Hydrogeological Field Guide to the Wessex Basin

Technical Report IR/00/77

R Tyler-Whittle, P Shand, K J Griffiths and W M Edmunds

British Geological Survey

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W M Edmunds

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Introduction

This report was produced as an itinerary for a European fieldtrip. The fieldtrip provided the introduction to a major programme of research into the Baseline water quality of European aquifers. Delegates from 10 countries attended the fieldtrip and this report was intended not only to provide details on the area, within the itinerary, but also to provide further information on the geology and hydrogeology of the Wessex Basin for future reference within the project.

1. ITINERARY: SUNDAY 14 MAY 2000

This itinerary was used for the BASELINE European party field trip on Sunday 14 May 2000 and therefore this section is intended to provide a brief overview of the day. Further details on each item are given in section 3 and are referenced here in italics. The route is illustrated in Figure 1 and approximate times of arrival are listed in brackets (i.e.: [10.00]).

1. The River Bourne [10.00]

Our route from Abingdon towards the south coast crosses both the London Basin and the Wessex Basin. The southern limb of the London Basin can be seen as we drive south of Newbury, where the road cuts through the chalk escarpment. However, this fieldtrip will focus on the Wessex Basin.

At Cholderton (home to the smallest water company in the UK), we turn south off the A303 to follow the River Bourne. The river runs mainly to the left of the road and demonstrates intermittent flow along its course and throughout the year. The Bourne forms the basis of a new research project for the BGS and the Environment Agency and there will be a chance to leave the bus and walk along a short stretch of the river (*Section 3: STOP 1*).

2. Salisbury

Continuing south, we drive around Salisbury whose cathedral forms a landmark with the highest spire in England. Salisbury also forms the junction of four major rivers: River Avon, River Bourne, River Wylye and River Nadder.

Leaving Salisbury, we continue to follow the River Bourne until Ringwood. Along this section we cross over from the gently dipping Chalk onto the Palaeogene. The western boundary of the New Forest follows the route, on our left, until we reach the A31 and travel west.

3. Aquifer Storage Recovery (ASR) [11.10]

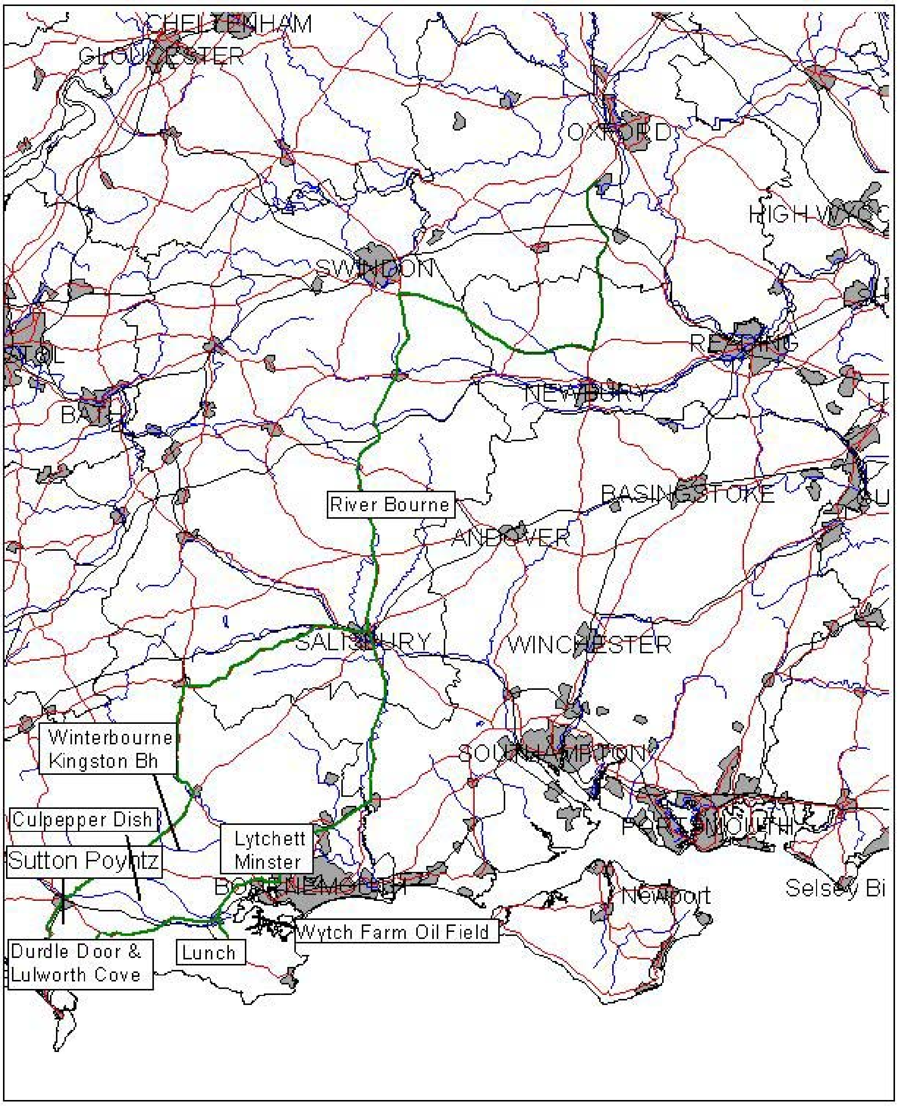
Arrive at Lytchett Minster, where Paul Stanfield from Wessex Water will explain the ASR programme (*Section 3: STOP 2*). There will be an opportunity for questions although discussion can continue over lunch as we will be pressed for time. On our route to lunch we will pass Wytch Farm Oil Field (*Section 4*), on our left, which is also an example of where geothermal investigations have taken place in the Wessex Basin (*Section 4*).

4. Lunch [12.30]

Lunch is at The Scott Arms pub in Kingston, which is located on the Isle of Purbeck. The location provides a fantastic view of the route we have just travelled including the Purbeck Hills and Corfe Castle.

5. Lulworth [13.45]

After lunch we travel west along the coast to Durdle Door. The route takes us past an army shooting range, on our left, and the Lulworth borehole (*Section 3.3.4*), which was drilled as part of the Lulworth Goundwater Scheme (*Section 3.3.3*).



Route taken on field trip

6. **Durdle Door [16.00]**

The bus will drop us at Durdle Door (*Section 3: STOP 3*), and we will walk down to the coast to see the emblem of the PALAEAUX project. The geological succession is exposed on the beach and there will be some time to take pictures and relax before walking back along the coast to Lulworth Cove (*Section 3: STOP 3*). The path ends at Lulworth car park and there are various shops and refreshments in the area.

On the path down to Lulworth Cove, we pass a major spring, issuing from the Chalk on the left of the road. Smaller springs can be seen along the beach at Lulworth Cove. A path can be climbed, at the western end of Lulworth Cove to view Stair Hole and the 'Lulworth Crumple'.

7. **Return Journey [16.30]**

We must leave the car park by 16.30 although the return journey is flexible. There are various possibilities depending on the traffic and your interests and energy levels. These include:

a) **Culpepper's Dish:** There are many solution features called 'dolines' (swallow holes) found along the junction of the Chalk and the overlying Palaeogene sediments. Culpepper's Dish is a spectacular doline, the largest of many such structures, developed in a belt where the Palaeogene Beds thin to a featheredge on the northern side of the Frome syncline (Figure 2). Some 50,000 cubic metres of sediment must have disappeared into a solution cavern below and the doline is now covered in thick vegetation. These large hollows are reported to be the result of intense and localised solution activity promoted by highly acidic conditions frequently found under heathland vegetation.

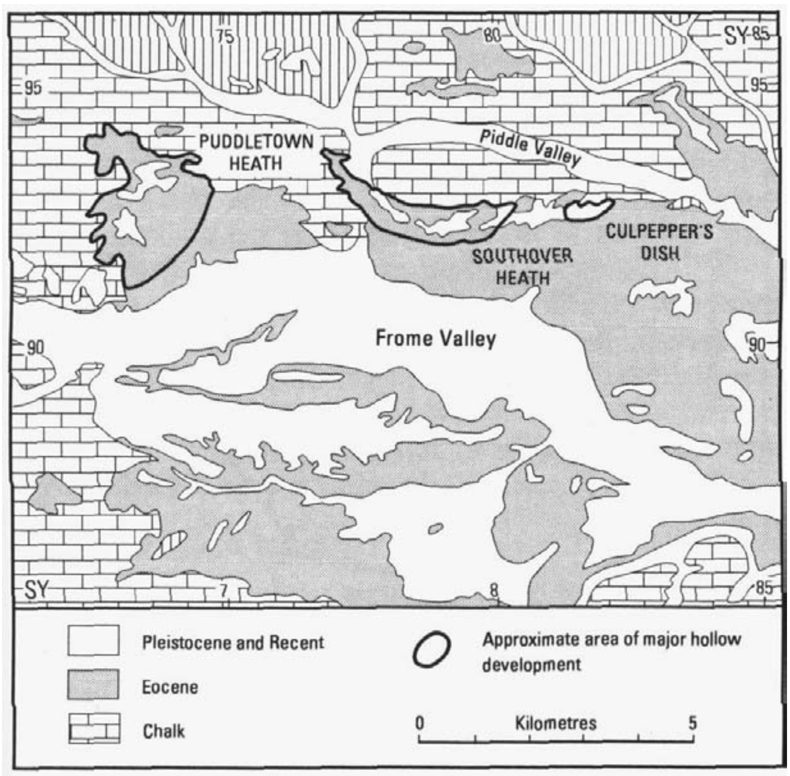


Figure 2 The distribution of solution features in the Chalk of the Dorset Heathlands (from Allen *et al.*, 1997).

b) **Winterborne Kingston Borehole:** Situated on the southern margin of the north Dorset Downs, the borehole was drilled both as a stratigraphic investigation and as part of the Department of Energy's programme of geothermal investigations in southern England. The drilling commenced on 30 November 1976 in Upper Cretaceous Chalk and reached the Permian at a total depth of approximately 2980 m below OD. Further details on the borehole can be found in *Section 4.2*.

c) **Sutton Poyntz:** Large springs issuing from the Chalk can be seen in the north of the village.

d) **Cerne Abbas:** Watercress Farm and interesting Celtic carvings on hillside (Baseline logo?).

If time does not allow us to visit all or any of the above they can be discussed during our return journey. Our return route will take us pass Stonehenge and we hope to arrive back in Abingdon between 18.30–19.00.

2. INTRODUCTION TO THE WESSEX BASIN

2.1 Geology

The Wessex Basin, located within the Hampshire basin, flanks the southern side of the London Platform and extends from Devon eastwards towards the Weald Basin. It formed at the same time as the London Basin, as part of the larger Anglo-Paris-Belgian Basin. The northern limit of the basin is defined by the Vale of Pewsey, and the southern limit by the outcrop of the Chalk along the Purbeck monocline. Chalk strata form the majority of the exposed area, although the central portion of the basin is capped by a younger sequence of Palaeogene rocks (Merrin, 1999). Figure 3 shows the main geological units and structural features of the Wessex Basin and the geological succession is shown in Table 1.

The sediments were deposited on a complex basement, ranging in age from at least Ordovician to Upper Carboniferous. The basement was affected by the Variscan Orogeny, an extended period of crustal subsidence along major growth-faults. These faults are normal, predominantly east-west trending, with a southern downthrow. The growth faults were active at various times form the Permian to early Cretaceous and exercised considerable control on subsidence and sedimentation. During the later Alpine compressional tectonic episode, the sense of movement of some of these faults were reversed, and numerous anticlines and periclines were formed, typically with steeper northern limits.

The Chalk of south Dorset is extensively deformed and is dominated by an east-west striking feature, the Purbeck Monocline, which we will visit today (*Section 3: Stop 3*). It demonstrates steeply inclined beds and a number of associated smaller folds and faults, thought to have originated from the reactivation of Variscan faults.

2.2 Hydrogeology

The Chalk is the major aquifer in the south of England and the chalk of south Dorset has undergone extensive deformation. Consequently, the geomorphology, hydrology and hydrogeology of the area are complex and do not conform to the patterns observed in other chalkland areas.

The average annual rainfall for the Wessex Basin varies considerably across the region, from 700 mm in the north-east to 1100 mm north of Poole. The variation in topography within the catchment also results in a large variation in the thickness of the unsaturated zone. The structural complexity has affected aquifer properties across the basin and the notes for this fieldtrip will focus on the Chalk of south Dorset, rather than the entire Wessex Basin.

The faults and folds, associated with the main Purbeck monocline, are significant in controlling the aquifer properties of the area. Laboratory work has illustrated that tectonically hardened chalk has a lower porosity and intergranular permeability than undisturbed chalk resulting in a reduced transmissivity and storage coefficient. However, faulting associated with the folded Chalk appears to have a significant effect by locally increasing transmissivity. In south Dorset, transmissivity values vary from 0.8 to 3000 m^2/d, with a median of 330 m^2/d. Storage coefficient varies from 9 x 10^{-5} to 0.064 with the higher values believed to be influenced by the Upper Greensand (Allen et.al., 1997). There are no pumping test data from the Purbeck Hills on top of the monocline, but it is thought that the aquifer properties will be poor as a result of the steep inclination and thick unsaturated zone.

The effective base of the aquifer is taken to be the middle of the Upper Greensand, at the top of the Exogra Sandstone, which is well cemented with a low permeability. Although the Chalk Marl, at the

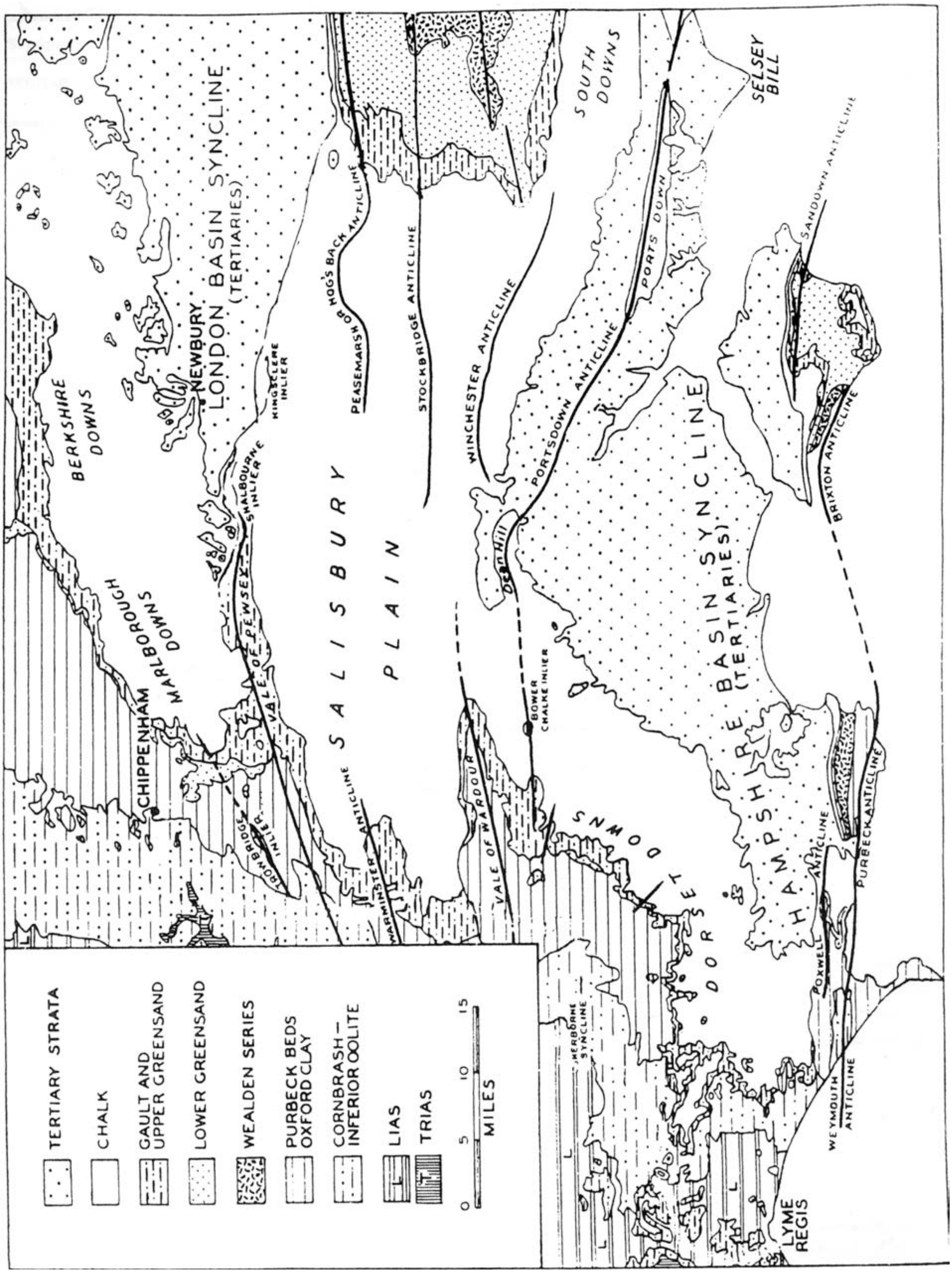


Figure 3 **Geological sketch map of the Wessex Basin, showing principal structures (from Chatwin, 1960)**

Table 1 **Geological succession in the Wessex Basin (modified from Melville and Freshney, 1982 and Downing and Grey, 1986).**

base of the Lower Chalk, also has a low permeability the lack of springs emerging from the top of the marls implies a large component of leakage down to the Upper Greensand (Allen *et al.,* 1997).

The boundaries of the surface water and groundwater catchments in south Dorset are not coincident. While the area is drained to the south-east by the rivers Frome and Piddle (Figure 4) and their tributaries, much of the groundwater in the area drains southward and discharges to the sea via large springs. Investigations were carried out in the 1970's to intercept groundwater flow before it reached the sea. This was named the Lulworth Groundwater Scheme and is discussed further in *Section 3.3.3*.

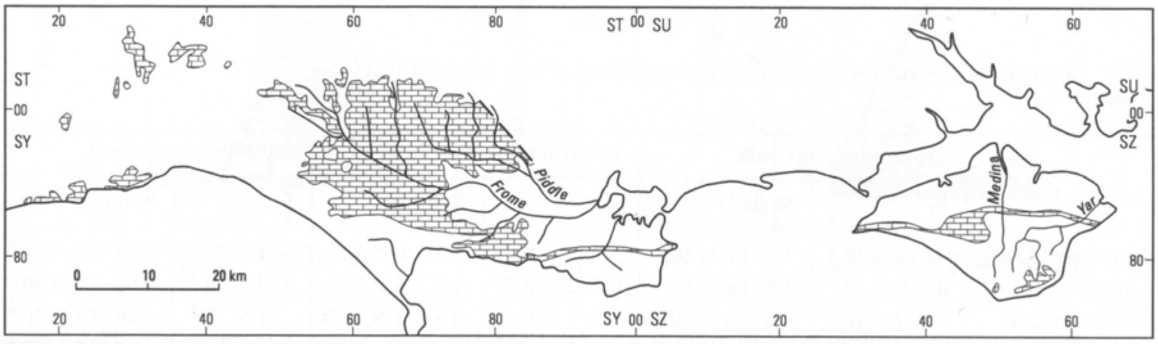


Figure 4 **Location map of the Chalk of south Dorset, illustrating the Chalk outcrop and the river network (from Allen *et al.,* 1997).**

2.3 Groundwater Quality

The Chalk groundwater chemistry in the Wessex Basin owes its characteristics to inputs from rainfall (seen in concentrations of Cl, Na, SO_4, for example) and rapid reaction with chalk sediment due to the increase in CO_2 derived from soils. Quite distinct changes in chemistry result from incongruent reactions of the impure marine sediment. For example, an increase in Mg and the trace elements Sr and F can be seen as water passes to greater depth along flow lines. A distinct redox boundary can be inferred in the aquifer (Figure 5), where rapid denitrification occurs and there is an increase in dissolved iron.

The chemical characteristics of groundwater in the confined aquifer at Wareham imply that it is of considerable age and unaffected by modern recharge. The groundwater is relatively fresh but contains excessive concentrations of F and Fe. Nonetheless, the waters are still potable and interstitial waters are fresh down to depths of 250 m below surface with no evidence of residual saline formation water or seawater contamination. It is possible the thickness of the Palaeogene cover and the London Clay has protected the Chalk aquifer from saline intrusion, in the recent geological past. Also, in comparison with elsewhere in the UK, much of the original saline formation water was expelled from the Chalk during the Alpine Orogeny 20-40 million years ago. The rise to the present sea level in the last 8000 years has been too recent to salinate the pressurised Chalk aquifer.

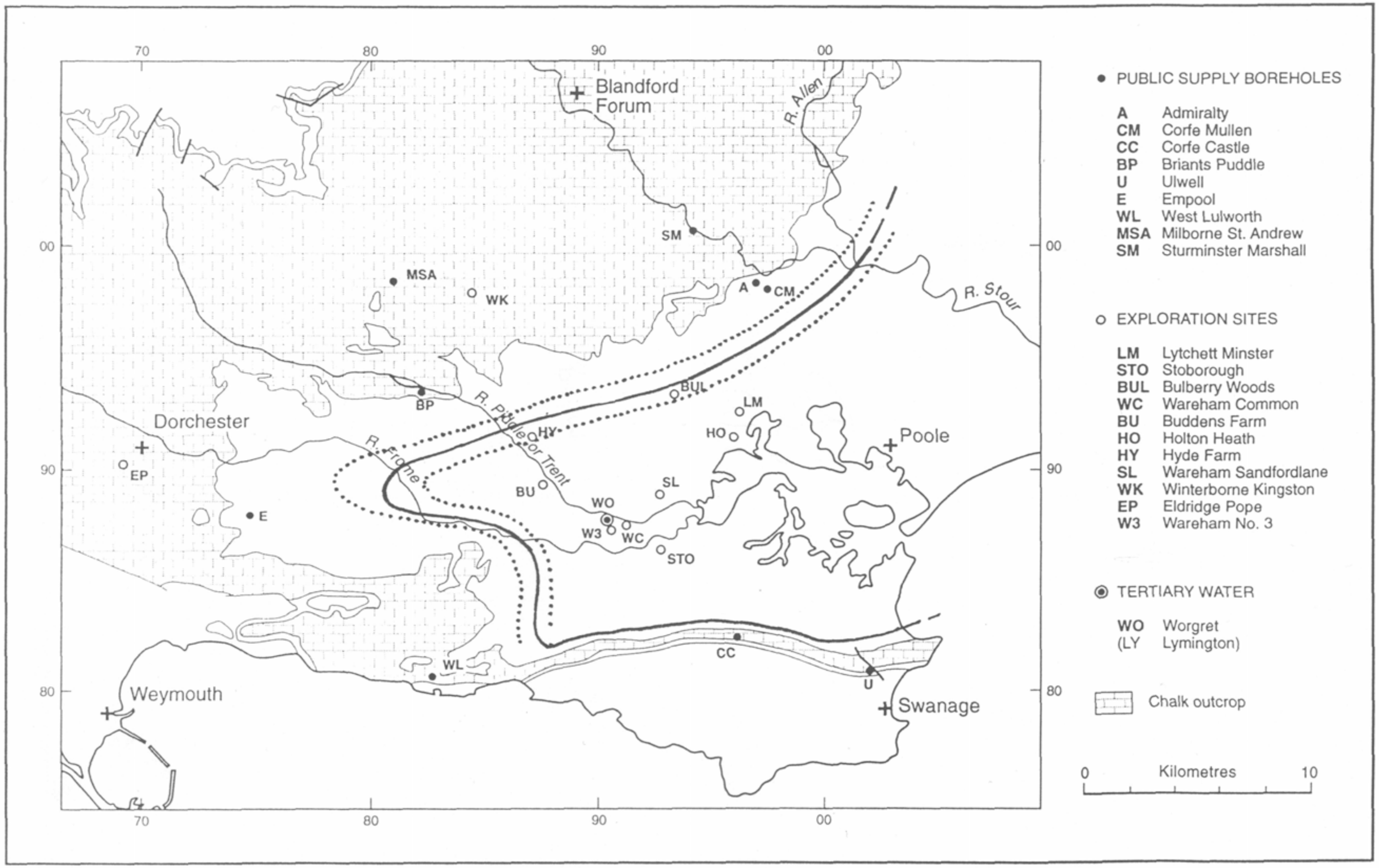


Figure 5 Likely position of the redox boundary in the Wessex basin area [solid line] (from Edmunds, 1996).

The main hydrochemical characteristics of the major cations are summarised in the trilinear diagram (Figure 6). Initially, groundwater acquires a calcium-rich composition, with an Mg/Ca ratio close to that of the Chalk as a result of congruent solution. Saturation with calcite is typically attained within a few metres of the ground surface (Edmunds *et al.,* 1992). Groundwaters in the shallow saturated zone generally have Mg/Ca ratios only slightly above those of the solid chalk implying that their composition has evolved very little since infiltration. In the Dorset syncline, several groundwaters have a higher Mg/Ca ratio (as well as other characteristics described below) which indicate a degree of water-rock interaction in which Mg (and other trace elements) have been preferentially released by incongruent dissolution of the Chalk. In this process the impure chalk sediment, under conditions of dynamic equilibrium, reacts to produce a purer secondary calcite and releases impurities to the groundwater. Chalk was deposited biogenically under marine conditions, requiring trace element 'impurities' to help stabilise the skeletal structure. This process is an adjustment of the chalk to fresh water conditions.

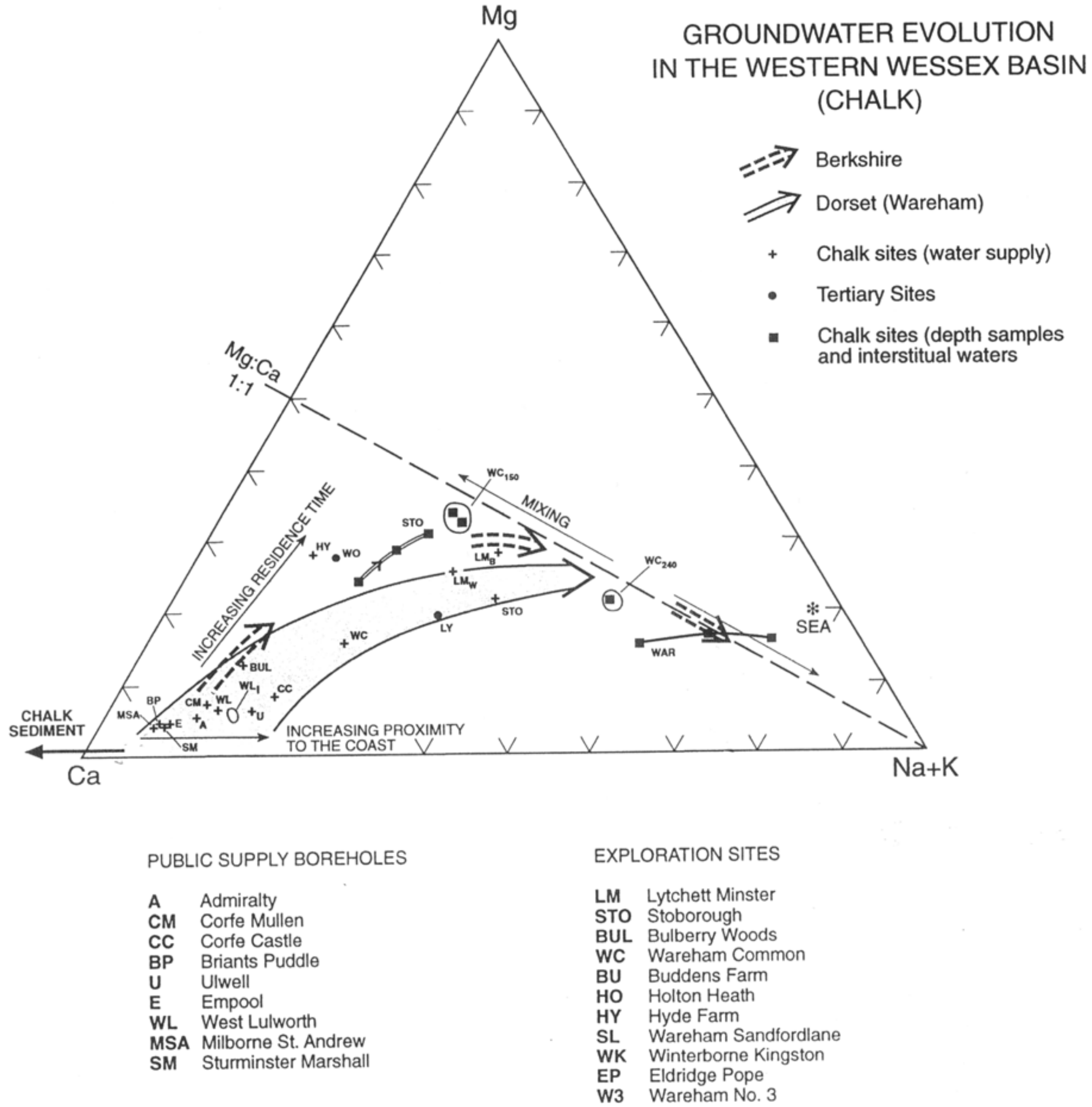


Figure 6 Trilinear plot of groundwaters in the Wessex Water area (from Edmunds, 1996).

2.4 Palaeowaters in the Wessex Basin

The palaeohydrology of Chalk groundwater has been investigated at several sites near the centre of the Dorset Basin during the PALAEAUX project (Edmunds and Milne, 1999). For this study water exploration boreholes have provided information down to about 300 m below OD and are located in Figure 5.

The confined groundwater in the Chalk aquifer near Wareham is relatively fresh to considerable depths, with a conductivity of <100 μS/cm down to at least -240 m OD in the Stoborough borehole. The deepest inflow is identified from hydrogeophysical logging in the Wareham Common borehole, at -210 m. Fluid temperature logging suggests present day groundwater circulation exists down to a depth of -170 m to -180 m OD. This is considerably deeper than elsewhere along the south coast and is believed to be affected by local geological structure. The vertical strata of the Lulworth monocline prevents groundwater from discharging to the normal hydraulically controlled base levels at shallow elevation. An outlet through the structure offshore was probably available from the late Pleistocene as shown by offshore channels (Veligrakis *et al.,* 1999). The Palaeogene cover is locally in excess of 100 m here so that the development of permeability associated with prior base level circulation took place mostly within the Palaeogene strata and not in the Chalk. Results of pumping tests on boreholes which line out the Palaeogene strata in the Poole Harbour area reveal very low yields with drawdowns in excess of 70 m confirming low permeability for the chalk of this area of the south coast.

Most of the radiocarbon data lie in the range 1-2 pmc (Table 2) implying that the bulk of the water from the depth profiles (based on levels of entry from hydrogeophysical logs) in the centre of the basin is of late Pleistocene age. The geochemical characteristics of the water (high F, Sr and enriched ^{13}C) confirm that despite the freshness, the water is of considerable age.

Table 2 Isotopic and chemical data for the Chalk groundwaters (depth profiles) in the Wessex Basin area (BGS, Unpublished data).

Locality	Depth	$\delta^{13}C$	^{14}C	Sr	Cl	$\delta^{18}O$	$\delta^{2}H$
	m	‰	pmc			‰	‰
Stoborough	120	–4.7	-	3.17	48.8	–7.2	–42
	130	–4.1	-	1.90	48.2	–6.9	–42
	180	–3.3	-	1.96	48.5	–7.0	–42
	195	–1	-	3.03	51.8	–7.0	–42
	240	–0.3	-	1.75	53	–6.9	–42
Wareham Common	120	1.5	1.64	3.27	240	–7.0	–41
	195	–0.2	1.84	3.28	239	–6.9	–38
	210	0	63.5	3.35	373	–7.1	–46
	240	–0.4	2.8	3.12	241	–7.0	–42
	266	–0.2	4.99	3.16	242	–7.0	–45
	280	–0.8	2.09	3.28	250	–7.0	–45
	299	–0.7		3.20	256	–6.8	–41
	230	–1	14.9	0.72	22	–7.8	–51

3. THE FIELD GUIDE

3.1 Stop 1: Bourne Catchment

Background

The River Bourne has been identified by the Environment Agency as a "low-flow river". A bourne is defined as an intermittent stream or river, flowing only during part of the year. Most bournes in the UK flow during winter, the most important time of recharge, and are dry for most of the late spring, summer and autumn. Many towns exist with Bourne in their name, for example: Winterborne Kingston and Collingbourne, reflecting their position along such rivers.

There is particular concern amongst the public that groundwater abstraction has a significant effect on the river flows. Four water companies (Wessex, Southern, Thames and Cholderton), in addition to the Ministry of Defence abstract from the catchment. Although the River Bourne has a long history of low flows, it is not known to what degree this is further affected by increased abstraction. The river is present for almost the entire length over Upper Chalk, with Lower and Middle Chalk being present in the upper parts of the catchment. The aquifer is unconfined over the entire length of the river.

Low flows in the Bourne

Although many bournes initially cease to flow at the top of the catchment and dry up further downstream with time, the River Bourne stops flowing close to Cholderton (Figure 7). In some years there is continuous flow upstream and downstream of this area with the river being dry only in the centre. A significant increase in flow occurs close to Idmiston where a number of springs discharge to the river. Work is in progress at the present time to try to understand the hydrogeology of the catchment and what geological controls exist on flow. This includes geological mapping, study of changes in groundwater levels and geophysical logging.

Hydrochemistry

The river water and groundwater are all of Ca-HCO_3 type and show remarkably little variation in relative proportions of the major elements. Specific electrical conductance (SEC) are variable (417 – 640 and 552 – 719 µS/cm in the river and groundwaters respectively). SEC decreases downstream in both surface and groundwaters, opposite to that expected from flowlines which trend from north to south. All waters are relatively oxidising with high DO and Eh.

Surface-groundwater interactions

Hydrochemical data are plotted against Northing on Figure 8 with flowlines trending from north to south (left to right on the diagram). There is significant overlap in concentrations between the river and groundwater and both show similar trends. This implies that the river is dominated by groundwater and that discharge to the river is local. This is consistent with the fact that flow in the catchment is sensitive to groundwater level fluctuation and that the water table is very shallow along the valley bottom. During sampling, the middle part of the river bed (around Northing 4500) was dry. Higher pH in the river is related to degassing of CO_2 and re-equilibration with the atmosphere. A component of shallow inputs is indicated by higher P, NO_3 and Cl probably derived from agricultural pollution.

Figure 7 **River Bourne at Cholderton on 2 February 2000 (upper) and 6 May 2000 (lower) following heavy April rainfall.**

Regional variations and chemical evolution

In general, groundwaters normally show an evolution of increasing TDS along flowlines and with depth related to increased water-rock interaction and residence time. There is a general decrease in SEC, Cl, Ca, SO_4, Si and Sr along potential flowlines in the Bourne catchment. It is difficult to envisage a process whereby the groundwaters in the south of the catchment can be directly evolved from those in the north. Hydrogeological work is in progress to understand groundwater flow and the limited data available may imply that there is some flow across the surface catchment prior to stream flow. This may explain differences in the River Bourne chemistry upstream and downstream of the dry bed section (i.e. the river water on re-entering the groundwater system is diverted away from the stream). It is possible that the lower SEC in the southern part of the catchment is related to higher transmissivities, hence the aquifer matrix is better flushed of a residual connate water and there has also been less time for water-rock interaction to take place. An alternative explanation may be that there is a component of high TDS groundwater from the greensand at the north of the catchment. This will form an important component of the research currently in progress.

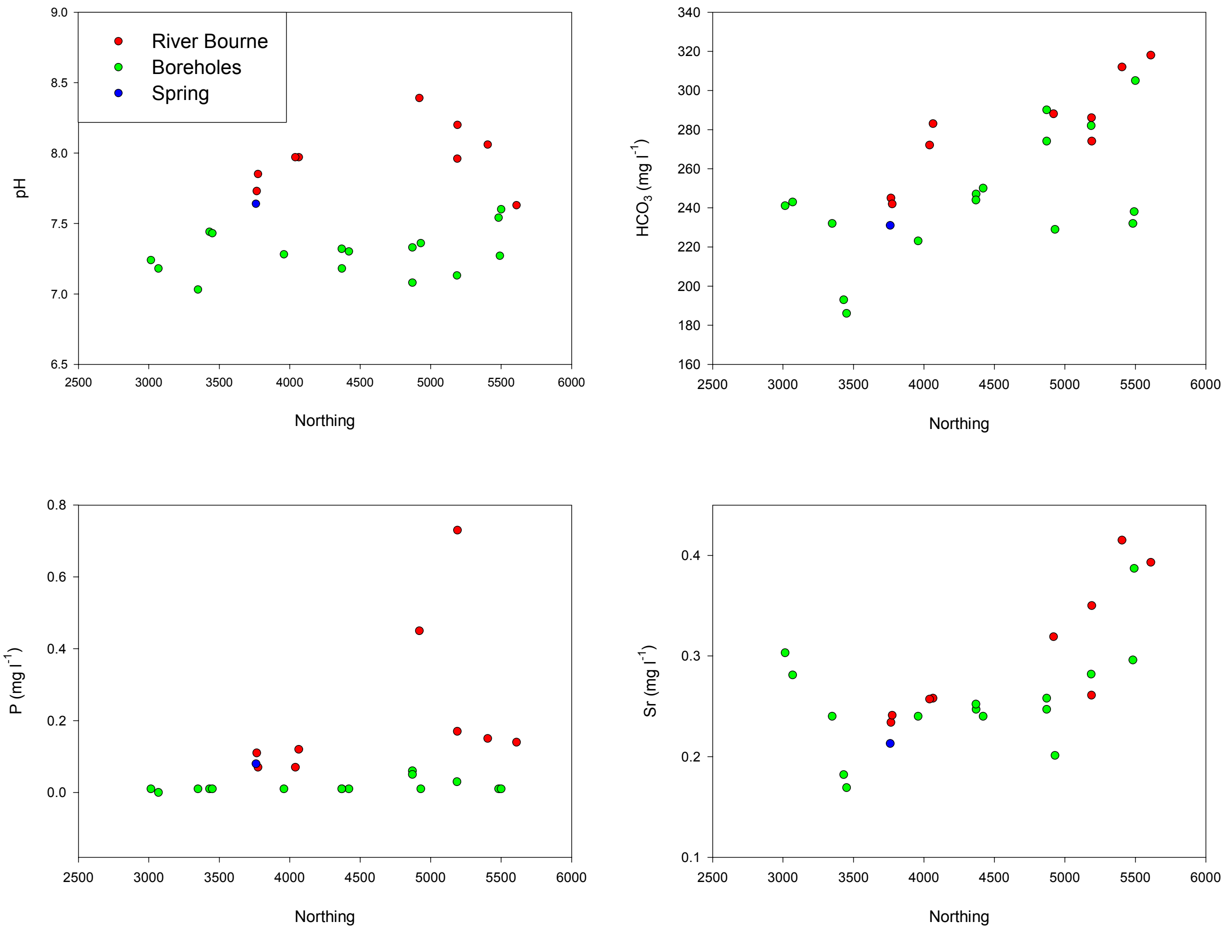


Figure 8 **Selected chemical parameters plotted against Northing for surface waters and groundwaters. General groundwater flow direction is right to left.**

3.2 Stop 2: ASR Site, Lytchett Minster, Wessex Water

What is ASR?

Aquifer Storage and Recovery (ASR) has been defined as “The storage of water in a suitable aquifer through a well during times when water is available and recovery of the water from the same well during times when it is needed” (Pyne, 1995). The storage zone may contain native water of poor or brackish quality where aquifer development is not otherwise possible (Jones *et al.,* 1999). A key element of the process is to inject more water than is recovered to build up a “bubble” of high quality water surrounded by a mixed zone to act as a buffer with the native groundwater.

Background and Geology of site

The location of the site at Lytchett Minster is shown in Figure 1. The Chalk is a dual porosity aquifer with a matrix porosity of about 30% and an effective fracture porosity of only about 0.1 – 1.0%. The fractures provide permeable pathways for flow and the matrix acts as a reservoir of immobile water that interacts with the fracture water through diffusive exchange. At Lytchett Minster, there is an artesian head of 40 m (illustrated in Figure 9). The Chalk is confined beneath around 60 m of Palaeogene sands and clay and a geological cross-section can be seen in Figure 10. The target storage zone is about 40 m thick with a transmissivity of 200 m^2/d, a storage coefficient of $2.7x10^{-4}$, an artesian head of 20 m above ground level and a flowing yield of about 3 Ml/d. The native groundwater is a palaeowater (> 10,000 years old) and generally of good quality, but contains relatively high concentrations of Fe and F (Buckley *et al.,* 1998).

The boreholes (abstraction and observation) and piezometers were drilled in 1993 during an investigation into the potential of the confined Chalk of the Wareham Basin as a groundwater resource. A six month pumping test showed local cones of depression and high drawdown around the wells. Analysis and modelling of the results at Lytchett Minster and nearby sites, indicated that there was little or no connection with the unconfined aquifer. Abstraction was therefore considered to be unsustainable owing to little natural recharge. However, the area was considered to have potential and a programme to ascertain its potential for ASR was initiated in 1997.

Figure 9 Original abstraction borehole at Lytchett Minster.

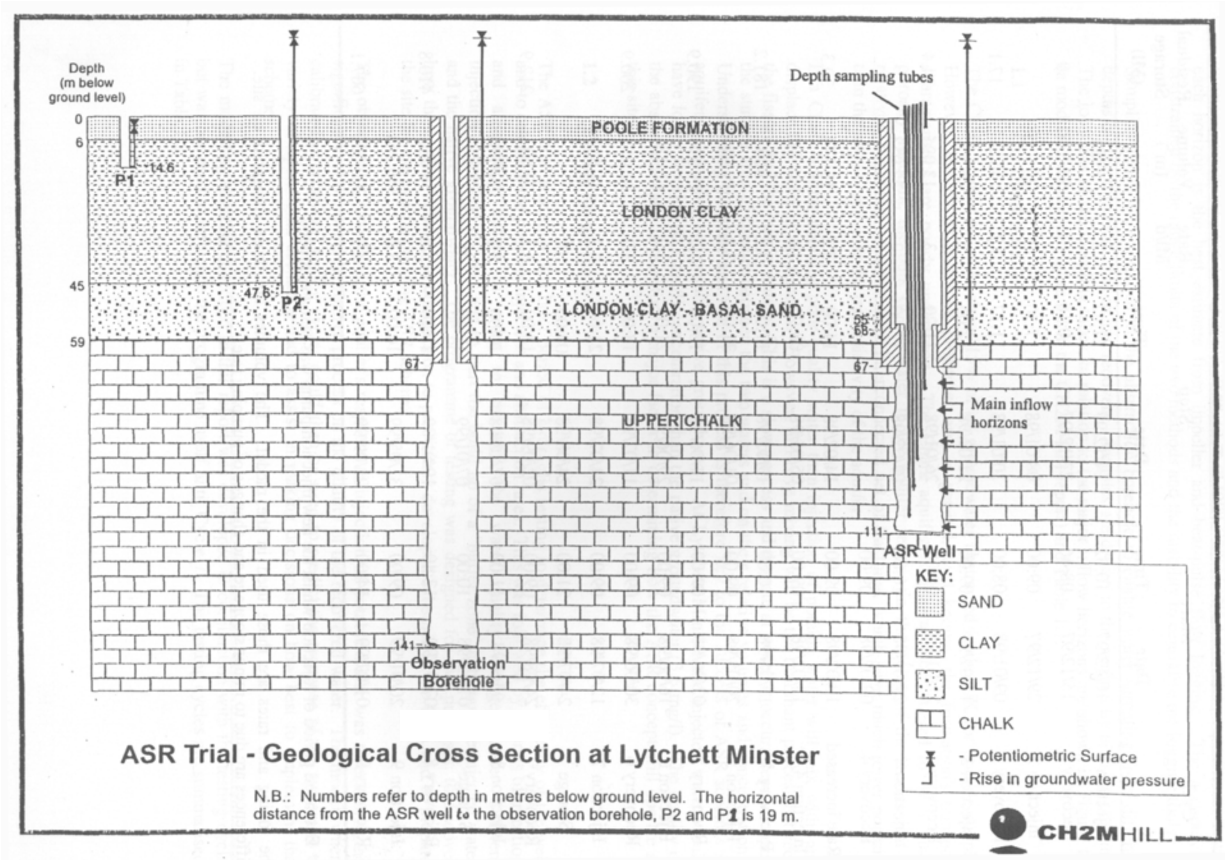


Figure 10 **Schematic section at Lytchett Minster showing location of depth sampling tubes and main inflow horizons in the ASR Well (modified from Williams *et al.*, 1999).**

Theoretical modelling of ASR

Figure 11 shows the modelled concentration of a conservative element (high in the aquifer; low in the injection water) during a single injection–recovery cycle. The graph displays the concentration of the solute in the well. During injection, the water flows mainly along fractures although diffusion will occur between the fractures and matrix. The injection phase is represented by the chemistry of the injection water. During the stand phase, flow in the fractures ceases but diffusion continues with the porewaters and thus increases the concentration in the injection waters (note that the porewaters will become more dilute). When recovery begins, water is drawn back along the fractures and this water is more saline than the injection water due to mixing/exchange. Ultimately, native groundwater may be expected to reach the borehole. During the final stand phase, a slight decrease in concentration will occur because the pores adjacent to the borehole will have been freshened by dilute injection water and will continue to exchange with the fracture/borehole water.

In general, ASR sites are situated in the confined parts of aquifers and the injection of oxidising water into a reducing environment may cause significant redox reactions to occur. Although mixing is likely to be the dominant control on water quality, other process with rapid reaction kinetics may also be important including mineral dissolution/precipitation, ion exchange and adsorption/desorption.

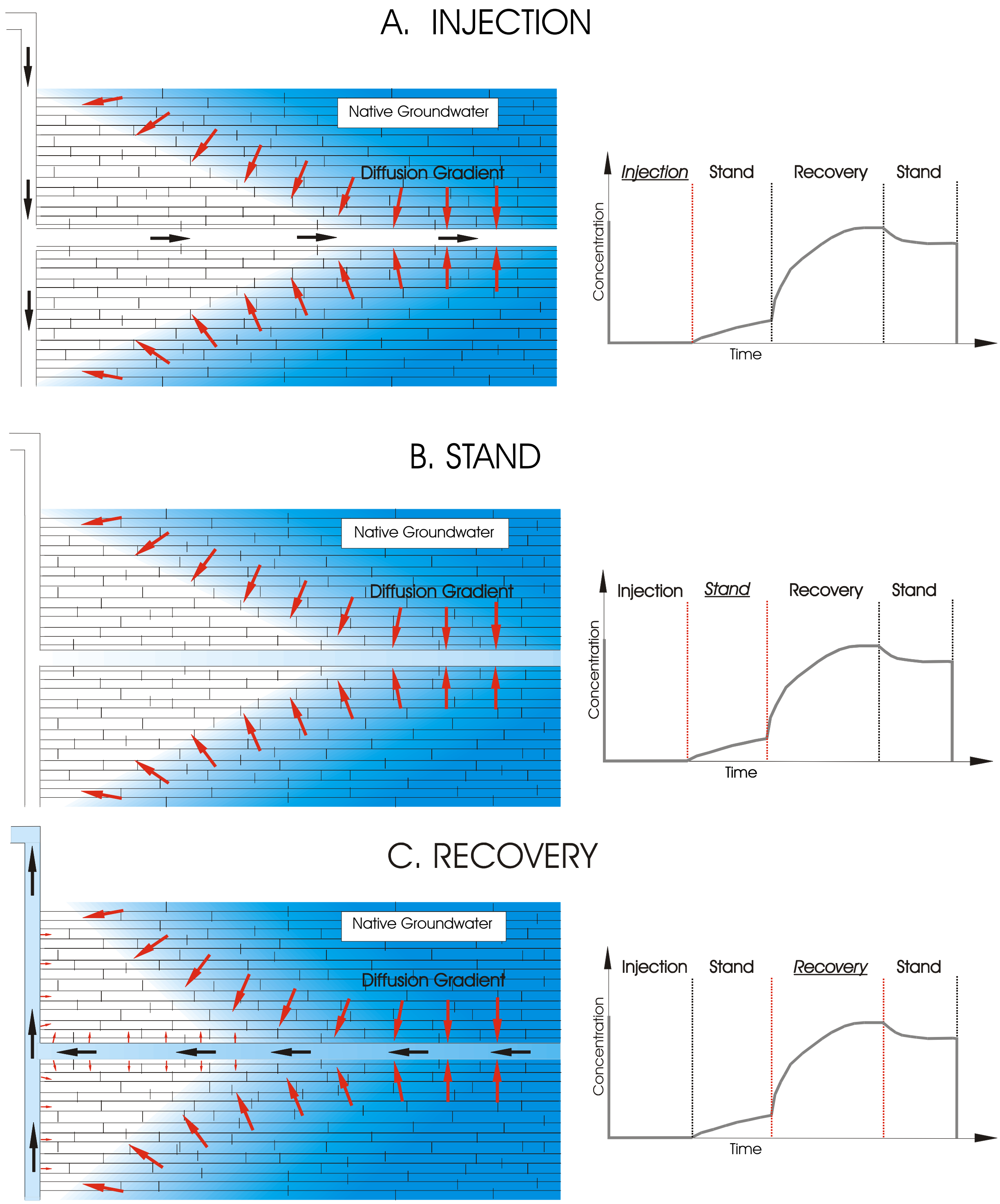


Figure 11 **Dual porosity effects illustrated for each stage of an ASR cycle (from Gaus *et. al*. 2000).**

Chemical reactions

Figure 12 shows the concentration of a range of elements during the first recovery cycle at Lytchett Minster normalised to the native groundwater. Chloride is assumed to behave conservatively and used as a reference to compare other solutes. Even with recoveries greater than 100%, Cl does not approach the original native groundwater due to mixing and diffusion. It is clear that not all elements behave conservatively and that their concentrations are often higher than expected. This is due to reaction with minerals in the aquifer e.g. calcite, pyrite, fluorite or possibly that the porewater chemistry is different from the fracture waters. Although F concentrations were still relatively high at the end of the research programme, either treatment or blending can be undertaken to lower concentrations to produce a potable resource.

For further information see the ASR website: www.nwl.ac.uk/gwf/asr/asr_intro.htm

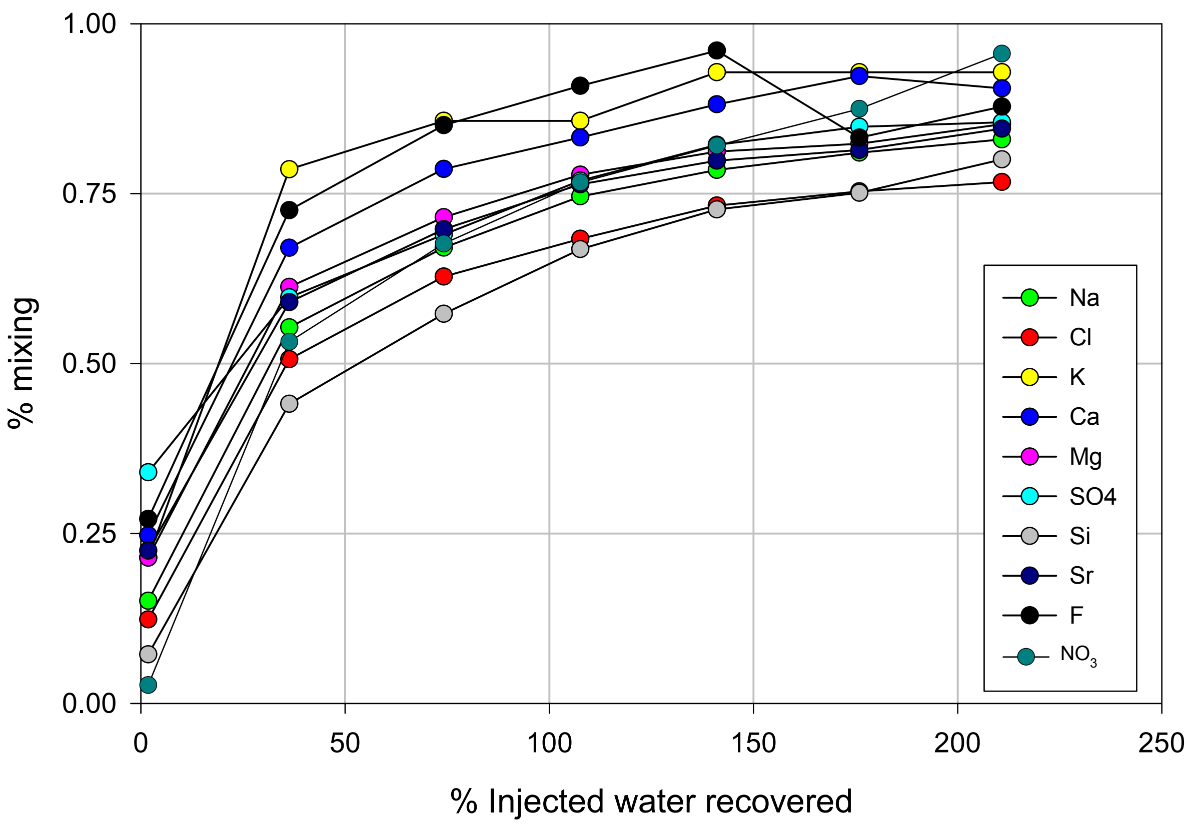


Figure 12 Lytchett Minster Injection-recovery phase 1: Percent mixing calculated for different solutes against percent water recovered.

3.3 Stop 3: The South Dorset Coast

The geology of the South Dorset coast consists of Late Jurassic to Upper Cretaceous rocks, lying parallel to the coastline. The structure and outcrops are very narrow due to the effect of the Purbeck anticline and westward thinning of the beds as illustrated in Figures 13 and 14. The Jurassic consists of Portland and Purbeck rocks, which are predominantly limestones but with some softer bands. The beds are steeply dipping, contorted and present a resistant rampart towards the forces of the sea. Behind them, the less resistant Cretaceous rocks comprising the Wealden Clays, the Upper Greensand and the Gault, are more easily eroded. In turn, behind these, the more massive escarpment of the Chalk is found, which tends to form a prominent escarpment, high hills and steep slopes inland.

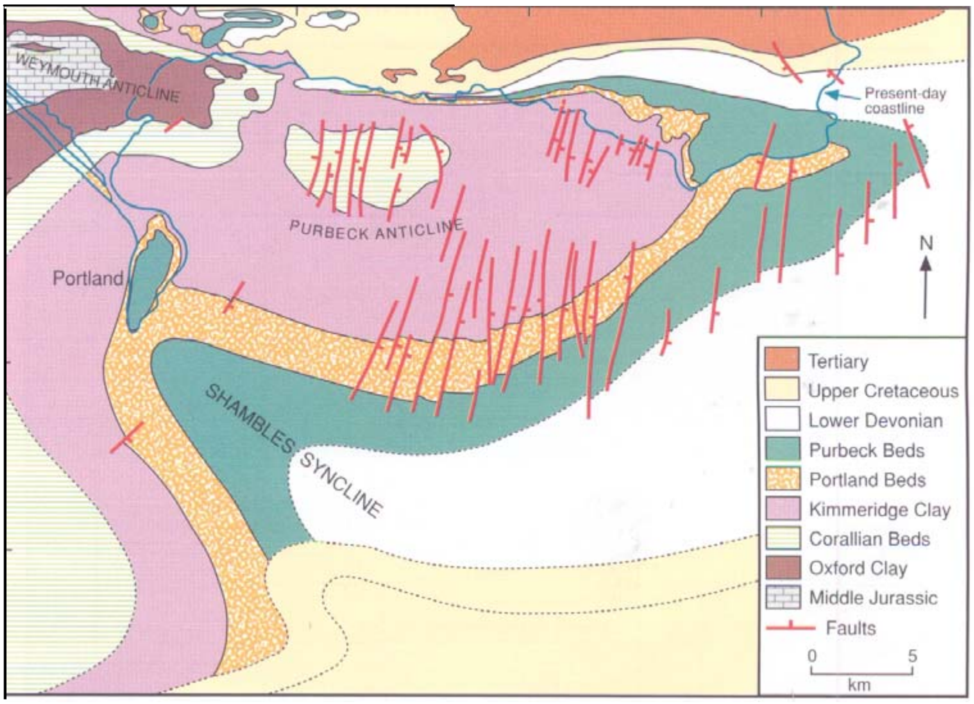


Figure 13 **Structural setting of the south Dorset coast showing the control exerted by the Weymouth and Purbeck anticlines (after Donovan and Stride, 1961). Reproduced with permission of the Geologists' Association.**

Although the Portland limestone provides a coastal barrier against erosion, there are a series of coves along the coast, partially or completely developed, which are illustrated in Figure 15. Stair Hole is an example where the sea has initially breached the limestone to rapidly erode the soft Wealden Beds. Continued erosion will develop a wide, near-circular symmetrical bay (i.e. Lulworth Cove) behind a narrow entrance. Once the cove has reached the Chalk the development of the bay becomes slower than the widening of the mouth. Progressively the Portland and Purbeck Beds are destroyed until only small stacks or arches remain, for example at Durdle Door. As shore erosion continues the bay widens, perhaps merging with neighbouring bays to form a straighter coastline. The coast to the east of Durdle Door, named St Oswald's Bay, is thought to be an amalgamation of three coves, representing the final stages of the sequence (Goudie and Brunsden, 1997). The limestone barrier has almost disappeared along the coast, although the Bull, Blind Cow, Cow and Calf rocks, located west of Durdle Door, are islands of Portland limestone exposed at low tide.

Landslides and mudslides are also responsible for shoreline erosion, and although this is a simplified explanation, most features can be seen along our coastal walk from Durdle Door to Lulworth Cove. Further details of the area can be found in the BGS 'Holiday Geology Guide: Lulworth Cove Area'(1995), which is provided with this guide.

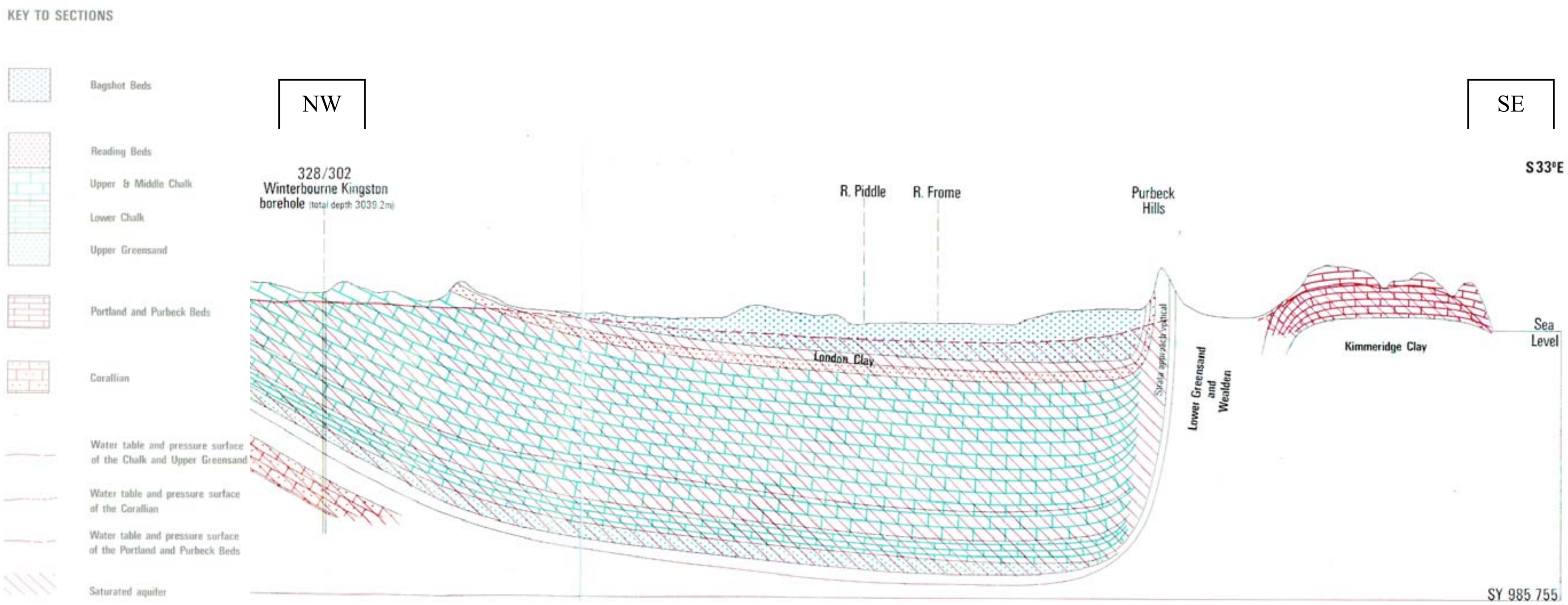


Figure 14 Cross section from the Winterbourne Kingston Borehole (north-west) through the Isle of Purbeck (south-east) [see Figure 1 for locations] (IGS and Wessex Water Authority, 1979).

3.3.1 Durdle Door

The Durdle Door viewpoint provides an ideal location to see the geological succession at the narrowest exposure. The units have thinned southwards due to the east-west trending growth faults and the lower Wealden and upper Purbeck Beds are absent at the neck of the Durdle promontory, due to a strike fault. The middle limb of the Purbeck monocline is vertical or overturned at this location resulting in steeply dipping beds, as illustrated in Figure 15 and 16.

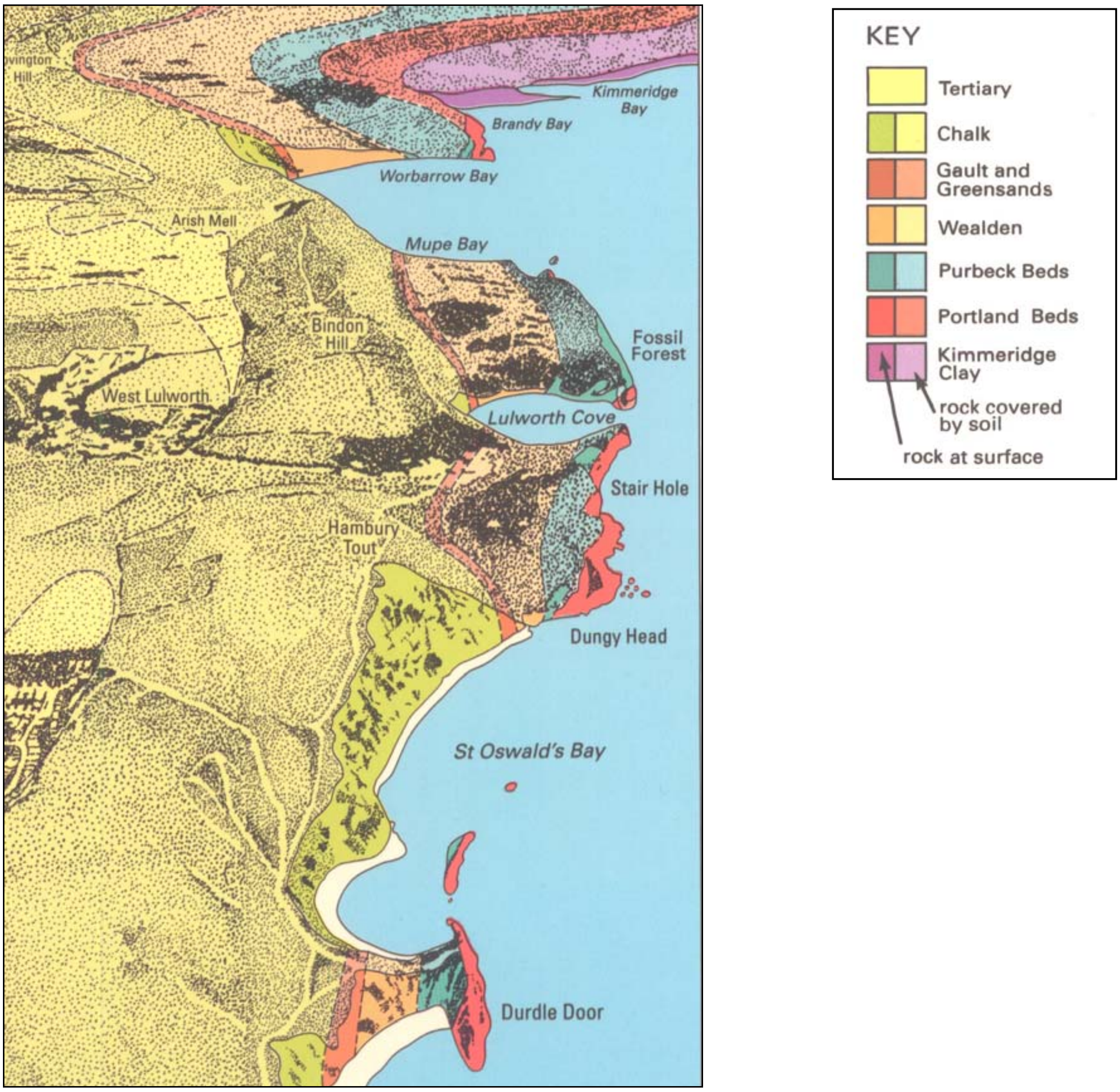


Figure 15 Aerial view eastwards from Durdle Door to Kimmeridge Bay (from BGS, 1995).

The Portland Beds are the oldest strata present and form the famous arch of Durdle Door. On the eastern side of the viewpoint, in the Man-O'-War cove, these beds can be clearly seen. Moving away from the sea, an unconformity lies between the Wealden Beds and the Purbeck Beds, but both strata are represented. The younger Gault can be identified by the basal pebble bed (Figure 17) and the Middle Chalk is found to be approximately vertical. Just above beach level, where the footpath to Lulworth Cove climbs up from St Oswald's Bay, oil can be seen seeping out of the Wealden.

Figure 16 View of the Durdle Door viewpoint looking south west over Durdle Cove.

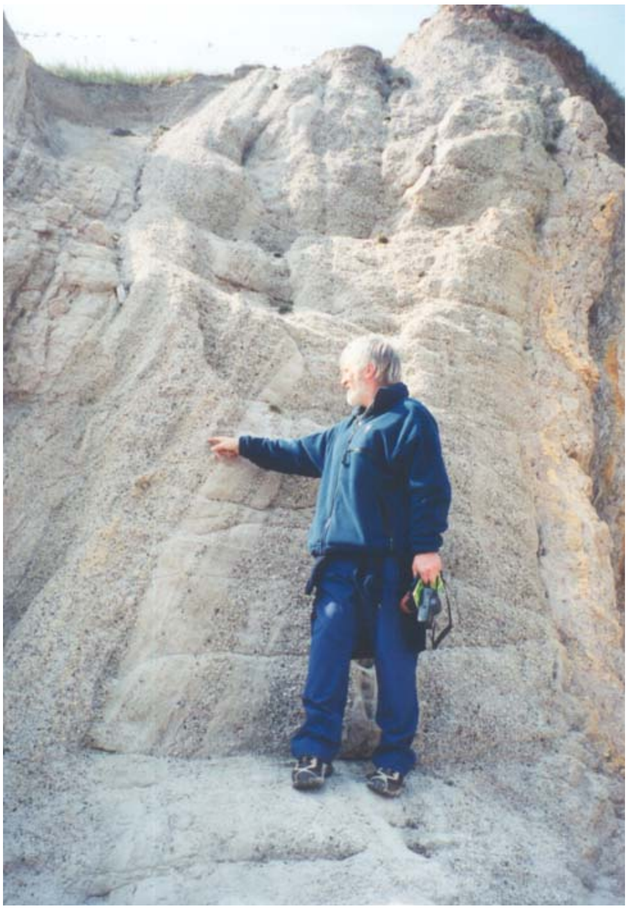


Figure 17 The basal pebble bed of the Gault.

On the western side of the viewpoint, in Durdle Cove, the same succession can be seen and the base of the Chalk is well exposed. The Chalk is vertical here and wave action has eroded along a thrust plane, forming hollows/caves, which can be seen in the cliff. Walking east, back towards Durdle Door, the Upper Greensand forms a prominent wall, dipping 77° south. Figure 18 demonstrates some of the features seen looking west along both sections of this coast either side of the Durdle Door viewpoint. The most accessible path to Lulworth Cove, begins from the Durdle Door viewpoint and traverses east along the cliffs.

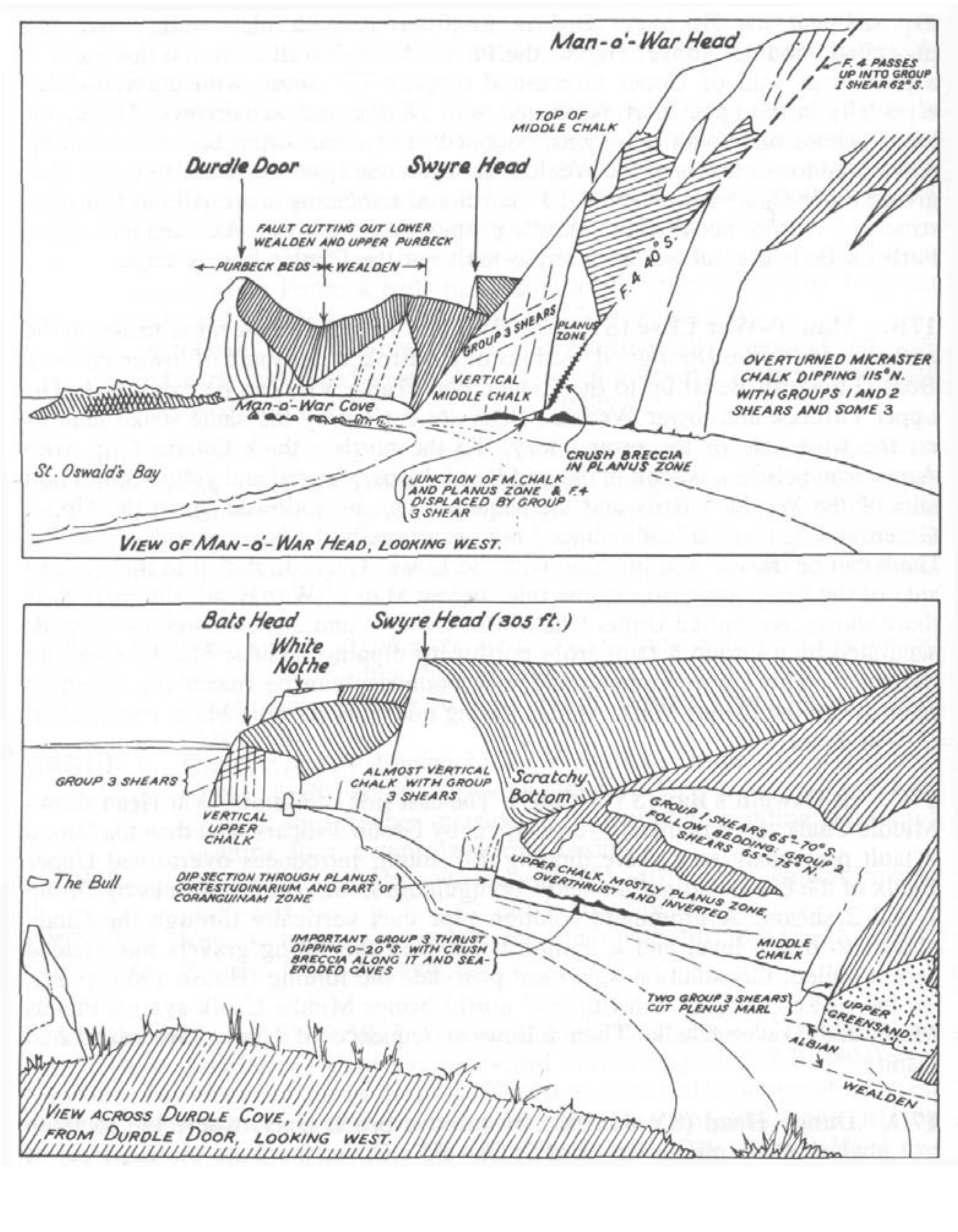


Figure 18 **The Dorset coast between Man-O'-War Head and Bat's Head showing features of geological interest (from House 1993). Reproduced with permission of the Geologists' Association.**

3.3.2 Lulworth Cove

Walking from Lulworth carpark down to Lulworth Cove, a large spring issues from the base of the aquifer, and forms a small river flowing towards the cove. Smaller springs can also be seen walking around the cove. The shape of Lulworth cove is not simply a result of marine erosion, but due possibly to a partially submerged river valley which has been eroded into a circular shape by fluvial and mass movement activity (Goudie and Brunsden, 1997).

At Lulworth Cove the Upper Jurassic and Cretaceous rocks of the middle limb of the Purbeck Monocline can again be seen (Figure 19). The strata form thicker units with a reduced dip compared to the geology seen at Durdle Door. Although the cliff behind Lulworth Cove comprises overturned Upper Chalk, a fault separates it from the Middle and Lower Chalk of the lower cliff which dips appoximately 55°-65° north (Figure 20). Towards the eastern horn of Lulworth Cove the Purbeck Beds can be seen again.

Walking up the west side of Lulworth Cove, you arrive at **Stair Hole**. A full sequence of the Purbeck Beds can be seen, with the contorted beds in the upper section referred to as the **Lulworth Crumple (**Figure 21). The folding and faulting of the Purbeck Beds in the Lulworth Crumple have been interpreted as a gravity collapse structure. The early stages of a coastal erosion sequence are seen here with tunnels breached through the Portland Stone to erode out the softer Purbeck and Wealden Beds.

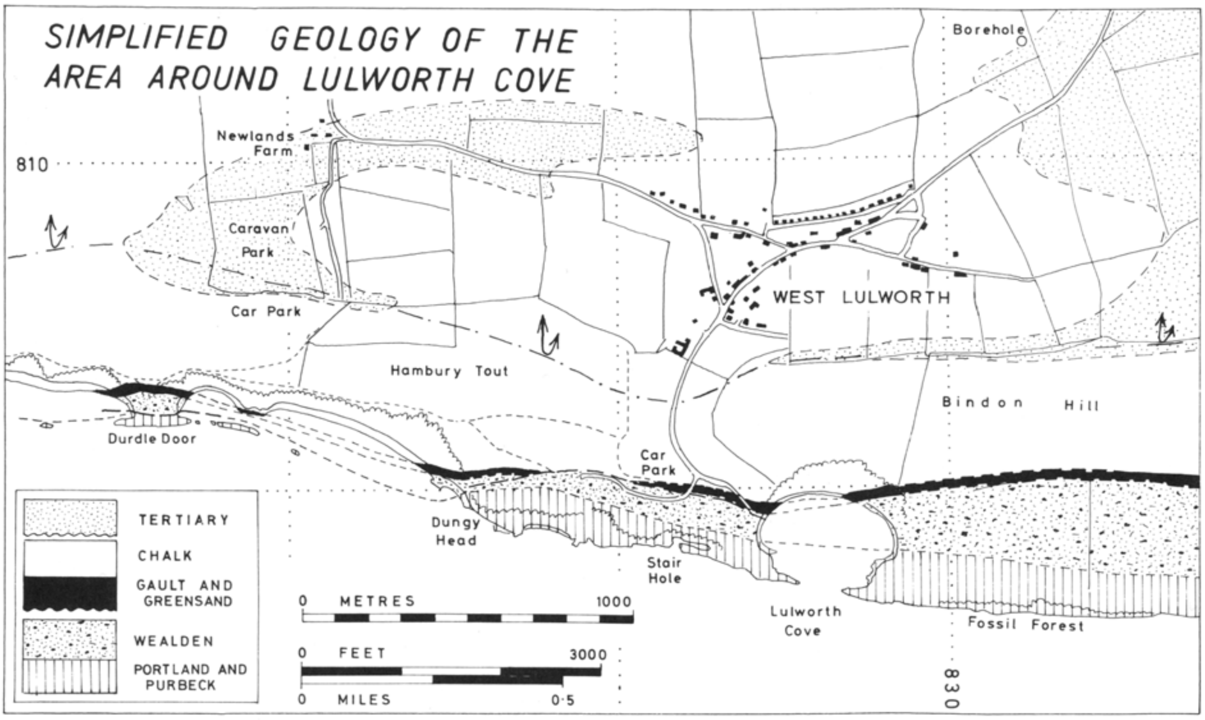


Figure 19 Geological sketch map of the Lulworth district (from House 1993). Reproduced with permission of the Geologists' Association.

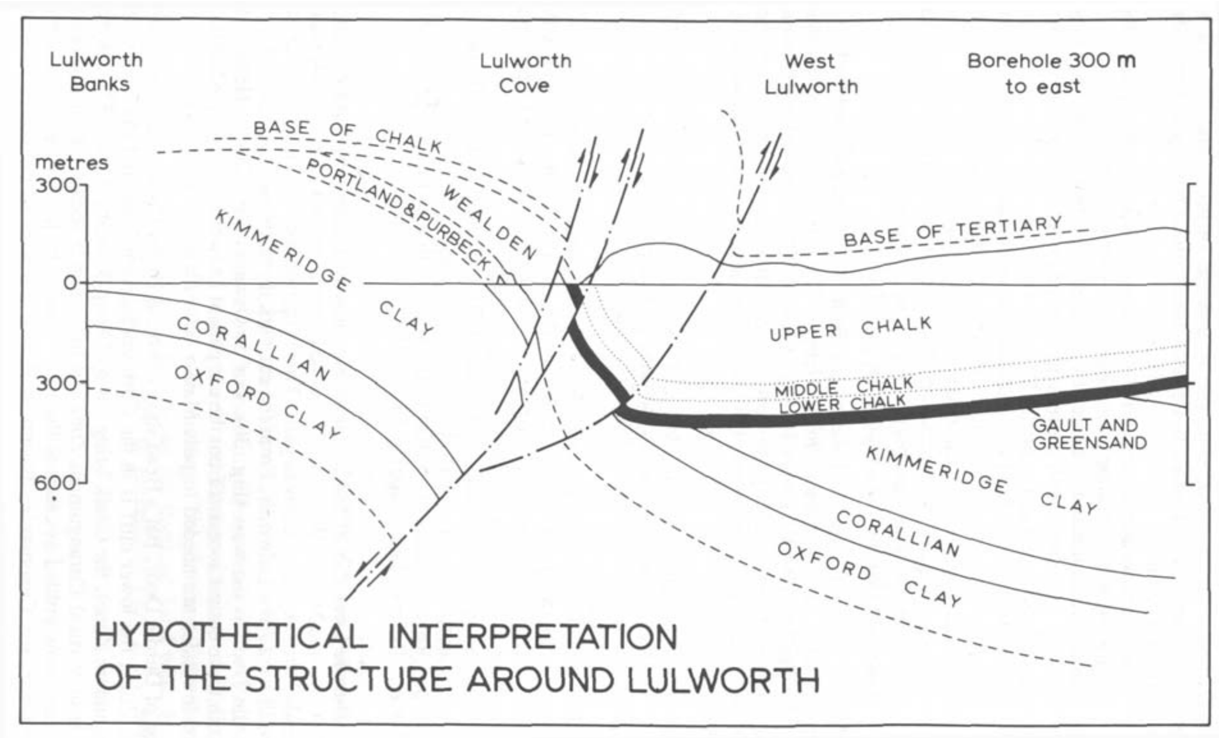


Figure 20 **Geological cross section north-south through Lulworth Cove, indicating the location of the Lulworth borehole (from House, 1993). Reproduced with permission of the Geologists' Association.**

Figure 21 **The Lulworth Crumple at Stair Hole.**

3.3.3 Lulworth Groundwater Scheme

In the vicinity of Lulworth groundwater flow divides are discordant with the surface water drainage pattern. This discordance was caused by coastal breaching of the aquifer resulting in reversal of flow i.e the direction of groundwater flow is towards the coast instead of towards the River Frome which the northward sloping topographic surface should promote (Alexander, 1981, Houston *et al.,* 1986). Groundwater contours for the area are given in Figure 22 and Figure 23. Significant groundwater discharges occur at the coast in the form of springs located at Lulworth Cove and Arish Mell and the total volume of water discharging to the sea is thought to be 40 to 50 Ml/d.

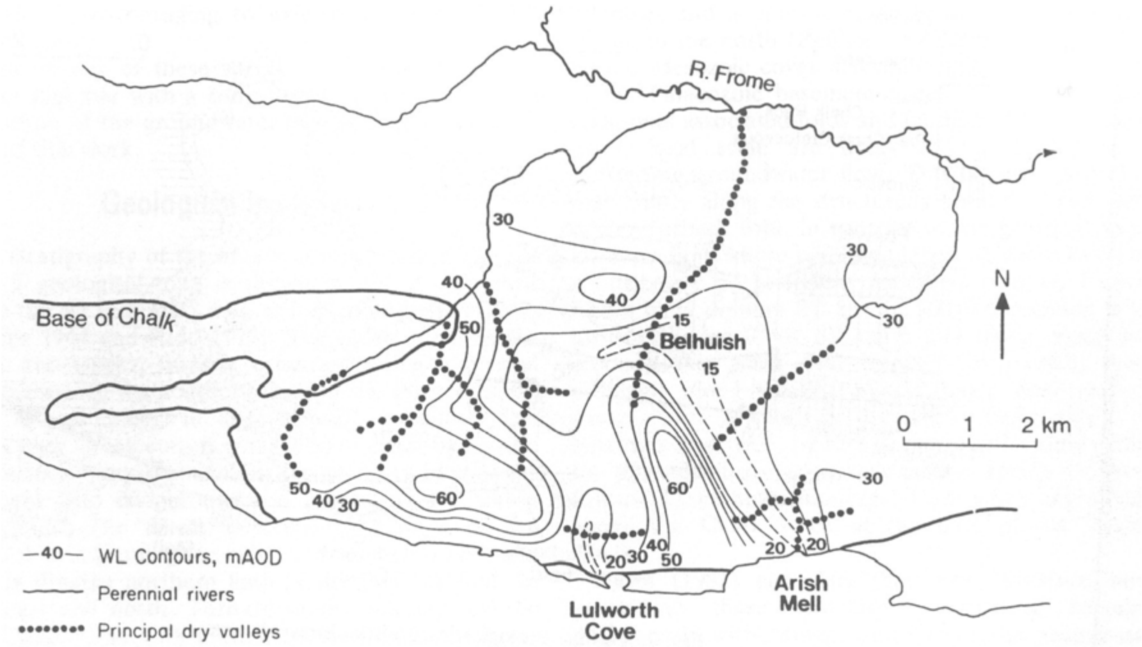
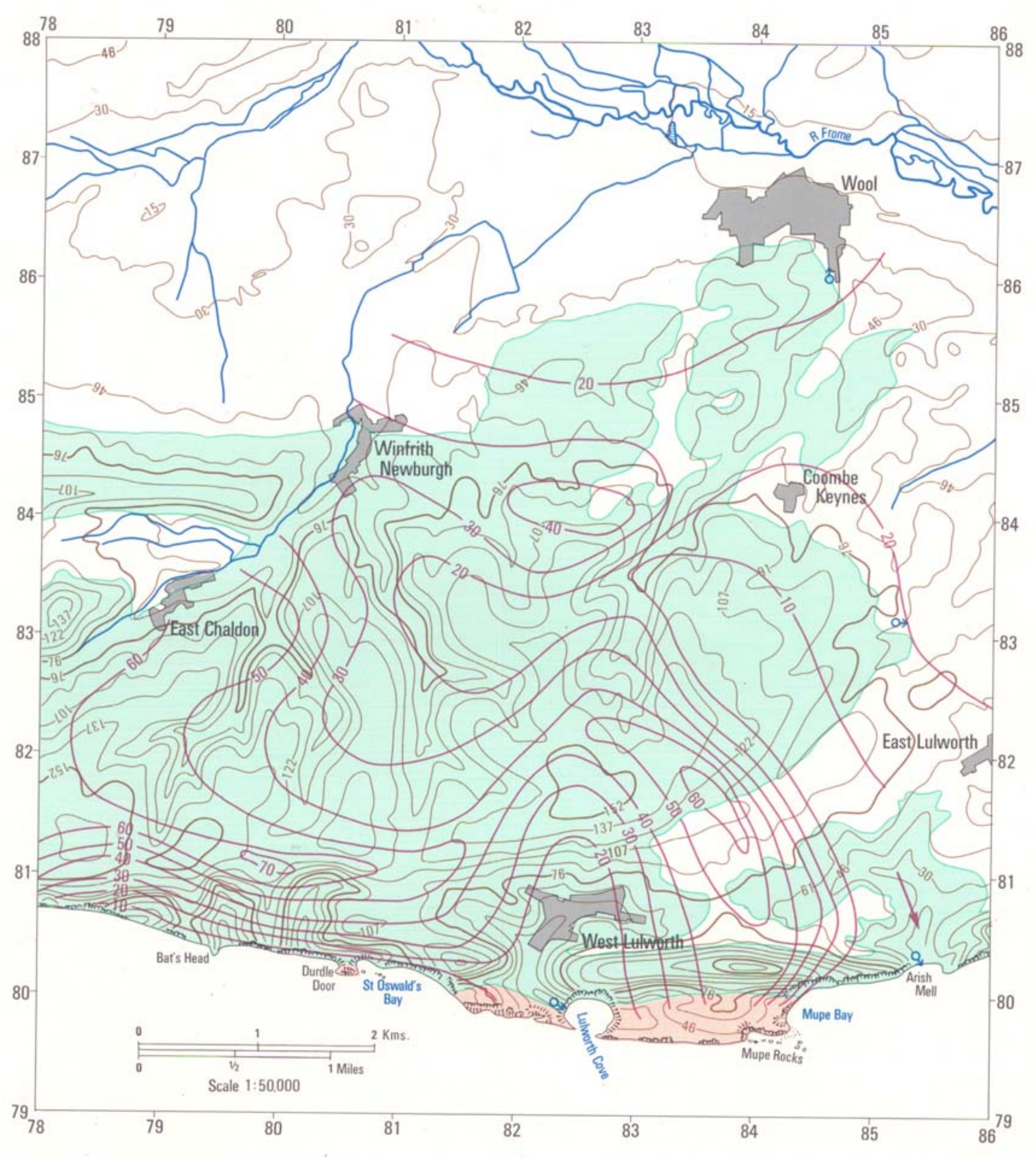


Figure 22 Contours on the surface on the water table for December 1982 (From Houston *et al.,* 1986). Quarterly Journal of Engineering Geology. Published with the permission of Geological Society Publishing House.

During the mid-1970's Wessex Water Authority began an investigation into the unconfined chalk aquifer at Lulworth, the main aim of which was to intercept groundwater resources that would be otherwise lost to the sea.

Evidence suggests that the bulk of the flow towards the coast occurs within narrow zones which resulted from sea breaching of the aquifer during the Holocene. This induced flow reversal, shifting the groundwater divide northwards and increased solution along NNW-SSE fault zones (Houston *et al.,* 1986) (Figure 24). A zone of enhanced flow has been demonstrated to exist between Belhuish (3 km inland) and Arish Mell using tracer tests and pumping tests. 13 ML/d was obtained from a pumping test at Belhuish at the expense of the discharge of the spring at Arish Mell. A similar zone of rapid groundwater flow exists at Lulworth Cove. Transmissivity values in these zones range from 1500 m^2/d to more than 2500 m^2/d and storage coefficients are from 0.0025 to 0.04 (Allen *et al.,* 1997). These zones have low hydraulic gradient and experience significant water level fluctuations in response to recharge.

Initial trial production boreholes designed to intercept this zone produced disappointing results. However, existing boreholes indicated that there was a correlation between high yielding fractures and low water levels and therefore further investigations employing the use of surface geophysics to identify these zones were conducted.



Key

WHITE	**Palaeogene**
GREEN	**Upper Cretaceous**
ORANGE	**Lower Cretaceous and Upper Jurassic**

Figure 23 **Lulworth groundwater investigation (from IGS and Wessex Water Authority, 1979).**

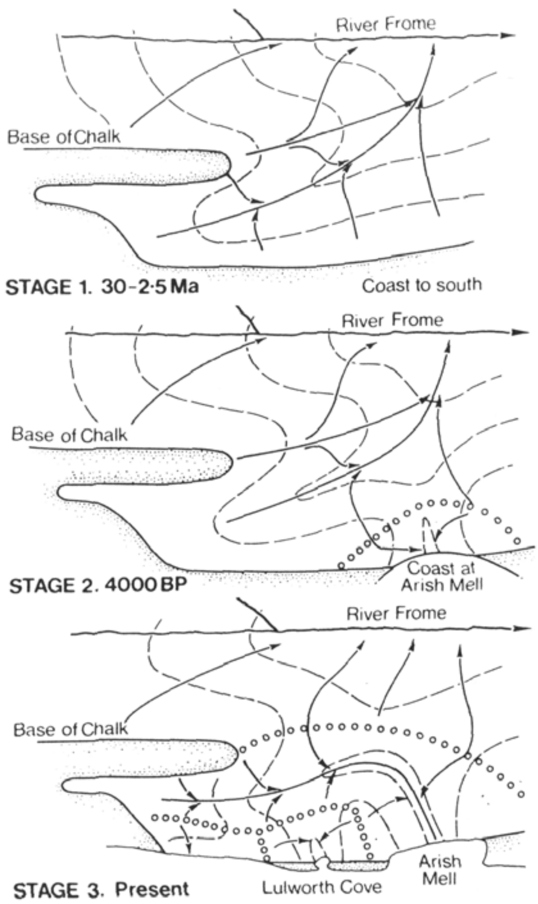


Figure 24 Stages in the postulated evolution of the groundwater flow regime [groundwater divides marked by lines of circles] (from Houston *et al.,* 1986). Quarterly Journal of Engineering Geology. Published with the permission of Geological Society Publishing House.

3.3.4 The Lulworth Borehole: Palaeohydrogeology

A research borehole was drilled to a depth of –170 m OD at West Lulworth, in the late 1970s to investigate the movement and quality of groundwater near the coast. Temperature, SEC and hydrochemical (interstitial water analyses) are shown in Figure 25. It is found that the base of the present-day flow system is at approximately –65 m OD as defined by the temperature profiles. Below this depth a very slight decrease in fluid conductivity is recorded which corresponds to chemical changes in the interstitial profile. Higher nitrate concentrations are found above 65 m confirming the penetration depth of modern groundwater. Below this depth baseline values occur. No radiocarbon data are available for this water but stable isotope results indicate a Holocene signature. Some suggestion of a more mature water is indicated by the pore water profile at a depth of below -140 m. It is probable that groundwater below –65 m OD to the total depth of -170 m, represents slower moving water of Holocene age, comparable to that found in the South Downs to the east of the Wessex basin. This water was emplaced at the time of lowered sea level, as the modern flow regime has been effective only for some 8000 years.

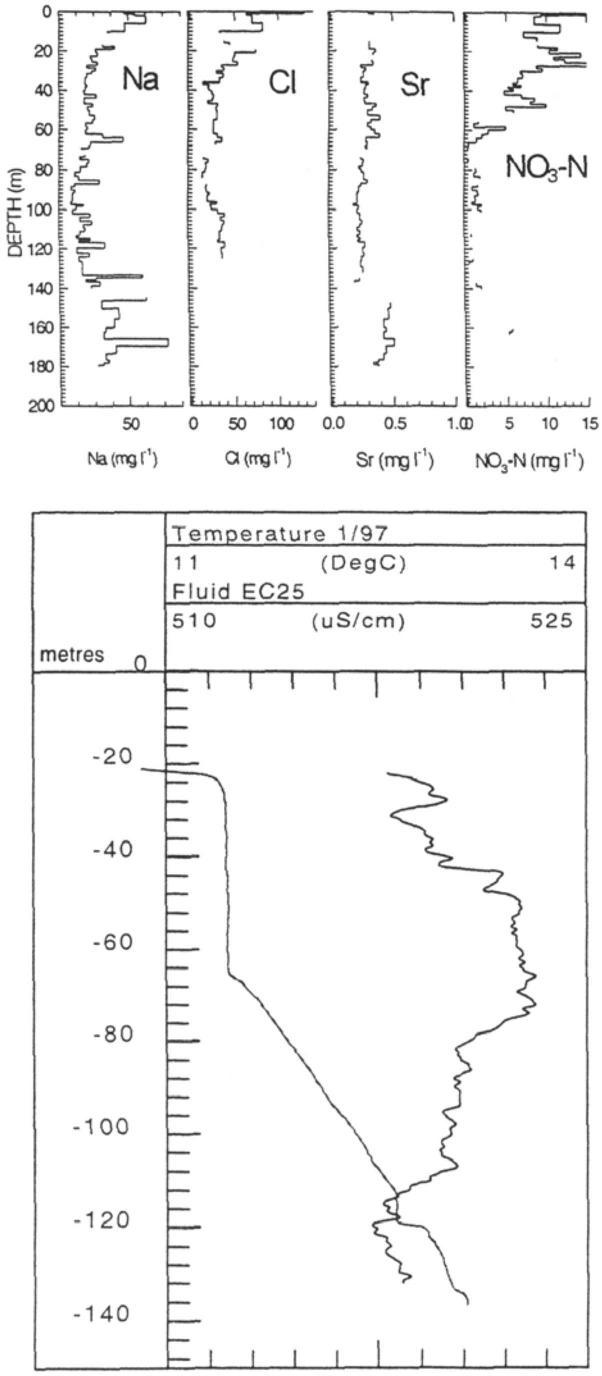


Figure 25 **(a) Interstitial water profiles and (b) recent geophysical logs for the Lulworth borehole (Edmunds *et al.,* 2001).**

OTHER FEATURES OF INTEREST

3.4 Oil Reserves in the Wessex Basin

The stratigraphic and tectonic characteristics of the Wessex Basin gives rise to a definable hydrocarbon system. Discoveries by the British Gas Corporation led to production from the Wytch Farm Field in 1973. It now forms the largest onshore oil field in the UK and is operated by BP.

The Sherwood Sandstone Group is the primary reservoir unit within the Wessex Basin and forms the main producing horizon within the Wytch Farm oil field. The facies includes conglomerate, fluvial and aeolian sediments and was deposited within an extensional basin, initiated by rifting of the crust in Britain and north west Europe.

Overlying the Sherwood Sandstone, the Mercia Mudstone Group forms part of a mudflat/playa lake succession, characterised by the development of evaporites towards the centre of the basin. The Bridport Sands (Lias) provide a secondary reservoir unit and the Lias marine mudstones form the key source rock within the region. In contrast, the overlying Oxford Clay and Kimmeridge Clay are found to be immature in the Wessex Basin. The geological evolution of the structure of the Wytch Farm oil field is illustrated in Figure 26 with the Portland Limestone now being the oldest lithology visible on the coast.

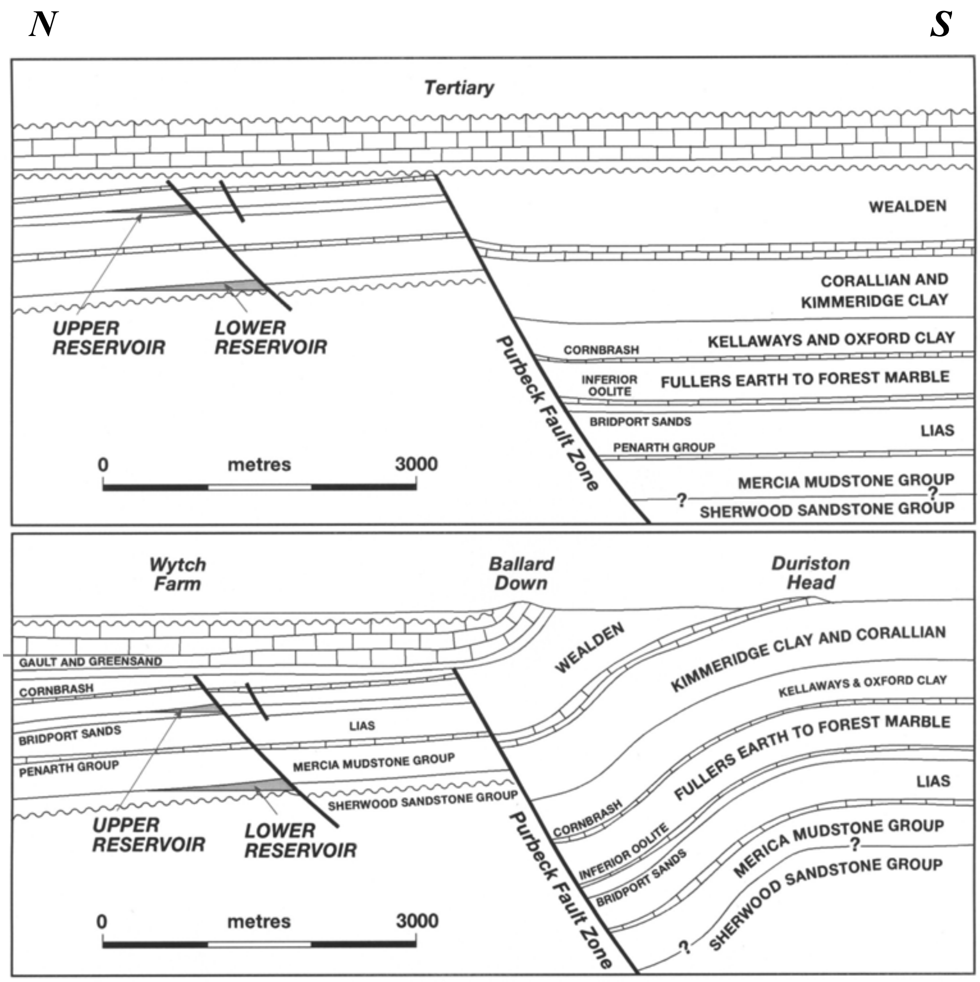


Figure 26 **Sections illustrating the geological evolution of the structure of the Wytch Farm Oilfield: Above; present day. Below; Tertiary, before alpine earth movements (from Colter and Harvard, 1981). This figure is reproduced with kind permission of the Institute of Petroleum (www.petroleum.co.uk)**

Early Cretaceous rifting represents a key event in the development of the Wessex Basin as an effective hydrocarbon system. Rift-related subsidence led to the initial maturation of the Lias and formed one of the primary trap-forming events that can be seen in the area. Tilt fault-block structures are found at Wytch Farm and post-rift thermal subsidence continued during the Late Cretaceous. Early Palaeogene subsidence led to the peak phase of oil generation. Significant regional uplift, resulting from Oligocene and Miocene inversion, terminated hydrocarbon expulsion from the Lias.

At Lulworth Cove some evidence can be seen of the initiation of hydrocarbon charge within the Wealden Beds. Further east, at Mupe Bay, oil-stained sandstone intraclasts are incorporated within Wealden fluvial channels, as illustrated in Figure 27.

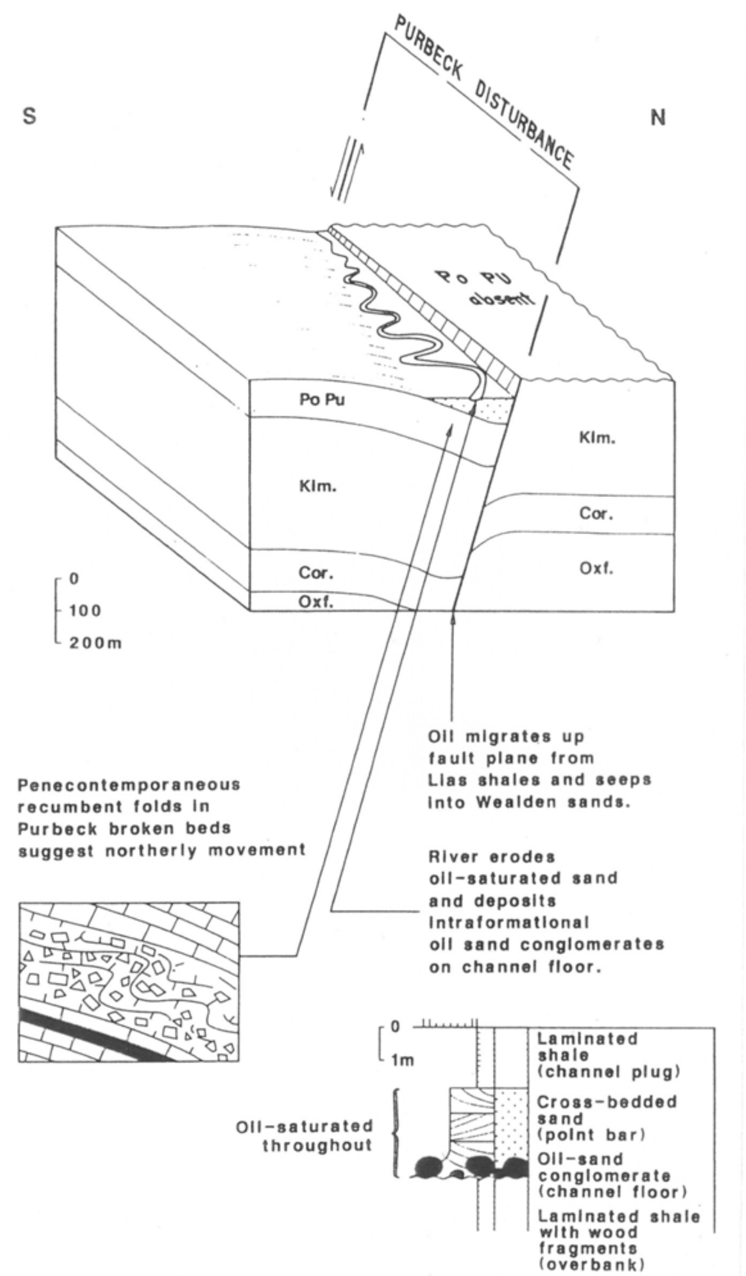


Figure 27 The Purbeck Fault and the Genesis of the Mupe Bay Palaeoseep (from Stoneley, 1982)

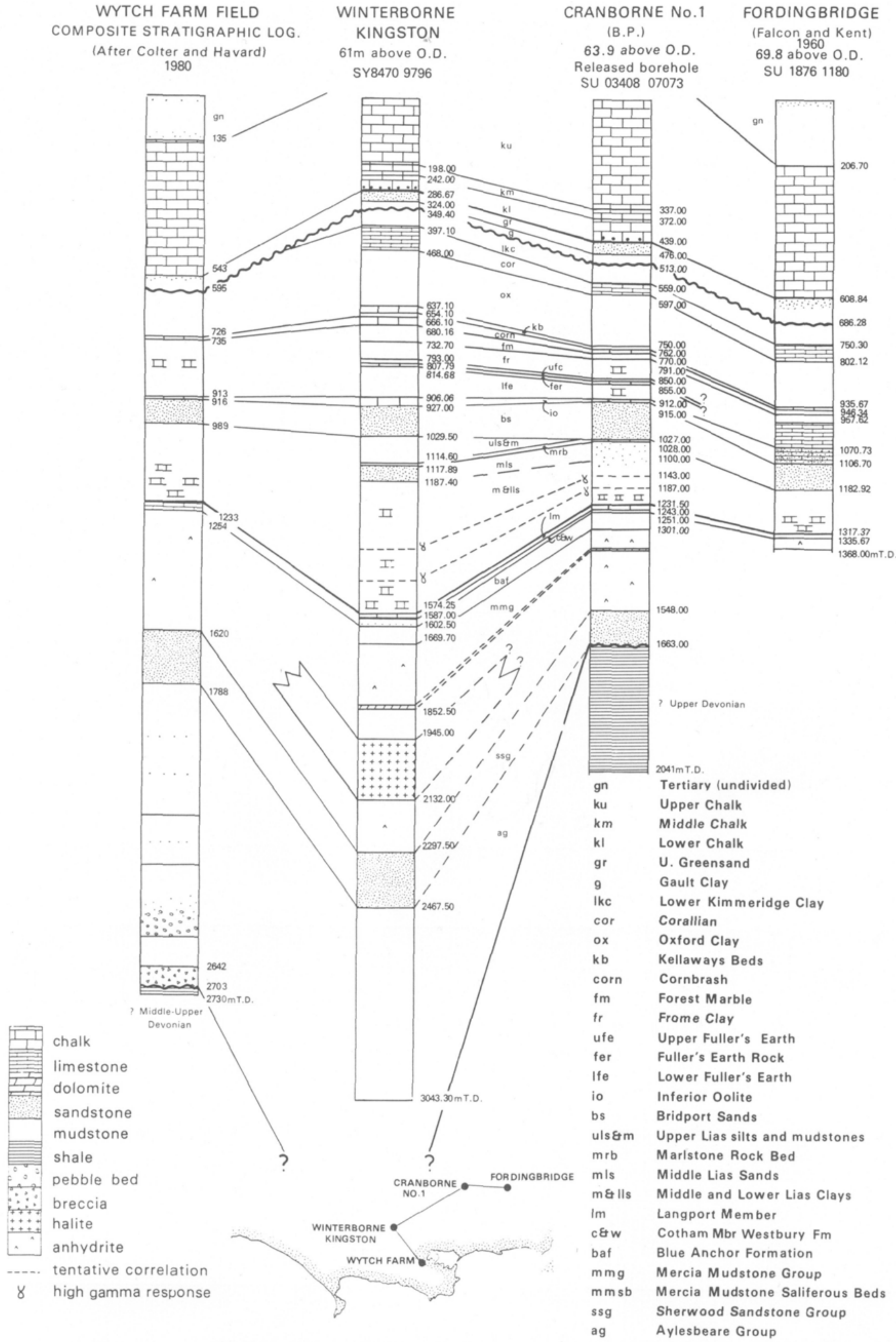


Figure 28 **A correlation between Winterbourne Kingston and adjacent deep boreholes (after Rhys *et al.,* 1982).**

3.5 Geothermal Energy

The Sherwood Sandstone represents the main geothermal potential in the Wessex Basin and exploration drilling was carried out at sites in the Wessex Basin and in Southampton during the 1980s. Considerable movement on faults across the basin has resulted in a variation in thickness of the strata and the majority of research has been concentrated in south Dorset, where the Sherwood Sandstone is up to 170 m thick. The thickest successions have been found in the Winterborne Kingston Trough (170 m) which was investigated for the geothermal and hydrocarbon potential.

The Winterborne Kingston Borehole log is given in Figure 28, where the top of the Sherwood Sandstone Group was at 2236 m below sea level. At this depth a drastic reduction in transmissivity was recorded due to the loss of fracture permeability and a reduction in porosity. The proximity of major growth-faults also caused adjacent strata to be heavily cemented forming a hydraulic boundary and producing disappointing results regarding the geothermal potential in the western area of the Wessex Basin.

However, production has been successful at Southampton where geothermal water has supplied part of the civic centre over the past decade (Barker *et al.,* 2000). The maximum recorded temperature at Southampton is 76.2 °C. Detailed analyses of the fluids for the Western Esplanade (Southampton) and Marchwood (test boreholes) are given in Table 3.

The isotopic analyses of geothermal waters and basinal brines in the Wessex Basin and also the Br/Cl plots are shown in Figure 29. The depleted bromide indicates the importance of formation halites in controlling the salinity. The explanation of the ^{18}O enrichment in the brines remains controversial. Figure 30 demonstrates the salinity of the area with maximum levels found near the Winterborne Kingston borehole.

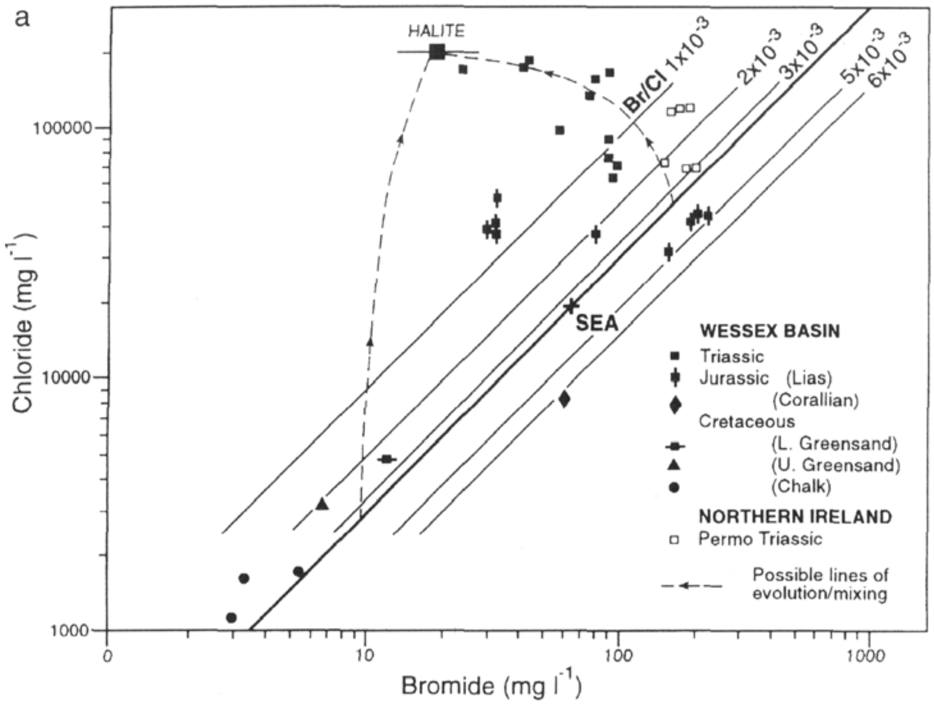


Figure 29 Bromide v. chloride in formation waters of the UK in relation to sea water: Mesozoic basins (from Edmunds, 1996b).

Table 3 **Geothermal Fluids from the Wessex Basin: Comparison of water from the Western Esplanade and Marchwood Wells (Southampton Area) (after Allen *et al.,* 1983).**

		WESTERN ESPLANADE PRODUCTION TEST	MARCHWOOD PRODUCTION TEST
Flow rate	(l/s)	20	29
Depth	(m)	1725 – 1791	1660 – 1719
Temperature	(formation)	76.0	73.6
Temperature	(wellhead)	74.9	71.6
pH	(wellhead)	6.0	6.75
pH	(laboratory)	6.1	6.9
Eh	(mV)	-200	-300
Density	(g/cm^3 @ 25°C)	1.088	1.079
SEC	(µS/cm @ 25°C)	155000	131000
Total mineralisation (mg/l)		124590	103370
Total suspended solids (mg/l)		<1.0	<1.0
Total alkalinity (mg/l)		111	124
MINOR AND TRACE CONSTITUENTS			
Ba^{2+}	(mg/l)	0.52	0.47
Li^+		31	22.6
NH_4^+		36	35
Rb^+		-	0.68
I^-		-	11.8
F^-		0.37	0.46
B		31	32.7
$Fe_{(total <0.45\mu)}$		4.1	4.2
$Mn_{(total <0.45\mu)}$		1.26	0.94
Ag		<0.01	<0.01
Be		<0.01	<0.002
Cd		<0.02	<0.02
Co		<0.05	<0.15
Cr		<0.05	<0.03
Al		<0.1	<0.07
Cu		<0.05	<0.01
Hg		<0.1	<0.03
Mo		<0.1	<0.03
Ni		<0.1	<0.05
Pb		<0.1	<0.1
Sn		<0.1	<0.1
Ti		<0.1	<0.01
V		<0.01	<0.006
W		<0.1	<0.07
Zn		<0.1	0.20
Bi		<0.1	<0.1
Y		<0.01	<0.001
U			0.03

		WESTERN ESPLANADE PRODUCTION TEST	MARCHWOOD PRODUCTION TEST
MAJOR INORGANIC CONSTITUENTS			
Ca^{2+}	(mg/l)	4240	3670
Mg^{2+}		752	658
Sr^{2+}		134	113
Na^+		41300	33240
K^+		705	582
HCO_3^-		71	81
SO_4^{2-}		1230	1400
Cl^-		75900	63815
Br^-		91	97
$Si_{(total)}$		17.8	15.5
ORGANIC ACIDS			
Acetic Acid	(mg/l)	40	43
DISSOLVED GASES			
N_2 volume %		74	77
CH_4		17.4	17.5
CO_2		6.7	4.5
Ar		1.0	0.8
H_2		0.6	0.5
INERT GASES			
^4He cm^3STP/cm^3H_2O		-	0.32×10^{-4}
Ne		0.36×10^{-7}	0.22×10^{-7}
Kr		1.37×10^{-8}	0.71×10^{-3}
Xe		0.25×10^{-8}	0.67×10^{-3}
Ar		0.66×10^{-4}	-
STABLE ISOTOPE RATIOS			
$\delta^{18}O$ SMOW		-2.2‰	-3.1 ‰
δ^2H SMOW		-35 ‰	-33 ‰
$\delta^{13}C$ PDB		-15.5 ‰	-15.8 ‰
RADIOISOTOPES			
^{222}Rn (pCi/kg)		154	100
^{226}Ra		39	34
$^{234}U/^{238}U$		2.09	1.76

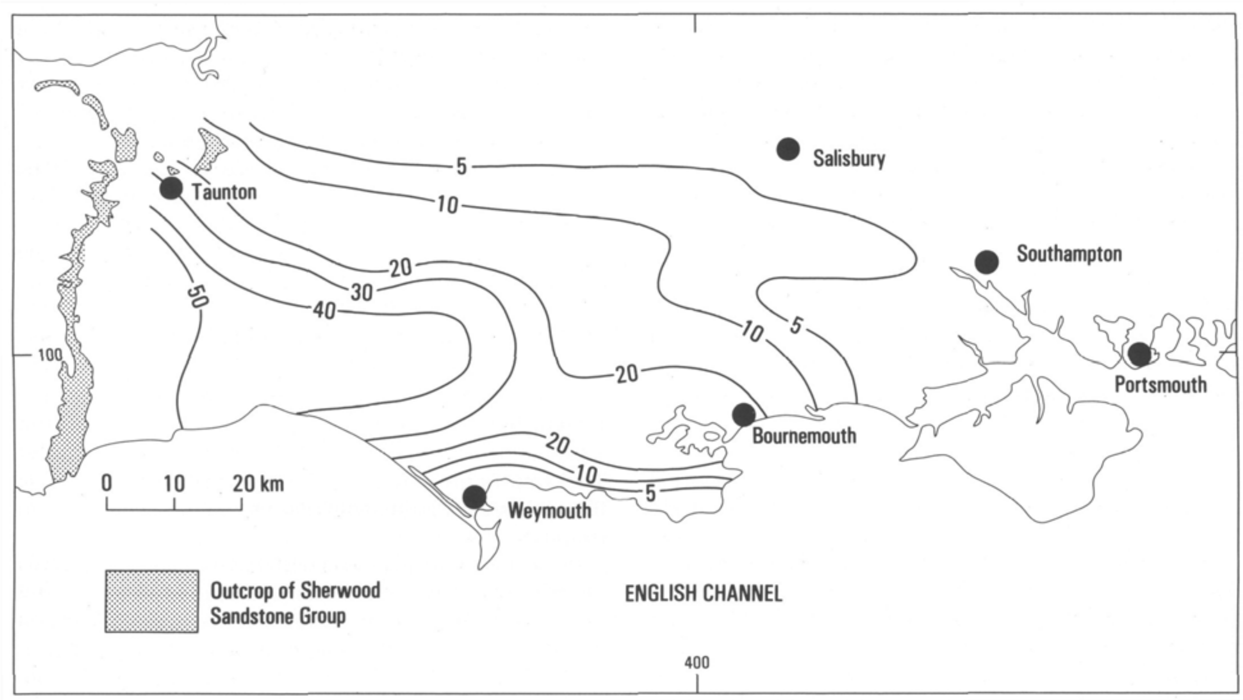


Figure 30 **Salinity of groundwater in the Sherwood Sandstone Group in the Wessex Basin [grams/litre] (after Downing and Gray, 1986).**

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