9</td>
</tr>
<tr>
<td>16 Nov 1869</td>
<td>Low Hall Colliery</td>
<td>Platt Bridge Wigan</td>
<td>27</td>
</tr>
</tbody>
</table>
The disaster occurred on Friday when an explosion of firedamp occurred at the pit entrance. About 20 were badly burned. Exploring parties were sent down but the pit was on fire and had to be blocked up. A second explosion sent flames from the shaft blowing the cages into the headgear. The colliery worked 10 days later. At the time of the disaster, 208 men were killed, 14 died of burns, and 20 were found alive. The disaster occurred on Friday when an explosion of firedamp killed 83 men. An explosion at the pit entrance, about 20 were badly burned. Six men died including two members of Boothstown mines rescue team.

An explosion killed 8 men and severely damaged the pit. An explosion after shot firing at the Mesnes pit killed 5 of the 75 men and boys who were working in the pit. About 20 were badly burned.

The explosion occurred at 9 p.m. and killed 344 men. The explosion occurred at 3 p.m. and killed 48 men. The explosion occurred at 5 a.m. and killed 6 men including the colliery manager.

An explosion caused by the ignition of a build up of methane, at Golborne Colliery killed 10 men and seriously injured several others. A fireball shot along a tunnel which was 1,800 feet underground.
SECTION FOUR

HS2

Discussion and Recommendations

Thumper Trucks passing over open land at Larne, Northern Ireland.

photo: courtesy of Mark Abbott
The report attempted to raise awareness of the existence of a network of onshore seismic lines in North-West England freely available to download from UK Onshore Geophysical Library to gain better understanding in depth of the geology beneath our feet. By using HS2 as a topic of interest to the public at large, the report aspired to draw attention to the value of UKOGL as a valuable free tool to a wider audience, far beyond the narrow realm of geophysicists and oil and gas geologists, to anyone interested in large-scale engineering projects, and be a major source of information complementing the impressive work of the British Geological Survey (BGS). Large-scale civil engineering project throughout the world exhibit a tendency for the footprint and routes to be fixed well in advance of capital expenditure, and for funding agencies to receive copious information on the benefits of the projects prior to the project funding being released. Too often this leads to budgets and routes being more-or-less fixed long before assessment of the geological challenges that then confront the engineers in charge of delivering the projects, resulting in major projects rarely being completed on time within budget. UKOGL seismic lines can assist funders, planners and engineers to predict such risks.

Construction of railway tunnels is a challenging task for engineers. Numerous examples exist of railway tunnels experiencing difficulties during construction, as shown by Anderson 1998, Deane 1994, HSE 1996, Jacobs 1975, Leichnitz 1990, New and Bowers 1994, Prein 1994, and Wallis 1987. After opening, railway tunnels often experience difficulties especially in claystones such as the London Clay, due to ground movement and building movement: Bowers et al. 1996, Harris 2002, Hover et al. 2015, Laver et al. 2010, 2016, Soga et al. 2017, Ward et al. 1965, Wongsaroj 2007, 2015, and Wright 2010. Unfortunately these bear scant resemblance to claystones in the path of the HS2 Manchester Tunnel: Glacial Till, Bollin Mudstone, Bollin Breccia, Keuper Waterstones, Eccles Mudstone, Manchester Marl and Pennsylvanian claystones. Fortunately UKOGL seismic lines predict when to expect them in the Manchester Tunnel, and reveal the sonic properties of each, enabling modelling of soil conditions if coupled with field sampling from the Fallowfield Loop Line. In a ground breaking recent paper on HS2, Song Qui et al. 2019, stressed high speed rail “demands precision” for monitoring “the structural health” of shallow environments near embankments. In Plain English, to give prior warning of any weaknesses in HS2 embankments. The same can also be said for HS2 cuttings and the HS2 Manchester Tunnel. Song Qui et al. 2019 point out “Traditional low frequency wireless channels can communicate with underground sensors, but its large antenna elements are prone to damage from geological stress.” To overcome this, Song Qui et al. 2019 designed a higher frequency compact system and experimentally characterise its performance in-situ, in different soil and moisture conditions representative of weather and soil conditions near the HS2 route. This work merits expanding to embrace the much more diverse claystones and subsoils evident from UKOGL seismic in the Manchester Tunnel and the approach cuttings to its portals.

Of interest, the fierce competition for global market share in sales of mobiles and laptops has led to an innovation race to mass-produce tinier, cheaper and more sensitive accelerometers in mobiles and laptops to shut down delicate electronic components in a fraction of a second if the accelerometer detects violent shaking or potential impact. Already the innovation race enables mobiles and laptops to be quake detectors, as exemplified by the free MyShake app linked to the “internet of things”. HS2 engineers should exploit this race to install strings of “static mobiles” along the HS2 route to detect and record vibrations and earthquakes using MyShake for line maintenance and safety, including the surface above the Manchester Tunnel. Useful literature includes: Geng et al. 2009, Hodge et al. 2015, Jo et al. 2018, Kece et al. 2019, Pagini et al. 2019, Sheth et al. 2005, Wright 2010, and Zou et al. 2014. Also of interest, the global race to mass-produce tinier, cheaper electronic components has opened the door to making miniature Vibroseis thumpers and recorders, able to filling the ‘missing link’ of shallowest geology between UKOGL seismic sections and the surface - of incalculable value to HS2 engineers (see: Timothy Dean et al. 2017a,b, 2018; Bojan Brodic 2018 and Nijhof 1989.

Concerns have been aired recently by Chris Eccles and Simon Fearnley 2018 regarding “Geological conditions and anthropogenic legacy” which they demonstrate “will significantly affect HS2 in mid-Cheshire". Likewise the present report shows unfavourable geological conditions will also significantly affect HS2 in north Cheshire and Greater Manchester as shown by UKOGL seismic lines.

Finally, lessons for the HS2 Tunnel can be learned from tragedies constructing the Mersey Tunnels between Liverpool and Birkenhead (Boswell 1925; Megaw and Brown 1972; Mc.Kenzie and Dodds 1972, and Hughes 2017). The HSE 2006 report - risk to third parties from bored tunnelling in soft ground - makes sombre reading.
23 RECOMMENDATIONS

Many recommendations are presented in the main body of this report to which the reader is referred. The following list of recommendations have been singled out as warranting special attention:

1. The UKOGL national network of seismic lines should be adopted as part and parcel of the school curriculum to serve as a window for staff and students alike on the local geology and to give insight into local geophysics and the use of computers in the oil and gas industry.

2. All Minerals Planning Officers should attend crash courses on the existence of UKOGL and the importance of using its network of seismic lines when advising Mineral Planning Authorities, and when commenting on major infrastructure projects, especially tunnels.

3. HS2 should consider funding UKOGL to organise geologists and geophysicists drawn from the UK onshore oil and gas industry to interpret several hundred UKOGL seismic lines relevant to HS2, in conjunction with local geological societies and strategic oversight by the British Geological Survey.

4. HS2 should consider funding low-cost miniature Vibroseis thumpers and recorders, able to fill the ‘missing link’ of shallowest geology between UKOGL seismic sections and the surface - of incalculable value to HS2 engineers (see: Timothy Dean et al. 2017a,b).

5. Advance drilling of a series of 200-metre deep cored holes is warranted to enable HS2 engineers to profile the geotechnical issues posed by units such as the Eccles Mudstone and Manchester Marl, and determine faults and bad ground in critical locations such as portals and ventilation shafts.

6. As a matter of urgency, a permanent grid of seismic stations across Manchester and Salford is warranted to safeguard the high-rise construction boom that began after the end of the Manchester Earthquake Swarm, and to understand a possible seismic risk to the HS2 and the vital Guardian Underground Telephone Exchange (GUTE) as described by Collins 1974, Warrender 2007, 2009; Brook and Dodge 2014; and by Mark Crossfield 2018.

7. HS2 should consider opening a dialogue with Sustrans and the Friends of Fallowfield Loop (Floop) regarding exposing to the public some of the continuous rock cutting in easterly downtilted Triassic Pebble Beds, Permian Zechstein Manchester Marl, basal Permian Collyhurst Sandstone and basal Permian unconformity upon the Pennsylvanian mudstones and limestones, recorded in the abandoned railway cutting. Especially so, as the cutting closely parallels UKOGL Seismic Line BRITOIL UK-86-422. The Loop is the best location for bulk samples of the problematic Manchester Marl, Eccles Mudstone, Stephanian mudstone and Ardwick Limestone for laboratory testing, and to inspect fault contacts between rock types of sharply contrasting engineering properties. The Loop has recently been designated as a Regionally Important Geodiversity Site (RIGS) on many grounds; and it is the best site in the region for introducing HS2 tunnel engineers, geophysicists, geologists, urban planners, students and public to the UKOGL seismic grid. Funding is desirable to clear small sections of the rock cutting.

8. HS2 should consider opening a dialogue with GT-Energy to explore the possibility of relocating the Ardwick Geothermal Project closer to the city centre, taking advantage of the viaducted footprint of HS2 on its final approach to Piccadilly Station, to heat a sustainable Green Gateway to Manchester.

9. HS2 should consider opening a dialogue with Manchester International Airport to explore the possibility of minor realignment of HS2 to mutual advantage and cutting HS2 costs:
   i) Make substantial cost savings to HS2 construction (fewer HS2 bridges over the M56).
   ii) Reduce environmental impact by safeguarding the Timperley Green Wedge in Trafford.
   iii) Reduce the carbon footprint of HS2 by a modest amount.
   iv) Decouple the Palatine Road Ventilation Shaft from proximity to housing.
   v) Halve the transfer-time of passengers and baggage between HS2 and Terminals.
   vi) Eliminate the HS2 footprint west of the M56 where land banks of investors are problematic.
   vii) Create the UK’s first high-speed rail station actually inside an international airport.
   viii) Create a cluster of hotel sites around the station each serving both the airport and HS2.
   ix) Reassess the HS2 Manchester Tunnel route in the light of potential sources of methane.
SECTION FIVE

HS2 & UKOGL

References and Links

Convoy of Thumper Trucks passing along a coastal road in Dorset.

photo: courtesy of Mark Abbott
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"Throughout, a rigorous process of longlisting possible options, shortlisting and selection was adopted. At each stage the proposals became more detailed as the route, design and mitigations were developed. Consequently, the selection criteria, costing and evaluation also became more detailed and specific."

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Transport secretary Chris Grayling has revealed that the new chair of High Speed 2 (HS2) promoter HS2 Ltd, Allan Cook, is undertaking a review of the project “to make sure the costs and budget are right and that it is deliverable”. 

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