Ground Related Risk to Transportation Infrastructure

SUB-SURFACE RISKS FOR THE CONSTRUCTION OF HS2 IN MID-CHESHIRE

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Dr Simon Ferley, Geotechnical Director

TerraConsult Ltd

27th October 2017

The Geological Society

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Hazards Beneath Mid-Cheshire

Hazards Beneath Mid-Cheshire

2 m Deep Subsidence Troughs Ch15+750

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2 m Deep Subsidence Troughs Ch15+750

Field was level in 1990

Cause – Salt dissolution at rockhead 50 to 80 m depth?

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The Route & Risk

This section of HS2:

- Complicated geological conditions
- Salt subsidence
- Major infrastructure below ground

This length of HS2 has the highest ground risk (higher than tunnels & Camden deep excavations)

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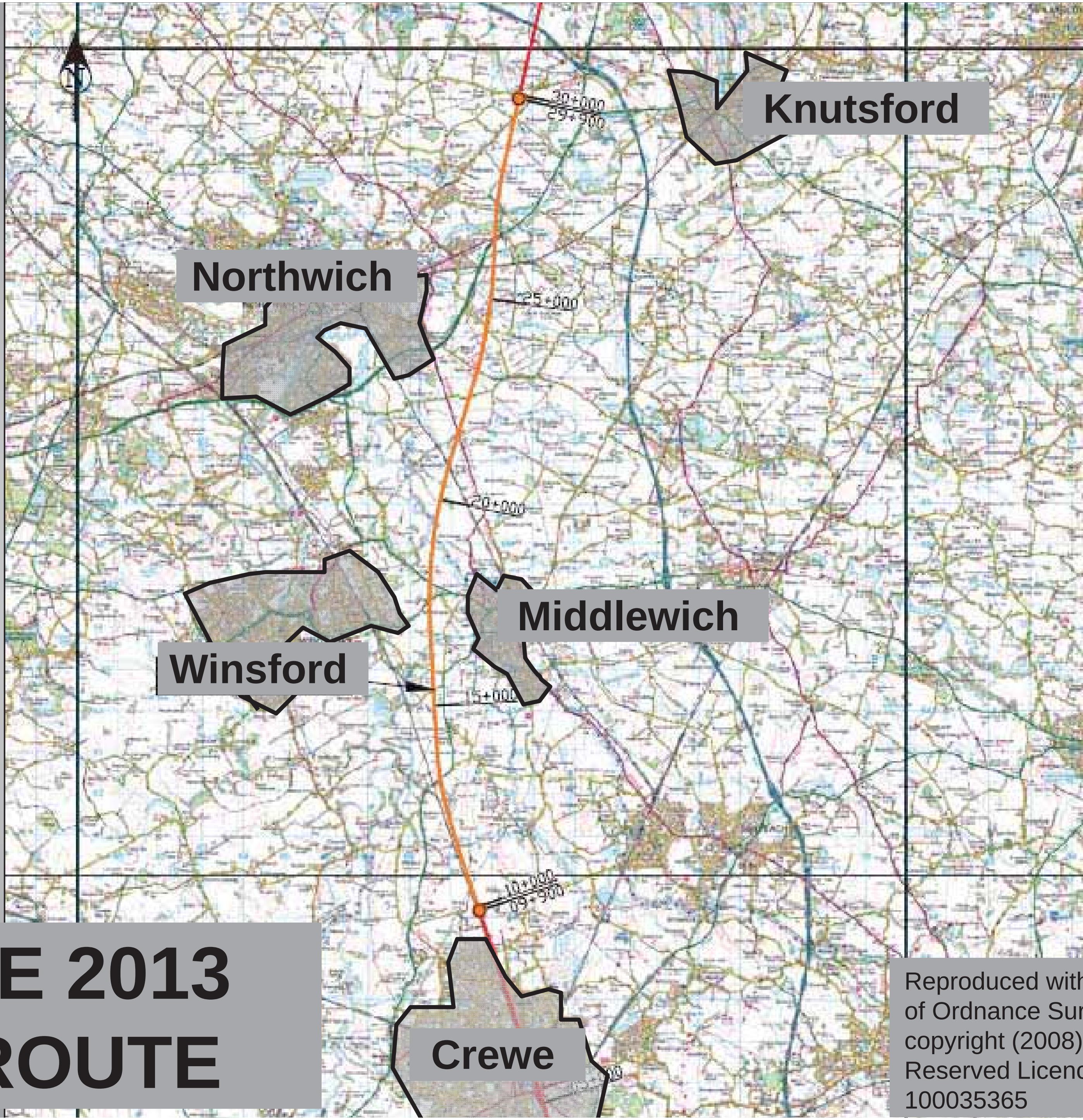
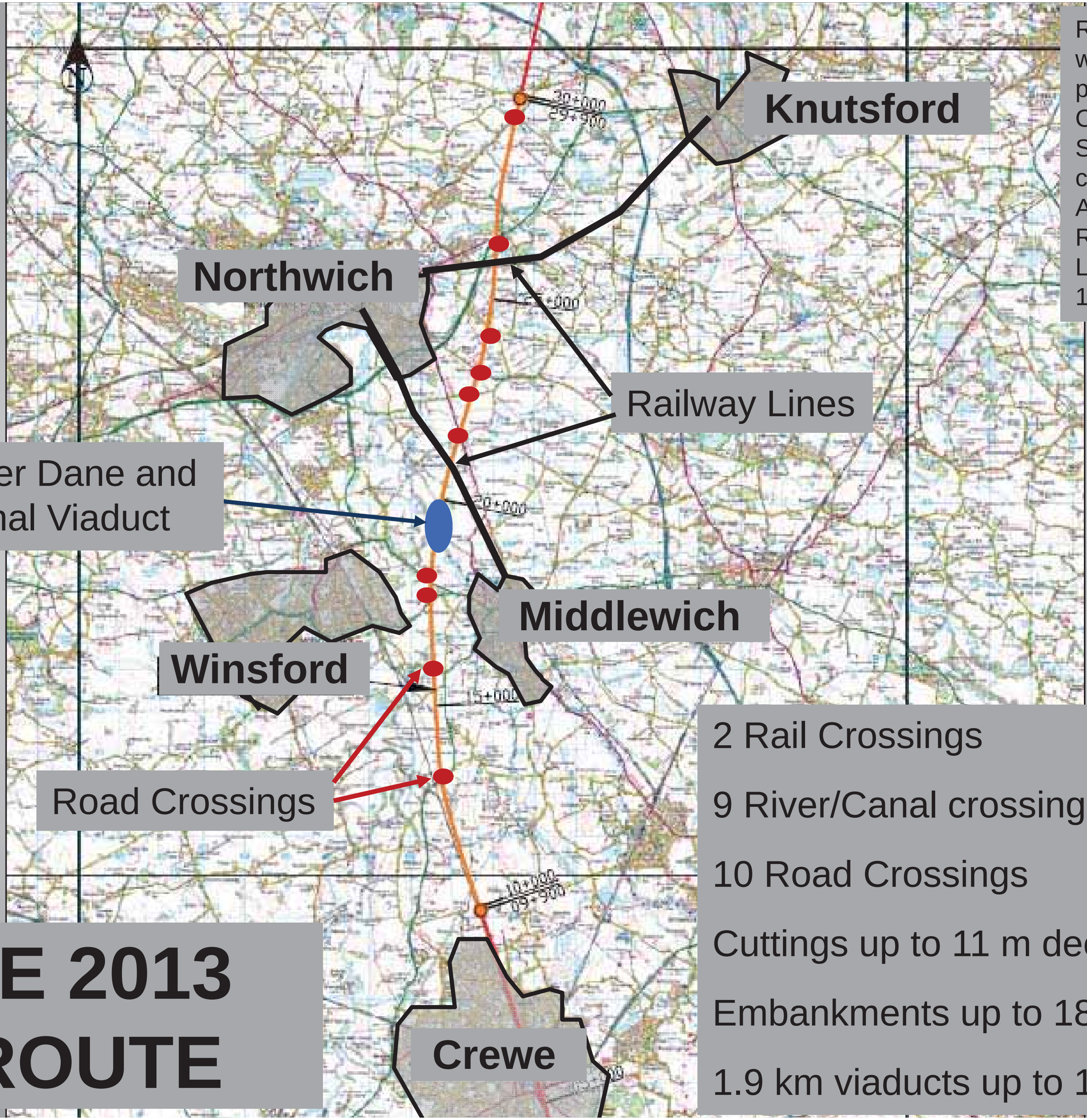
THE 2013 ROUTE

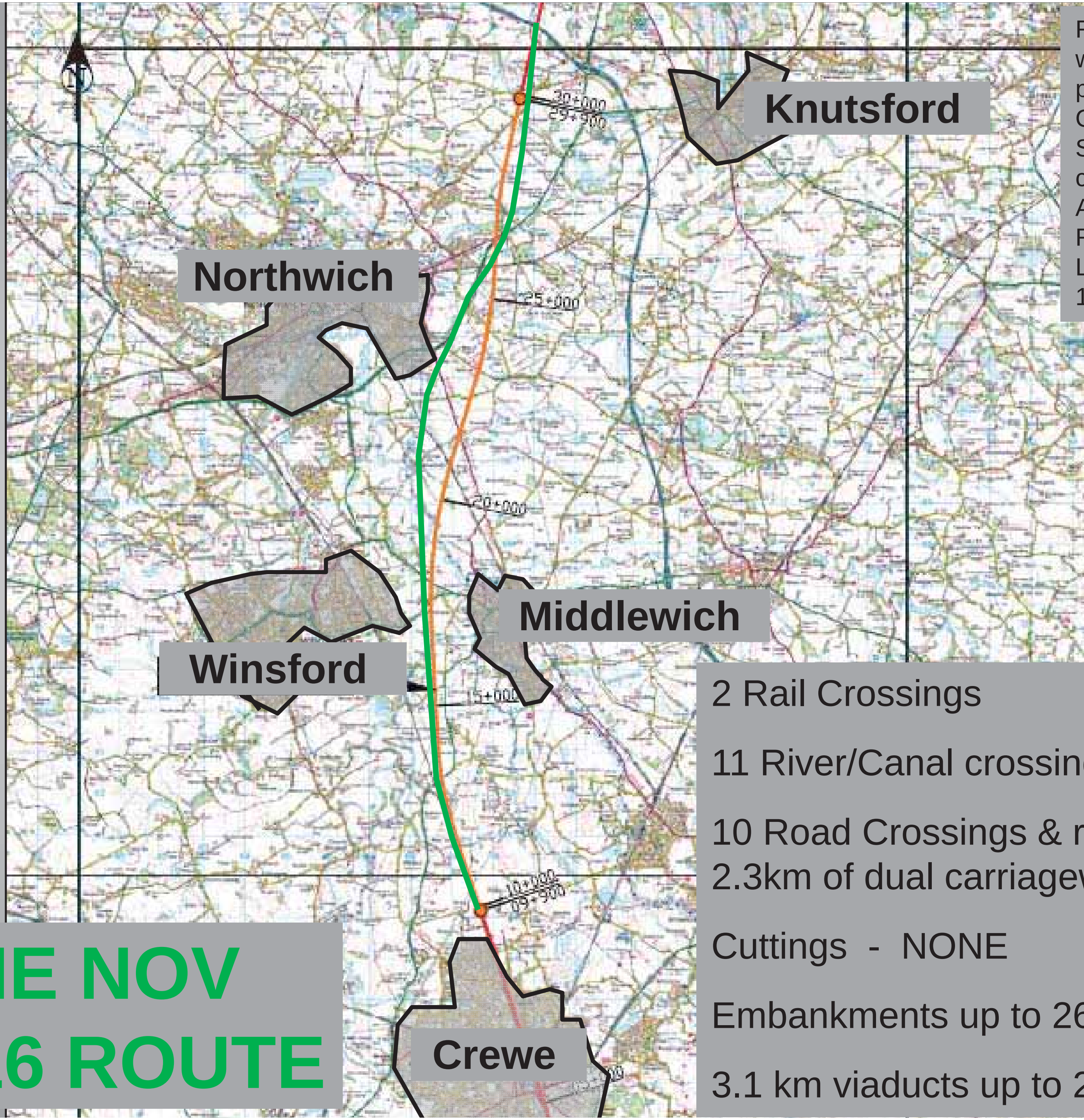


THE 2013 ROUTE



- 2 Rail Crossings
- 9 River/Canal crossings
- 10 Road Crossings
- Cuttings up to 11 m deep
- Embankments up to 18 m high
- 1.9 km viaducts up to 18 m high

THE NOV 2016 ROUTE



2 Rail Crossings

11 River/Canal crossings

10 Road Crossings & re-route 2.3km of dual carriageway

Cuttings - NONE

Embankments up to 26 m high

3.1 km viaducts up to 26 m high

Talk in three parts:

- Geology
- Natural Risks
- Anthropogenic Risks

GEOLOGY

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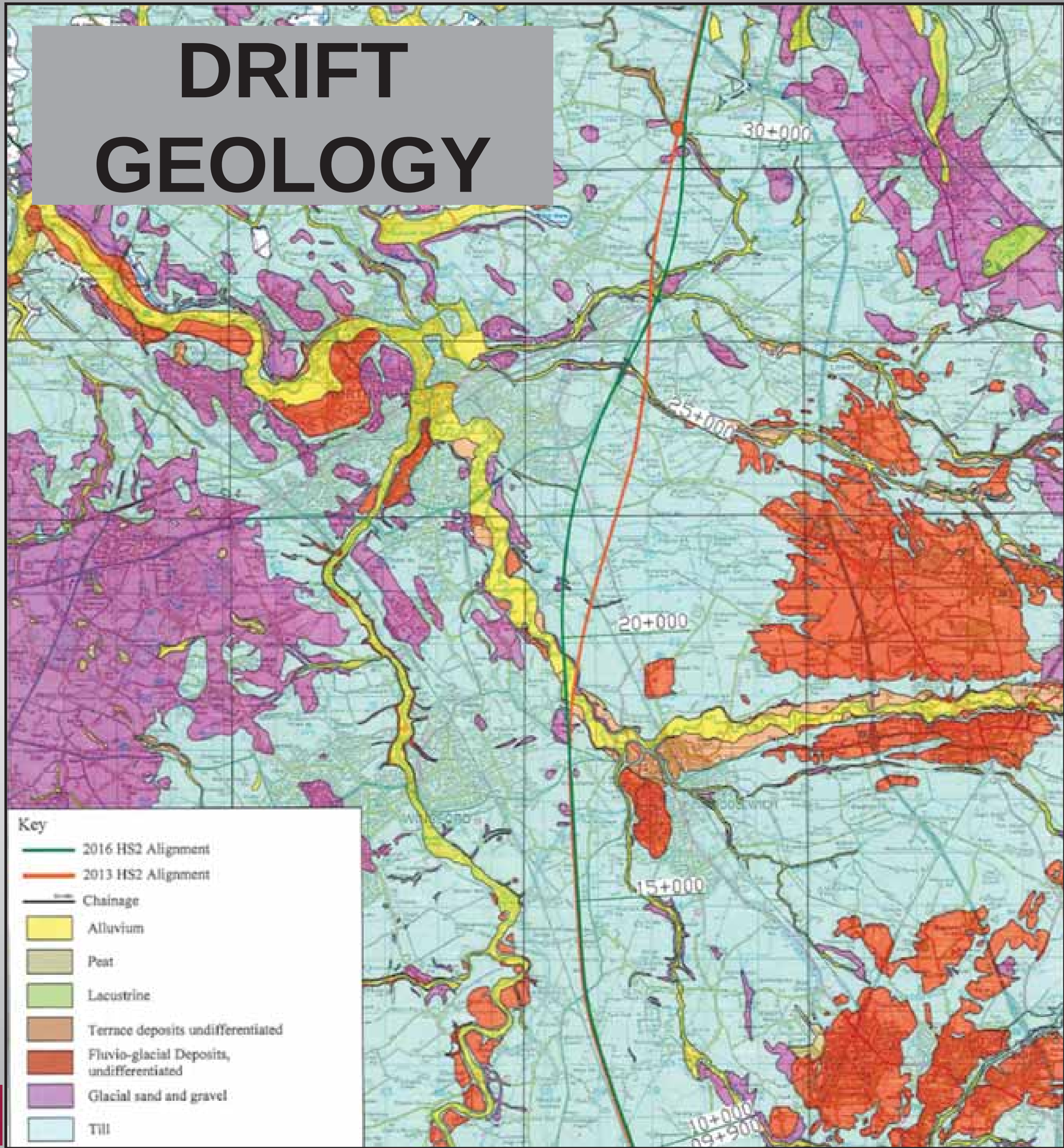
DRIFT GEOLOGY



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BEDROCK GEOLOGY - Triassic

Formerly Keuper Mudstone

Cheshire - Lower Keuper Saliferous Beds

Mercia Mudstone (2008) -

- Blue Anchor Formation
- Branscombe Mudstone Formation
- Arden Sandstone Formation
- Sidmouth Mudstone Formation
- Tarporley Siltstone Formation

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BEDROCK GEOLOGY

Lower part of the Mercia Mudstone Group

Sidmouth Mudstone Formation (1.3 km thick):

In the Cheshire Basin it supersedes the former:

- **Wilkesley Halite Member -** Upper Keuper Saliferous Beds
- **Byley Mudstone Member -** Middle Keuper Marl
- **Wych Mudstone Member -** Lower part of Middle Keuper Marl
- **Northwich Halite Member -** Lower Keuper Saliferous Beds
- **Bollin Mudstone Member -** Lower Keuper Marl, lower mudstone

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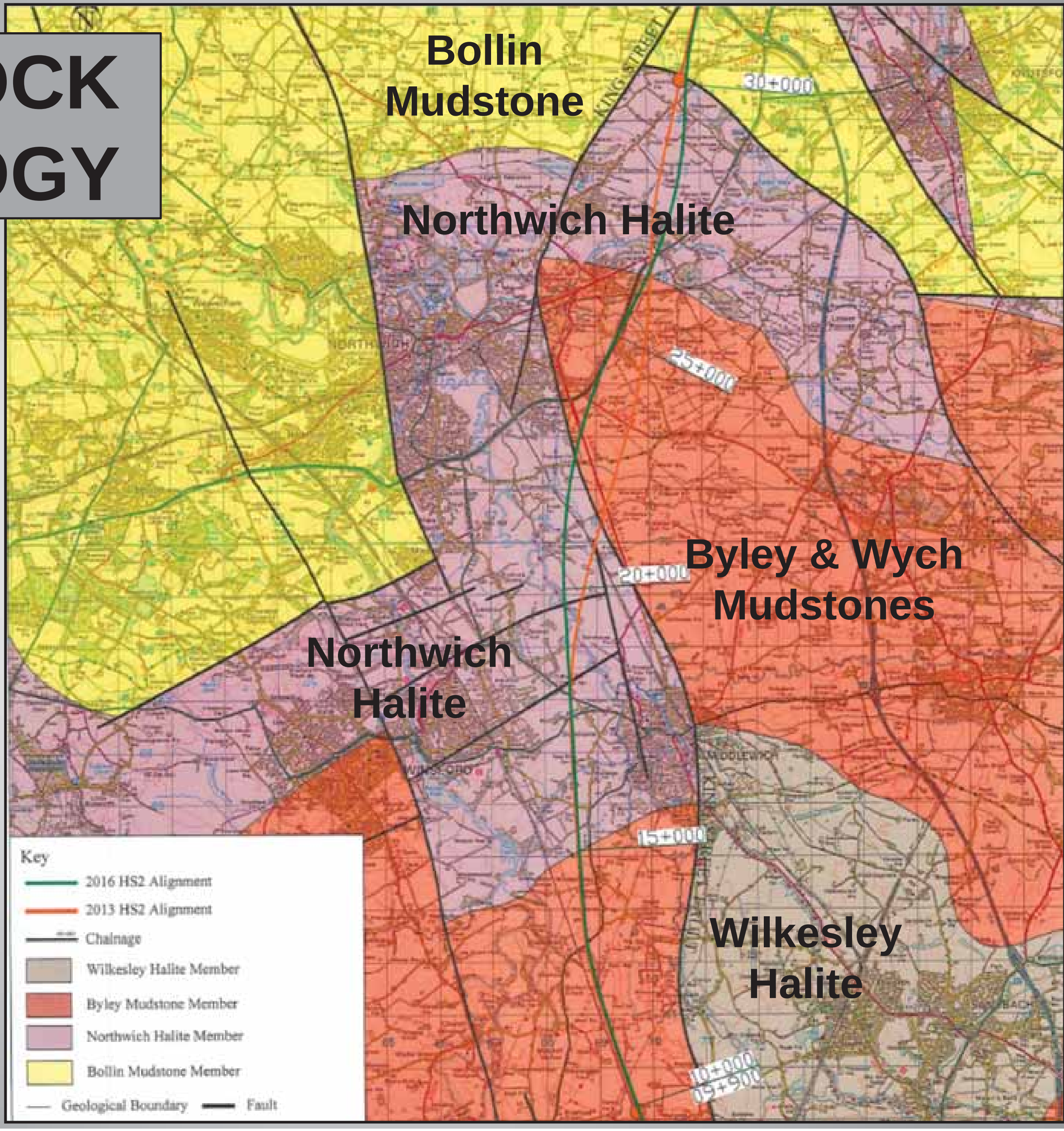
BEDROCK GEOLOGY



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Northwich Halite Member

1. The main salt bed in this area is the Northwich Halite Member
2. The Northwich Halite Member is 200 to 285 m thick, and is thicker in east Cheshire than west.
3. Overall it is composed of 75% salt, 25% marl.
4. There are individual thick beds of salt which are more than 95 % rock salt and also beds which are nearly all marl.
5. The principal mined units (both current and historic) are separated by marl beds.

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SALT KARST

Wet & Dry Rockhead

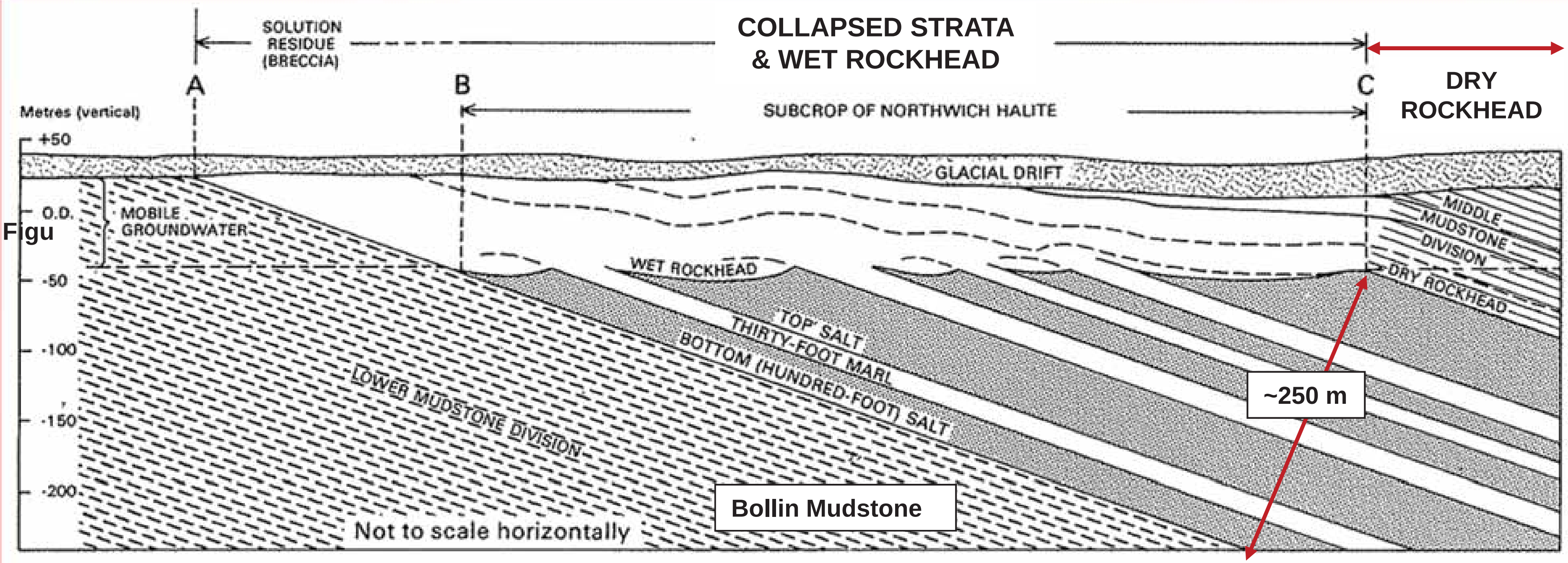

Figure 15 Diagram showing the relationship of 'Wet' and 'Dry' rockhead to the subcrop of the Northwich Halite

From BGS Memoir for Sheet 109 (Earp J R and Taylor BJ: 1986 :Memoir: BGS Sheet 109 Geology of the country around Chester and Winsford. British Geological Survey)

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GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

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GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

Areas mapped as being underlain by the Northwich Halite with “wet rockhead”

49% of 2013 route, 54% of 2016 route

Groundwater flowing at rockhead in depressions – slow dissolution

Groundwater flow is not uniform, preferential pathways – depressions.

Ground in areas of “wet rockhead” often appear stable for long periods.

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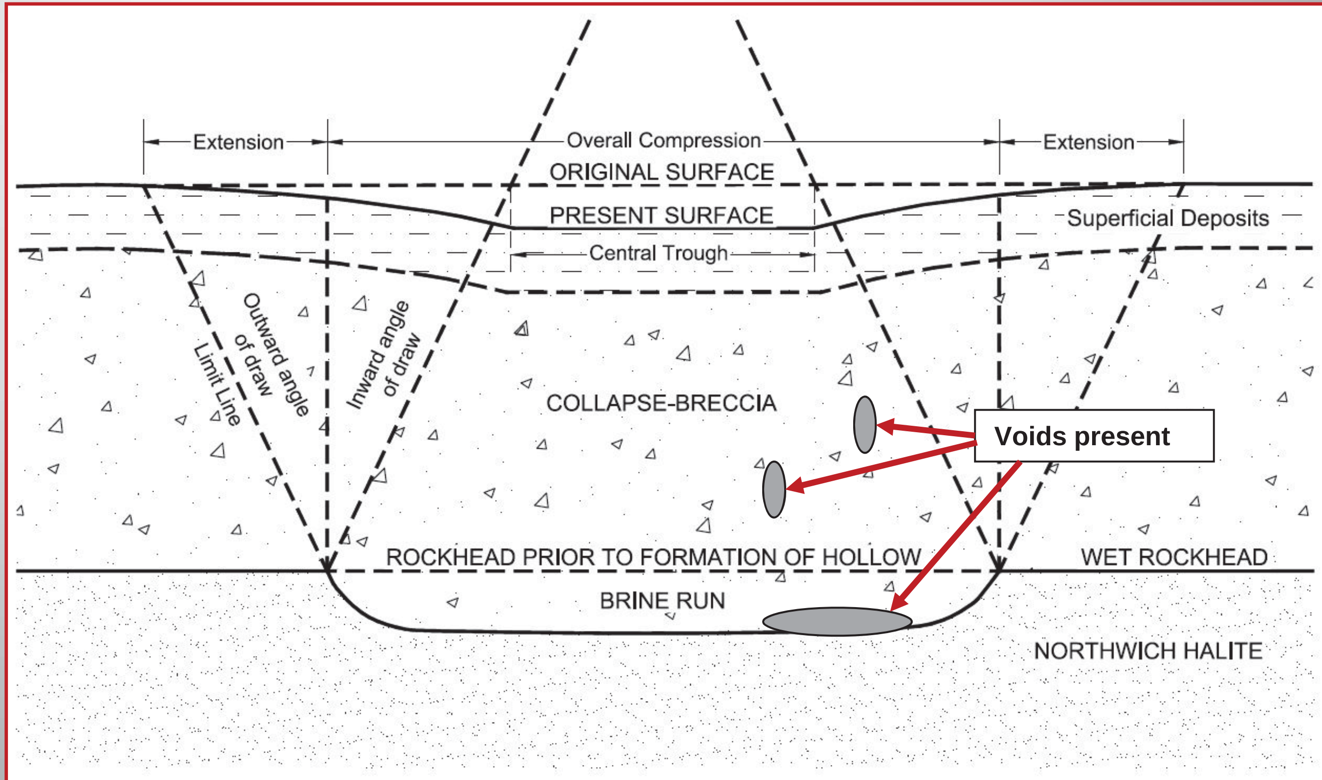
GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

Voids at “wet rockhead”

Voids can migrate upwards and then choke

Voids can be stable for 1,000s of years.

Schematic of subsidence feature



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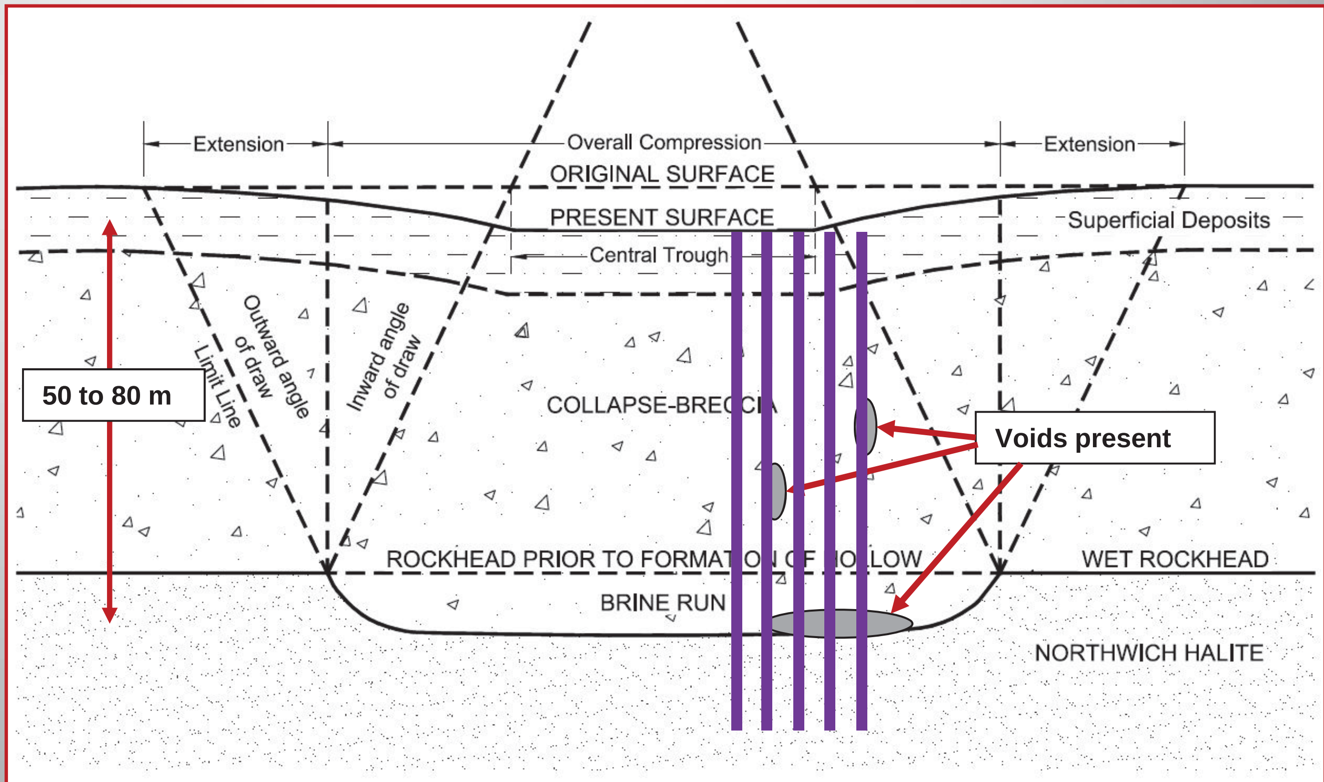
GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

Viaducts over “wet rockhead”

Very long piles – Down Drag

Very difficult to construct

Schematic of subsidence feature



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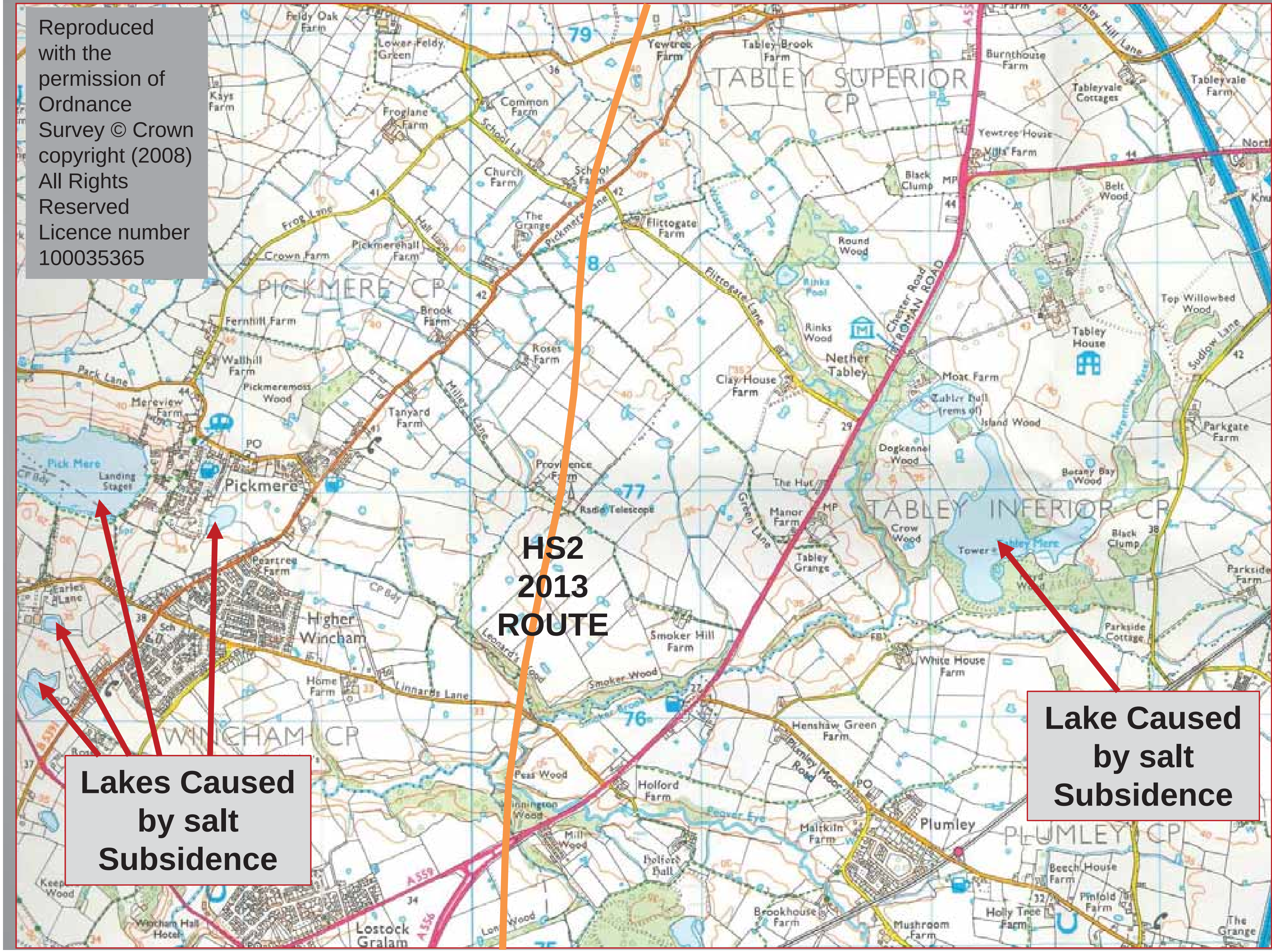
GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

Numerous small ponds present



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HS2 2013 ROUTE
Lakes Caused by salt Subsidence
Lake Caused by salt Subsidence
TABLEY SUPERIOR CP
TABLEY INFERIOR CP
PICKMERE CP
WINCHAM CP
PLUMLEY CP
Pickmere
Pick Mere
Higher Wincham
Plumley
Lostock Gralam
Tabley House
Nether Tabley
Tabley Mere
Tatton Dale

GROUND AFFECTED BY NATURAL SALT SUBSIDENCE

Numerous small ponds present

Formed by:

- **Glacial – kettle holes**
- **Excavations by farmers**
- **Salt subsidence**
- **Subsidence in drift**


Pond not on
2004 OS Maps
on centreline of
HS2 2013 route
©TerraConsult Ltd


Steep sided.
Crown Hole?
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PONDS - SALT SUBSIDENCE OR DRIFT SUBSIDENCE

From a HS2 report on another pond which formed about 1 km from here indicates subsidence feature due to:

> **"*uneven drainage and consolidation of heterogeneous drift deposits was the most likely cause for the observed surface subsidence effects.*"**

This unusual mechanism could affect large lengths

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ANTHROPOGENIC EFFECTS

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Effects – Brine Pumping Induced

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Railway Lines North of Crewe…HS2 !!

ANTHROPOGENIC EFFECTS

Wild brine pumping

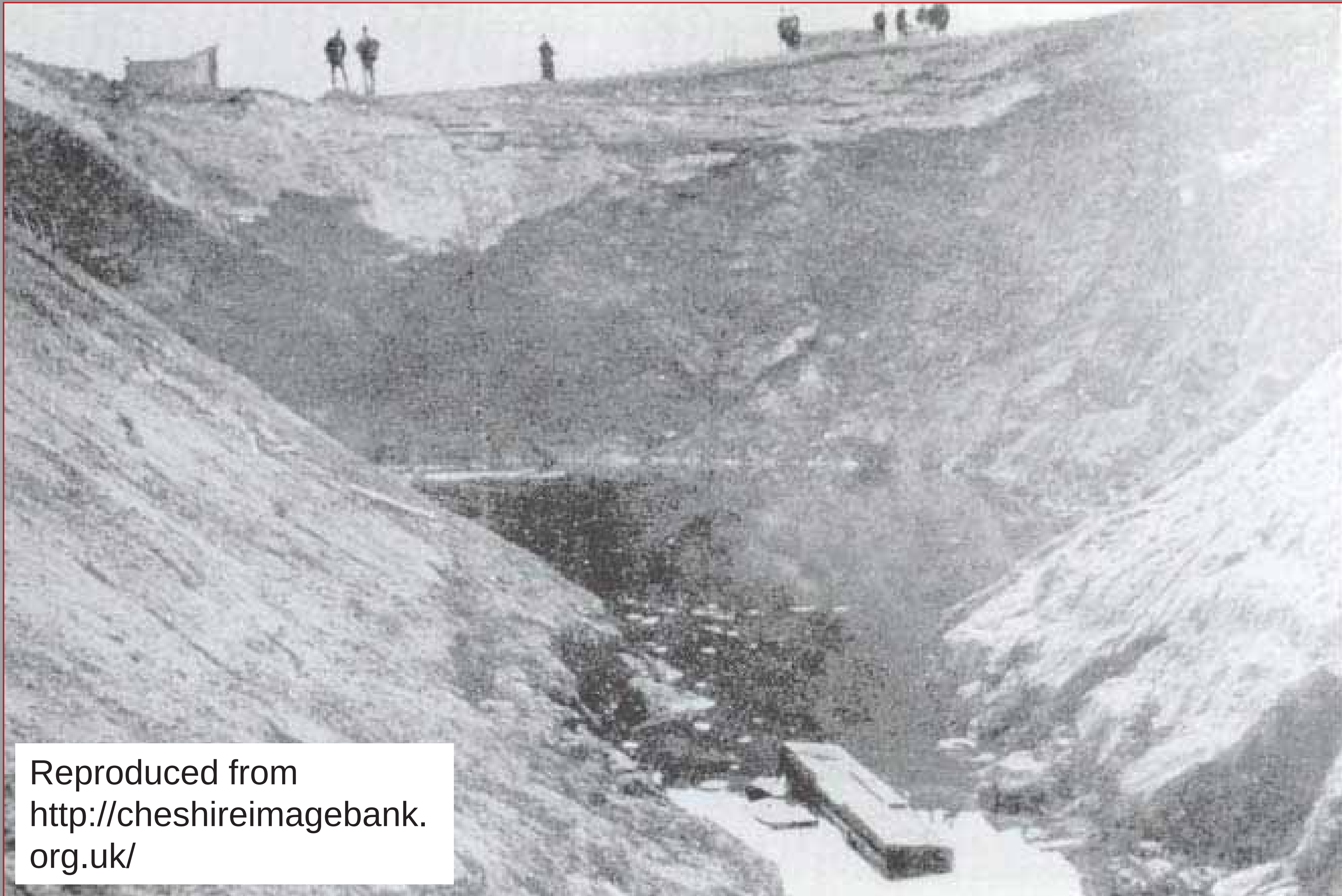
Conventional mining

Solution mining

Gas storage caverns

Oil storage caverns - storing UK strategic oil reserves (currently being decommissioned)

Wild Brine Pumping – Large Voids



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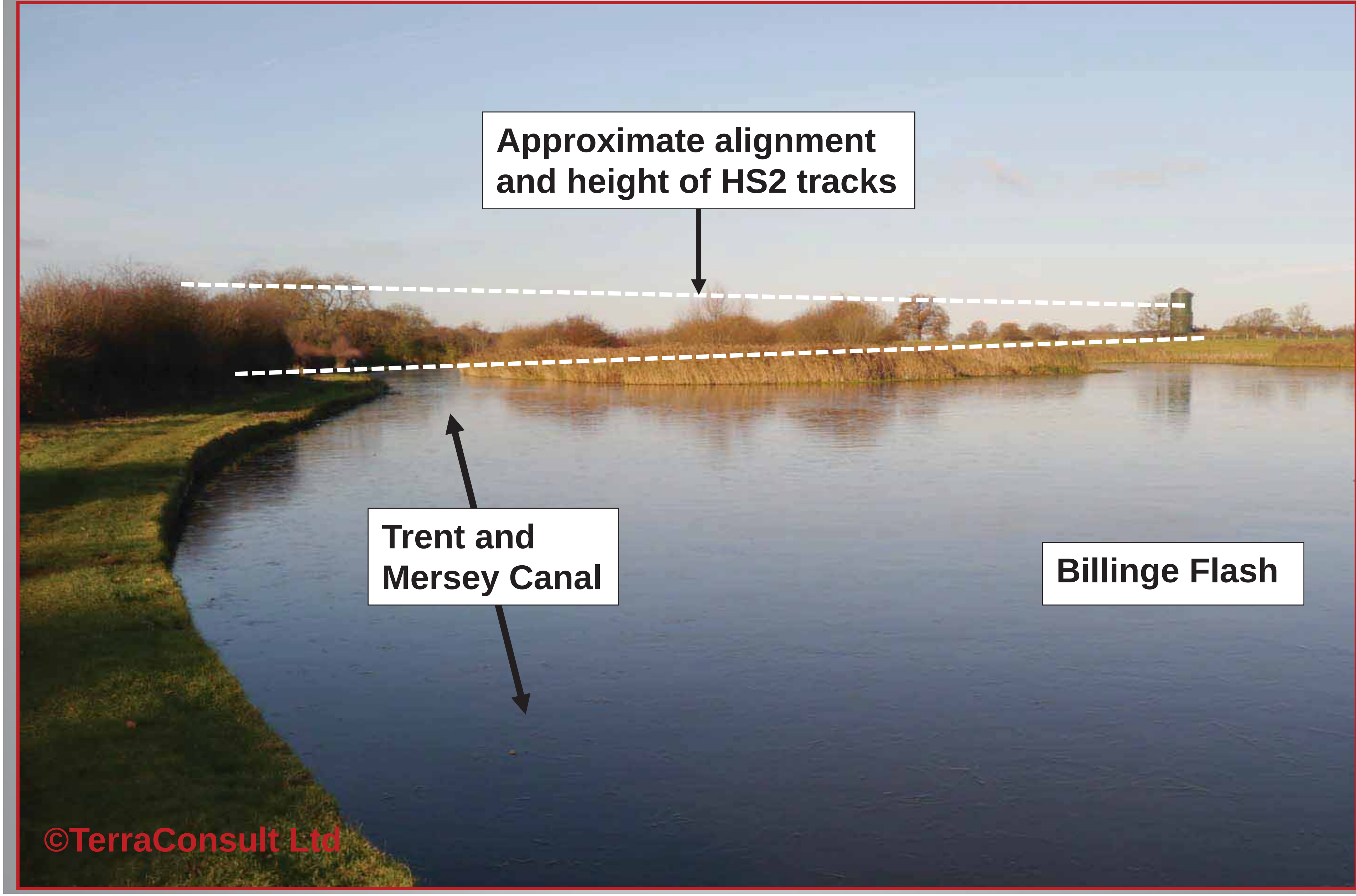
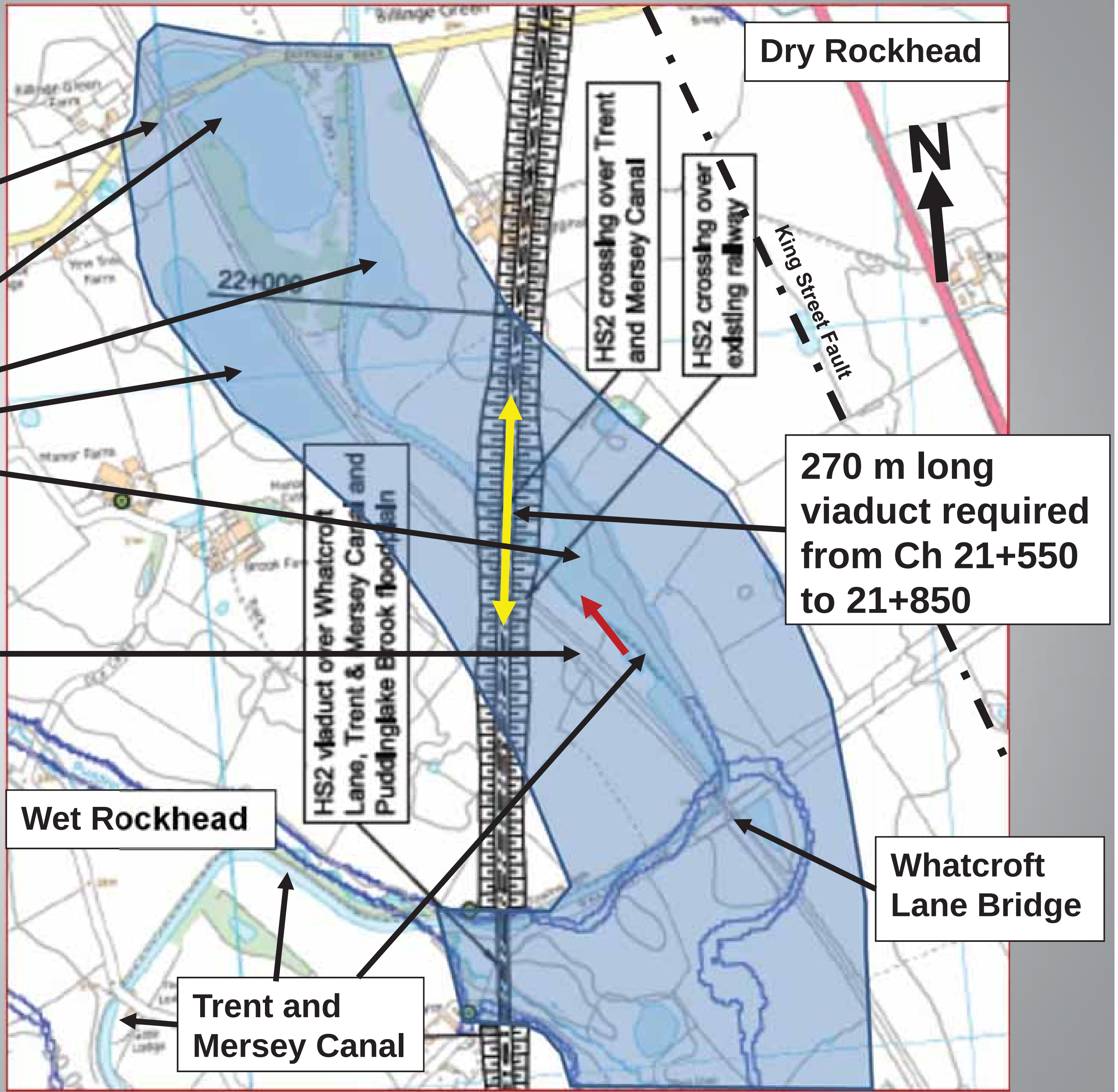
WILD BRINE PUMPING - BILLINGE FLASH



BILLINGE FLASHES



Base plan from HS2 Drawing No C320-AEC-RT-DPP-220-061002 to 061005: Design Stage Post-Consultation. Preferred Route HSM10B Plan and Profile" Sheet 4 of 6.

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WHATCROFT LANE BRIDGE

WHATCROFT LANE BRIDGE

WHATCROFT LANE BRIDGE

CONVENTIONAL MINING
WINSFORD SALT MINE

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CONVENTIONAL MINING
WINSFORD SALT MINE

Located to the northeast of Winsford

Owned & operated by Compass Minerals Ltd.

Salt mining began at Winsford 173 years ago.

An extensive network of caverns typically 140 to 220 m below ground but at about 75 depth in north.

Room and pillar mining:

- Caverns up to 20 m wide and 8 m high,
- Solid pillars of salt up to 24 m square.
- 68 to 75% extraction ratio.

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NOW MINED AT TWO LEVELS

Room & Pillar

Extraction Ratio Much Lower Than Historic

This is a 4 m initial cut

WINSFORD SALT MINE

Mining

Document Storage

Hazardous Waste Landfill

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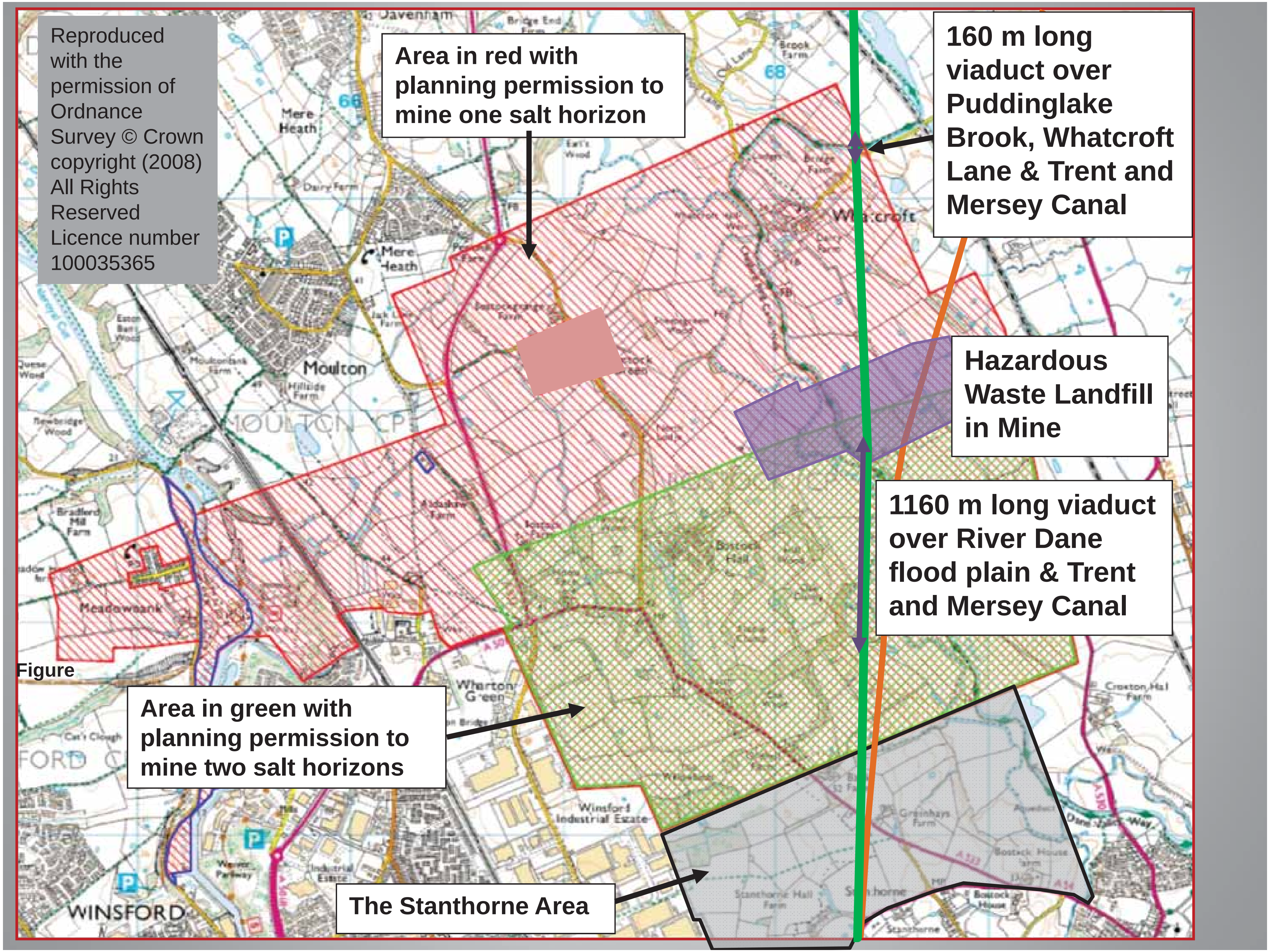
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Area in red with planning permission to mine one salt horizon
160 m long viaduct over Puddinglake Brook, Whatcroft Lane & Trent and Mersey Canal
Hazardous Waste Landfill in Mine
1160 m long viaduct over River Dane flood plain & Trent and Mersey Canal
Area in green with planning permission to mine two salt horizons
The Stanthorne Area
Davenham
Mere Heath
Moulton
Whatcroft
Wharton Green
Winsford Industrial Estate
WINSFORD
Meadowbank
Figure

ANTHROPOGENIC EFFECTS

Areas of “Dry Rockhead”

Solution Mining – Holford Brinefield

– Feedstock for Chemical Industry

Gas Storage Caverns

Need Cover of Byley & Wych Mudstones

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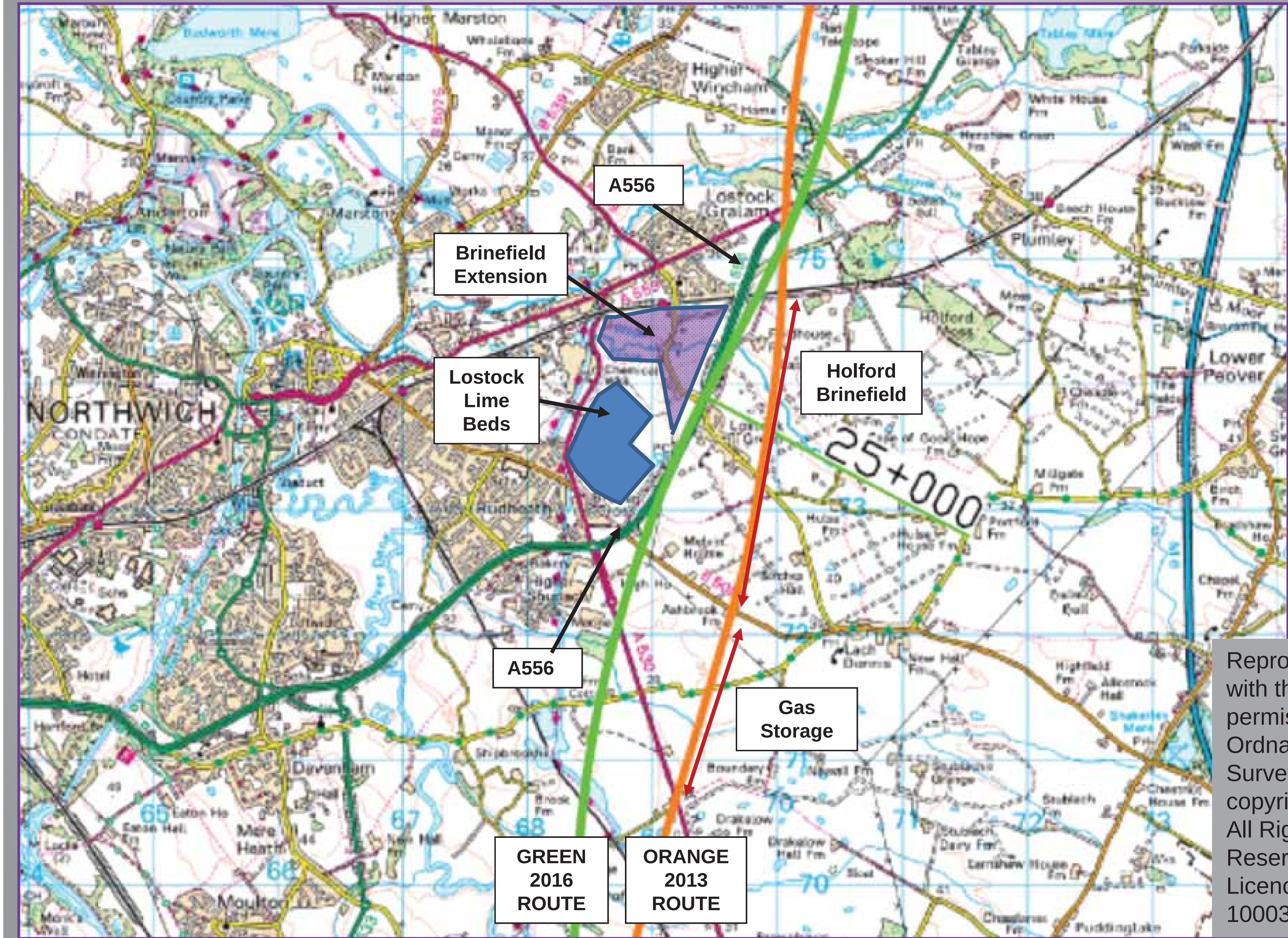
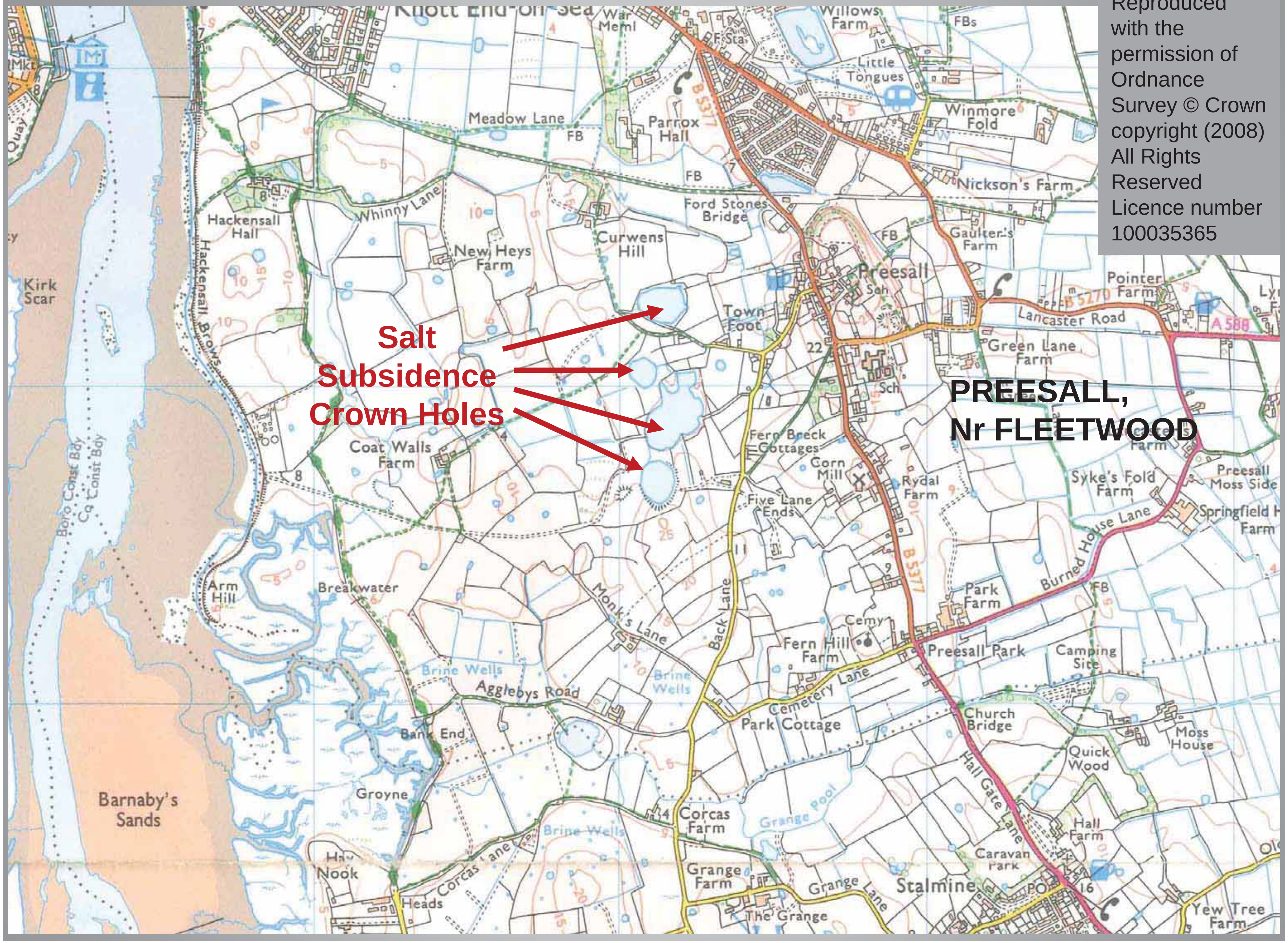
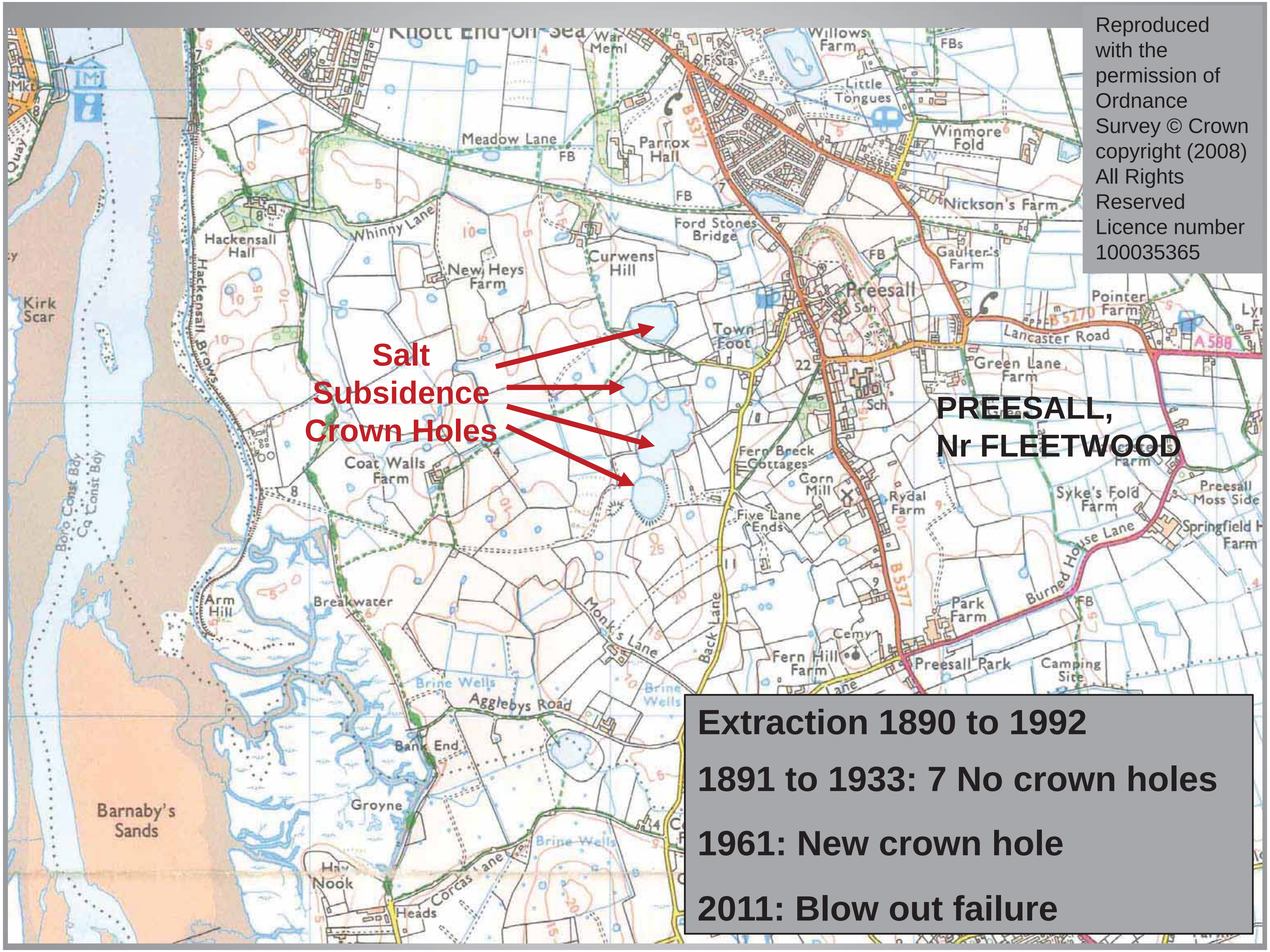
HOLFORD BRINE WELLS & GAS STORAGE




PREESALL,
Nr FLEETWOOD
Salt
Subsidence
Crown Holes
Knott End-on-Sea
War Meml
Willows Farm
FBs
Little Tongues
Winmore Fold
Meadow Lane
Parrox Hall
Nickson's Farm
Ford Stones Bridge
Gaulter's Farm
Hackensall Hall
Whinny Lane
New Heys Farm
Curwens Hill
Preesall
Pointer Farm
Lancaster Road
Green Lane Farm
Town Foot
Kirk Scar
Hackensall Brows
Coat Walls Farm
Fern Breck Cottages
Corn Mill
Rydal Farm
Syke's Fold Farm
Preesall Moss Side
Springfield Farm
Burned House Lane
Five Lane Ends
B 5377
B 5270
A 588
Arm Hill
Breakwater
Monk's Lane
Back Lane
Park Farm
Cemy
Fern Hill Farm
Preesall Park
Camping Site
Brine Wells
Agglebys Road
Cemetery Lane
Park Cottage
Church Bridge
Moss House
Quick Wood
Bank End
Groyne
Barnaby's Sands
Hall Gate Lane
Hall Farm
Corcas Farm
Grange Pool
Caravan Park
Corcas Lane
Heads
Nook
Grange Farm
The Grange
Grange Lane
Stalmine
Yew Tree Farm
Boro Const Bdy
Co Const Bdy


PREESALL,
Nr FLEETWOOD
Salt
Subsidence
Crown Holes
Extraction 1890 to 1992
1891 to 1933: 7 No crown holes
1961: New crown hole
2011: Blow out failure
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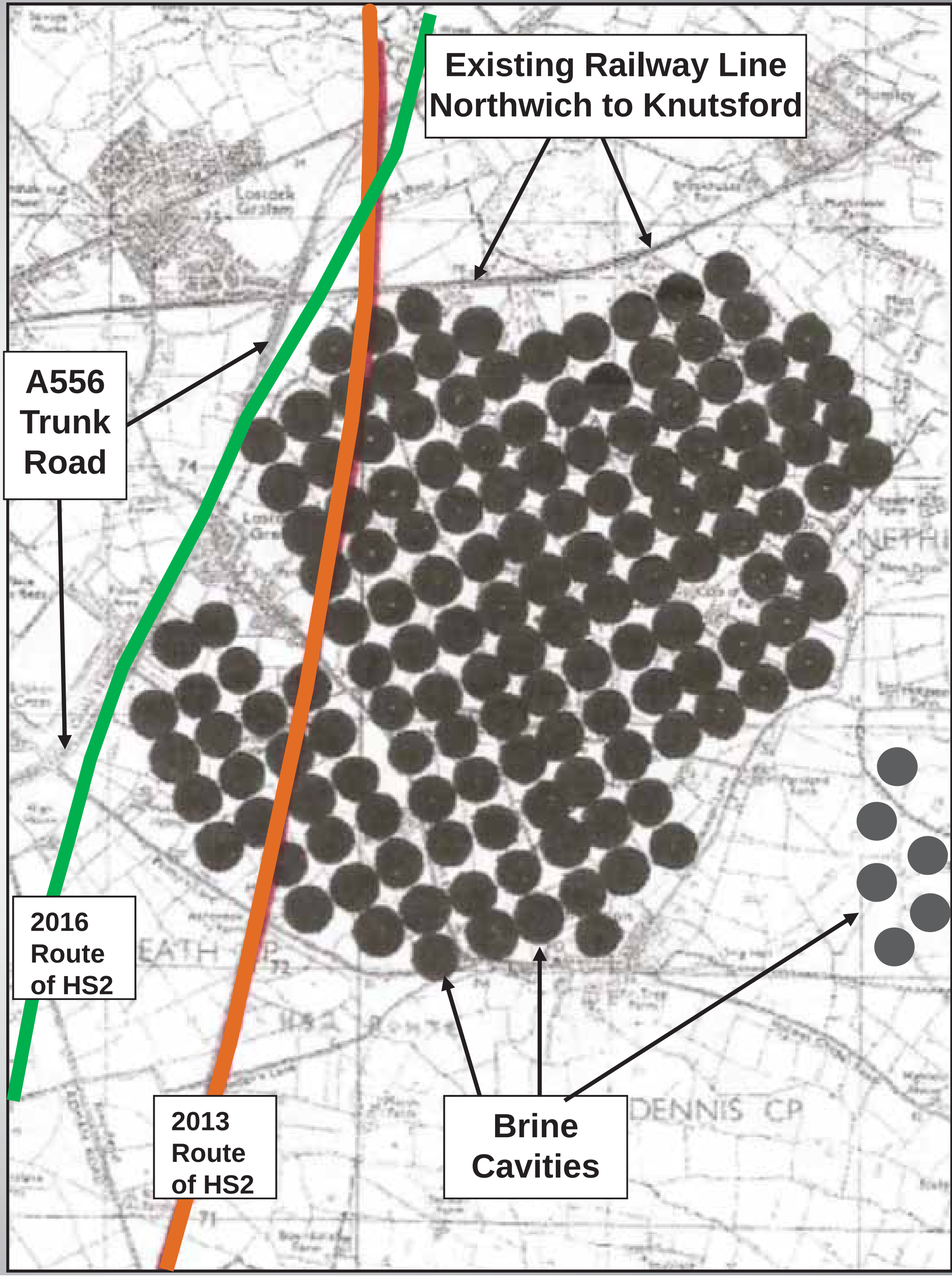
Holford Brinefield 2013 route

1.5 km of brinefield

Intersected 14 brine cavities



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Holford Brinefield

Geology:

- 20 m drift over Byley and Wych Mudstones.
- Solution Mine in the underlying Northwich Halite
- Shallowest cavern crown at 50 m depth.

Holford Brinefield

Geology:

- 20 m drift over Byley and Wych Mudstones.
- Solution Mine in the underlying Northwich Halite
- Shallowest cavern crown at 50 m depth.

Cavities 170 m dia, as little as 30 m apart or less!

Pressurised to reduce creep of Halite.

Some cavities are known to have coalesced

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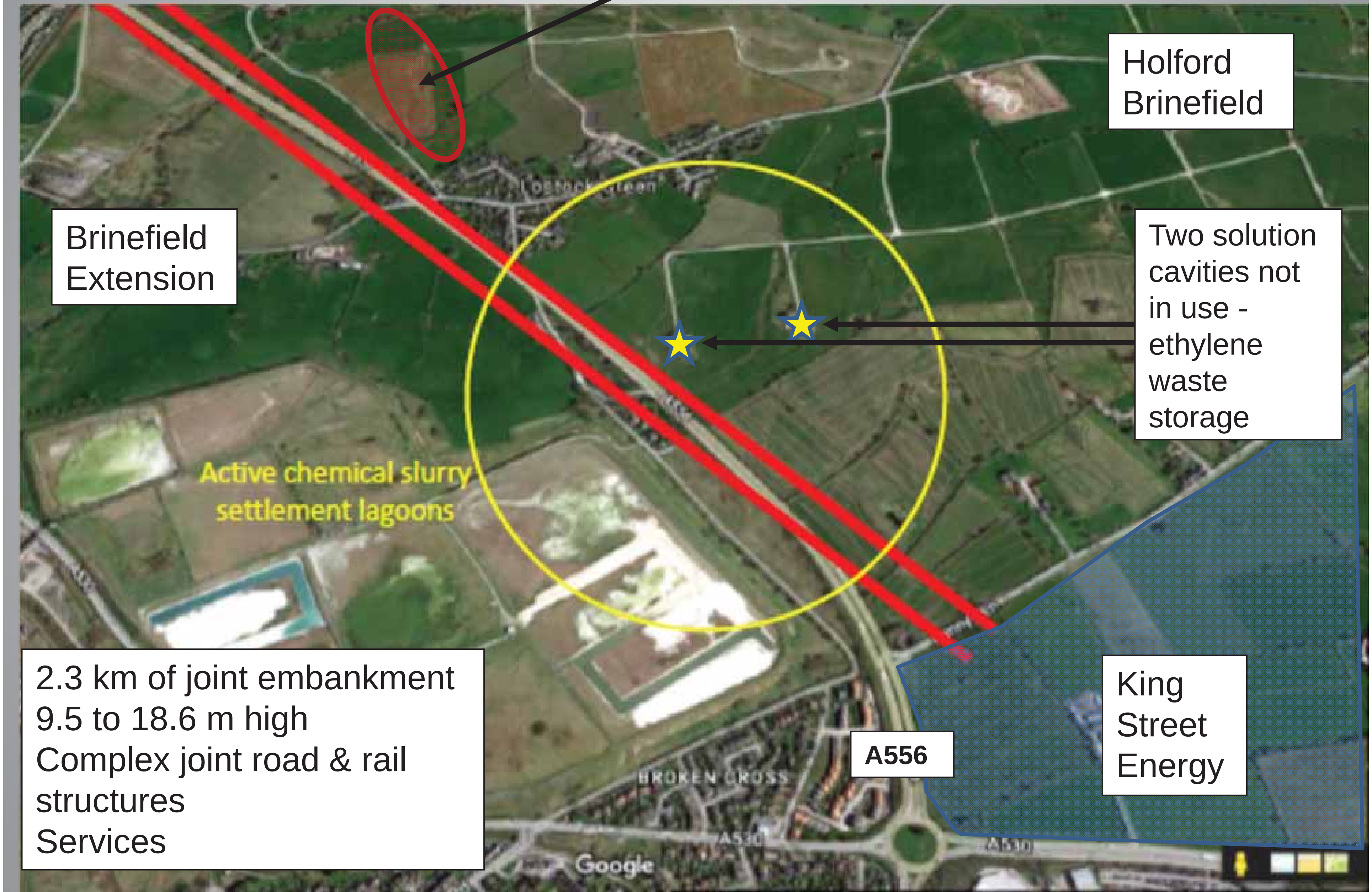
A556 RE-ALIGNMENT



2.3 km of joint embankment
9.5 to 18.6 m high
Complex joint road & rail structures
Services

GAS STORAGE FACILITIES

2013 & 2016 routes avoid the EDF gas storage facility Warmingham between Crewe & Middlewich

Three facilities southwest of Northwich:

- **Byley Gas Storage,**
- **Holford Gas Storage Facility (E.ON)**
- **Stublach Gas Storage Project (Storengy) Crossed by 2013 route**

King Street Energy - planning permission for a field of nine gas storage caverns crossed by the 2013 HS2 alignment – three caverns affected

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GAS STORAGE FACILITIES

UK Government classifies the gas storage facilities as “*nationally strategic.*”

COMAH regulated

(Control of Major Accident Hazards)

The 2016 route also avoids the gas storage caverns but it crosses the surface facilities for the planned King Street Energy Storage Facility

2016 HS2 ROUTE CHANGES

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2016 ROUTE & RISK

The net result of the proposed changes increased the risk profile outside the solution mined area:

- **Increase over higher risk wet rockhead (1,080m increase, +11%).**
- **Elimination of all cuttings – thus removing the possibility of re-using excavated soil as fill.**
- **More Embankment fill – + 3.5 M m^3**
- **Embankments higher – 18 m max increased to 26 m**
- **Longer Embankments – length + 42%**
- **More embankment on wet rockhead – + 81 %**

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2016 ROUTE & VIADUCTS

Viaducts are now:

- Higher (26 m) - increasing costs due to both the increased structural above ground costs and the larger foundations required to support the increased loads.
- Longer - 1.9 km more (120% increase) - hence the cost of the route increases of which nearly all (1.8km) is an increase in viaduct length over the higher risk wet rockhead.
- Differential settlement - With higher embankments & viaducts the potential for differential settlement between the embankment & the viaduct increases.

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DRAINAGE

DRAINAGE

HS2 2013 – 33% cuttings

HS2 2016 – none

HS2 changed the design philosophy due to assessed risk from subsidence caused from drainage of water in areas of wet rockhead.

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DRAINAGE

Still need to manage drainage from structures which are now larger.

Dr Tony Waltham – *"95 % of all subsidence collapses are the result of engineering structures interfering with natural drainage."*

54 % of route with wet rockhead needs careful design and management of drainage to prevent the HS2 structures reinvigorating existing subsidence features and creating new areas of subsidence.

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GLOBAL WARMING

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GLOBAL WARMING

Well known effects on embankment slopes.

Main issue groundwater & increased subsidence:

- **BGS has liked major storms December 2013 to January 2014 to increased subsidence.**
- **Climate change more & bigger storms.**
- **More subsidence in areas of wet rockhead.**

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Global Warming – Subsidence rate increasing

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CONCLUSION

This 20.1 km section of HS2 Phase 2B route passes through ground which is technically challenging for the construction of a high speed rail link.

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This 20.1 km section of HS2 Phase 2B route passes through ground which is technically challenging for the construction of a high speed rail link.

All of the engineering difficulties can be overcome but this section will cost significantly more per km than a comparable section of HS2 which also passes through rural countryside which does not have such challenging ground engineering conditions.

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The 2016 Route & Risk

It can be built to produce a safe railway by:

- Site Investigation
- Design
- Construction
- Monitoring & Maintenance

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The 2016 Route & Risk

It can be built to produce a safe railway by:

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INNOVATION

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