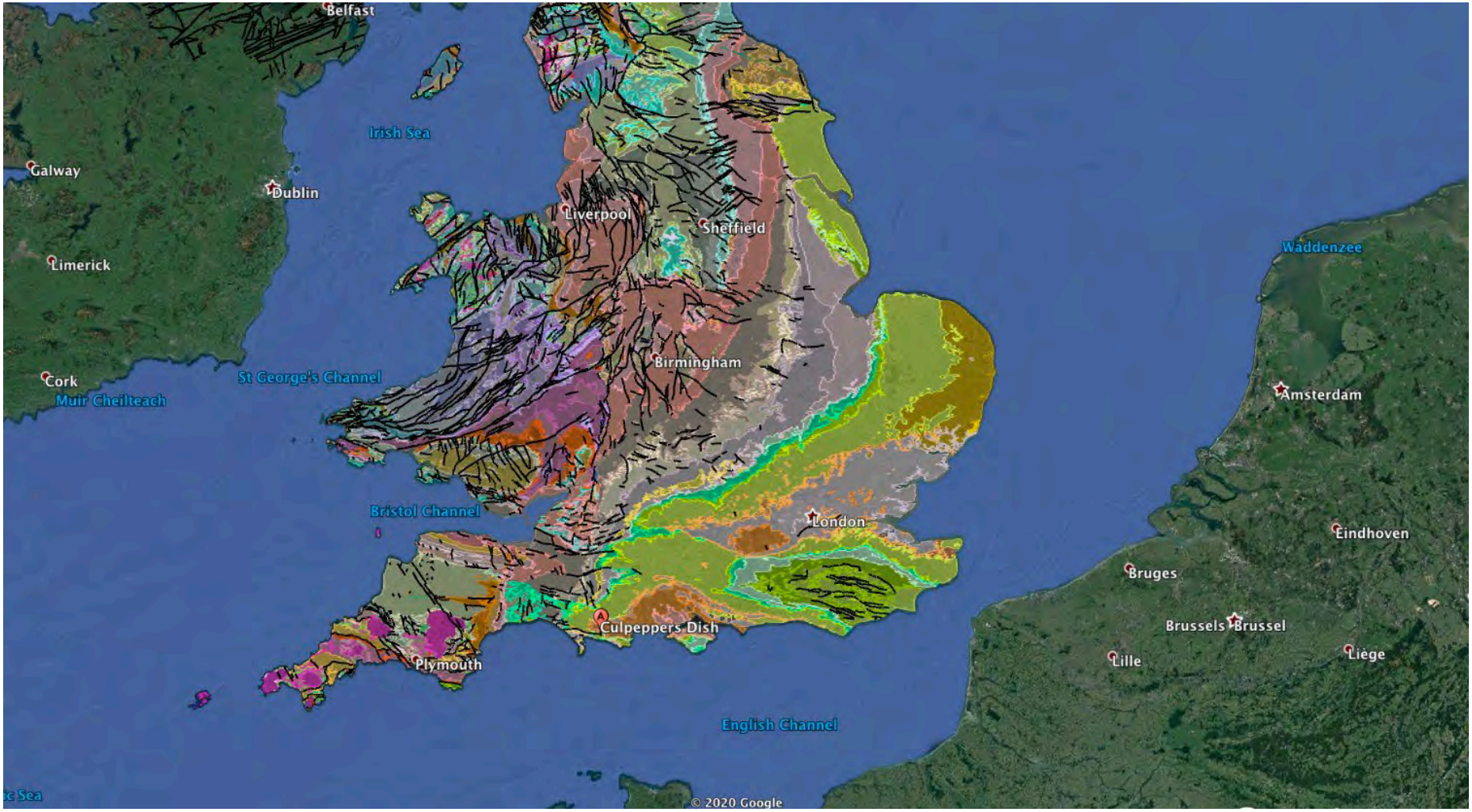
The Chalk and Jurassic Carbonates of England: Karst or Not? – Does it Matter?

Gareth J. Davies
Stephen R. H. Worthington

Field Visits to Public Supply Wells, Springs, and other Features

- Steve Worthington and myself, (1994, 2003)
- The Chalk is one of the two major aquifers of the UK supplying e.g., one third of the City of London and its suburbs, as well as many other areas to the southwest and as far north as Yorkshire.
- The other aquifer is that of the Jurassic Carbonates mostly in the Thames Valley (west of London), but also in the same way to the northeast also.
- These areas are all supplied mostly using wells that pump water that is then piped to water-utility facilities around and about where it is cleaned and distributed
- Wales, Scotland utilizes surface reservoirs almost exclusively – very few wells, except for research
- In 1994 we visited both the South of England, (Jurassic and Chalk) and Wales (classical karst and caves) – where in one cave we did some of the fastest tracer tests ever done (~1 m/s)
- We also developed the basis for papers on the proportions of groundwater flowing in conduits, fractures and the matrix in carbonates in general….including in traditionally non-karstic rocks

Britain, Chalk (green), Jurassic (grey/tan)



Mainly south central, eastern-northern England. The major water supply aquifers of England. Rocks get older to the west, Precambrian in West Wales, Paleogene – Quaternary south east.

The Chalk

- The UK Chalk (Cretaceous, 145.5 – 65.5 Ma) is mostly a pelagic carbonate with some marl layers, nodules of flint, and iron (marcasite) balls
- Northwest Europe in the Late Cretaceous and Early Cenozoic was influenced by the opening of the North Atlantic and the onset of the collision of Africa and Europe (Ziegler, 1981)
- It should be noted by Ager (1980) that the North Sea structures record:
  "The British Isles hesitated for a long time whether to depart from North America or Europe."
- The geologic record shows that Britain firmly stayed in Europe, 60 million years before Boris Johnson decided to change that
- Between Britain and Europe (North Sea Basin) is the Triassic – Cretaceous north-south rift system and the Viking and Central Grabens
- During the Late Cretaceous the area was a passive continental margin still with regional-scale subsidence.
- From this the Chalk pelagic sediments filled the Central Graben
- Thereafter the Paris Basin and Danish-Polish Troughs filled

Steve Worthington in a small quarry in the Chalk

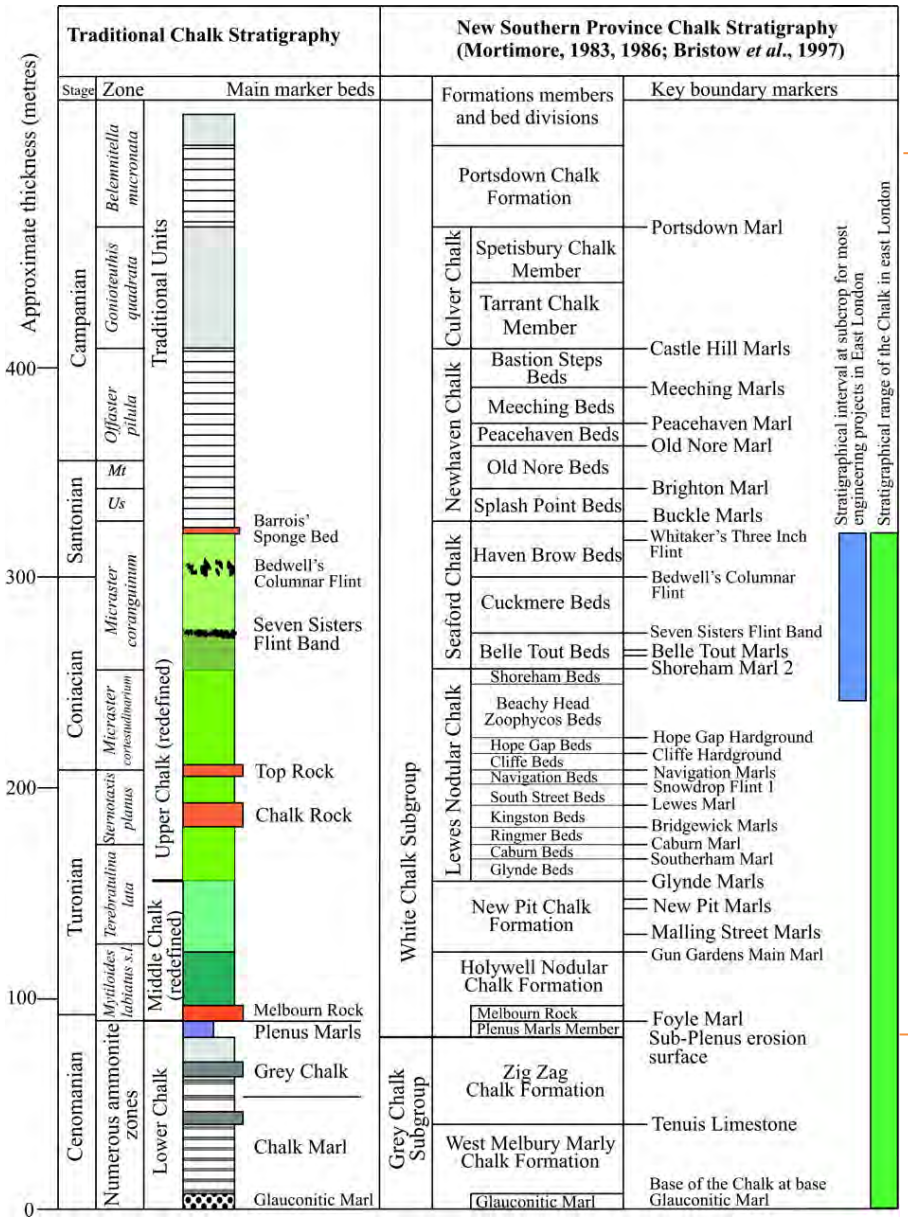
Chalk Landscape

- Chalk Escarpment
- Dolines - quite prolific – Puddletown Heath, Dorset (200 km Southwest of London) (157 / 100 km^2) - highest density
- Chalk Downs (actually hills, ridges) from old English, “Duns”

The Downs, in the Weald Area

Dry valley, in the Weald Area

The Chalk



Kilham, Yorkshire Wolds

White Chalk

Beachy Head Cave, St Margaret's Cave, Water End, Mimmshall Brook Swallow Holes Chadwell Spring

Uffington White Horse,

Grey Chalk

The Jurassic

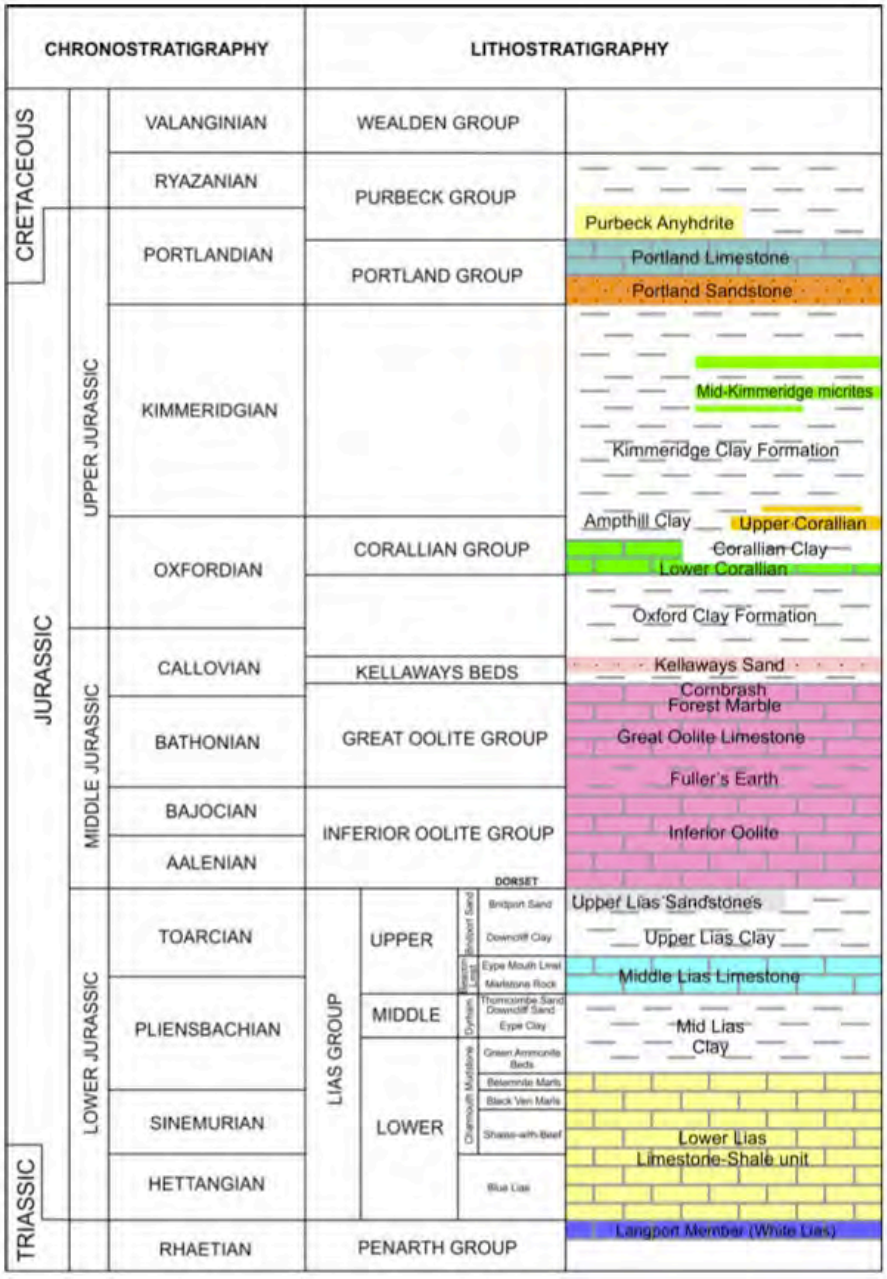
- (Middle Jurassic)–
- Great Oolite, White Limestone, Cornbrash, Forest Marble (the latter often a mudstone with shelly limestones), Inferior Oolite Group, others, Bath Oolite, Comb Down Oolite, Athelstan Oolite (if you like oolites….)
- As well there are interbedded Estuarian Limestones, clay and channel sands, also lagoonal, deltaic, sediments that have generally formed in a near shore, shallow inner shelf environment
- The aquifer surface: lots of sinks, springs. Boreholes used for aquifer research, to enhance production from abstraction wells for supplies to pumping stations – same methods as in the Chalk.

Alexander Klimchouk in a Quarry in the Great Oolite NW of Oxford

Jurassic Landscape

Escarpments are the common landscape feature in the Jurassic, the scourge of Brunel's Great Western Railway (1833-1947) from London to Bristol and the West of England and the gradients over these hills, or through them – via a (1 in 100 grade) to and through Box Tunnel, which at one time was the longest in the world. Brunel's dream was to go from London – New York – by steam - train and then via steam ships from Bristol

Jurassic



Sinks,
springs,

Inferior Oolite, Leckhampton Hill

View from Leckhampton Hill (escarpment)

Springs in the Jurassic Landscape

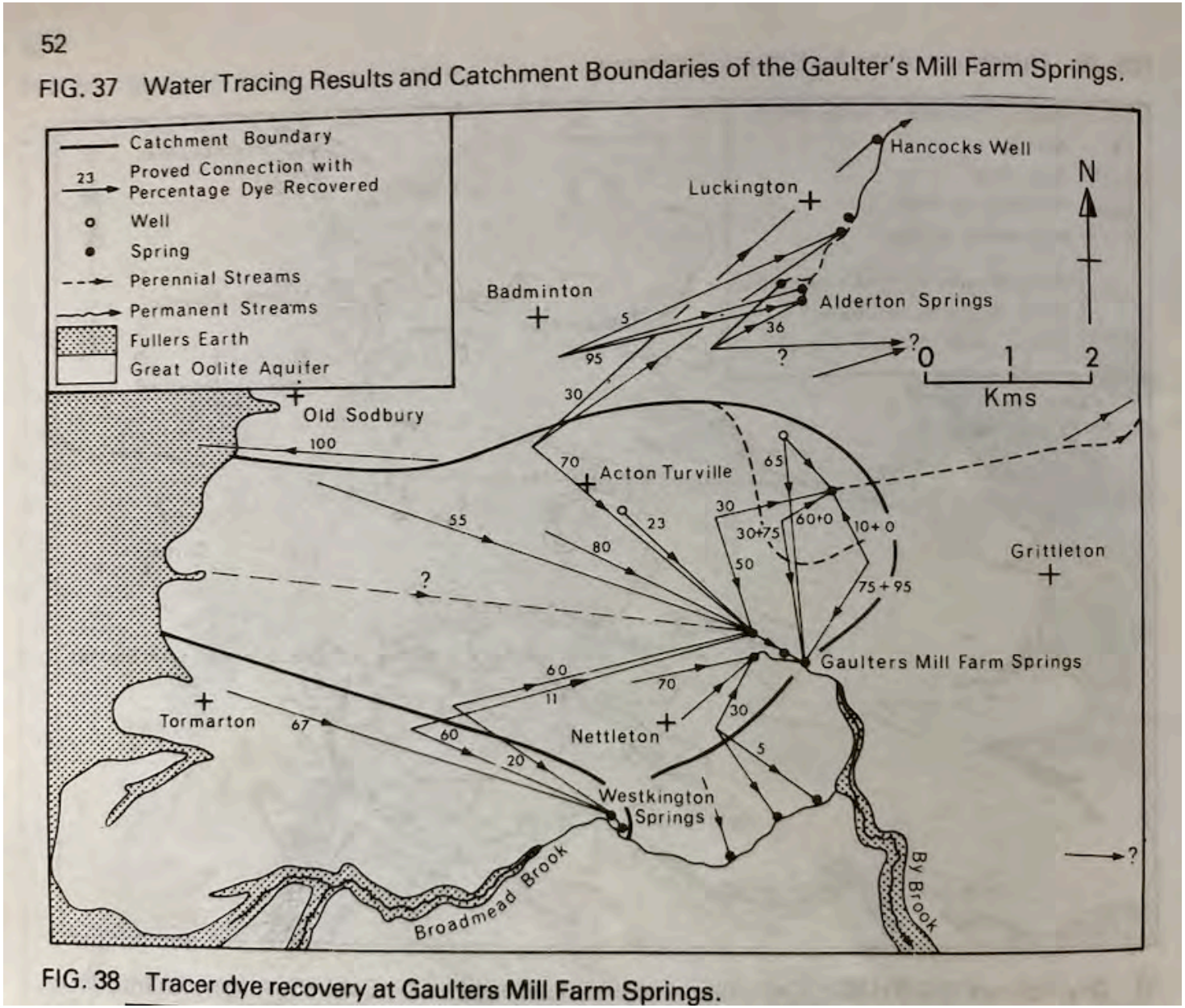
Gaulter's Mill Spring (above)
Many streams (spring-fed) are gauged

There is a bigger emphasis on boreholes or wells and both Great Oolite and the Inferior Oolite are penetrated by many abstraction boreholes. Tracing and other hydraulic tests have been done.

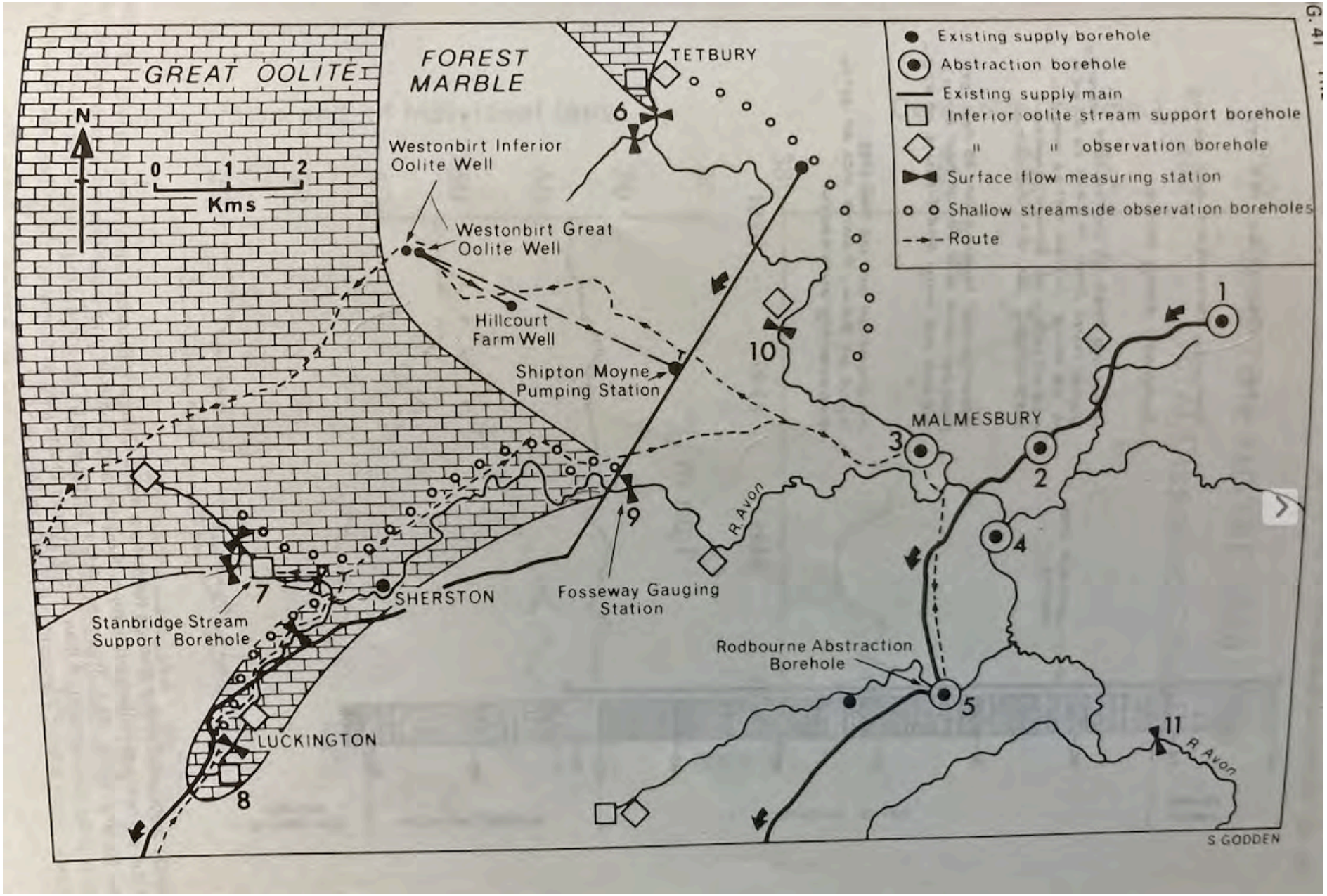
The Fosse Way is a Roman Road, built around 45 AD by the Roman General Vespasian and his legions. It passes northeastwards across southern Britain from Exeter to Lincoln (370 km).

Fosse Way Gauging Station

Jurassic Aquifer Tracing (Atkinson and Smart, 1977)



Boreholes, Pumping Stations, Stream Guages



Traced velocities and other data (Atkinson and Smart, 1977)

- Peak travel times (injected dyes) Cotswolds, Great Oolite, 12-58 mm/s, 1,032 – 5,011 m/day, sinkholes – springs (therefore conduits)
- From Chestnut Farm Well, tracing results calculated travel times ~ 500 times faster than calculated from well data
- Lots of dispersion on some traces – with long tails on breakthough curves, although time to peak concentration is typically rapid…
- Most traces > 3 km, about 20 tests

So, a question emerges ….

- The Chalk/Jurassic carbonates are today, subaerially-exposed
- There are numerous published investigations that show the Chalk to be a typical subaerially-exposed carbonate with typical “karstic” properties
- The largest spring in Britain is in the Chalk (Arish Mell) (~1 m^3/s) known and used since Anglo-Saxon times (from about 450 – 1066).
- Most have not visited it, probably because it is on a beach surrounded by up to 200 m high cliffs, and adjacent to a British Army tank firing range (that is closed but for a few weekends a year); no road within ~3 km
- These days it is not very impressive because pumping up the basin/ valley has reduced the discharge
- So the question is: should the Chalk, with all the characteristics, be considered karstic?
- The same question is posed for the Jurassic carbonates….,

And then a sort of meeting of minds…

- Oxford University, 1994, St. Hugh's College – School of Geography and Environment – Conference Changing Karst Environments (in Majorie Sweetings' teaching room)
- Richard A. Downing (Chief Hydrogeologist, British Geological Survey), Michael Price, Hydrogeology Professor, Reading University
- Issue: Having seen Mike Price's slides of huge natural groundwater discharges into Roman Tunnels dug beneath London, I foolishly asked Mike Price if the Chalk is considered karstic?
- He responded with, "…of course not, karst is geomorphology, I speak only about hydrogeology…"
- Dick Downing's talk was next, where Steve asked, (referring to the Chalk and Jurassic), had anyone studied springs?
- Dick Downing's response: "we believe professionals study wells, and only amateurs study springs"…
- Following was my talk (about springs,) and Steve's (more about springs) where we received no comments or questions….
- However, that afternoon, in true Oxford style, an informal, and rather splendid wine and cheese reception, and get to know each other unwind , where…
- To their credit, Downing and Price both profusely apologized to Steve and I….they had no idea….
- Next day, a field trip… and we saw lots of springs and sinking streams….but not pointed out by the field trip leaders (of course they are geomorphologists…), glad we visited them ourselves….before we got to Oxford....

The Field Trip…

- To Bourton-on-the-Water, (Cotswolds, Jurassic) buildings are constructed of the Jurassic Carbonates and everybody drives Range Rovers pulling horse boxes…. Normal Thames Valley stuff….
- Thence to Wallingford, (Thames Valley, Grey Chalk) and more springs and a BGS Land Rover with a camera down a 50 m borehole …showing a 15 cm fissure in the subsurface… also, sinkholes everywhere filled with farmers trash… it now felt quite "normal"
- The field trip started to become more and more like one in a karst setting without acknowledgement of it being….
- Springs were everywhere – nobody talked karst, Steve and I remained pensive
- We travelled further west and ate lunch at White Horse Hill, Uffington (Chalk)
- So, it appeared that Oxford University, with (Majorie Sweeting, Andrew Goudie, Heather Viles, Peter Bull) acknowledged the geomorphology ….
- It was Peter Smart (Bristol University) and Tim Atkinson (University of East Anglia) who had done all the work on tracing and such…

Chalk Landscape as viewed from Uffington Hill

Uffington White Horse carving ~ 3,000 y B.P., trenches dug and filled with crushed White Chalk rock, a wonderful packed lunch here…

The Cotswold Hills, Jurassic Carbonates (we visited before and after the conference)

- Steve, Alexander (Sasha) Klimchouk who was on the team that explored Krubera Cave, >2,200 m deep, Causcuses, Abkazia) and I filled in later with visits to quarries, and a few sinking streams and springs
- The Jurassic has mostly been studied by Peter Smart (Univ. of Bristol) and Tim Atkinson (Univ. of East Anglia) and we visited many of these features
- In the Jurassic and Chalk, they have completed traces from sinking streams and springs, from and to boreholes, most with rapid travel times
- A few traces with bacteria too, because pathogenic pollution is becoming a problem, and was misunderstood, because of ^{3}H in groundwater interpretations suggesting otherwise, but the ^{3}H is retarded at the water table so does not behave conservatively
- So, the Oxford University trip was mostly geomorphology, and drove past many sites that would have been very informative from the hydrogeology – but we had visited anyway….
- After the Oxford meeting, the second part was at the University of Huddersfield and was in the Yorkshire Dales Karst (real karst?...). Steve and I went to Wales and sitting in a dry conduit, we conjured up more mischief about flow proportions in the matrix, fractures and conduits…

Jurassic: Dry Valley

Water Supplies

- The Chalk
- The Jurassic carbonates
- Via abstraction boreholes, (often pumping to manufactured surface channels and pumping stations)
- Then through filtration to the storage and distributed to domestic and industrial supplies –
- Huge supplies to the City of London (and suburbs), other towns and cities
- So, anything that happens in the area of these carbonates can drastically affect the water supply
- Many main highways and railway lines pass through the area
- Not a vast amount of heavy industry today, (except building Formula 1 racing cars, Williams, McLaren) previously and now rail – Great Western Railway, but still a vulnerable setting
- All over there are sinking streams and springs, sinkholes, dry valleys, - but no caves, - so, not considered karst (by geomorphologists)…
- Later ModFlow was used to delineate capture zones, strongly contrasting with tracing results, most demonstrably incorrect in direction and flow velocity
- Academia: lots of work on better modeling, and profiling of boreholes, conventional hydrogeology (porous medium based), and geomorphology
- But, it appears things are improving… wine and cheese is influential….

Shipton Moyne Pumping Station

Has borehole penetrating both the Great and Inferior Oolites (dates from 1914 – 1933) and traces have been done to this well from the WNW from farm wells,
The initial pumping rate was 100 l/s, but was reduced to 78 l/s to reduce drawdown (Atkinson and Smart, 1977)

Swallet, Littleton Drew

The tracing done by Pete Smart, Tim Atkinson and students, they have traced over distances of several kilometers with velocities of > 100 m/day

Water Abstraction Numbers (Atkinson and Smart, 1977)

- Great Oolite Abstraction Boreholes: ~35 Ml/day (8 Mgal/day)
- Recharge about ~150 Ml/day
- Continuous Safe Reliable Yield of ~100 Ml/day
- Wells are pumped in a sequence so water levels are maintained and no one well is stressed during maximum use
- Estimated storage capacity of the Great Oolite is ~240,000 Ml

The Chalk

- Another major supply to London and its suburbs
- Covers a larger portion of the UK
- A major aquifer supplying water to many small towns and communities in the N and S of England
- Again, a network of abstraction boreholes and pumping stations
- The research work on the Chalk is similar to the Jurassic but also consists of modeling by the UK Environment Agency and tracing by water authorities and more recently some academic institutions – but most official work only using porous medium concepts
- The Chalk groundwater quality: < 100 µS/cm to a depth of -240m (in the Stoborough Borehole, Dorset, 9.5 km NE of Arish Mell Spring – largest spring in the Chalk and UK….)
- Obviously some clear signals about the nature of things
- So, the Chalk is a normal carbonate aquifer….. sinkholes, springs, rapid flow, etc.

The most civilized of Field Trip stops… Avebury Henge + Village (…and an excellent Pub.), on White Chalk

420 m diameter
(largest henge known)

2.5 m Sarsen boulder at Avebury

So, Neolithic people probably used springs, and why not, they are abundant…..

Silbury Hill (Burial Mound)

Sarsen boulders form the main ring of Stonehenge

Neolithic, 2400 – 2300 BC, 130 m diameter, 30 m high

”Kerb” stones of Sarsen Boulders (sandstone) also erected as “heel” stones at Stonehenge (right), (Neogene to Quaternary weathering by the silicification of Upper Paleocene, Lambeth Group sediments)

Stonehenge (on White Chalk)

3000 -2620 BC, stone ring 34 m diameter, Sarsen Stones (outer ring) nearby, and, Bluestones (inner ring) from Pembrokeshire, West Wales, about 230 km away. Bluestones are diabase (dolerite) (microgabbro), and they appear to have been deliberately transported from 230 km away….

The Worthington Plan….

- Before the 1994 Oxford Conference, Steve and I had followed via Peter Smart's (Univ. of Bristol) guide book (a previous International Congress of Speleology) on the sinks and springs, mostly in the Jurassic
- But, unfortunately we did not visit any of these in the field trip in 1994
- So, the Oxford field trip was a little bit lacking in what we could have seen
- However, we did see the landscape and this later led Steve and I to plan a return – which we did in 2003
- On that trip we wanted to go much further than southern England, and see the organization of water resource use – as now was the onset of modeling and other work to protect these aquifers
- Between 1994 and 2003 several PhDs and MS theses had been done and we planned to visit these locations as well as travel across to Wales and look at that karst – as well as visit my relatives of course…

(Even more work has now been done, and things are improving)

So, with the “diplomatic” issues of 1994 resolved….

- In 2003, we came back, to visit other areas of the Chalk
- This time we travelled north to East Yorkshire, an area called the Wolds
- Here we were on/in an aquifer in the younger White Chalk again (White Cliffs of Dover rock)
- A PhD thesis had been done by Rob Ward (who was now head of the UK Environment Agency)
- His work centered on the public water supply to the village/small town of Kilham
- There are some historic villages (some that may date to 500 AD (Vikings landed here) – borders on the North Sea – a “riviera” for the industrial north east of England
- South of the Cathedral City of Durham and Sunderland and Newcastle Upon Tyne- both of ship building fame….(and near the birthplace of Anita Hill...)
- Not far from the setting of “All Creatures Great and Small” the Yorkshire vet (Alf Whyte, [aka James Heriott])

Kilham, Yorkshire Wolds

A gently rolling upland area. Tracer tests done to test various numerical models used for simulation of protection zones. Injected tracers used from boreholes and sinkholes – collapses (often called pits here) to springs and observation wells (Ward et al., 2000) – again there is a stark contrast between the results of numerical modeling and injected tracing

A Classic Yorkshire Wolds Lunch – Fish and Chips and Best Yorkshire Bitter

Geological explanation: I am using the map to confirm the “terroir” of the beer

Swaythorpe Medieval Village (a Dug Well)

Village is along tree line in left center of picture on the other side of the field

Tancred Pit (sink)

Bellguy Springs (south of Kilham Public Water Supply well)

Modeled results vs Tracer test results (Ward et al., 2000)

- Model: velocities 28 m/day – 62 m/day
- Injected tracer velocities: 440 m/day – 480 m/day, from mostly sinkhole (pit) injections
- Modeled capture zone extends from NE to NW and a nitrate sensitive area to the W of the Kilham PWS (Public Water Supply) well
- The GW basin is a sub basin of the Driffield PWS basin generally further to the SE
- Kilham and Driffield very appealing places to move to or retire and communities expected to grow – so water use will increase.
- The tracers bypassed the Kilham PWS (no tracers recovered there) and were recovered in abundance further to the south – at Bellguy Springs ((3.8 km south) and an observation well nearby (velocities of 300 – 375 m/day)
- Flow therefore is in conduits and the Kilham PWS well does not intersect the flow in those conduits…
- Interpretation: “a complex juxtaposition of capture zones complicated by flow mechanisms dominated by fracture flow that neither of the applied models could emulate.” (= we probably don’t understand this)

Etton Wold Pumping Station, Yorkshire Chalk

....Discovery of rapid flow

Acidification of a well in this field and monitoring of another well ~100 m away led to the pH of the distant well changing in hours, revealing rapid flow in channels in the Chalk…. enlightening and surprising the researchers (Ah, that‘s why we don‘t understand this)

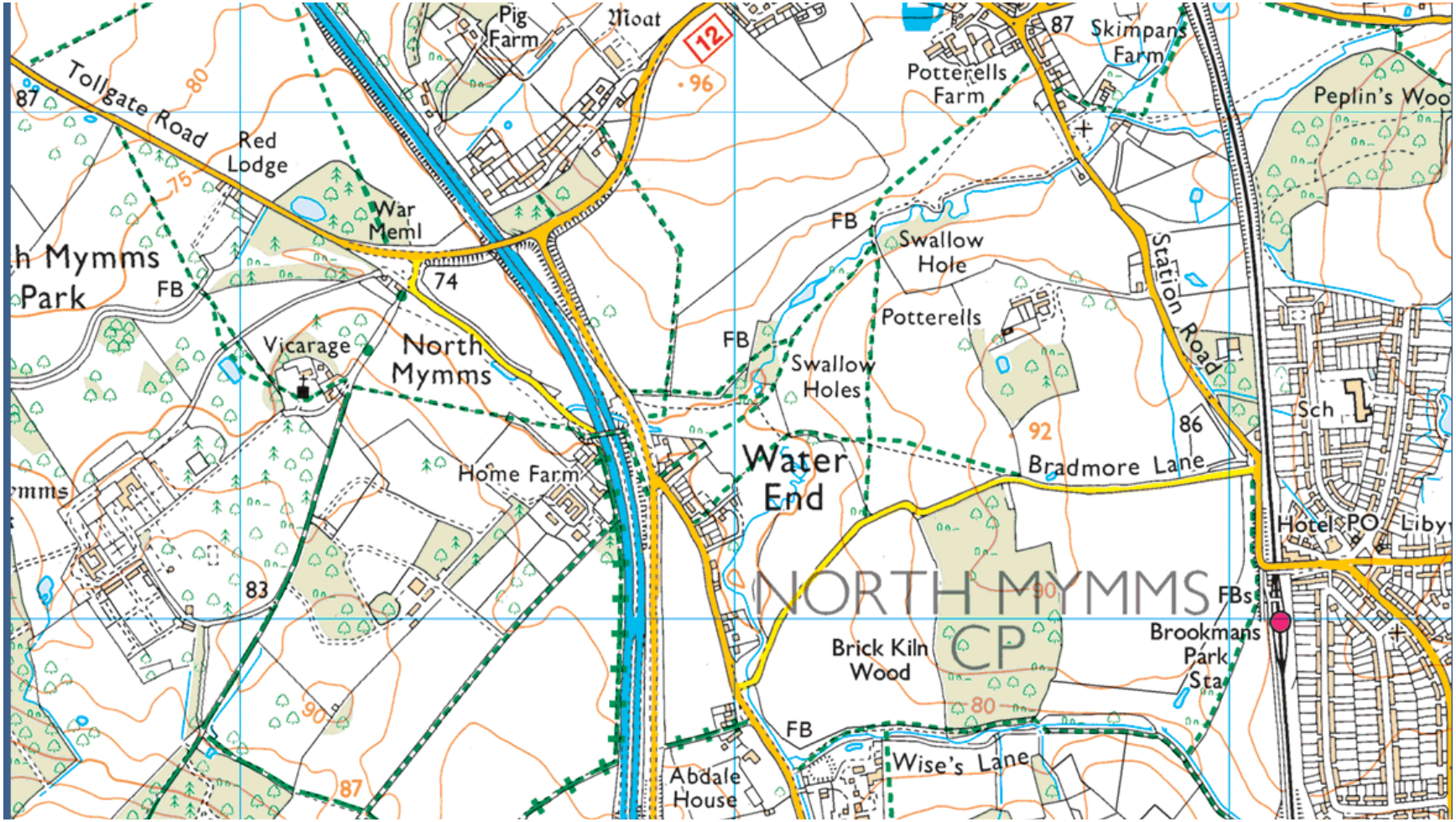
So, back to the Southern Chalk Area

- To visit a major spring supplying the City of London and the suburbs
- And, to look at small caves on the Chalk coast
- … Near the site of the Norman landings in 1066, and having to avoid high tides, spend a day at Canterbury Cathedral,
- Then to go west along the British Riviera coast of Hampshire and Dorset – lots of Chalk springs and other features….and wonderful strawberries and real clotted cream….
- Field work need not be that hard….

Broadmeads Pumping Station

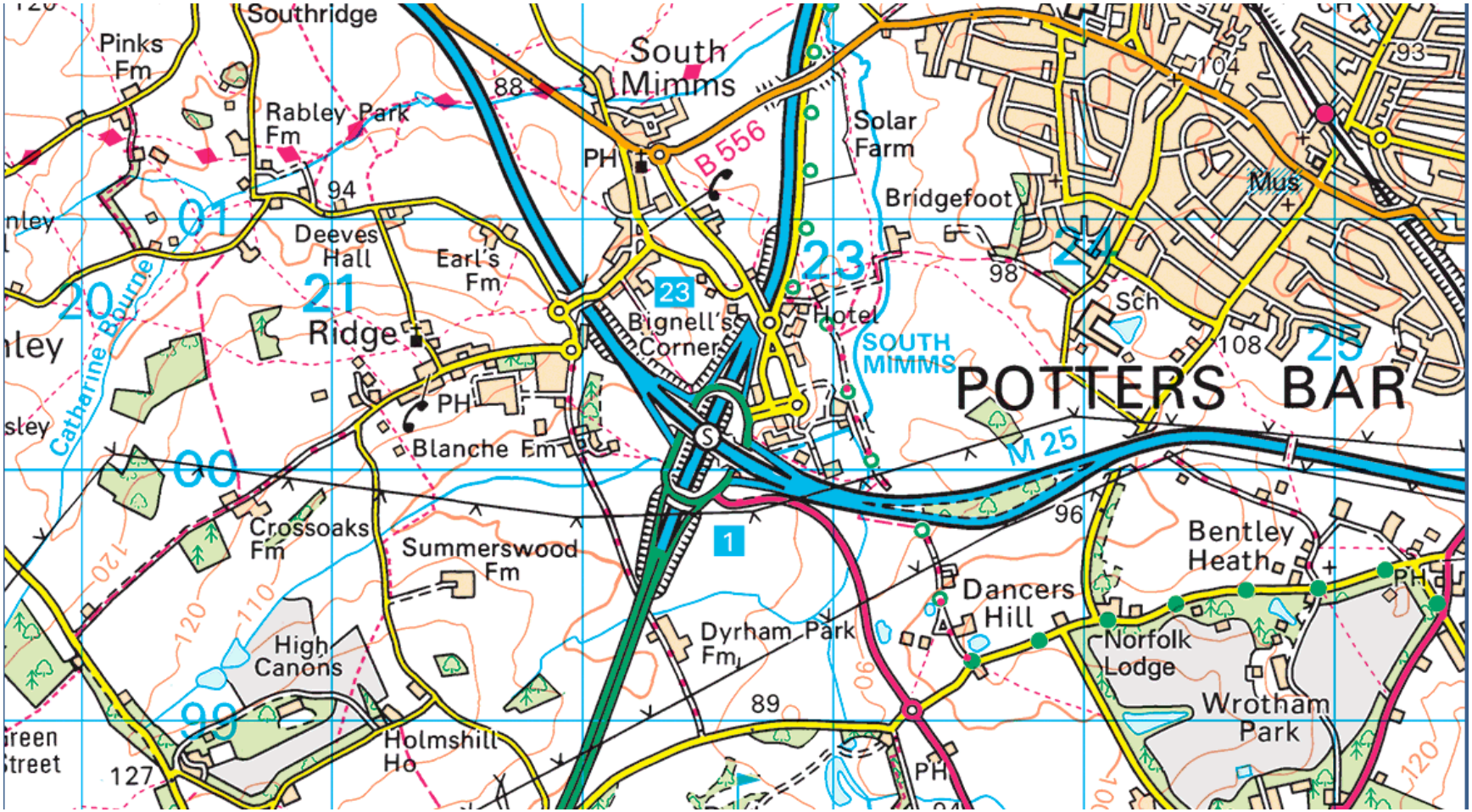
North of London and amongst a spaghetti of the busiest highways there

Water End – Swallow Holes



~30 km NW of Central London

“Soak Away” [a drain for rain water run off] (here a former sinkhole…) on the A1 (M) Motorway



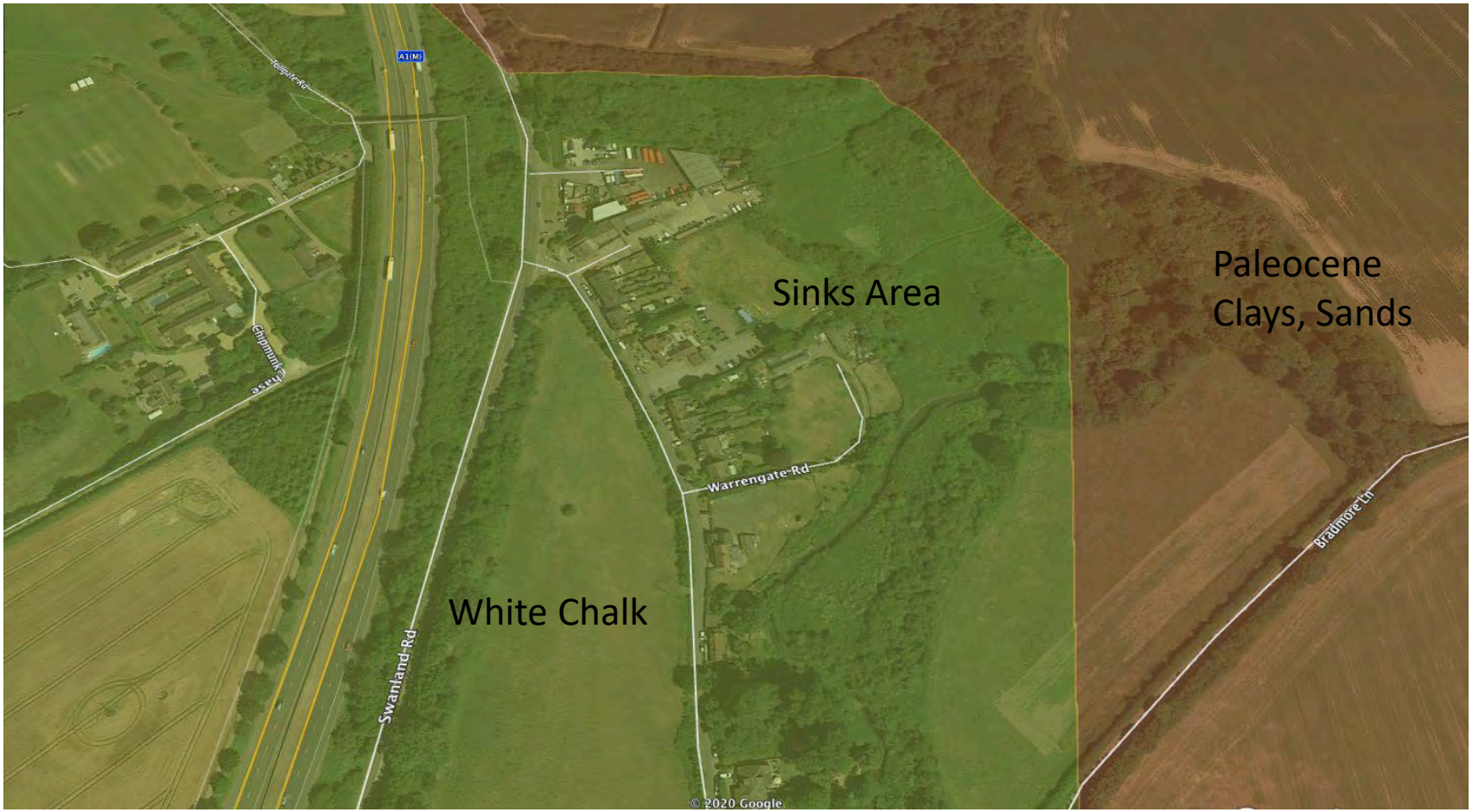
~30 km NW of Central London

An impromptu lunch alongside the M1 Motorway

…a convenient cherry tree

M1 Motorway “Soak Away” (= Culvert), (previously was a sinkhole from where one trace to Chadwell Spring was done) ~20 km in 6 days

Water End, Mimmshall Brook Swallow Holes



Near intersection of the M1 and M25 motorways north of London, 19 km SW of Chadwell Spr. (traced in 6 days)

An ephemeral stream sink point for the traces of 1927, 1928, 1932

Injected tracer tests done (fluorescein dye) from here and Water End to Chadwell Spring, and wells up to 20 km away. Bacteria traces too, travel time only a little slower, travel time was a several weeks.

Chadwell Spring, Ware, Lea Valley

Chadwell Spring Q = 0.1 - 0.15. m^3/s. Other Chalk Springs, across the outcrop – southwest of here Q = ~0.06 m^3/s

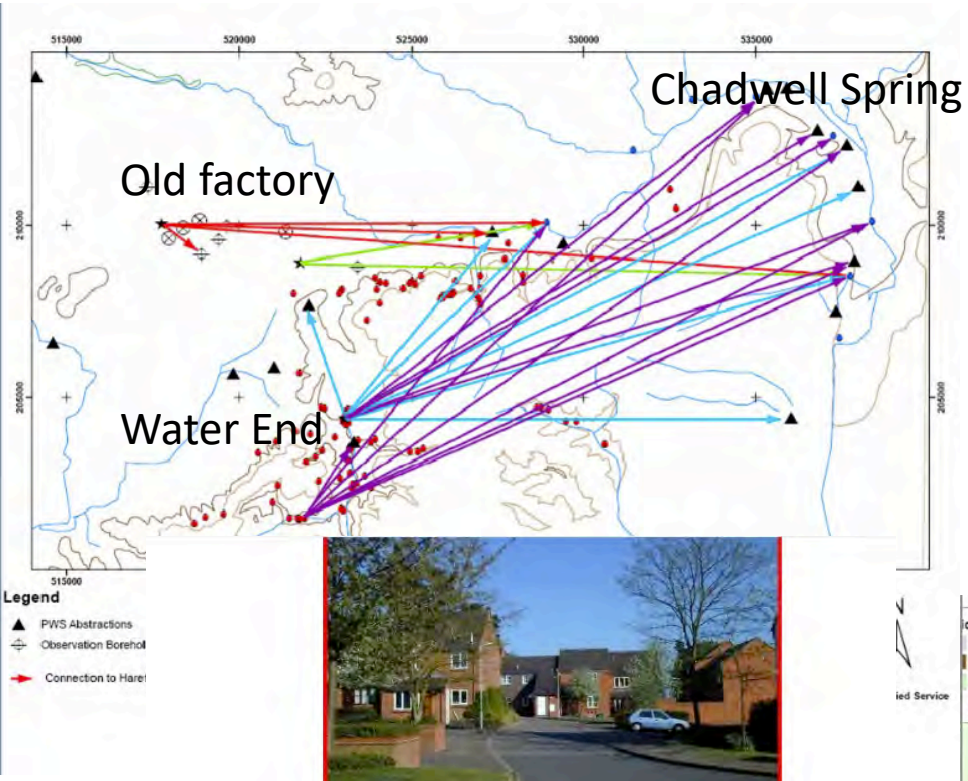
Chadwell Spring

Lea Valley Water, (one third of supply to the City of London)

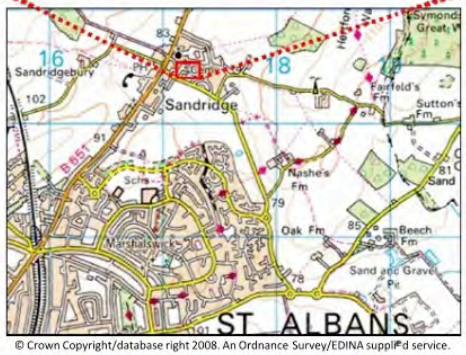
Pumps water from channel from Chadwell Spring for the City of London

Lea Valley, Amwell Pumping Station

Lea Valley Pollution Problem



The Lea (Lee) Valley situation: Chadwell and other springs, originally traced in the 1920's and 30's (concerns from bacterial contamination) from Water End 20 km away in 6 days. In recent years, old bromate contamination in the spring at a former factory reared its head and this work was done in response to that



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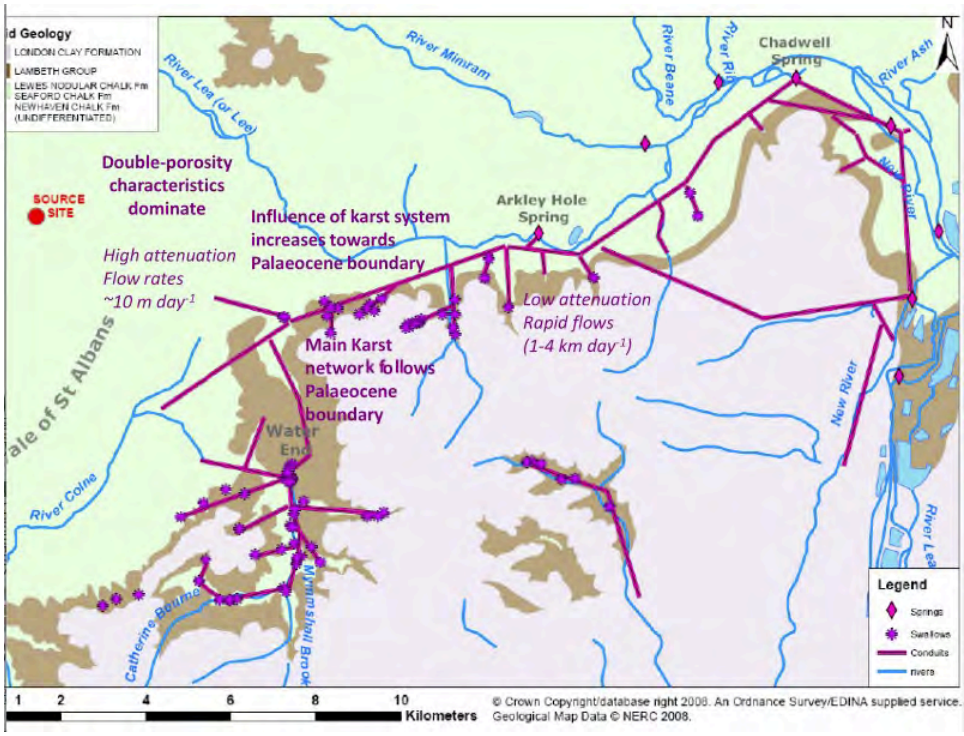

Figure 5.1: Location of the source site in Sandridge, Hertfordshire. Formerly the Steetly chemical works, now the St Leonard's Court residential development.

St. Margaret's Bay, Canterbury Cave (about 120 m long)

Springs discharge fresh water onto the beach in the foreground, observable at low tide

Beachy Head Cave, (about 360 m long)

A walk (about 3 km one way) at low tide and get a close-up look at the rather spectacular 150 m-high cliffs

The cliff face retreat means the extent of the cave is probably being reduced

This picture shows clearly why this is a favorite suicide spot

Beachy Head Cave

We failed to get into the cave, the short rock climb up was too dicey (friable rock), even though we both had rock climbed and Steve had done much of the Yosemite classics … Would be a bad place to be stranded ….

Lulworth Cove (top), Durdle Door (below)

Spectacular south coast of England

Arish Mell Spring

In the Portsdown Chalk (Upper White Chalk), 2 km east of Lulworth Cove, Dorset

Has been traced from a borehole 400 m inland – velocity of peak concentration 0.1 km/day

Table 1. Comparison of Matrix, Fracture and Conduit Porosity

	Porosity (%)		
Setting	**Matrix**	**Fractures**	**Conduit/Channels**
Mammoth Cave, Kentucky, USA[1]	2.4	0.02	0.003
Nohoch Na Chich, Yucatan, Mexico[1]	17	0.1	0.5
The Chalk, UK[1]	30	0.01	0.02
Woodville Karst Plain, Florida, USA	27	0.1	0.02

[1] Worthington et al., 2000

So, the longest cave setting has matrix porosity 800 times *larger* than the conduit porosity
And, the Chalk (few caves) and Floridan Aquifer look similar

Table 2. Flow Assuming Triple Porosity

	Proportion of Flow (%)		
Setting	**Matrix**	**Fractures**	**Conduit/Channels**
Mammoth Cave, Kentucky, USA[1]	0.0000005	0.3	99.7
Nohoch Na Chich, Yucatan, Mexico[1]	0.02	0.2	99.7
The Chalk, UK[1]	0.002	6.0	94
Woodville Karst Plain, Florida, USA	0.009	0.03	99.9

[1] Worthington et al., 2000

So, all the flow is in conduits, regardless of the porosity differences, age of limestone, settings etc., etc.,

Summary

- Things are improving somewhat…
- The Chalk and Jurassic are karst – because that is how they behave –

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