Further Developments with Embankment Dams on the Mercia Mudstone

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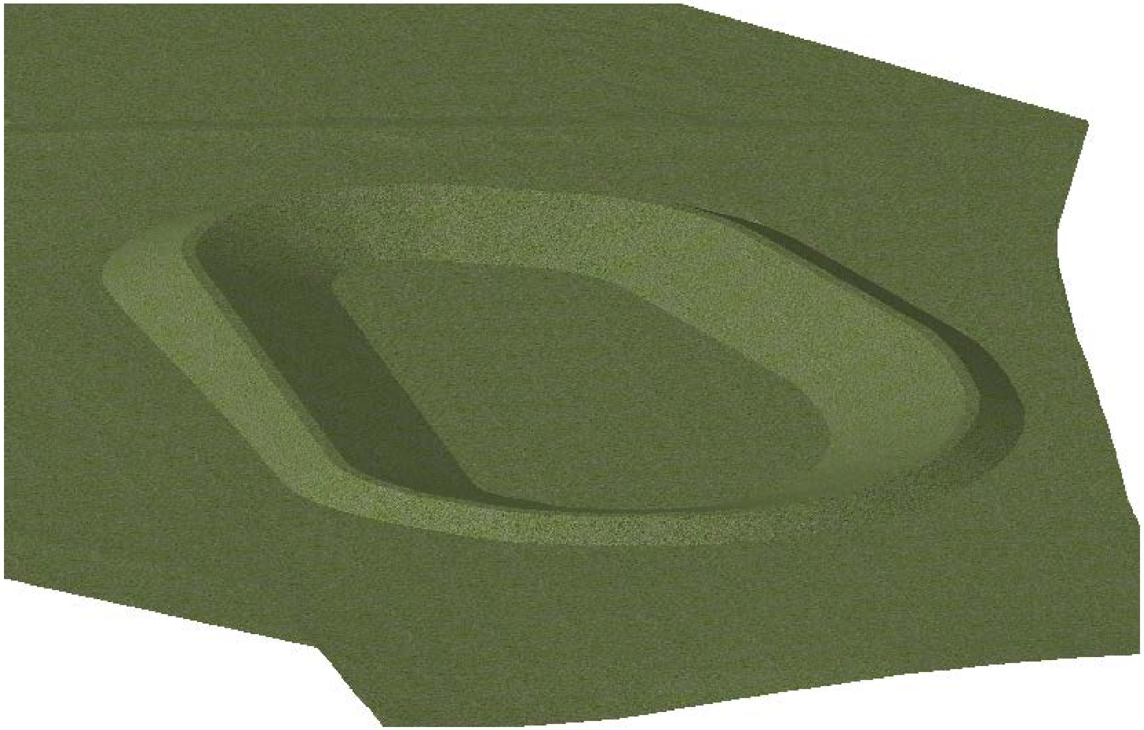
Outline of Presentation

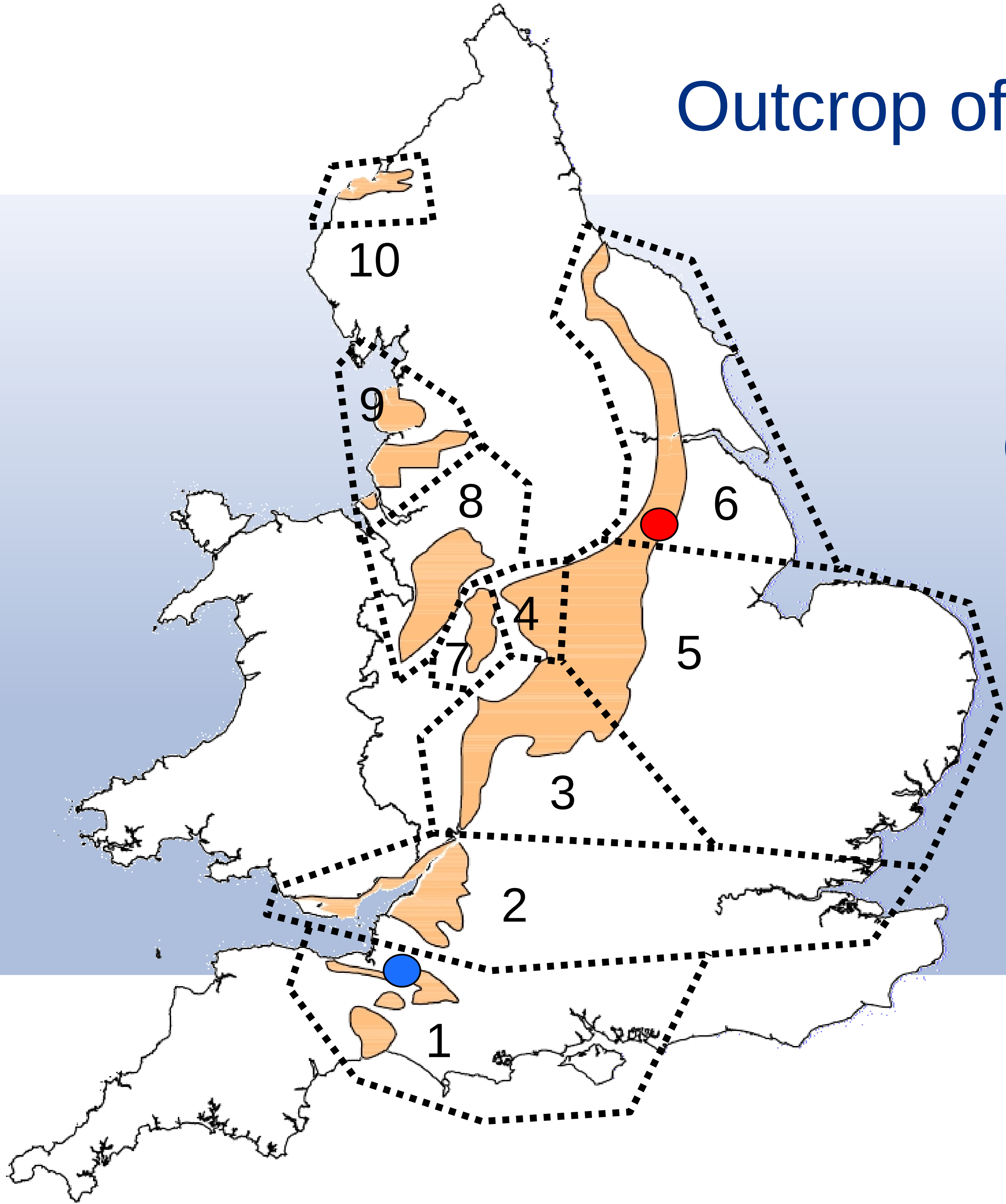
- Introduction to Lincoln case study
- [Mercia Mudstone: Initial studies & site investigations]
- Research on historical case histories
- Observations
- Lincoln case study – design, construction, commissioning

Lincoln WTW Project – Storage Reservoir

- Anglian Water raw water storage reservoir
- Earth fill embankment dam, oval shape
- 10 days storage including outage time
- Capacity 285,000m^3
- Earthworks volumes - cut & fill: 220,000m^3



Outcrop of Mercia Mudstone



MM age :

Mid Triassic (Anisian) to Late Triassic (Rhaetian)

(241 – 205 mybp).

Mercia Mudstone Zones

after BGS, 2008

Lincoln RWR

Cheddar Resr

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Stratigraphy

(after BGS Report RR/08/04, 2008)

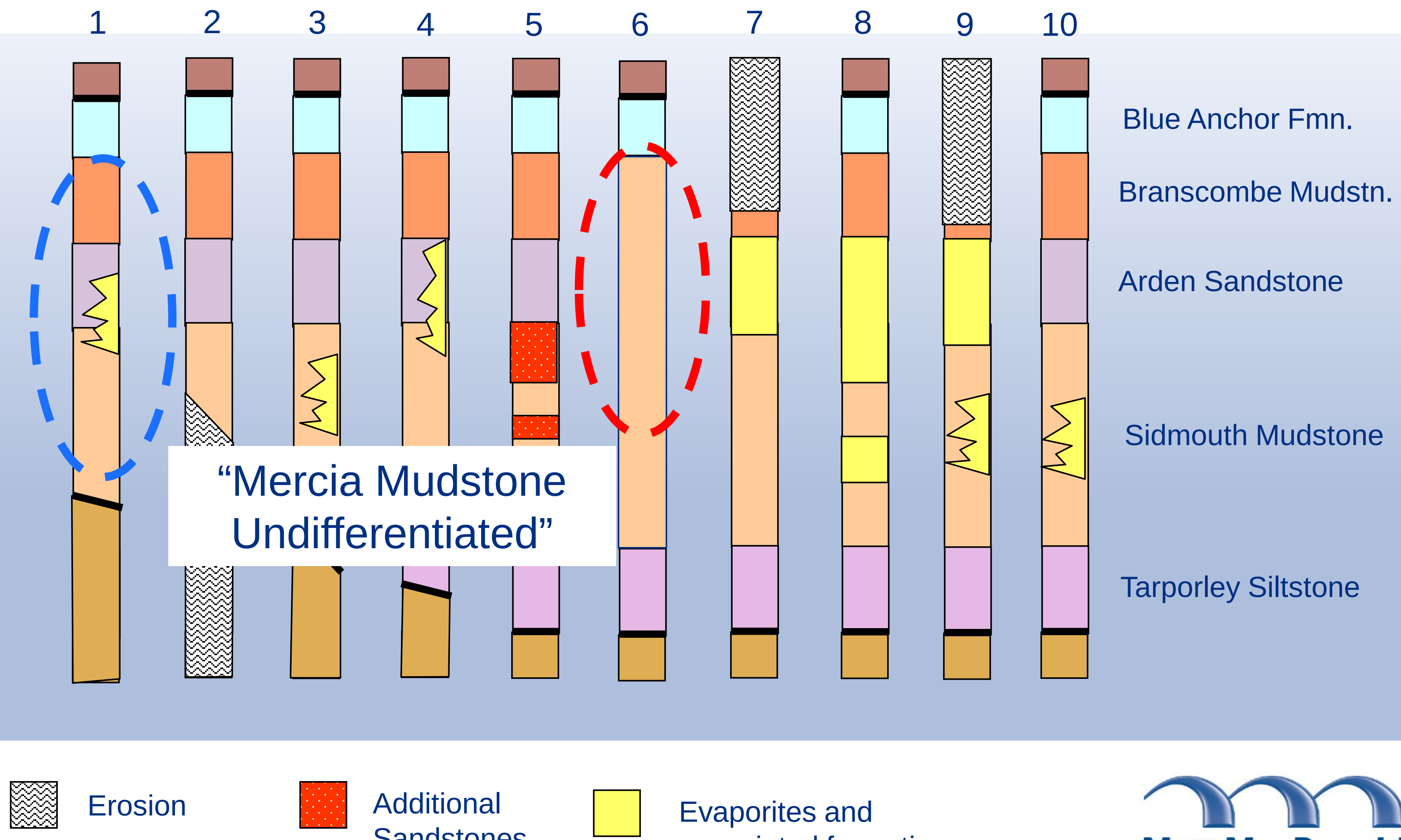
Penarth Group

E	Blue Anchor Formation	Green-grey dolomitic siltstone & silty mudstone
D	Branscombe Mudstone Formation	Red-brown mudstone and siltstone with grey patches; gypsum/anhydrite in nodules and veins.
C	Arden Sandstone Formation	Grey, green and purple mudstone interbedded with paler siltstone and sandstone
B	Sidmouth Mudstone Formation	Red-brown mudstone and siltstone with reduction patches; dolomitic siltstone; gypsum/anhydrite in nodules and veins. Thick halite in some areas.
A	Tarporley Siltstone Formation	Interbedded micaceous siltstone, mudstone and fine sandstone; gypsum in small nodules

Sherwood Sandstone Group

Stratigraphy

(after BGS Report RR/08/04, 2008)



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Depositional Environments

- Mercia Mudstone Group: deposited in a mudflat environment
- Four main depositional processes
  - Settling out of mud and silt in brackish or hypersaline estuarine waters;
  - Rapid deposition of sheets of silt / fine sand, transported by flash floods;
  - Accumulation of wind blown dust on wet mudflat surfaces, and
  - Chemical precipitation of salts, principally halite & gypsum, from marine-sourced hypersaline water bodies.

Conclusions from Initial Studies

- Mercia Mudstone Group:
- Clays & mudstones of variable strength & stiffness
- Lithologically variable (siltstones, sandstones, skerries)
- Highly variable permeability – fissure permeability
- Weathering has significant influence on behaviour
- Evaporites
  - Chemically aggressive
  - Dissolution issues

Ground Investigations

Field Observations

Field Observations on Permeability

- Trial pit spoil - crumbly, almost granular appearance
- When wetted & moulded, became very plastic – “gritty clay”
- Appears to be of low permeability

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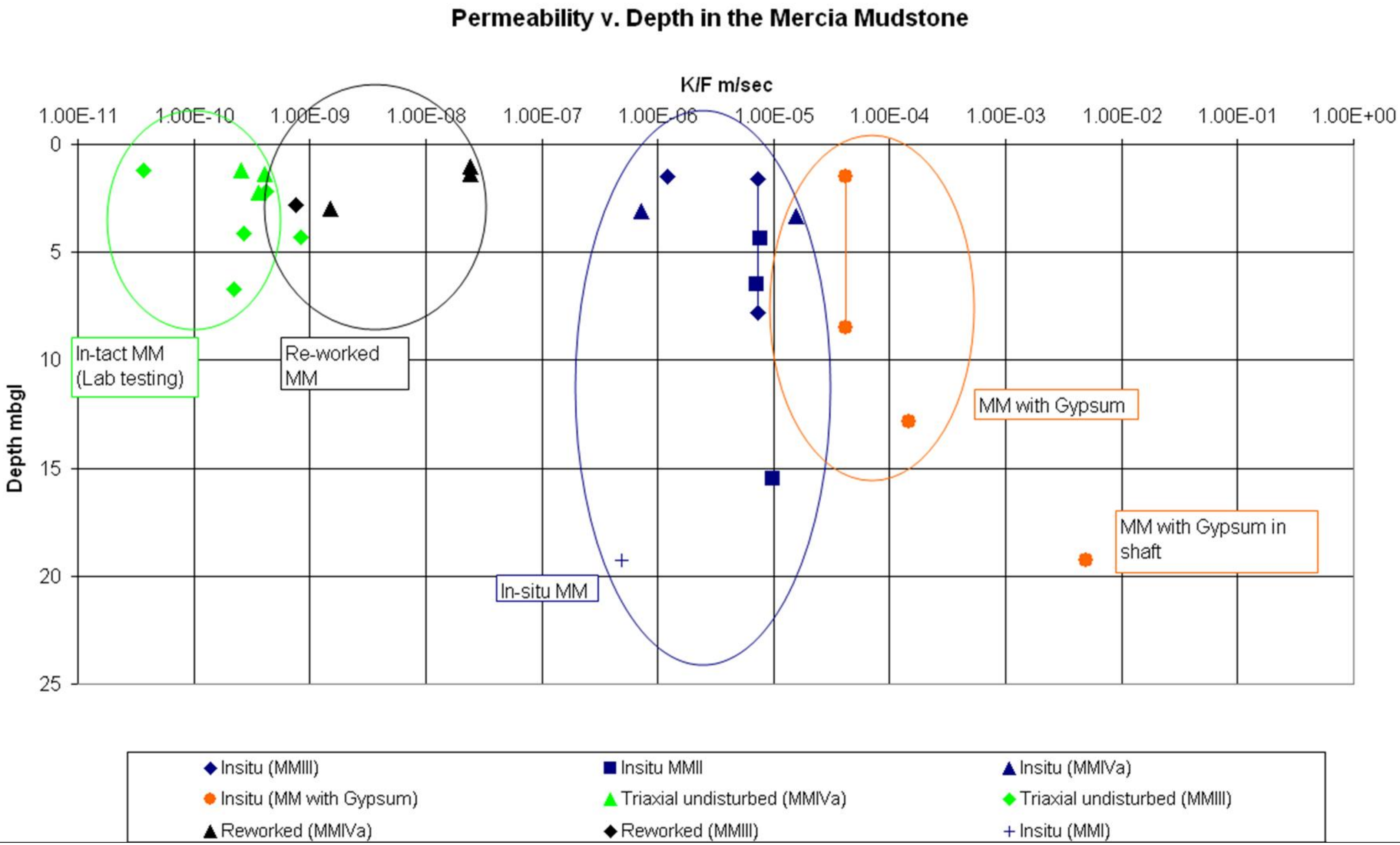


Permeability v. Depth in the Mercia Mudstone
K/F m/sec
1.00E-11
1.00E-10
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
0
5
10
15
20
25
Depth mbgl
In-tact MM (Lab testing)
Re-worked MM
In-situ MM
MM with Gypsum
MM with Gypsum in shaft
Insitu (MMIII)
Insitu MMII
Insitu (MMIVa)
Insitu (MM with Gypsum)
Triaxial undisturbed (MMIVa)
Triaxial undisturbed (MMIII)
Reworked (MMIVa)
Reworked (MMIII)
Insitu (MMI)

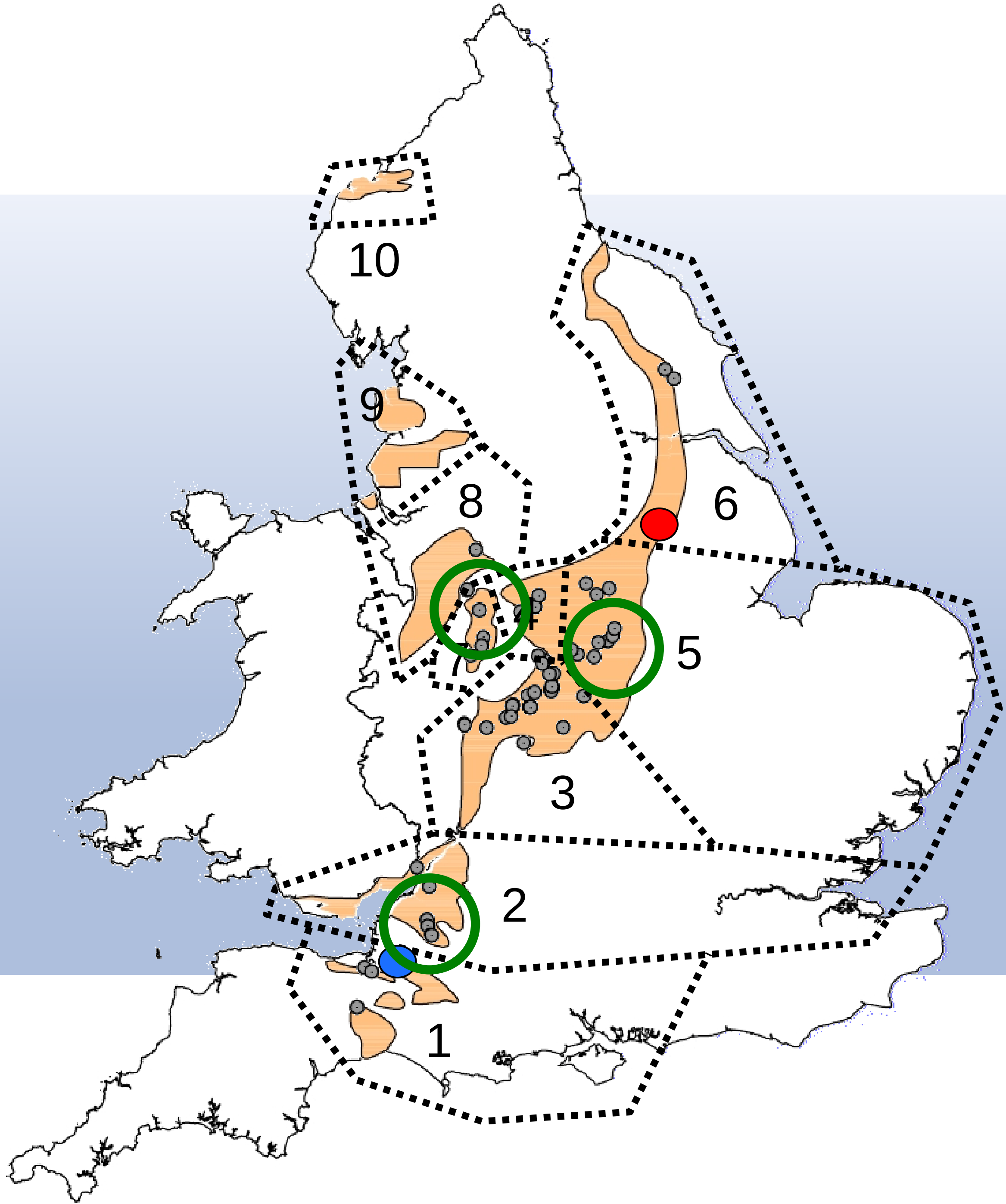
Conclusions from Site Investigations

Ideal properties for an earth-filled embankment dam

- Consistent and predictable strength — ✓ ✓ ✗
- Consistently low permeability — ✗ ✗ ✗
- Workable in bulk earthworks — ✓ ✓ ✓
- Resistant to deterioration in poor weather — ✓ ✓ ✗
- Chemically inert and non aggressive — ✓ ✗ ✗

In the light of these uncertainties, it was considered appropriate to examine previous case histories of dams on Mercia Mudstone

Dams on MM



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58 Dams identified wholly or substantially on MM strata

= Dams visited

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Dams on MM

Dam	Year Built	Primary Function	Dam Type	Height (m)	Length (m)	Capacity (m^3)
Upper Litton	1850	River Flow Compensation	Earthfill Embankment	19	120	459,100
Tardebigge	1822	Canal feeder	Gravity & Earthfill	18	460	396,640
Blithfield	1953	Public Water Supply	Earthfill Embankment	16	856	18,172,000
Cropston	1870	Public Water Supply	Gravity & Earthfill	15	600	2,528,000
Bittell Upper	1832	Canal feeder	Earthfill Embankment	15	255	1,022,400
Belvide	1833	Canal feeder	Earthfill Embankment	14	1,025	2,196,000
Leigh	1889	Public Water Supply	Gravity & Earthfill	13	300	120,000
Chew Valley Lake	1957	Public Water Supply	Earthfill Embankment	12	470	20,457,000
Thornton	1854	Public Water Supply	Gravity & Earthfill	12	500	1,320,000
Chew Magna	1850	River Flow Compensation	Gravity & Earthfill	12	98	113,650
Swithland	1894	Public Water Supply	Earthfill Embankment	11	406	2,227,540
Durleigh	1839	Public Water Supply	Gravity & Earthfill	11	430	959,000
Lawton Hall Lake	1760*	Fishing	Earthfill Embankment	11	-	127,000
Church Wilne	1971	Public Water Supply	Gravity & Earthfill	10	2,220	2,790,000
Westwood Gt Pool	1870	Landscape	Gravity & Earthfill	10	270	400,000
New Waters	1765	Landscape	Gravity & Earthfill	10	-	110,000
Washing Pool	1750*	Landscape	-	10	-	38,010
Hundred Pool	1750*	Landscape	-	10	-	27,300
Shustoke Lower	1885	Public Water Supply	Earthfill Embankment	8	1,950	1,921,000
Bittell Lower	1811	Canal feeder	Gravity & Earthfill	8	260	196,400
Lower Litton	1850	River Flow Compensation	Gravity & Earthfill	8	160	109,100
Ragley Hall Lake	1625	Landscape	Gravity & Earthfill	8	100	55,000

Chew Valley Dam, Bristol

- Bristol Water
- Constructed 1957
- Public Water Supply
- 12m high, 470m long
- Capacity 20,457,000 m3
- Clay core with concrete cut-off
- Minor leakages only

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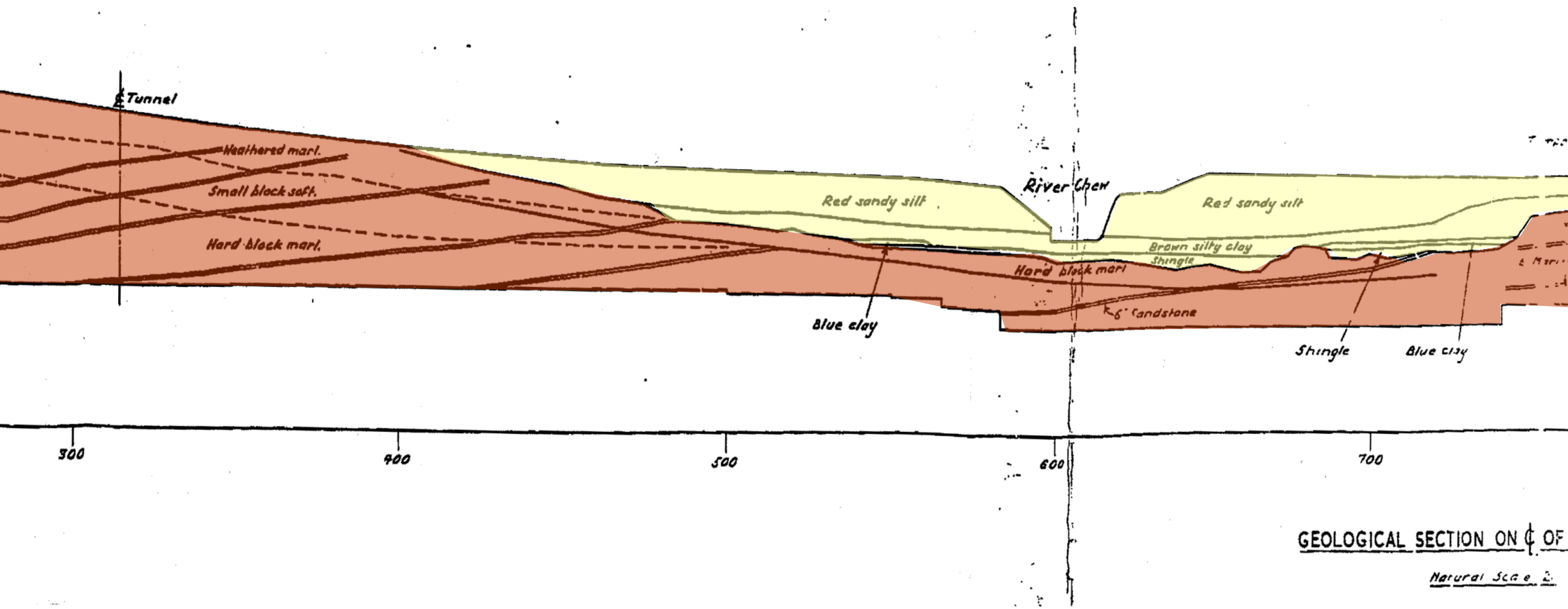
Chew Valley Dam, Bristol



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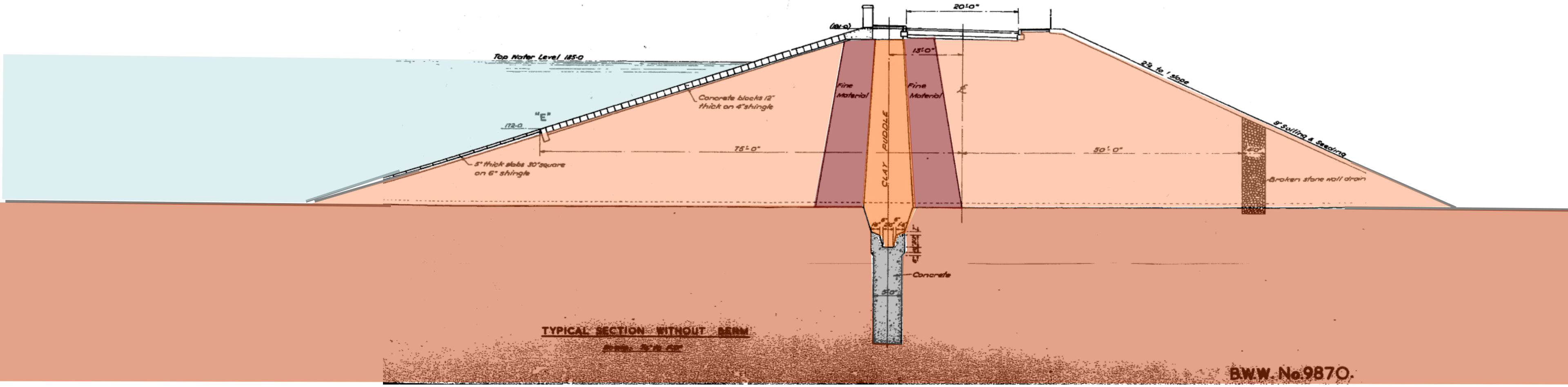
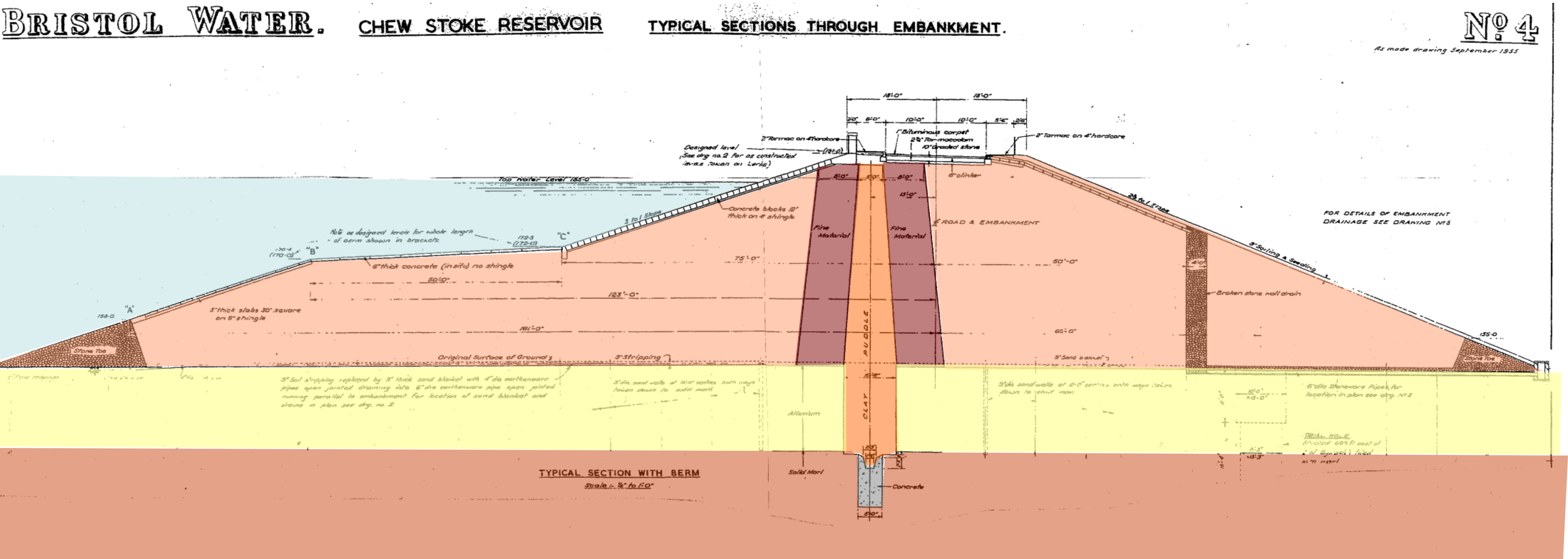
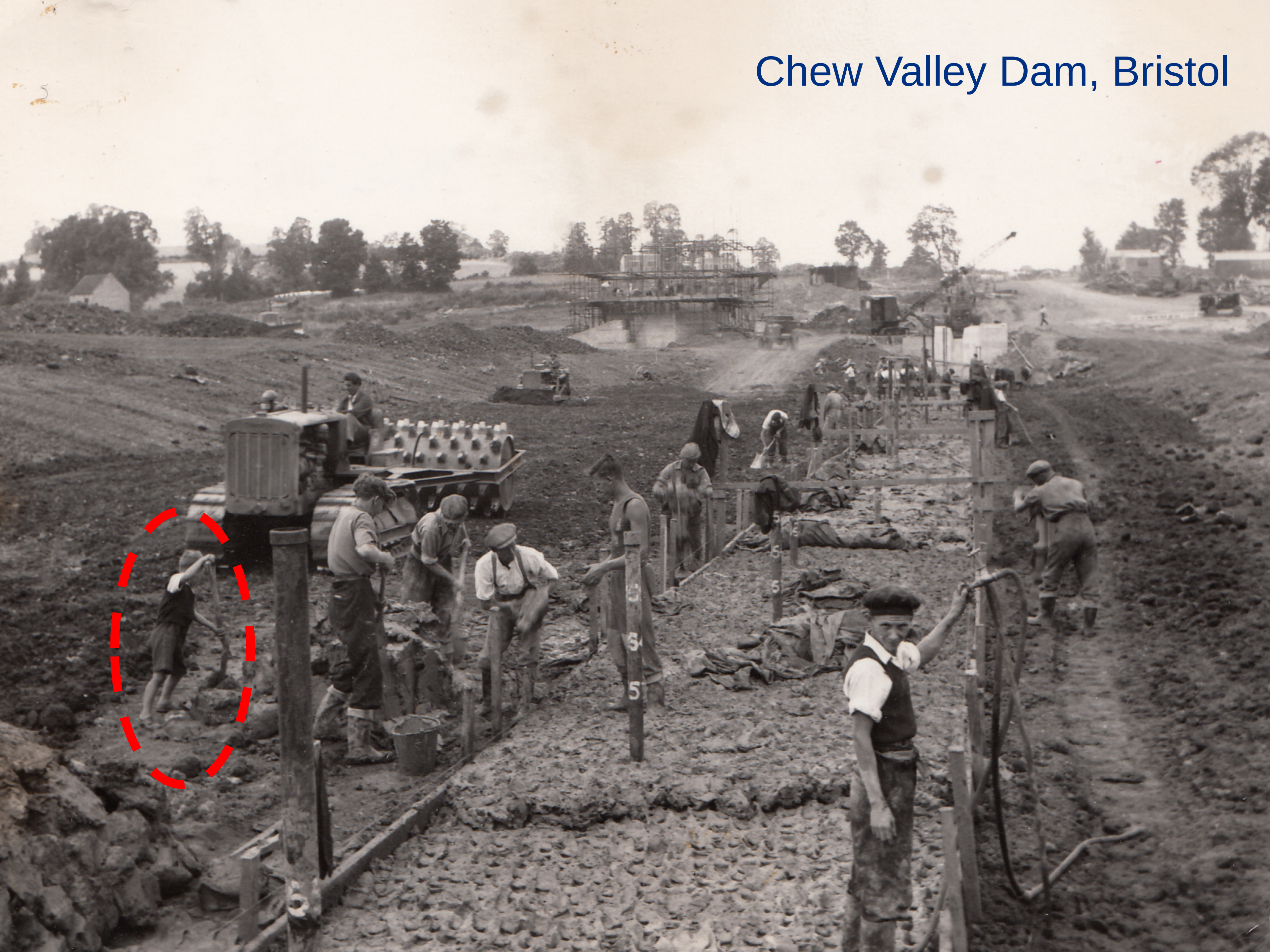
Chew Valley Dam, Bristol





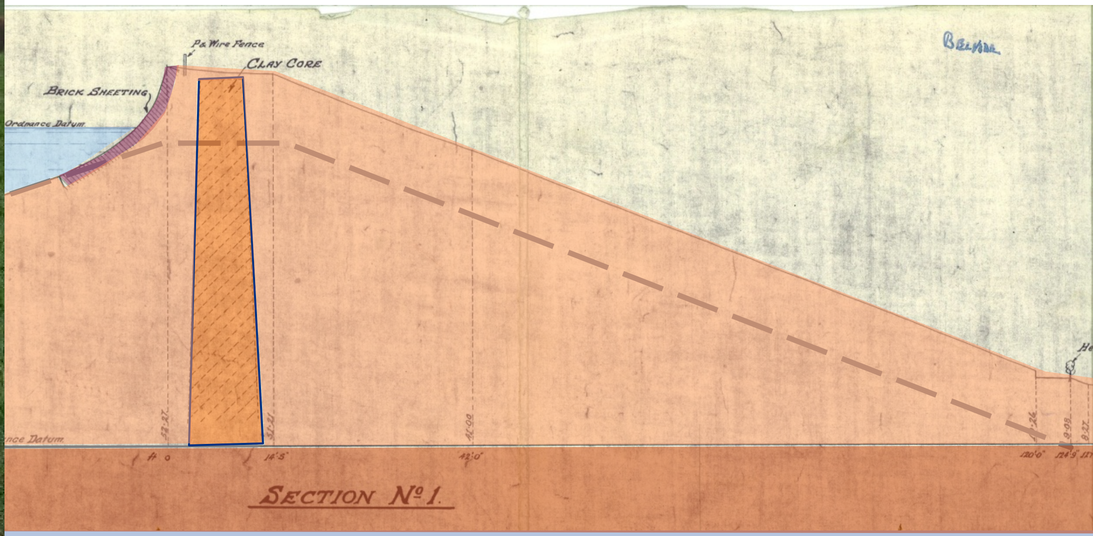
Chew Valley Dam, Bristol



Belvide Dam, Shropshire

- British Waterways
- Constructed 1833
- Canal Feeder
- 14m high, 1,025m long
- Capacity 2,196,000 m3
- Clay core
- Foundation leakages around the “morass”

Belvide Dam, Shropshire



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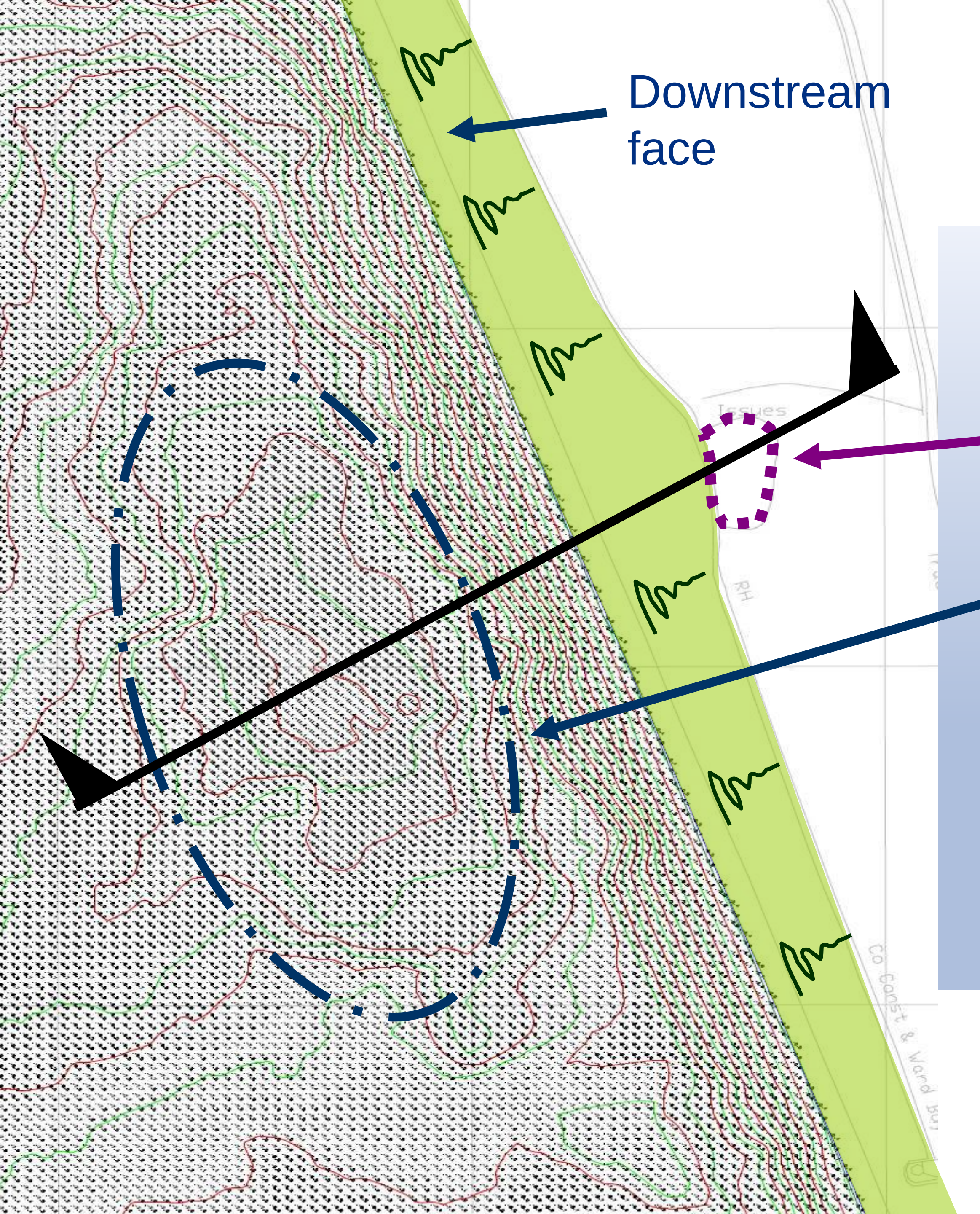
Belvide Dam, Shropshire

Hydrographic survey



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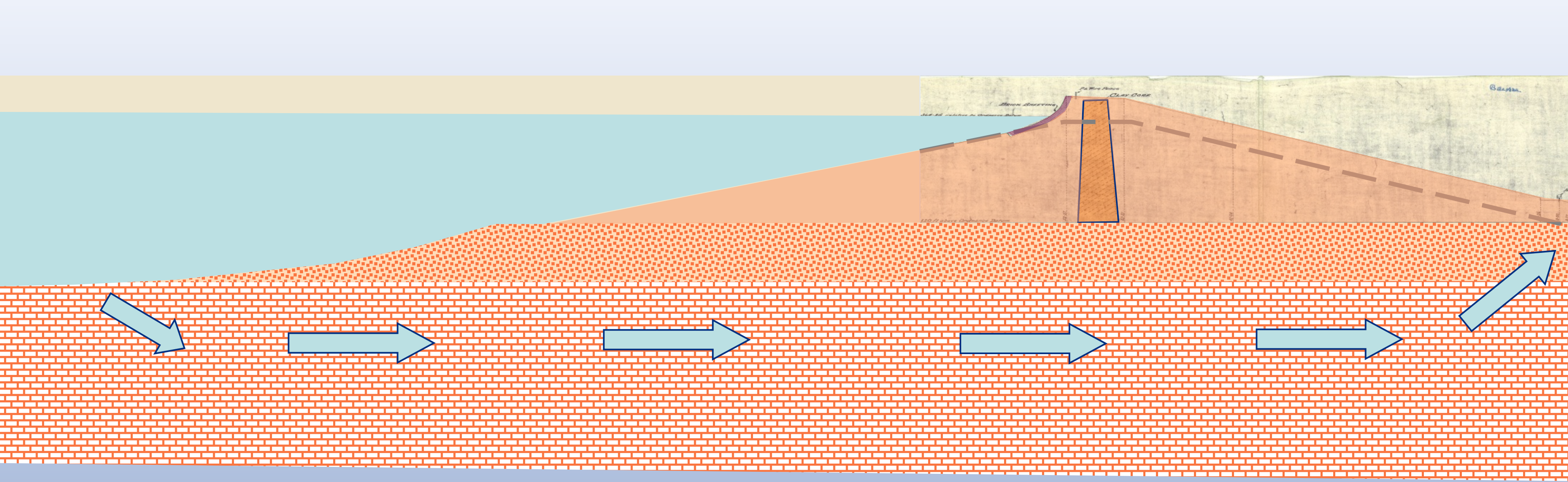
Belvide Dam, Shropshire



- More weathered (less permeable) material near surface .....
- removed by borrow pit, exposing the less weathered, more fissured and more permeable layers at depth, ...
- allowing seepage below the dam at a deeper level.

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Conclusions from Case Histories

- Dams of homogeneous construction
  - Older dams
  - Smaller dams < 10m (mostly < 7m)
  - Private ownership
  - Less information, more difficult to obtain
- Numerous dams – successful & long-lived despite poor construction techniques

Name	Date	Height (m)
Westwood Great Pool	1870	10
Ragley Hall Lake	1625	8
Gap Pool, Ranton	1800	7
Canwell Estate Reservoir	1880	7
Olton	1798	6
Ashford	1934	6
Mallory Park Large Lake	1950	5
Wollaton Park Lake	1800	5
Broadwater, Packington	1970	5
Middleton Hall Lake	1875	5
Kilnwick Percy Fish Pond	1784	5
Park Meadow, Packington	1600	5
Coombe Pool	1718	4
Holly Bush Lake	1700	4
Hall Pool, Packington	1751	4
Groby Pool	1900	3
Londesborough Park Lake	1700	2
Sudbury Lake	1785	1

Conclusions from Case Histories

- Larger dams have puddle clay cores, suggesting leakage is a significant concern
- Many smaller ones do not, suggesting that it may be possible to form an impermeable embankment from the weathered material, which has fewer open fissures
- Belvide example seems to support the idea that fissure permeability is dominant, so that the more weathered material is less permeable

Conclusions from Case Histories

- Dam construction on MM can be successful
- No instances of slope failures, inadequate strength, excessive settlement due to MM
- No instances of dissolution failure or water quality issues due to presence of sulphate minerals
- Several instances of leakage

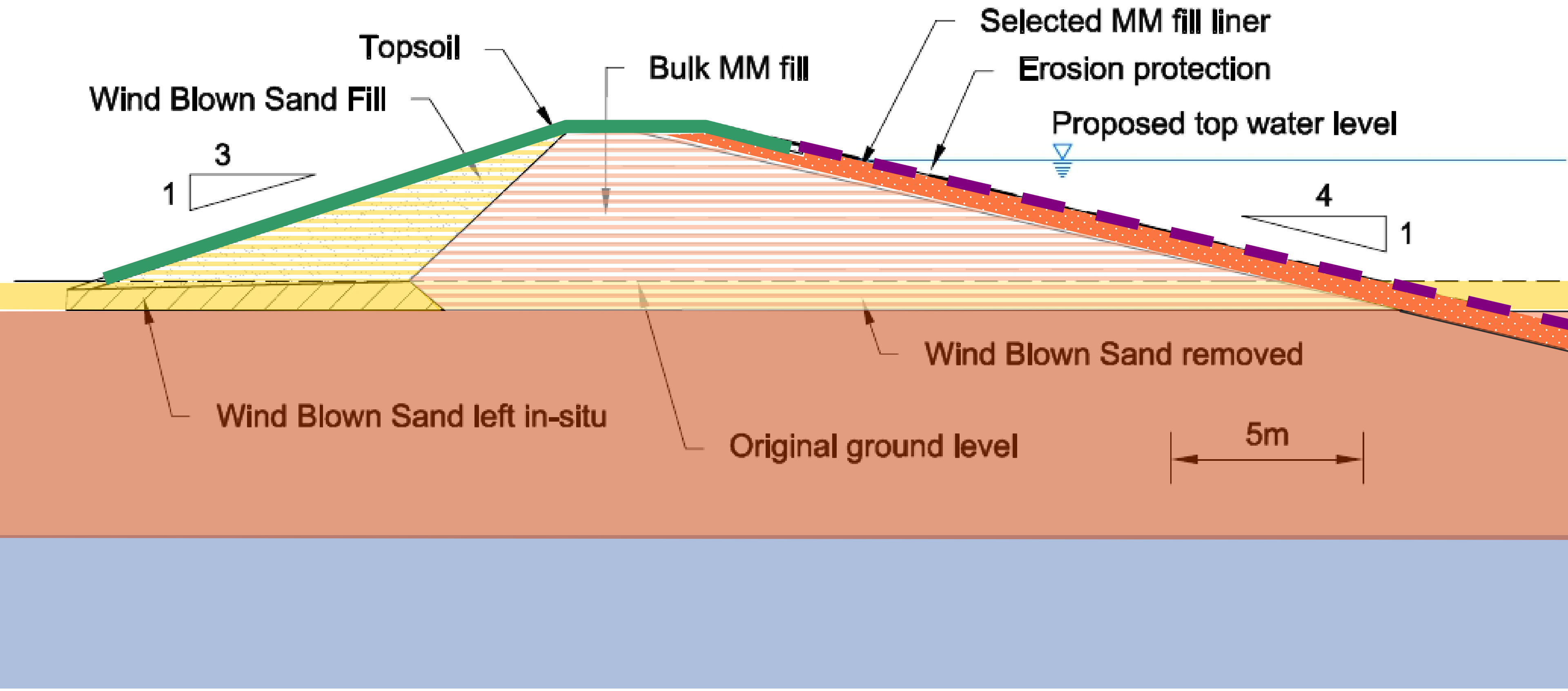
Importance of Compaction

"The permeability of in-situ clays and soft mudrocks is strongly affected by slightly open fissures. These are difficult to discover from site investigation as the permeability of the parent intact material is very low." ...

"It is difficult to prove the absence of open fissures and low bulk permeability. However, field experience is that when these materials are placed as fills using modern plant, a uniform low permeability results."

The effect of compaction on bulk permeability of stiff clay and mudrock – field experience from embankment dams, by Vaughan, P.R., et al. – 5th ICEG Conf on Environmental Geotechnics, 2006

Lincoln Raw Water Reservoir



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Lincoln RWR – Compaction Trials

Earthworks trial: June 2012

Topsoil stripped

Borrow area selection

Compaction properties

Strength

Permeability

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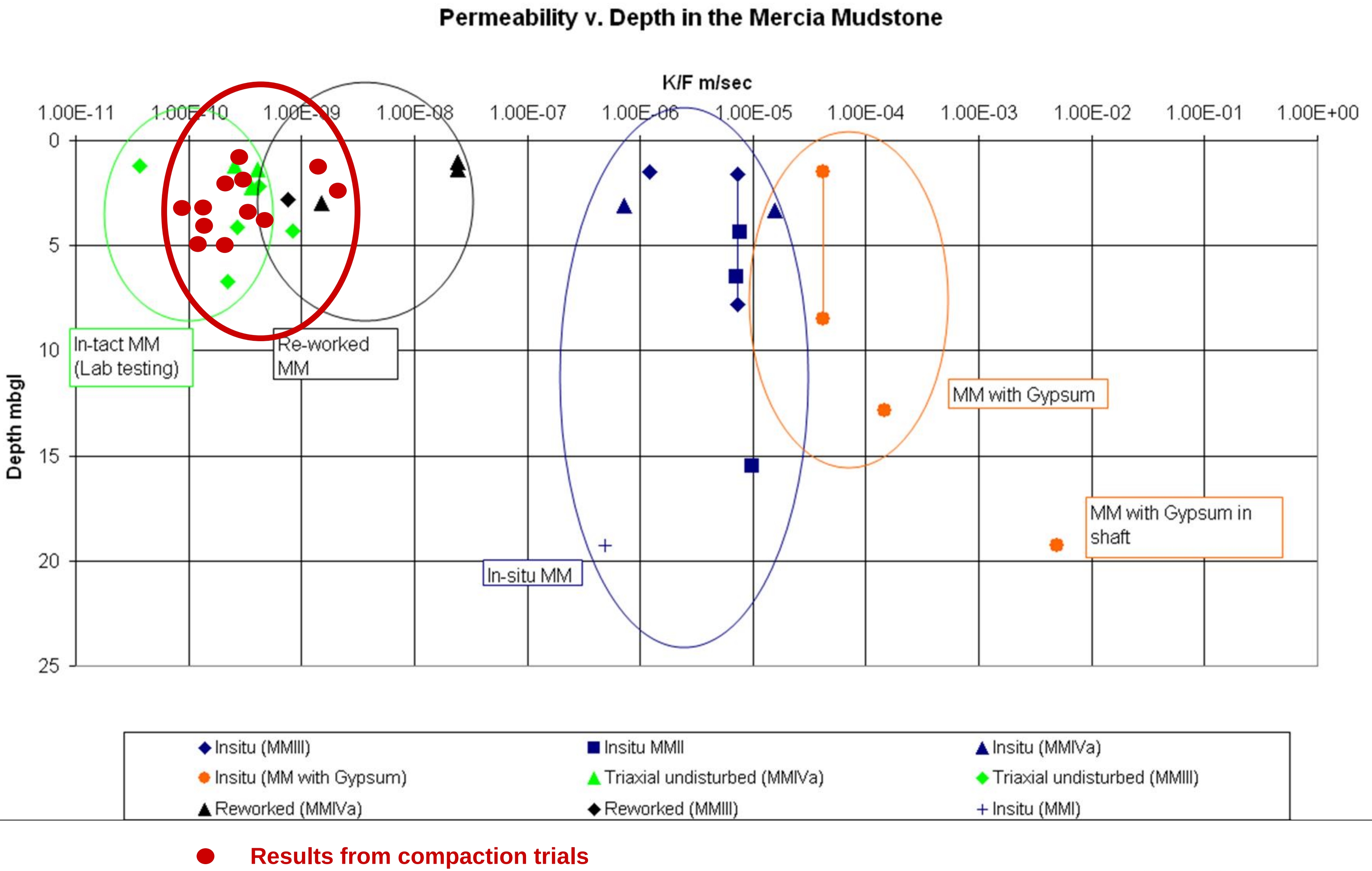

Embankment Dams on Mercia Mudstone

Lincoln WTW – Topsoil and sand strip

Lincoln WTW – Plant

Lincoln WTW – Compaction on RWR site

July 2012

January 2013

July 2013

August 2013

October 2013

October 2013

November 2013 - Commissioning

2nd March 2015

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Cheddar Reservoir 2 – MM involvement

Coxon Report (1986)

- Independent Review
- Knowledge sharing

Special thanks to ....

Anglian Water	-	Lincoln Project Case
Bristol Water	-	Cheddar Reservoir
British Waterways	-	David Brown
Severn Trent Water	-	Ian Hope
Environment Agency	-	data on dams
GTM	-	project partners
Site Team	-	Laura Jarvis
Arup	-	Saeed & colleagues