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Understanding hydrothermal circulation patterns at a low-enthalpy thermal spring using audio-magnetotelluric data: A case study from Ireland

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ABSTRACT

Kilbrook spring is a thermal spring in east-central Ireland. The temperatures in the spring are the highest recorded for any thermal spring in Ireland (maximum of 25 °C). The temperature is elevated with respect to average Irish groundwater temperatures (9.5–10.5 °C), and represents a geothermal energy potential, which is currently under evaluation. A multi-disciplinary investigation based upon an audio-magnetotelluric (AMT) survey, and hydrochemical analysis including time-lapse temperature and chemistry measurements, has been undertaken with the aims of investigating the provenance of the thermal groundwater and characterising the geological structures facilitating groundwater circulation in the bedrock.

The three-dimensional (3-D) electrical resistivity model of the subsurface at Kilbrook spring was obtained by the inversion of AMT impedances and vertical magnetic transfer functions. The model is interpreted alongside high resolution temperature and electrical conductivity measurements, and a previous hydrochemical analysis.

The hydrochemical analysis and time-lapse measurements suggest that the thermal waters have a relatively stable temperature and major ion hydrochemistry, and flow within the limestones of the Carboniferous Dublin Basin at all times. The 3-D resistivity model of the subsurface reveals a prominent NNW aligned structure within a highly resistive limestone lithology that is interpreted as a dissolutionally enhanced strike-slip fault, of Cenozoic age. The karstification of this structure, which extends to depths of at least 500 m directly beneath the spring, has provided conduits that facilitate the operation of a relatively deep hydrothermal circulation pattern (likely estimated depths between 560 and 1000 m) within the limestone succession of the Dublin Basin. The results of this study support the hypothesis that the winter thermal maximum and simultaneous increased discharge at Kilbrook spring is the result of rapid infiltration, heating and re-circulation of meteoric waters within this structurally controlled hydrothermal circulation system.

This paper illustrates how AMT may be useful in a multi-disciplinary investigation of an intermediate-depth (100–1000 m), low-enthalpy, geothermal target, and shows how the different strands of inquiry from a multi-disciplinary investigation may be woven together to gain a deeper understanding of a complex hydrothermal system.

1. Introduction

Deep hydrothermal systems are well-established geothermal exploration targets. The potential of these systems is now being investigated in Ireland as part of the IRETHERM project (funded by Science Foundation Ireland). A multi-disciplinary approach has been adopted, integrating geophysical surveys and hydrochemical analysis with the aims of (1) identifying the source aquifer(s) for the thermal groundwater, (2) characterising the circulatory systems, and (3) assessing the potential for the existence of deeper, higher temperature, circulation patterns for future geothermal exploitation. A number of thermal springs have been identified that are currently being investigated. This paper presents a case study of one of these, Kilbrook spring, which has the highest recorded temperatures of any thermal spring in Ireland

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(maximum of 25.0 °C recorded during this study). This study shows how the use of geophysics as part of a multi-disciplinary investigation can result in a better understanding of the operation of a low-enthalpy hydrothermal system.

In Ireland, average groundwater temperatures typically range from 9.5 to 10.5 °C (Aldwell and Burdon, 1980) and thermal springs are considered to be those natural groundwater springs where the mean annual temperature is appreciably warmer than average groundwater temperatures (Aldwell and Burdon, 1980; Goodman et al., 2004). The spring is located in east-central Ireland (Fig. 1) and was first discovered in the late 19th century when the nearby Royal Canal was constructed (Burdon, 1983). The spring discharges from a glaciofluvial sand and gravel deposit in a disused quarry, which is located between the urban centres of Enfield, Co. Meath, and Kilcock, Co. Kildare. The temperature

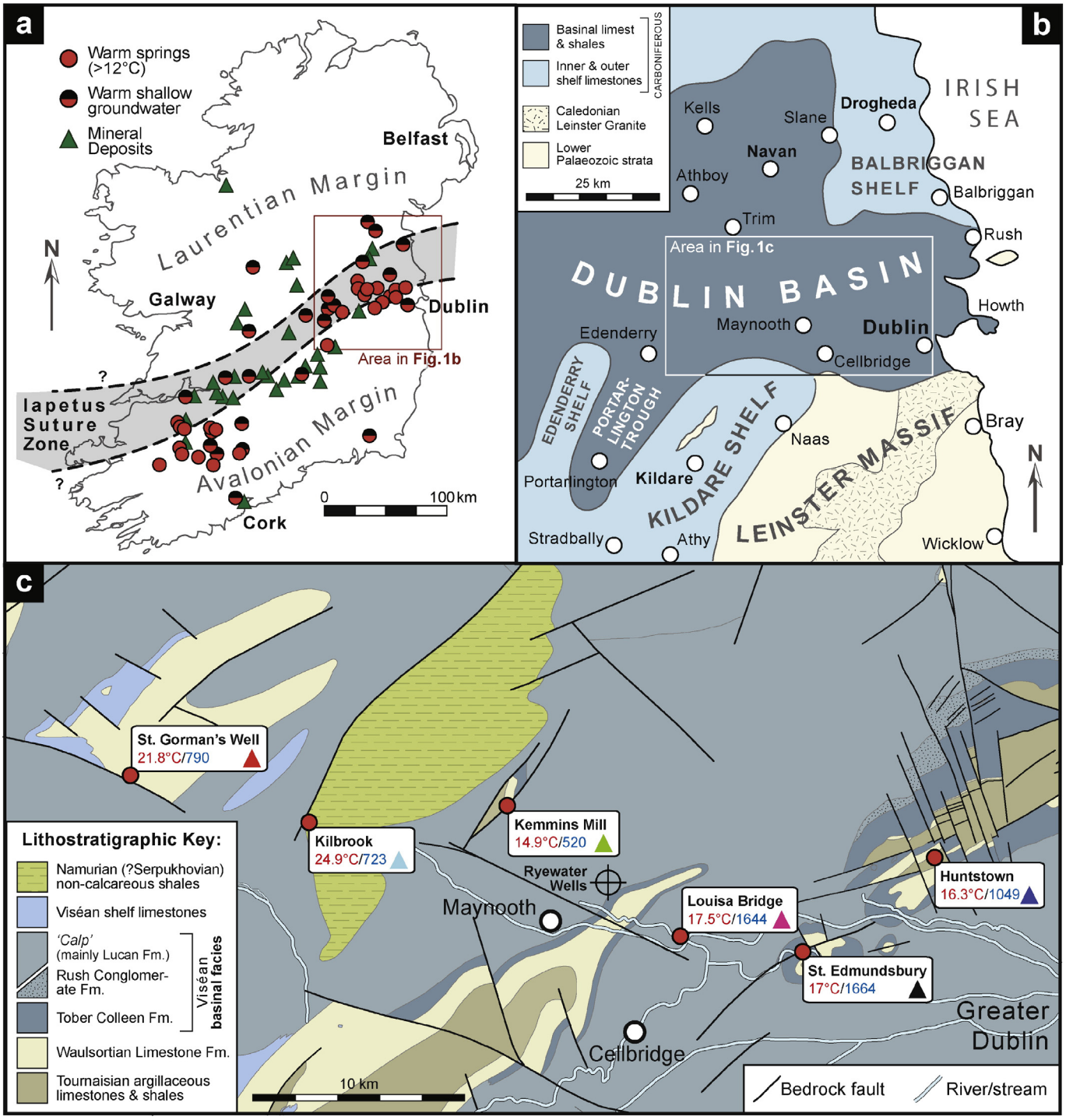

Fig. 1. Geological setting of Irish thermal groundwaters, sourced from Blake et al. (2016): (a) Irish thermal spring and thermal shallow groundwater locations (after Goodman et al., 2004), with significant mineral deposits and the approximate trace of the Iapetus Suture Zone (after Wilkinson, 2010); (b) palaeogeographic map of the Dublin Basin during the Viséan Stage (modified from Sevastopulo and Wyse Jackson (2009)); and (c) geological map of the study area (from www.gsi.ie) showing warm springs included in the hydrochemical sampling programme. Maximum temperatures (red) and mean electrical conductivities in μS/cm (blue) are given for each thermal spring. Coloured triangles in each of the thermal spring labels refer to colour coding used for these locations in subsequent figures. Further information on the springs can be found in the supplementary material. (For interpretation of the references to color in this figure legend, the reader is referred to the online version of this chapter.)