Response to Professor Paul Younger (SC20) on faulted limestone systems

David Smythe

Introduction

The issue here concerns two case histories of potential targets for fracking of shale in faulted karst and/or limestone terrains. In my SED paper I wrote:

> *"In 2011 the University of Montpellier-2 published two explanatory documents on the risks of potential fracking in the south of France (Arnaud et al, 2011; Séranne et al., 2011), following the granting of shale exploration permits in the region a year earlier. They drew attention to the crucial role that faults play in the groundwater circulation system (Bicalho, 2010; Bicalho et al., 2012)."*

Professor Younger initially commented (SC6):

> *"... the two papers he cites in support of his claims over fault permeability (Bilcalho 2010; Bilcalho et al. 2012) both relate to karstified limestones – the most extremely permeable of all natural hydrogeological systems, in which fault apertures are widened by dissolution of the soluble wall-rocks!"* [NB the author cited by me is Bicalho, not Bilcalho]

I responded as follows (AC8)

> *"I am well aware that the French work I cited concerns – in part - karstified limestones, an extreme kind of rock formation, hydrogeologically speaking. However, it is demonstrated there that deep pathways down to greater than 2 km depth involving faults do exist, and limestone plays little or no part in the flow systems at depths greater than 1 km. The studies show that upward fault pathways exist through Lias shales, which were the target of a Total exploration licence (since annuled) for fracking."*

The Languedoc example

Professor Younger has rejoindered (SC20):

> *"Having been forced by my comments to acknowledge that he misleading* [sic] *cited irrelevant papers concerning karstified limestones, Smythe clings to the wreckage of his argument by referring to (though not, I note, citing any literature to support) deep circulation systems that are very definitely hosted by limestones."*

Note that I cited four publications, not two, concerning the deep water circulation system in the eastern Languedoc region, which was formerly under licence to Total for unconventional shale exploitation. Since Professor Younger has evidently not actually read these cited works, it is worthwhile setting out here for the general reader a little more detail, to show why these French studies are important and relevant.

Figure 1 shows the stratigraphic column of the region, with the two main shale sequences highlighted (Séranne et al. 2011). The mid and light blues of Bajocian to Portlandian age (Jurassic) are the karstified limestones in the cross-section shown in Figure 2, in which these rocks are depicted by a white brick pattern (Bicalho 2010). It is differentiated thus because it is the main aquifer of the system.

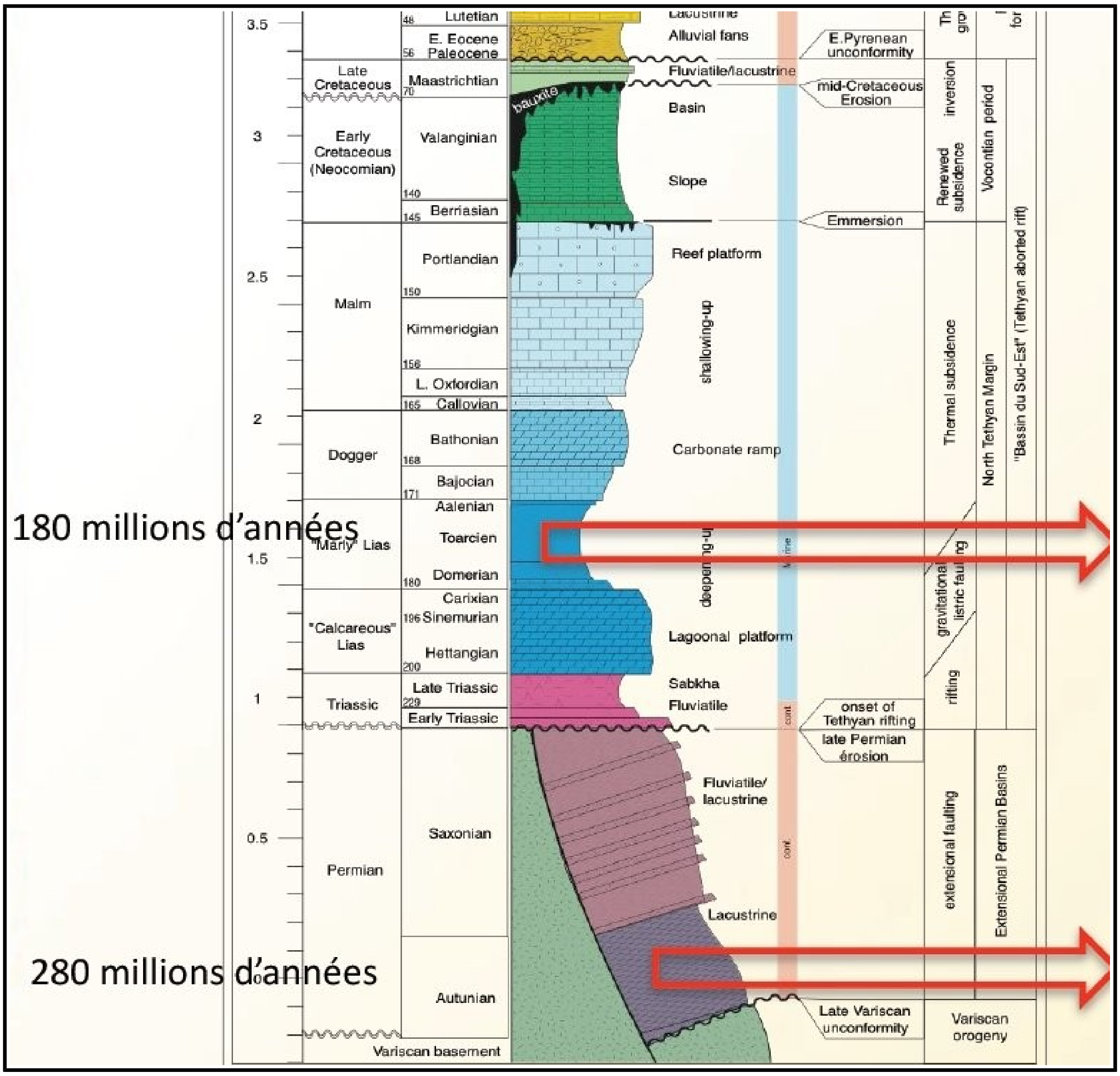

Figure 1 Stratigraphic column of the Languedoc region, with the two main shale targets highlighted by red arrows (Séranne et al. 2011). Upper arrow – 'card shales' of Toarcian (Lias) age. Lower arrow – 'black shale' of Autunian (Permian) age.

The royal blue and brown layers in Figure 2 are Bajocian to Callovian in age, predominantly carbonates. The deeper layers below about 1200 m, coloured grey, lilac and purple in Figure 2, comprise marls, marly limestones, limestones, dolomites, sandstones, clays and evaporites, of Triassic to Aalenian (Early Jurassic) age. These include the upper target shale sequence of Toarcian (Lias) age.Bicalho (2010) postulates that a small proportion of the Lez spring waters originates from deep Triassic evaporites. This water flows up along a fault, where it is buffered by the main aquifer system (light blue ellipse in Figure 2). The evidence for the deep origin comprises various hydrogeochemical signatures.

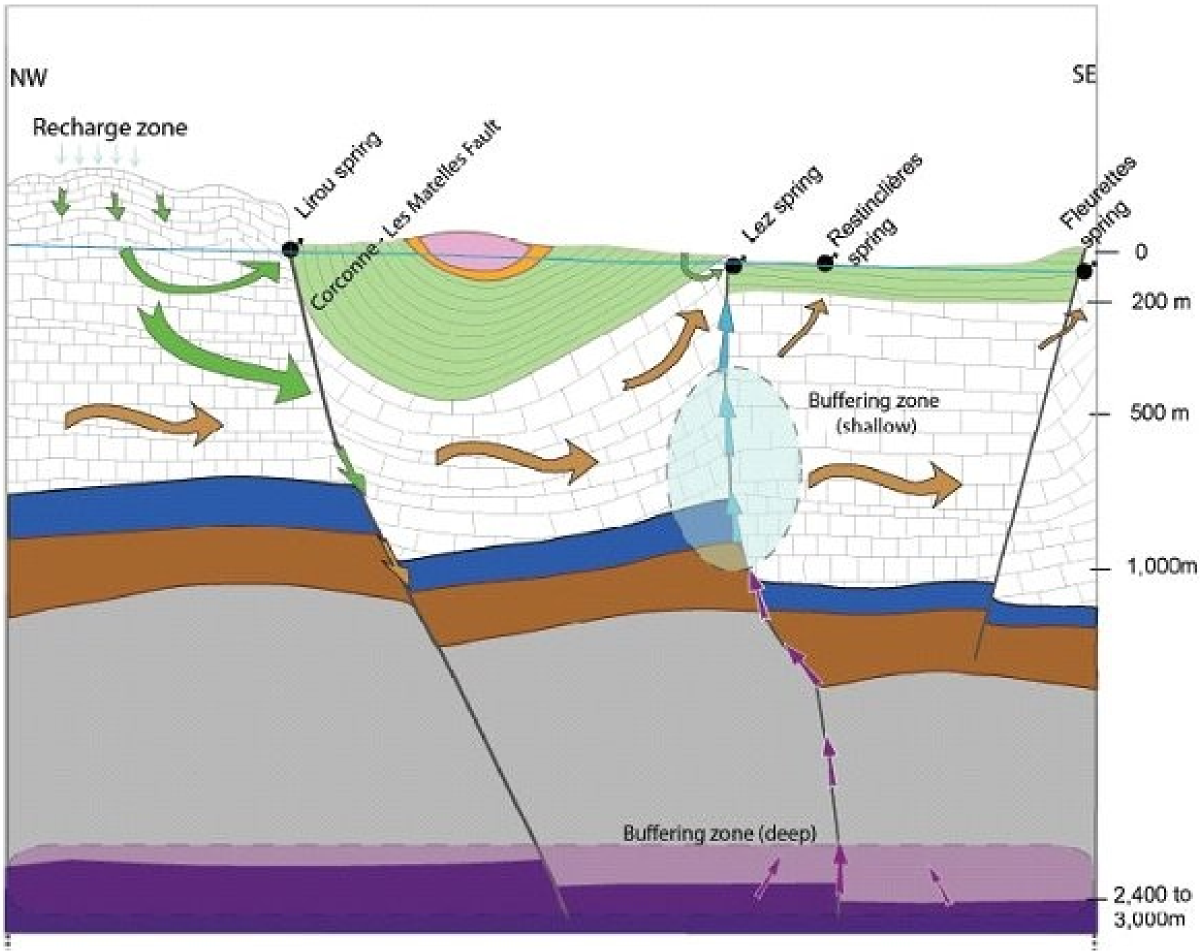

Figure 2. Cross-section showing the flow model from the karstified limestones in the Languedoc (Bicalho 2010). The recharge zone and the white brick pattern are Jurassic limestones (light blue in Figure 1 above) of the main aquifer. Note the subsidiary system extending through the Toarcian shales (within the grey layer) down to 2400-3000 m depth, emerging at the Lez spring. Aquifer-confining rocks are: light green – Valanginian marls; orange and pink – Tertiary.

The Bath example

Professor Younger berates me for not citing sources in my mention (AC8) of the Bath hot springs circulation system:

> *"Smythe does not bother to cite any of the many papers on the origin of the Bath hot springs; had he referred to the literature he might have discovered that, although the Carboniferous Limestone source and approximate minimum age of the waters (1,000 years) are now reasonably well constrained (Edmunds 2004), the actual location of the recharge area has never been definitively established; while the Mendips is widely presumed (e.g. Atkinson and Davison 2002), other karst hydrogeology specialists argue convincing for a South Wales source area (Wilcock and Lowe 1999)".*

It was hardly necessary to cite sources in my reply because the system is very well known. The reason I brought up the subject was because, like the Languedoc, it is another area of sensitive groundwater supply which had been licensed for unconventional exploration – in this case for coal bed methane (CBM) extraction, rather than for shale gas/oil. Professor Younger goes off at a tangent on the age of the waters, and tries to revive a controversy over the location of the recharge; but one of his own sources (Atkinson and Davison 2002) states: "*A different northern source was proposed by Wilcock & Lowe (1999), but is convincingly dismissed by Stanton (2000).*" The detailed report by the British Geological Survey (BGS) for Bath and North-East Somerset Council (Smith and Darling 2012) accepts the consensus 'Mendips Model', and does not even cite the Wilcock and Lowe paper promoted by Professor Younger.

So I shall stick with the consensus 'Mendips Model' for the purpose of completing this discussion, while not necessarily rejecting outright the sub-Severn model proposed by Wilcock and Lowe (1999). Figure 3 is reproduced from Atkinson and Davison (2002). Recharge in the Mendips passes down along the Carboniferous Limestone and emerges at Bath. Thrust faults appear to play a part in the pathways.

The label '3' in the square box refers to "*possible downward leakage*" from the Coal Measures overlying the limestone. It is curious that the very similar diagram in Edmunds (1986) has the same labels, but no. 3 in this case indicates "*possible gain from Lower Palaeozoic and leakage to Upper Carboniferous via Farmborough compression zone*". The two arrows present in Edmunds's version, postulating flow up the thrust compression zone, have been removed in the later version shown here, without explanation.

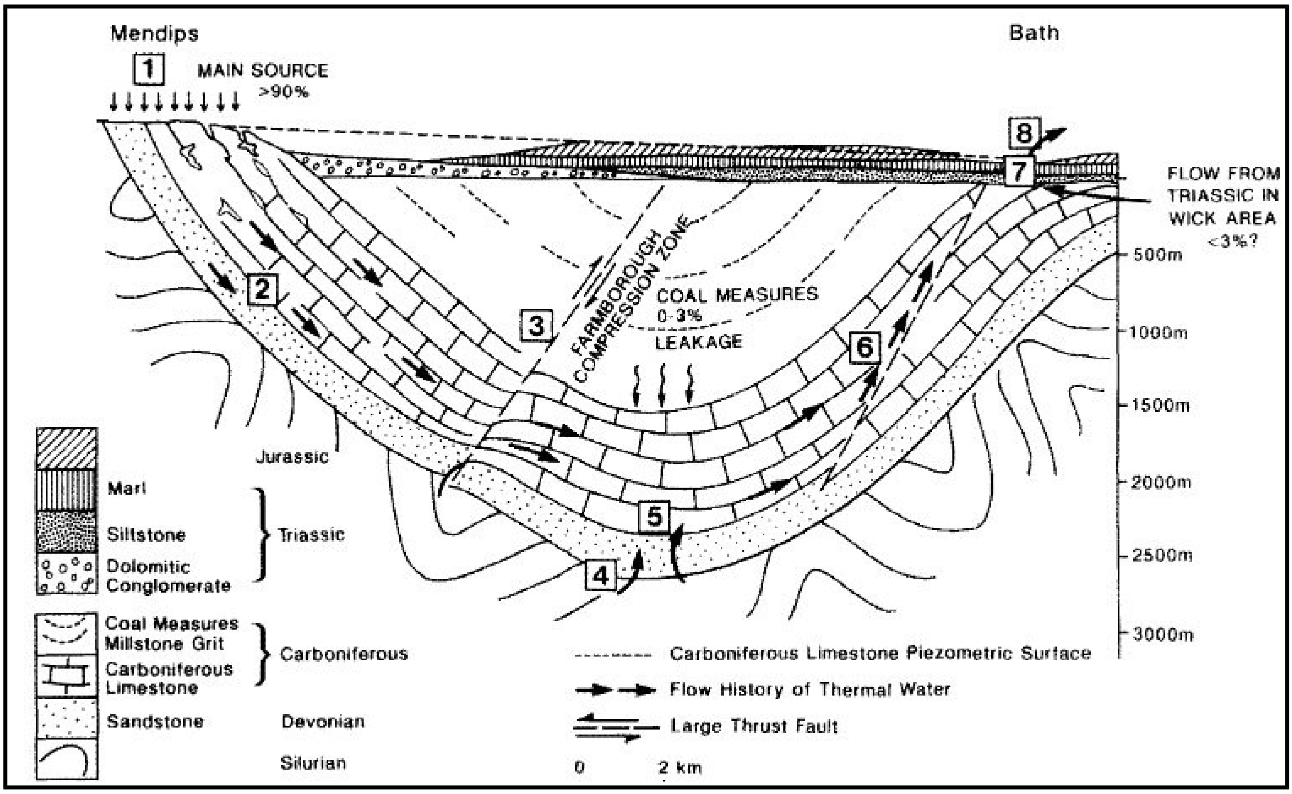

Figure 3. Cross-section showing the deep limestone aquifer system recharging in the Mendip Hills and emerging at 46.5°C at Bath (Atkinson and Davison 2002; diagram © Geological Society of London 2002).

Discussion and conclusion

The purpose of my mention of the two examples is to show that deep groundwater circulation systems exist, and that faults act as flow pathways. Professor Younger has evidently not studied the Languedoc example, because otherwise he would have noted the the subsidiary lower system has nothing to do with karstified limestones. It shows (that is, if hydrogeochemical methods are to be believed) upward passage from Triassic evaporites at 2400-3000 m depth, along a fault cutting Toarcian shales, and emerging at the Lez spring.

The second example, the Bath thermal water system (Fig. 3), which I mentioned in my initial response (AC8) to Professor Younger illustrates two overthrust fault zones, with possible and probable upward flow, respectively.

The overall purpose of citing the two examples was to demonstrate that:

- Deep (2-3 km) groundwater flow systems exist, using faults as upward pathways,
- Unconventional hydrocarbon exploitation licences were granted in these areas, and

- France annuled all these licences, whereas in the UK similar licences continue to be granted, illustrating the regulatory difference between one state applying the precautionary principle and the other state permitting development with inadequate controls.

Atkinson and Davison (2002) modelled the mixing of cold and thermal waters at Hotwells, Bristol, by varying the transmissivity of two important thrusts (labelled T2 and T3) which cut the aquifer some 10-20 km to the south. They applied sound Popperian logic (as discussed in my response AC2 to Dr Engelder's comment SC4) to their model testing. The variation of transmissivity was tested as follows:

> *"Five different simulations were made for each configuration. In the first, the thrusts completely cut the limestone reducing the transmissivity to zero. In the remaining four cases, partial cut-off merely tends to diminish the transmissivity through a local reduction in aquifer thickness while also creating a zone of intense fracturing. If the fractures are open they may enhance the transmissivity, but if filled with secondary minerals or fault gouge they may decrease it. These four cases were modelled by assigning transmissivities to the 'thrust zones' of one thousandth, one hundredth, one tenth, and ten times the regional value."*

Only two cases fitted the data – the base case of equal transmissivity, and the models with a transmissivity of ten times. In conclusion, the thrusts do not act as aquitards; the presumptions of secondary mineralisation and/or fault gouge reducing fault transmissivity do not appear to be valid.

The BGS report on the risks to the hot spring waters concluded that CBM development would pose an insignificant risk to the resource, but that shale gas development would pose an "*undefinable risk*". This report, dating from November 2012, post-dates the granting by DECC of the several hydrocarbon licences in the area. The 14th round of onshore hydrocarbon licensing was opened by DECC in July 2014. It included the Bath-Bristol-Mendips region in its entirety. The problem with this *laissez-faire* licensing approach is that it is then left to mineral planning authorities (in practice, county councils) to try to estimate the risks of any proposed development following the award of a PEDL.

In conclusion, Professor Younger has once again demonstrated that he does not study the issues in adequate depth, but merely skims the surface of the problem. Karst terrain and limestone aquifers offer a particular kind of hydrogeology, but their study is pertinent to unconventional shale exploitation, by demonstrating deep circulation controlled in part by faults.

References

Arnaud, N., Séranne, M., Pistre, S. and Buffenoir, E. 2011. 'Gaz de schiste': les questions qui se posent. Contribution au débat sur l'exploration pétrolière dans le sud de la France, de l'Université de Montpellier 2 (Shale gas: the questions which are asked. Contribution to the debate on petroleum exploration in the south of France, by the University of Montpellier 2), http://www.gm.univ-montp2.fr/spip.php?article1312&lang=fr.

Atkinson, T.C., and Davison, R.M. 2002. Is the water still hot? Sustainability and the thermal springs at Bath, England. In: Hiscock, K. M., Rivett, M.O. & Davison, R. M. (eds) Sustainable Groundwater Development. Geological Society, London, Special Publications, 193: 15-40.

Bicalho, C. C. 2010. Hydrochemical characterization of transfers in karst aquifers by natural and anthropogenic tracers. Example of a Mediterranean karst system, the Lez karst aquifer (Southern France), Thesis accomplished in the Laboratory: HydroSciences Montpellier (UMR 5569, CNRS-IRD-UM1-UM2).

Bicalho, C. C., Batiot-Guilhe, C. Seidel, J. L., Van Exter, S., and Jourde, H. 2012. Geochemical evidence of water source characterization and hydrodynamic responses in a karst aquifer, http://www.sciencedirect.com/science/article/pii/S0022169412003733.

Edmunds, W.M. 1986. Geochemistry of geothermal waters in the UK. In Downing, R.A. and Gray, D.A. (eds) Geothermal energy – the potential in the United Kingdom, 111-123. British Geological Survey.

Séranne, M., Pistre, S., Soliva, R., and Poulichet, F. E. 2011. Gaz de schiste dans le sud de la France. Questions géologiques, hydrologiques et environnementales (Shale gas in the south of France. Geological, hydrological and environmental questions), http://www.gm.univ-montp2.fr/spip.php?article1312&lang=fr.

Smith, N. J. P. and Darling, W.G. 2012. Potential problems within the Bath and North East Somerset Council and surrounding area with respect to hydrocarbon and other exploration and production. British Geological Survey Commissioned Report CR/12/055, 26 pp.

Wilcock, J., and Lowe, D.J. 1999, On the origin of the thermal waters at Bath, United Kingdom: A sub-Severn hypothesis. Cave and Karst Science 26 (2): 69 – 80.