'Wonder-working water': the history and hydrogeology of the Chalice Well and other Glastonbury springs

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The Chalice Well occupies a prominent place in Glastonbury mythology. Used as a supply for the abbey from the 12th Century, in 1751 its waters became celebrated as a treatment for a wide range of ailments. A pump room and baths opened in 1753 but the waters rapidly lost their reputation largely because they were no different chemically from common spring water. Today the Chalice Well forms the centrepiece of a peaceful garden where the water is still revered for its healing properties. Modern mapping shows that the Chalice Well, White Spring, and other Glastonbury springs surrounding the Tor and Edmund Hill, all arise from the Pennard Sand. The main flow of most of these springs depends upon recent rainfall and flows vary seasonally. The exception is the Chalice Well where flow is relatively constant and is derived from storage. It discharges mature reduced groundwater which is brought to the surface along a fault. All the springs arise from the same aquifer but water at the Chalice Well differs because it has been in the aquifer for a longer period giving more time for water-rock interaction to occur.

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Introduction

Glastonbury presents two contrasting images to the world. On the one hand it is a traditional Somerset market town providing facilities to the local agricultural community and on the other a centre of myth and magic which caters to those seeking an alternative lifestyle. Mythological Glastonbury is based around two separate legends. Firstly, that in about 60 AD, Joseph of Arimathea was sent over to Britain at the head of 12 disciples bringing with him the Holy Grail, the sacred dish of the Last Supper. Settling in Glastonbury he built a wattle church, the first Christian church in the country. Secondly, that Glastonbury can be identified as the Isle of Avalon, the burial place of King Arthur, whose body was supposedly discovered in the abbey in 1191.

Knowledge of the early history of Glastonbury and its abbey is based mainly on a manuscript written by William of Malmesbury who stayed with the monks of the abbey in about 1129 (for translations and commentaries see Stokes, 1932 and Scott, 1981). Many monasteries rewrote their histories in order to exaggerate the antiquity of their foundation, and to add to the aura of sanctity that surrounded them, in the hope of attracting more pilgrims and revenue. This was particularly necessary at Glastonbury following the great fire which destroyed much of the abbey in 1184. William of Malmesbury's text began to be rewritten soon after its completion to include new stories and claims about the abbey's history and estates, a process which continued well into the 13th Century. Textual evidence leads to the conclusion that the claim of Glastonbury monks to King Arthur's grave was not put forward prior to the supposed discovery of his body in 1191 and that the legend of Joseph of Arimathea and the Grail was incorporated some 50 years later as a result of Joseph's close association with Arthur in Grail stories (for a discussion of the legends and their evolution see Robinson, 1926; Lagorio, 1971; Gransden, 1976).

Later in the 14th Century Glastonbury writers transmuted the Grail into two silver cruets, containing the blood and other body fluids collected during Christ's burial, perhaps because this was more acceptable than a claim to be the final resting place of the Grail, a claim made also by other European monastic establishments. Not even the dissolution of the abbey in the mid-16th Century could stop the legend-making process and a thorn tree, which flowered at Christmas time, was transformed into Joseph's staff driven into a hillside as he stopped to rest. In the mid 18th Century the water from a spring, which had been used by the abbey for centuries as a water supply, suddenly became a miracle cure for a variety of complaints. The spring water is mildly chalybeate and the dissolved iron oxidises on contact with the atmosphere leaving a red deposit in the channel, as water flows down the valley to the west of Glastonbury Tor (Figure 1). In places this deposit gives the appearance of clots of blood leading to its name, the Red or Blood Spring. Joseph is said to have buried the cruets (and/or Grail) in the vicinity of the spring which thereafter provided a constant flow of water tinged red by the healing blood of Christ. Because of this association with Joseph the spring is also known as the Holy Well or Chalice Well and the hill above the spring as Chalice Hill.

The Chalice Well is now surrounded by attractive gardens close to the junction of Wellhouse Lane and Chilkwell Street. It is looked after by a trust which organises events celebrating the cycle of the year as well as retreats and healing sessions. Water from the well differs from that from other springs which surround Glastonbury and its Tor in its chemistry and relatively constant flow. The present paper reviews the history of this interesting groundwater source and investigates why there should be these differences, which have given the Chalice Well its unique place in Glastonbury mythology.

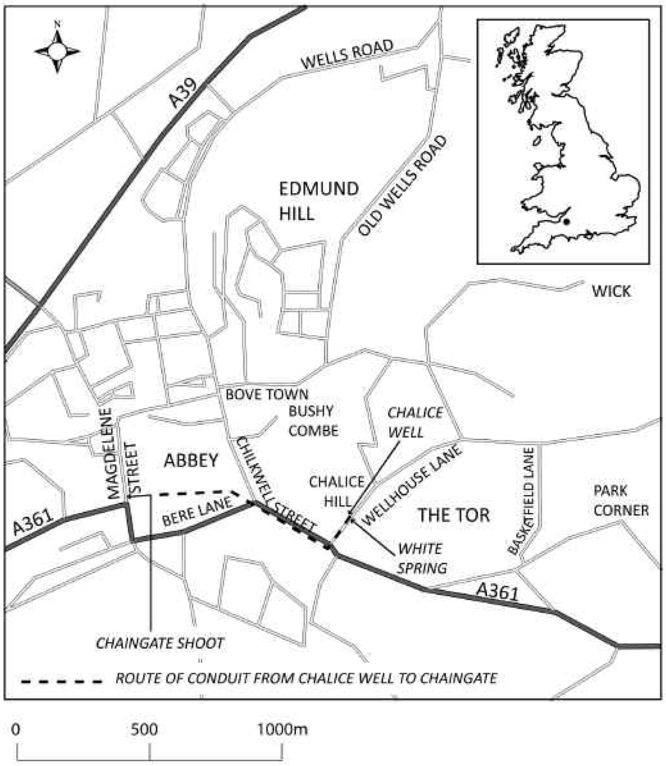

Figure 1. *Map of Glastonbury and its Tor showing localities mentioned in the text.*

History of the Chalice Well

Although only in use for around 250 years, the name Chalice Well is used in the following account as this is the name by which the well is currently known. Excavations around the well in 1961 found 20 flints whose small size was suggestive of a Mesolithic date (8500-4000 BC) and a few Iron Age, Roman and medieval sherds (Rahtz, 1964). This implies no more than a few casual visits to the site with no evidence of permanent settlement. The well was found to be constructed from large squared blocks of locally sourced Blue Lias limestone with a total depth of 9 ft (2.74 m). The excavations suggested that the present wellhead was possibly a hole made in the roof of a small, free-standing, late 12th Century well-house which had been gradually inundated by fine sand and silt washed down from the hill above. The current well shaft is thus the walls of this original well-house with a contemporary ground level some 8 ft (2.44 m) below the current level (Rahtz, 1964). This would be also the elevation of the 12th Century spring discharge.

Excavations at the abbey have shown that, in the 12th Century, the water supply was drawn from sources northeast of the abbey church (Rahtz, 1964), perhaps from springs in Bushy Coombe or on the west side of Edmund Hill (Figure 1) from which water was later piped to public conduits in the town (Clark, 1821). Following the 1184 fire, a water supply was drawn from sources further to the south and it seems probable that the medieval well house at Chalice Well dates from this time, with water fed by gravity to the abbey which is over 30 m lower than the well. The discharge still follows its medieval route to the abbey. It joins that from other springs, close to the junction of Wellhouse Lane and Chilkwell Street, from where it flows below ground, parallel to Chilkwell Street, crossing the eastern end of Bere Lane into the south eastern corner of the abbey grounds (Figure 1).

In one of the Arthurian interpolations in William of Malmesbury's text a hermit is explaining to Walwan, Arthur's nephew, *'…the mystery of a particular fountain, the water from which continually changed its taste and colour…'* (Scott, 1981 p.47). This may be the first written reference to the Chalice Well. In the collection of charters, tithe deeds and related documents belonging to the abbey, the well is variously recorded as Chalcwelle, [document 558, *c.* 1210], Chalcwell' [document 633, August, 1256], Chalwelle [document 461, April 1305], Chakwelle [document 464, November 1305] and Chalkwell' [document 462, January 1306] (Watkin, 1952). These names reflect the chalky or calcium bicarbonate-rich nature of the water.

Following the dissolution of the abbey in 1539, and the execution of the last abbot, most of the abbey buildings were gradually destroyed and the stone used elsewhere. Water continued to flow from the Chalice Well towards the abbey ruins where it flowed through the grounds, exiting on the western side close to Chaingate on what is now Magdalene Street (Figure 1). However, there is no evidence that it was regarded as anything other than a useful water supply. Celia Fiennes, traveller and inveterate imbiber of mineral waters, visited Glastonbury in 1698 and ascended the Tor. Her diary refers to the abbey and to the holy thorn but makes no mention of the well (Morris, 1947). Early editions of Daniel Defoe's tour guide mention a spring, half way up the Tor, but assign no special properties to it (Defoe, 1748). Medicinal waters are recorded at both Alford and Queen Camel in south east Somerset by Allen (1699) who would surely have noted any noteworthy source at nearby Glastonbury. Similarly early treatises on chalybeate waters (Linden, 1743) and early Glastonbury guidebooks (Eyston, 1722) omit any mention of a medicinal or healing spring. All this was to change in 1751 when, for a few years and on the basis of a dream, Glastonbury was briefly invaded by the sick and infirm in their search for a miraculous cure.

The dreamer was Matthew Chancellor, from the parish of North Wootton, about 7 km to the northeast of Glastonbury. His story first appeared in local newspapers and in the pages of the *Gentleman's Magazine* for 1751, and has since been retold by many authors (e.g. Collinson, 1792; Wright, 1887; Hembry, 1990; Stout, 2008). Chancellor had suffered with asthma for 30 years until, around the middle of October 1750, he had a violent fit during the night. He swore on oath that he subsequently fell asleep and dreamt that he was in Glastonbury, in the horse track some way above Chaingate. Here he saw some of the clearest water he had ever seen in his life and knelt down to drink. As he stood up again he sensed someone standing before him who instructed him to drink a glass full of the water issuing from an adjacent freestone shoot [a sloping channel for conveying water to a lower level]. He was told that if he did this for the following seven Sunday mornings, before he had eaten and without being seen, he would be cured. He asked why seven days and was told that the world was made in six and on the seventh God rested and blessed this day above all other days. He was further told that the water came from holy ground where many saints and martyrs had been buried.

According to his sworn statement, Chancellor followed the instructions carefully and went the following Sunday to Glastonbury where he found the freestone shoot exactly as seen in his dream. Unfortunately there was little water flowing in the shoot and he had to dip his glass three times into the hole below it in order to drink the equivalent of a full glass! However, he persevered for seven Sundays as directed and was completely cured.

According to Stout (2008) the earliest published accounts in local newspapers, of the miraculous cures effected by the waters, do not mention Chancellor's dream. However, it seems that by mid-March 1751 a sizable number of people had embarked on a programme of Sunday drinking. Following publicity concerning the dream and the nature of the cures, people began to flock to Glastonbury. According to a report in the *Gentleman's Magazine* over 10,000 people were there on Sunday 5th May 1751 to drink the waters. Every inn and house in the town and the surrounding farms and villages were crowded with lodgers and guests.

Pamphlets publicising the waters began to appear. In the form of a letter to a lady, the Reverend J. Davies, of Plympton in Devon, gave a detailed account of the sites used for drinking and suggested a regime for their consumption (Davies, 1751). An anonymous '*inhabitant of Bath*', who had a child suffering from the King's Evil (a disease with glandular swellings, probably a form of tuberculosis) visited Glastonbury to discover if the waters had cured anyone with this disorder. His pamphlet (Anon, 1751a) includes an account, written by an *'ingenious and worthy clergyman to a friend'*, first published in the *Sherbourn and Yeovil Mercury* on the 29th April 1751. Later in 1751, a history of Glastonbury written by an anonymous '*physician*', included an account of the properties and uses of the mineral waters (Anon, 1751b). All the accounts give case histories of successful cures. An analysis by Stout (2008) yielded 72 attested cures involving 99 different ailments with many individuals having more than one complaint !

Chancellor's dream was quite definite in that the water should be drunk at the freestone shoot at the Chaingate and this seems to be where the majority of drinkers congregated. The 'ingenious and worthy clergyman' was unable to get nearer than ten yards to the Chaingate Shoot even as early as 04.00 am on a Sunday morning (Anon, 1751a). When he eventually got a glass of water he found it differed little in taste from common spring water. He followed the channel back to its source, which he called the Bloody Well, at the foot of the Tor, where he found mineralised water.

The Reverend Davies also traced the water back to its source at the Bloody Well which he found to be about 7 ft (2.1 m) deep (Davies, 1751). He reported that over the well had been lately built a large house, designed as a pump room, although no evidence of this remains and it may not have got past the planning stage. Davies recognised that the water which flowed to the Chaingate was in fact derived from a number of springs apart from the Bloody Well. These consisted of another strong mineral spring about 50 or 60 paces (approximately 40 to 50 m) away and two springs of '*soft common water*' similar distances away which all joined about '*six score paces*' (*c*. 60 m) from their respective sources to form the stream which eventually discharged at the shoot near Chaingate (Davies, 1751, p.4). By the time it reached the Chaingate any taste of the mineral had long gone which led him to question the best place to drink the water.

The anonymous physician (Anon, 1751b) also recognised that the water at the Chaingate spout was a mixture from a number of springs which joined at the foot of the Tor. He observed that the essential difference between the water at the two places was that, at the spout, the water had been *'rendered weaker by dilution and leaving some of its mineral qualities behind it'* (Anon, 1751b, p.51). His account is of particular interest because the source well is described as the Blood or Chalice Well. As noted by Stout (2008) this is perhaps the first time that the name Chalice Well appears in print.

If one believed that the water had medicinal properties, more benefit was likely to be gained by drinking it at the Chalice Well rather than the Chaingate Spout. However, it was the latter which developed as the favoured site for drinking. The belief seems to have been that the water owed its virtue to some property it acquired through passing over the graves of holy men rather than to its mineral content. Superstition rather than common sense prevailed leading to a lively correspondence in the *Gentleman's Magazine* in the latter part of 1751. On the one hand, there were those who evaporated the water finding in it nothing which was not present in common spring water and, on the other, those who justified Sunday drinking at the spout with the claim that the specific gravity of the water increased every Sunday.

Despite its detractors, water from both the Chaingate and springhead (Chalice Well) was soon available in London. Bottles from the latter were on sale through an enterprise established by the novelist, entrepreneur and social reformer Henry Fielding and his brother John, who had strong local connections (Stout, 2008). The 1961 excavations at the Chalice Well (Rahtz, 1964) showed that, adjacent to the 12th Century well shaft, there was a second chamber present on the western side reached through an opening at the base of the shaft. The lower parts of the walls of this chamber are not older than the 17th Century and probably date from *c*. 1750 (Rahtz, 1964). The purpose of this inner chamber is unclear; Rahtz suggested that it may have served as a sedimentation tank to ensure a clean supply from the outflow but it seems equally possible that it was constructed as a reservoir for the 1751 bottling operation.

The 18th Century saw the development of small provincial spas in many parts of England (Hembry, 1990). The publicity surrounding Matthew Chancellor's dream presented a business opportunity which was exploited, not by the usual local gentry or medical practitioners but by a woman, Anne Galloway. Previously she had kept a shop in Cheltenham and had probably run a lodging-house in Bath, so knew something of spa towns (Hembry, 1990). In June 1752 she put advertisements in West Country newspapers announcing the forthcoming erection of a pump room and baths and the *Gentleman's Magazine* for February 1753 reproduced an elevation of this new pump room (Figure 2). In its edition of August 1753 the *Magazine* announced that on Sunday 12th August 1753 *'Was opened the pump room at Glastonbury with a concert of vocal and instrumental music, at which were upward of a thousand persons'*. The pump room was almost opposite the Chaingate Spout on the west side of what is now Magdalene Street. It was not a new building but the conversion of a series of pre-existing cottages by the addition of classical façades. These façades are largely unchanged today (compare Figures 2 and 3) and the discharge from the spout still passes beneath the building, flowing above ground through the garden, westwards to the River Brue.

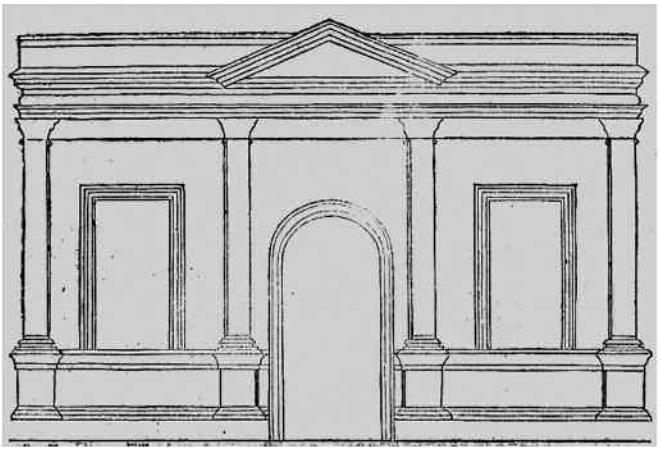

Figure 2. *'Elevation of a pump-room erecting at Glastonbury. This room which is 24 feet square, with other accommodations, such as walks, gardens, etc is preparing for the ensuing season at the expense of Mrs Anne Galloway....' From the Gentleman's Magazine for February 1753 p.64.*

Figure 3. *The Old Pump House at Glastonbury as it is today, with classical facades superimposed on existing cottages.*

The spa was not successful and, certainly by 1779, the waters had '*entirely lost their reputation*' (Collinson, 1779, p.229). A visitor reported that *'All th[at] remains of the former notice taken of these waters, is a neat and commodious pump-room, built at the expence of a lady; but is now converted into a shop'* (Saunders, 1780, p.18). Perhaps like Alford to the south, 70 years before (Mather and Prudden, 2005), the lack of suitable accommodation and services and the presence of large numbers of poor country people frightened away the fashionable clientele who could have made the spa a success. In addition, Matthew Chancellor's dream, with its connotations of Glastonbury's Catholic past, was derided by many as a scheme trumped up to bring custom to the town, which had dwindled since the demolition of the abbey (Collinson, 1792). Being branded as a gullible fool would hardly have encouraged patrons to visit the spa.

However, the underlying problem was that the water from the Chaingate Spout, which supplied the pump room, appeared to be no different from common spring water. As Samuel Bowden concluded in a poem first published in the Bath Journal in June 1751 and later in an anthology (Bowden, 1754, p.63);

'Water that has intrinsic merit,
Needs no support from dream, or spirit.
True virtue in this fountain lies,
Without imputed sanctities;
Founded on solid fact, and cure,
This only will its fame secure;
Fixt on this basis, 'twill not mock us,
But all the rest is Hocus Pocus.'

A number of prominent chemists and physicians analysed the spa waters. In the second edition of his *Treatise on Chalybeate Waters*, Linden reports on experiments on a bottle of water bought in London. In all his trials he *'….never could discover the least Mineral Contents it had….'* (Linden, 1752, p.338). In July 1751 seven bottles were sent to Dublin where the water was analysed by the English born, Irish based, Quaker physician, Dr John Rutty. A gallon of the water yielded, in different trials, 24 and 36 grains of sediment, equivalent to 343 and 515 mg/l of total dissolved solids (TDS) respectively (Rutty, 1757). The Lewes physician, Richard Russell, who pioneered the drinking of seawater and sea bathing as treatments for a wide range of ailments, averaged these analyses quoting a figure of 30 grains per gallon, equivalent to a TDS of 430 mg/l. He concluded that *'the infatuation [with this water] is now over and it is generally thought to be no better than any other common water'* (Russell, 1760, p.296).

Based on the publication of an anonymous guidebook in 1792 (Anon, 1792), Hembry (1990) suggests that an attempt was made to revive the spa towards the end of the 18th Century. However, the account of the mineral waters does not refer to the pump room or to the Chaingate Spout but to the iron rich waters at the Chalice Well. The cheap format of the guidebook (Stout, 2008), suggests that it was not aimed at the gentry who might have frequented the pump room, but at those of a less genteel disposition who frequented a public house, called the Anchor, which had existed next to the Chalice Well since 1768. It seems that, although the spa close to Chaingate was not sustainable, the Chalice Well continued to attract common people who were able to drink the water free of charge. The site was probably poorly maintained and when Samuel Saunders visited the spring he found it *'in a state of equal ruin with the rest [of the town]'* (Saunders, 1780, p.17).

In the first half of the nineteenth century the Chalice Well continued to be mentioned in local guidebooks and the water retained something of its former reputation. The source was described as '*under a high bank*' from where water was carried by a pipe across the road where '*baths and accommodations*' had been built, although, *'few persons avail themselves of these conveniences and they are little frequented'* (Phelps, 1836 p.556). Phelps' account is interesting as it implies that the water for the baths was obtained from the other side of the road (now Wellhouse Lane, Figure 1), possibly from one of the other springs described by Davies (1751). Chalybeate waters are not favoured for bathing as iron hydroxides are precipitated rapidly on exposure to the atmosphere forming a brown scum which many bathers would find objectionable. It seems possible that the baths built in the Chalice Well grounds were supplied by water from a non-chalybeate spring, with water from the Chalice Well reserved for drinking.

In contrast to the '*few persons*' noted by Phelps, the local antiquarian George Wright quotes a friend who remembered *'when Chilkwell Street was lined every Sunday morning with all kinds of conveyances from the neighbouring villages, bringing those who desired to drink, or bathe in, the waters'* (Wright, 1887, p.34). Towards the end of the century guidebooks briefly mentioned the mineral waters rising at the foot of the Tor but there is little reference to people still drinking the waters. The Anchor Inn became the Tor House Inn and then simply Tor House, suggesting that, as drinking the waters went out of fashion, the public house was no longer a viable concern.

Tor House and the Chalice Well came into the ownership of George Wright and his diaries (Wright, 1822-1890) contain details of overtures which were constantly being made to him by Glastonbury Corporation who wished to buy the spring for use as a town water supply. He found their attentions a constant source of annoyance and worry and when he finally agreed to sell asked for much more money than they could raise. Eventually in 1886 he sold to a religious community and Tor House became the Roman Catholic Missionary College of the Sacred Heart. The Chalice Well was supposedly accessible *'at any time to friendly antiquarians'* (Wright, 1887, p.35), but visitors were not always made welcome and often turned away (Fletcher, 2006). The area around the well became forlorn and unkempt, and the well itself was covered by an unhinged wooden slab.

In 1912 the site, which now included a seminary building, was purchased by Alice Mary Buckton, who moved there with her partner, Annet Schepel, the following year. They renamed the site Chalice Well and ran a series of summer schools where the emphasis was on drama and the performing arts together with traditional crafts (Mathivet, 2006). Buckton became one of a group of spiritually motivated individuals, known as the Avalonians, inspired by the legends and mystical history of Glastonbury.

The Chalice Well itself was important to Buckton. She believed in the healing properties of its waters and began work to create a garden surrounding the well as a place of peace and quiet reflection. In 1919 another Avalonian, Frederick Bligh Bond the excavator of Glastonbury Abbey, presented her with a wrought iron symbol of two overlapping circles pierced by a lance which was attached to the lid of the well. Bligh Bond was an enthusiast for what was later termed '*sacred geometry*' (Gilbert, 2004) and this symbol is still used in the garden today (Figure 4). Buckton gathered about her a small group of craft workers who used traditional methods; for example pottery was made from clay dug in the orchard and thrown on a primitive kickwheel (Mathivet, 2006). Small beakers, which may have been made for drinking the water, can still be found at local antique fairs today (Figure 5).

In the final years of her life Buckton became frail and was looked after by friends. She directed that a trust should be formed to ensure the future of her estate. However, the seminary building had already been leased to a boys' school and was sold to them in 1949, five years after her death, on condition that the well would remain accessible to visitors. In 1959 a second trust was formed through the initiative of a friend of Buckton, the spiritualist and early British member of the Bahai Movement, Wellesley Tudor Pole, and the property was repurchased. The boys' school closed in the 1970s and the old seminary building and Tor House were demolished (Mathivet,

Figure 4. *The Chalice Well in January 2009, showing the symbol of two overlapping circles, pierced by a lance, attached to the lid of the well.*

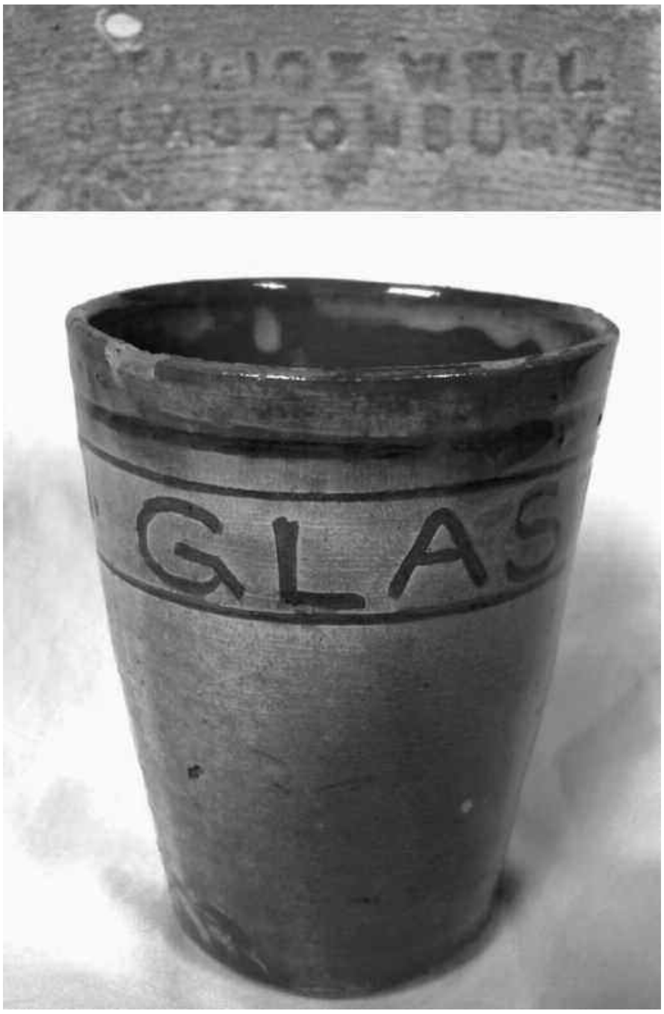

Figure 5. *Small (10 cm tall) earthenware beaker, in the possession of the author, with "Chalice Well Glastonbury" impressed in the base. The style of the beaker and the lettering suggests late 1920s or 1930s.*

2006). Over the intervening years successive guardians, employed by the trust, have continued to maintain and develop the Chalice Well itself and the gardens into the attractive and peaceful place it is today.

Some modern accounts of the Chalice Well (Hardcastle, 1959; Mann and Glasson, 2005) have connected it with the Elizabethan scientist and magician, Dr John Dee (1527-1608). In 1583 his magical assistant and medium, Edward Kelley (1555-1597/8) supposedly found a red powder or elixir, claimed to be a sample of the Philosopher's Stone, which turned base metal into gold. The story circulated that the elixir had been found *'in some part of the Ruines of Glastenbury-Abbey'* (Vaughan, 1652 p.481). However, this seems to be yet another Glastonbury legend introduced because the resting place of King Arthur and the birthplace of English Christianity was the perfect setting for the discovery of such a magical artefact (Woolley, 2002).

Geology and hydrogeology

The currently available Geological Survey map is rather dated. Published in 1969, it is a compilation of mapping undertaken between 1867 and 1872 supplemented by some later work carried out in the 1950s. However, the Glastonbury sheet has been the subject of a recent mapping programme and preliminary results from this are available (Figure 6 from Bristow, 2008). The oldest rocks exposed in the area immediately around the town of Glastonbury are from the Green Ammonite Bed, the upper member of the Jurassic Charmouth Mudstone Formation, previously known as the Lower Lias Clay. These silty mudstones have a thick weathering profile of grey and yellow clay and underlie the abbey and much of the western part of the town. Groundwater within these mudstones is invariably brackish or saline. This was demonstrated, in about 1790, when a pit was sunk in an attempt to discover coal at Glastonbury. *'After cutting through the surface of black mould, a stratum of clay, and another of marle, in which were numerous resemblances of crushed snail shells [ammonites], there was found, instead of coal a salt spring, which might perhaps have been valuable, but the mining was discontinued and the pit was soon after filled up'* (Clark, 1821, p.24).

Overlying the Green Ammonite Bed and usually distinguished from it by a prominent feature break is a silty and sandy mudstone assigned to the Dyrham Formation (Bristow, 2008). This is equivalent to the Middle Lias silt and clay on the 1969 geological map. Around Glastonbury Tor there is a median unit of coarse silt/very fine-grained sand known as the Pennard Sand which is about 20-25 m in thickness and is well exposed in some of the deeply cut lanes in the town.

The Dyrham Formation is overlain by the Junction Bed, now known as the Beacon Limestone Formation (Cox *et al*., 1999), which is divisible into a basal ferruginous oolitic limestone (Marlstone) and an upper micritic limestone (Eype Mouth Member). This is 1 to 3 m thick on the Tor and is succeeded by the Down Cliff Clay a silty mudstone about 25 to 30 m in thickness. Some 25 m of fine-grained sandstone, the Bridport Sand, the highest unit of the Lias, caps the Tor.

The Bridport Sand is an important aquifer in Dorset and South Somerset (Evans, 1993; Shand *et al*., 2004). However, the limited extent of its outcrop on the summit of the Tor means that it is unlikely to make a significant contribution to the discharge from local springs. Both the Junction Bed and the Pennard Sand crop out over significant areas to the north of the Tor and on Edmund Hill (Figure 6). It is suggested that these sediments together with the silty/sandy mudstones of the upper part of the Dyrham Formation can be regarded as one hydrogeological unit which discharges towards the base of the Pennard Sand close to its junction with the underlying mudstones, where discrete springs occur. The nature of the Pennard Sand, which varies from well cemented sandstones to clay-rich friable sandstones, will produce significant anisotropy within the aquifer.

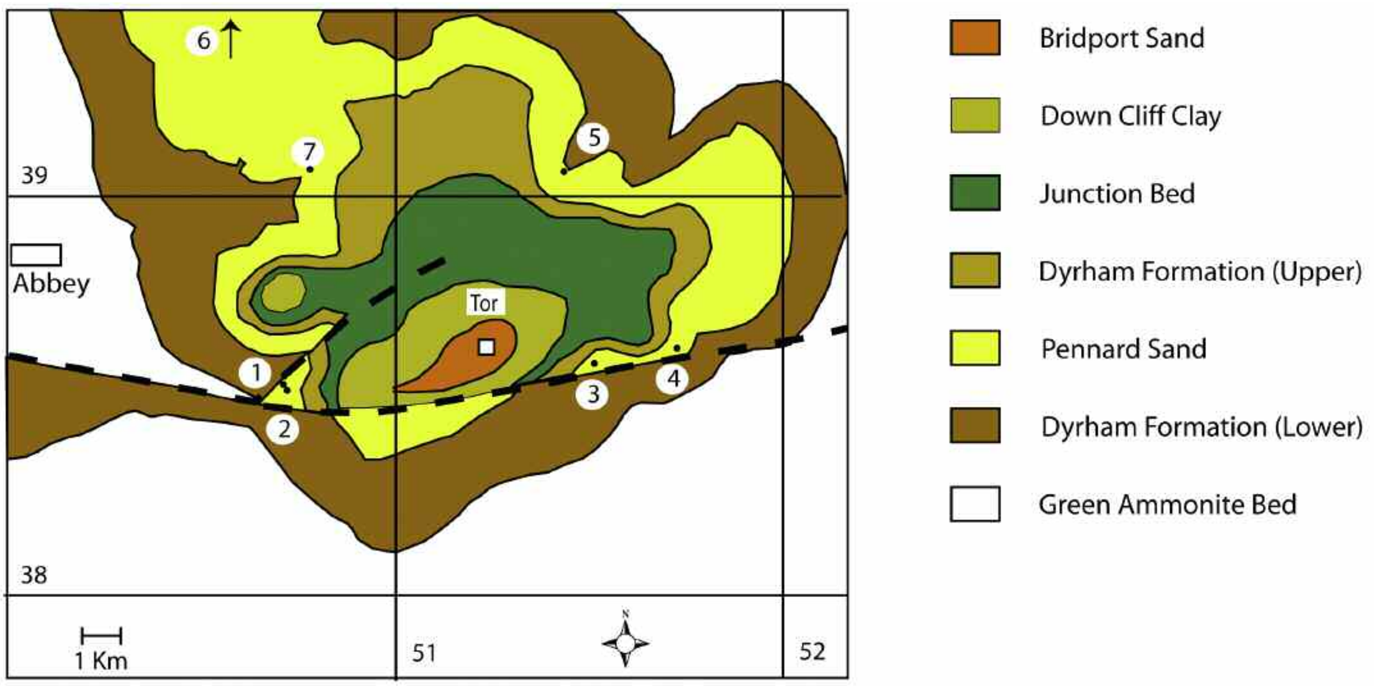

Figure 6. *Generalised geological map of Glastonbury and its Tor showing the position of the major springs (after Bristow, 2008). 1-Chalice Well; 2-White Spring; 3-Ashwell Springs; 4-Park Corner Farm B/H; 5-Wick Valley Springs; 6-Edmund Hill Springs; 7-Bushy Combe Springs.*

Perhaps the most significant feature revealed by the new mapping is an approximately east/west trending fault, which skirts the southern flanks of the Tor (Figure 6). With a down throw to the north, the fault probably plays an important role in the movement of groundwater within the sediments. The more permeable Pennard Sand to the north is faulted against poorly permeable mudstones of the Dyrham Formation to the south and where Pennard Sands crop out to the south of the fault they abut the Down Cliff Clay to the north. Thus movement of Pennard Sand groundwater across this fault is likely to be severely inhibited.

The distribution and flow of the springs

There are numerous springs both around the Tor and Edmund Hill, which all arise from the Pennard Sand. Traditionally these formed the main source of water supply to Glastonbury until continuing growth meant that more copious and reliable supplies had to be sought. These were derived from springs and boreholes around the villages of West Compton and Pilton, some 10 km to the east-north-east, from the end of the 19th Century (Richardson, 1928). Historical data on the springs are given in two memoranda from the Borough Surveyor's Office at Glastonbury, dated 11th March 1898 and 10th June 1948 respectively, which are preserved in the Well Record Collection of the British Geological Survey at Wallingford. Information from the 1898 memorandum was used by Richardson (1928) when writing the *'Wells and Springs of Somerset'*.

The best known of the springs is the Chalice Well (ST 507 385), which rises in a valley separating the Tor from Chalice Hill (Figure 1), and whose history has been discussed earlier. At the close of the 19th Century the yield from the spring was said to be constant at about 23 000 gallons per day (gpd) (105 m^3/d). The flow in 1948 varied from 25 000 to 20 000 gpd (114 to 91 m^3/d) and more recent measurements show that the flow varies from a peak of approximately 25 000 gpd (114 m^3/d) to a low of 18 000 gpd (82 m^3/d) in a dry summer (Mann and Glasson, 2005). In both 1898 and 1948 the local council was purchasing water from the spring during the summer months when supplies were short. During the excavations of 1961, yellow micaceous sandy shales with some harder intervals, assigned to the Middle Lias, were seen *in situ* in the three highest trenches, between 50 and 100 m upslope from the Chalice Well to the west of Wellhouse Lane (Rahtz, 1964).

Less than 100 m from the Chalice Well, on the opposite side of Wellhouse Lane, is another source. Called the Wellhouse Spring by Richardson (1928), it is now known as the White Spring (ST 507 387) and flows into a stone and brick reservoir dating from 1872 (Figure 7). The flow is derived, not from one discrete spring, but from four springs which mix before discharging into the reservoir (Mann and Glasson, 2005). The main spring has been captured by an adit driven westwards into the hillside in the direction of the Tor. One or more of the springs is mildly chalybeate and the discharge into the reservoir is marked by a deposit of iron hydroxide. It is tempting to equate the springs which flow into the reservoir with those described by Davies (1751) as joining the flow from Chalice Well in Wellhouse Lane.

Figure 7. *Stone plaque on the outside of the reservoir which receives the flow of the White Spring, giving the date of 1872.*

A description of Wellhouse Lane in around 1850, prior to construction of the reservoir, is given by Wright (1890). *'There was a copse of small bushes on the right hand running up the hill, and through it could be, not seen, but heard, the rush of running water, which made itself visible as it poured into the lane. But the lane itself was beautiful, for the whole bank was a series of fairy dropping wells – little caverns clothed with moss and verdure, and each small twig and leaf was a medium for the water to flow, drop, drop, drop, into a small basin below. This water contained lime, and pieces of wood or leaves subject to this dropping became encrusted with a covering of lime.'* The origin of the name White Spring is clear from this description.

In 1898 this spring formed the chief supply to Glastonbury. Yields varied from 60 000 to 90 000 gpd (272 to 409 m^3/d) but dropped to 26 000 gpd (118 m^3/d) and less following dry weather. By 1948 the spring formed a minor component of the council's supply with yields as low as 5 000 gpd (22 m^3/d) in the summer. In the 1980s the spring and reservoir passed into private hands and a few years ago the water was bottled and marketed as Glastonbury Spring Water. Currently it has passed to a group calling itself *'The Companions of the White Spring'* who have removed internal structures from the reservoir with the intention of creating a 'water temple' by 2012. Although Richardson (1928) thought that the White Spring issued from the Bridport Sand, modern mapping shows that both the White Spring and Chalice Well discharge from a small outcrop of Pennard Sand, to the west of the Tor, which is faulted to the north and south against poorly permeable mudstones of the Dyrham Formation (Figure 6).

To the east of the Tor where sands are again faulted against mudstones another spring, or group of springs, occurs (Figure 6). Called the Ashwell Springs by Richardson (1928) water was collected from gathering pipes laid about 4 ft (1.2 m) below the surface. In the late 19th Century this spring yielded as much as 100 000 gpd (455 m^3/d) during winter months but could be dry for 2 or 3 months over the summer. By 1918 the spring had ceased to be used for public supply. It was not possible to identify this exact locality but during the early months of 2009 water was flowing from a spring on Basketfield Lane (ST 515 384) just north of Ashwell Lane close to the line of the fault (Figure 6). Historically, further east at Park Corner Farm (ST 518 385), there was also a spring. The farm now houses a processing plant which bottles Glastonbury Spring Water. Originally bottling water from the White Spring, the company now obtains water from a borehole into the Pennard Sand immediately north of the farm and the fault. Water from this borehole is mildly chalybeate and iron has to be removed prior to bottling.

Continuing around the Tor, on its north-eastern side, are the Wick Valley Springs (ST 516 391) (Figure 6). In the wet season of 1897 there was a flow of 100 000 gpd (455 m^3/d) but by July this had dropped to 8000 gpd (36 m^3/d). To the north of Glastonbury water from springs on Edmund Hill (ST 505 398), supplemented by water from a spring at Bovetown (exact location unknown), once supplied a conduit at the top of the High Street and subsequently was piped into the general supply. By the end of the 19th Century flows were weak varying from 30 000 gpd (136 m^3/d) in winter to 4 000 gpd (18 m^3/d) in dry seasons. Flows were even less by 1948 and the springs were discontinued as a public supply source at about that time. In this area there is also a spring known as the Holy Well (ST 510 394) although the reason for this attribution is unknown. Inspection of a spring on the flanks of Edmund Hill, above the cemetery (ST 505 399), in March 2009 showed an area of seepage, rather than a discrete spring.

Another spring important in the history of Glastonbury is the Lambrook Spring (ST 507 390), the source of the stream which flows down Bushy Combe to the north of Chalice Hill (Figure 6). This entered the abbey grounds at their northeastern corner and Launder Close, adjacent to the stream, marks the traditional site of the abbey laundry. This stream might also have supplied the monks' washroom in which there was *'….a great cistern or conduit, with several cocks, which was always supplied with water….'* (Eyston, 1722, p.69).

The significant characteristic of the majority of the springs is the wide seasonal variations in flow. There may be a ten-fold difference between winter flows and flows following periods of dry weather at the end of the summer. The notable exception is the Chalice Well where the flow is relatively constant regardless of the time of year or weather conditions.

GROUNDWATER CHEMISTRY

On 23rd January 2009, samples for geochemical analysis were collected from a number of springs, including the Chalice and White Springs, the spring on Basketfield Lane to the east and from two springs in Bushy Combe. The latter included the spring at the head of the Combe together with a discharge part way up its steep southern slope. Analysis for major species was carried out in the School of Geography at Exeter University. Cations were determined using atomic adsorption spectrophotometry and anions colourometrically using an autoanalyser. Analytical data are presented in Table 1, together with an analysis of the water from the borehole at Park Corner Farm provided by the Glastonbury Spring Water Company and a partial analysis from Chalice Well, including some trace element data, carried out by Somerset Scientific Services, which was obtained from the Gatehouse at Chalice Well Gardens. The final column of Table 1 shows the mean of some 50 analyses of groundwaters from the Bridport Sand quoted by Shand *et al.* (2004). Sampling was carried out during a very wet period and a further set of samples were collected 2 months later, on the 30th March 2009, following two weeks with little rain. Data from these latter samples are presented in Table 2. There are no fundamental differences between the two sets of analyses. In both sample runs the method used for NO_3 analysis was not sensitive at low concentrations and inconsistencies in the SO_4 data mean that anion ratios have not been used in the following discussion.

Many modern descriptions of the Chalice Well characterise its waters as high in iron but even a perfunctory visual appraisal of the amount of iron hydroxide deposited in the channels leading away from the well suggests that it is only mildly chalybeate. Measured concentrations of some 1 mg/l compare with 27 mg/l at Tunbridge Wells (Fuller, 2004) and concentrations as high as 76 mg/l in the Brighton Chalybeate (Marcet, 1805).

In the absence of anthropogenic contamination, groundwater composition is determined by rainfall whose chemistry is modified within the soil zone, by water-rock interaction at the soil/bedrock interface and longer-term reactions as water moves along flow paths within the saturated zone (Edmunds and Shand, 2008). The chemistry of the spring waters is dominated by high concentrations of Ca and HCO_3 demonstrating that the dominant control on the groundwater chemistry is the dissolution of calcite in the aquifer. However, the analyses show some subtle differences and can be divided into 2 groups. Group 1 includes the bulk of the springs with Group 2 including the Chalice Well and the Park Corner Farm Borehole. The Group 2 analyses are distinguished by Fe concentrations of around 1 mg/l, higher Mg/Ca and Na/Cl ratios, lower nitrate concentrations and higher Sr concentrations than the Group 1 waters. The spring at the head of Bushy Combe (Bushy Combe 1 in tables 1 and 2) contains high concentrations of NO_3, K, and Cl and is affected by agricultural or urban contaminants.

CO_2 produced within the soil zone produces a weak acid which dissolves carbonate minerals during recharge. Congruent dissolution occurs such that the groundwater assumes cation ratios similar to those in the source carbonate. As groundwater moves along the flow path, diffusive exchange with the soil zone becomes negligible. Incongruent dissolution becomes dominant, where impurities in the solid phase are progressively released and a purer mineral produced (for a discussion of these reactions see Edmunds and Shand, 2008). In the Pennard Sand aquifer the carbonate is likely to be

Species	Chalice Sampled Sept '08	Chalice Sampled 23.1.09	White Sampled 23.1.09	Basketfd Lane 23.1.09	Bushy Combe 1 23.1.09	Bushy Combe 2 23.1.09	Park Corner Farm BH	Bridport Sands mean
as mg/l								
Ca		103	99.1	92.6	99.3	86.3	105	115
Mg		19.4	9.0	7.4	11.5	10.1	16.4	5.9
Na		25.1	13.6	12.5	21.3	14.1	46.4	22
K		2.7	1.3	1.5	13.4	2.1	3.12	2.4
as _g/l								
Fe	1000						867	133
Al	5						173	29
Mn	76						110	29
Sr		625	522	496	382	300	653	348
B							374	58
as mg/l								
Cl	24	23.8	17.9	16.3	28.6	23.3	21	28
SO_4							53	50
HCO_3		354	336	301	281	224	441	297
NO_3	0.30	3.4	6.4	6.4	37.9	5.4	0.20	22.1
pH	6.9	7.02	7.35	7.19	7.8	6.75	7.15	7.15
Molar Ratios								
Mg/Ca		0.31	0.15	0.13	0.19	0.19	0.26	0.08
Na/Cl		1.63	1.17	1.18	1.19	0.93	3.41	1.21

Table 1. *Analyses of springs sampled on 23rd January 2009 following a wet period, together with other hydrochemical data.*

Species	Chalice Sampled 30 3 09	White 30 3 09	Basketfd Lane 30 3 09	Bushy Combe 1 30 3 09	Bushy Combe 2 30 3 09
As mg/l					
Ca	99.1	96.3	93.5	105.5	97.7
Mg	20.9	10.8	8.8	13.2	12.4
Na	26.4	16.3	13.3	25.1	17.2
K	3.4	1.8	1.3	10.6	1.7
as mg/l					
Cl	23.6	19	18	33.3	27.1
SO_4	77	47	26	75	58
HCO_3	400	371	352	283	352
NO_3	3.1	4.1	4.1	21.3	4.1
Molar Ratios					
Mg/Ca	0.35	0.18	0.16	0.21	0.21
Na/Cl	1.72	1.32	1.14	1.16	0.98

Table 2. *Analyses of springs sampled on 30th March 2009 following a period of two weeks with little rain.*

ferroan low-Mg calcite which is known to be the most significant authigenic mineral in the overlying Bridport Sand (Evans, 1993). Young groundwaters will have Mg/Ca ratios characteristic of the low-Mg calcite. With continuing dissolution, a lower-Mg calcite will be produced and the Mg/Ca ratio in groundwaters will increase. Group 1 groundwaters are characterised by a mean Mg/Ca ratio of 0.16, but this increases in the Group 2 waters to as high as 0.31 at Chalice Well. This is interpreted to mean that the Group 2 waters are more geochemically mature and have had a longer residence time than the Group 1 waters. A similar argument can be advanced with respect to Sr, the higher concentrations in the Group 2 waters being indicative of longer residence times.

In Britain rainfall originates mainly from the sea and carries with it an aerosol composition dominated by Na and Cl, with a molar ratio of around 0.86. Table 1 shows that the ratio in all the groundwaters is above this and, as Cl is unreactive, this indicates a source of Na other than rainfall. The excess Na could derive from the dissolution of albite, known to be present in the overlying Bridport Sand at concentrations of up to 7% by volume (Evans, 1993), or by cation exchange. Whichever of these processes is responsible, the higher Na/Cl ratios in the Group 2 groundwaters suggest that dissolution or cation exchange has progressed further than in the Group 1 waters, implying longer residence times.

Shallow groundwaters will contain dissolved oxygen which will be steadily consumed as groundwater moves down hydraulic gradient. Under oxidising conditions Fe, from the dissolution of ferroan calcite, will be present as insoluble oxy-hydroxides. Once O_2 is used up, NO_3 becomes the next electron acceptor and is reduced to N_2 gas. This is followed by the reduction of the Fe hydroxides during which Fe^{2+} becomes stable in solution. The very low NO_3 concentrations and presence of Fe^{2+} in solution in the Group 2 waters suggest that these are reduced groundwaters from depth within the Pennard Sand where they may be partially confined by well-cemented horizons within the anisotropic aquifer.

The differences in composition between the sampled groundwaters can be explained by considering the Group 2 groundwaters to be Group 1 groundwaters which have evolved through their longer residence times and penetration to greater depths within the Pennard Sand aquifer. The Chalice Well and Park Corner Farm Borehole discharge an older more mature groundwater than the seasonally variable Group 1 springs.

ORIGIN OF THE SPRINGS

The presence of two springs, the Chalice Well and the White Spring, close together but with different properties has long been a subject of debate and speculation. Some claim that the chalybeate water is primary water which *'comes from deep within the earth and has not previously seen the light of day: it is not part of the cycle of rain, collection in the earth's surface crust, leading to evaporation, cloud formation and more rain'* (Chalice Well Trust, *c.* 2000 p.2). In 1998 this primary vein of water was traced by a dowser from beneath the Mendip Hills to the north. An alternative view is that both springs arise from *'an extremely complex subterranean system'* beneath the Tor (Mann and Glasson, 2005 p.15). Simple calculations are used to show that the Tor receives sufficient rainfall to supply the springs and a conceptual model is proposed in which a calcium-bearing aquifer overlies an iron-bearing aquifer (Mann and Glasson, 2005 p.22). Richardson (1928) also thought that two aquifers were involved, the Chalice Well water coming from the sandy beds of the Middle Lias (Pennard Sand) with that from the White Spring coming from the Bridport Sand.

It has been demonstrated earlier that all the spring waters are related geochemically and there is no evidence that the water at the Chalice Well is 'primary water' or that it is derived from the Carboniferous Limestone to the north. All the waters come from the same aquifer but water at the Chalice Well differs because it is geochemically more mature and has been in the aquifer longer giving more time for water-rock interactions to occur.

Infiltrating rainfall recharging the Tor aquifer will flow laterally discharging at springs towards the base of the Pennard Sand around the Tor, Chalice Hill and Edmund Hill. Movement towards the south will be restricted because the Pennard Sand is faulted against the mudstones of the Dyrham Formation. Water will move laterally along the fault discharging where the Pennard Sand is exposed to the east of the Tor at the Ashwell Springs and to the west of the Tor in the Chalice Well Valley. The presence of a second fault which follows the line of this valley (Figure 6) means that groundwater from a significant segment of the Tor will be channelled westwards and will discharge where the Pennard Sand is exposed towards the foot of the valley. Thus a network of springs, which includes the Chalice Well, and the four separate springs which contribute to the flow of the White Spring, are concentrated within the limited outcrop of Pennard Sand on both sides of Wellhouse Lane.

A conceptual model of the origin of the springs in the valley is shown in Figure 8. Water with a relatively short residence time is discharged by springs on the hillside, which have been captured to form the flow of the White Spring. Water from deeper in the aquifer, which may be partially confined by well-cemented sands, moves laterally, until it is forced upwards where the Pennard Sand is faulted against Dyrham Formation mudstones, and forms the flow of the Chalice Well. The relatively constant flow of the Chalice Well occurs because the spring derives its flow from storage within the aquifer and is not as reliant on recent rainfall as the White Spring. However, the White Spring also includes some water from deeper in the aquifer, as indicated by the chalybeate nature of one of the contributing springs and the precipitation of iron hydroxide within the reservoir into which the spring discharges.

Early references to Glastonbury's springs (Scott, 1981) refer to a fountain [spring] which continually changed its taste and colour. It is suggested that the overall discharge from the various springs in the Chalice Well Valley would have such characteristics. In winter months this discharge would be dominated by flow from the White Spring whereas in the summer months it would be dominated by water from aquifer storage flowing predominantly from the Chalice Well. Thus both the colour and taste would vary seasonally. There is some evidence for such variations in the samples taken in January and March 2009. All the March samples, taken following a dry period, have higher Mg/Ca ratios than the January samples, suggesting that they contain a higher percentage of more mature groundwater.

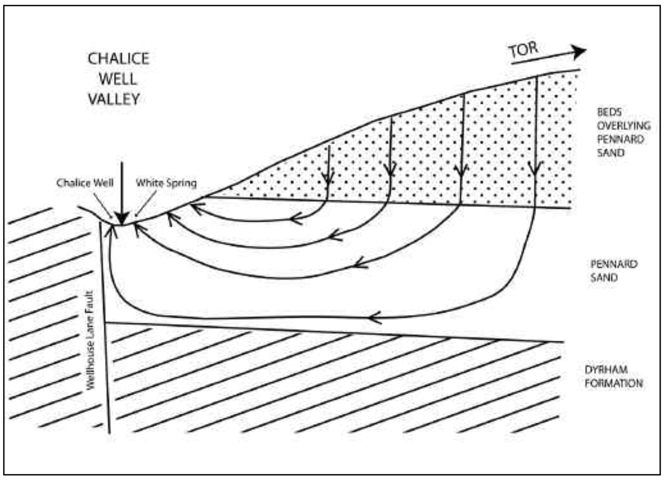

Figure 8. *Conceptual model of the flow of groundwater to the springs in the Chalice Well Valley. The movement of water through the beds overlying the Pennard Sand will be much more complex than the simple flow pattern shown.*

The characteristics of the Glastonbury springs, including the Chalice Well and White Spring, can be explained by a simple model involving discharge from the Pennard Sand. The main flow of the White Spring, and most other springs in the area, is characterised by predominantly young groundwaters whose flow varies with rainfall. The Chalice Well discharges a more mature groundwater close to the line of a fault. On the basis of the data, the Chalice Well water is only mildly chalybeate and any medicinal or healing properties will rely on faith rather than hydrochemistry.

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