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Borehole temperature log from the Glasgow Geothermal Energy Research Field Site: a record of past changes to ground surface temperature caused by urban development

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History of Coal Mining in the vicinity of the GGERFS site

Coal mining was already underway in the 18th century south of the River Clyde near the present study area (Fig. 2), progressively exploiting the succession of coal seams in Table 3. Macnab (2011) provided views of a three-dimensional subsurface GIS for this area, which indicate extensive production from the Splint Coal and shallower seams but only localized production from deeper seams, notably from the Kiltongue Coal (cf. Table 3). This mining activity has been summarised in relation to the GGERFS development by Monaghan et al. (2017), and is discussed in many histories of the area (e.g., Shearer, 1922; Anderson, 1935; Anderson, 1943; Adams, 1995; Smart, 2002; Naughton, 2014), but greater detail, especially chronological information, is needed for the present study. The collieries nearest the GGERFS site are Farme, Govan, and Dalmarnock (Figs 2 and 4).

Farme Colliery

Farme Colliery was located south of the River Clyde, northeast of Rutherglen (Fig. 2); its history has recently been elaborated by Findlay et al. (2019). These authors report that this colliery was sunk in 1805 and initially consisted of two pits, Old Farme (at British National Grid reference NS 62210 62448) and New Farme (at NS 61733 62188; Fig. 2). These pits were not served by any waggonway and relied on road transport for sale of coal, which was transported across the Clyde into Glasgow at Dalmarnock Bridge (NS 61724 62655). Cleland (1825) reported that in 1825 Old Farme colliery had one pumping engine of 72 horsepower (h.p.), two pumping and winding engines of 19 h,p. each, and winding engines of 18 and 10 h.p. A rail connection for this colliery was proposed in 1831 but was not built (Grant, 2017). Maps dating from the 1850s (e.g., the twenty five inch to one mile sheet Lanarkshire X.4, surveyed in 1857; https://maps.nls.uk/view/74955847) show this configuration of mine shafts. On later maps (e.g., those summarized in Fig. 2) the New Farme pit is no longer depicted and the Old Farme pit, now simply known as Farme Colliery, is connected to the railway network at Rutherglen via the Farme Colliery Branch. However, we have been unable to establish precisely when this rail connection was installed.

According to NRS (1915), the Upper, Ell, Main, Humph, Splint, Virgin, Virtuewell and Kiltongue coal seams were worked from this colliery. This plan indicates depths to seams: Humph, 106 m; Splint, 112 m; Virtuewell, 157 m; and Kiltongue, 182 m. These workings extend beneath Cuningar Loop and northward beyond the River Clyde (NRS, 1915, 1950). Findlay et al. (2019) reported that production continued until Farme Colliery closed in 1931.

Govan Colliery

Govan Colliery began operating in the 18th century, developing into a major enterprise during the 19th century, its proprietors diversifying into other industries including iron smelting and development of its own railway network, lasting into the early 20th century. Mining was already under way in this area when William Dixon became colliery manager in 1771; an experienced mine manager from the Northumberland coalfield of northeast England, he instigated dramatic

expansion of operations at Govan Colliery, becoming proprietor in 1820 (Maver, 2004). Multiple pits were opened by this company, which in the 1820s was arguably the largest mining operation in Europe; production on the largest scale took place at Pit No. 5, or Toryglen Pit (at NS 60347 62392), and Pit No. 6 (at NS 59944 61704) (Fig. 2). Pit No. 5 was closest to Dalmarnock so of greatest relevance to the present study, the stratigraphy at its shaft being summarized in Table 3. As Dott (1947) has described (see, also, https://www.railscot.co.uk/Polloc_and_Govan_Railway/), in 1778 the Govan Colliery Company opened a waggonway connecting its pits to the River Clyde at Windmillcroft Quay (NS 58389 64811), opposite Glasgow city centre; coal was exported there, as well as supplying the city. In 1811 a branch was added to the newly completed Glasgow, Paisley and Ardrossan Canal at Port Eglinton (NS 58359 64038). Cleland (1825) reported that in 1825, across all its pits, the Govan Colliery operated pumping engines of 54 and 42 h.p., a pumping and winding engine of 19 h.p., winding engines of 18, 14, 14 and 9 h,p., and a rotary engine of 16 h.p. In 1840 this waggonway network was converted into a railway, the Polloc and Govan Railway, providing additional commercial opportunities. The provision of this infrastructure, lacking to other early local mining enterprises, ensured commercial survival into the twentieth century. Indeed, although the rail link to the Clyde was abandoned as early as 1867 (West Street now occupying its alignment), much of the Polloc and Govan Railway remains in use as part of the main railway line between Glasgow and London.

The Govan Colliery Company has been documented by many workers, including Tancred (1842), Lewis (1846), Randolph (1856), and Payne (1961). However, it is not always clear from these accounts which of the pits is being discussed. By the 1840s, production was from the Upper, Ell, Main, Humph, Splint and Virgin seams (Tancred, 1842; Lewis, 1846), a total of seven seams if the two leaves of the Splint seam are counted separately (Table 3), at four pits (Corner, Firrs, Bankhall and Quarry pits, circa British National Grid references NS 59756 62947, 59478 62625, 58828 62612, and 59245 62261; Fig. 2). Development of Pit No. 5, or Toryglen Pit, began in 1858; it is shown under construction on a map published that year (Ordnance Survey 25 inches to one mile sheet Renfrewshire XIII.7; https://maps.nls.uk/view/74479339) and noted in a contemporaneous gazetteer (Ordnance Survey, 1861). By 1868 this pit had been developed to the 200 m depth of the Virgin Coal, as illustrated in Table 3. It was later deepened to include working the Airdrie Virtuewell and Kiltongue seams, as illustrated on mine plans summarized by Ellen et al. (2013). The northeastern extremities of these workings, in closest proximity to the GGC-01 borehole, were circa NS 60740 62903, at ~210 m below O.D., for the Airdrie Virtuewell Coal, and circa NS 60505 62760, at ~245 m below O.D., for the Kiltongue Coal; at their deepest, farther southwest, these workings were (respectively) ~280 and ~290 m below O.D. In 1913-1914 an exploratory boring took place from the working level in the Kiltongue Coal to investigate deeper seams, resulting in the deeper part of the stratigraphic record in Table 3. However, these deeper seams were never worked; the mine was subsequently closed. The workings in the Kiltongue Coal at Govan No. 5 Pit were abandoned in 1923 according to Mines Department (1931). On the 1935 revision of the local map (Ordnance Survey 25 inches to one mile sheet Lanarkshire X.3; https://maps.nls.uk/view/82892259) this pit is no longer shown, having closed more than a decade beforehand, whereas the No. 6 Pit (at NS 59946 61702) was shown as disused, suggesting recent closure.

Dalmarnock Colliery

Dalmarnock Colliery is known from many historical accounts to have been worked during the early to mid 19th century. For example, in 1825 one steam engine of 46 h.p. operated for pumping and another of 18 h,p for pumping and winding (Cleland, 1825). The surface facilities at Dalmarnock No. 1 Pit (at NS 61181 62715; Fig. 4, Table 2) were connected to a blind pit (i.e., a shaft between coal seams, not reaching the Earth's surface) farther north (at NS 61198 63331) via an underground adit used for hauling coal, through the Main and Ell seams (NRS 1853a, 1853b). Guthrie (1905) reported that by 1830 a waggonway had been constructed between this No. 1 Pit and the River Clyde (at NS 60972 62796), where a landing

stage had been erected for loading coal onto barges for transport to Glasgow; these features are illustrated in Fig. 4. As Shearer (1922) has described, at this time the river was navigable upstream as far as Rutherglen, but this mode of transport was in decline; it depended on the water level being maintained by a weir on the eastern edge of Glasgow city centre, which was bypassed by a narrow lock (at NS 59540 64405) that was difficult for coal barges to negotiate. Unlike the other collieries already discussed, Dalmarnock Colliery never became rail-connected; its lack of efficient transport may well have contributed to its early closure. The Clyde weir and lock were removed in 1879 (Shearer, 1922). The present Glasgow Tidal Weir was constructed in roughly the same place in 1901, its main original purpose being to maintain a steady high-water level to provide a reservoir of water for use by local industry, with the disadvantage of making river navigation impossible.

The seams worked at Dalmarnock Colliery comprised the Ell, Upper, Humph, Main and Splint coals (Mines Department, 1931). As is detailed in Table 3, the local stratigraphy is known in part from the shaft log and in part from a deeper exploratory boring, made in 1848. The available online log includes (http://scans.bgs.ac.uk/sobi_scans/boreholes/1079959/images/12347725.html) the note that 'a great quantity of water flowed from the bore while passing through this sandstone, increasing as the bore deepened. Pipes were then put in and taken to the pithead frame. The water however still flowed out.' However, it is unclear to which of several sandstone beds this statement refers, thick beds of sandstone being present beneath depths of 203, 238 and 250 m (Table 3).

Although many historical sources indicate the approximate time scale when Dalmarnock Colliery operated, we found it most difficult to establish precise dates. The best guide to its year of closure is from Riddet (1961), who stated that it 'ceased working about 1859'. Its year of opening was found to be 1824. This date was disclosed during a series of court cases against its proprietors, reported by Dunlop et al. (1839, pp. 89-91) and Dunbar et al. (1841, pp. 893-903); at the time, collieries in the Glasgow area were taxed to fund a social welfare programme, but for as long as they could get away with it the proprietors of Dalmarnock Colliery refused to disclose its production to enable the tax to be determined. We also checked the online catalogue of fatal accidents at Dalmarnock Colliery (http://www.scottishmining.co.uk/326.html), which (as was typical for mining at the time) were so frequent as to provide an approximate time-line for mining operations: the first occurred on 23 December 1829 and the last on 26 December 1853. The 1859 date of closure is significant, because (as previously discussed, e.g. by Westaway and Younger, 2016) from 1850 onward colliery proprietors had a statutory duty to report mine plans; as a result, the extent of mining of each seam in the Dalmarnock Colliery has been reported (NRS, 1853a, 1853b). This information, along with older mine plans (GCA, 1830, 1842, 1844), has been incorporated into a subsurface GIS by Monaghan et al. (2017); the western edge of this mined area extends northward from the vicinity of the colliery to circa NS 6135 6335, passing ~400 m east of the GGC-01 borehole. However, Monaghan et al. (2017) also reported an area of 'probable' mine workings, west of the area known to have been mined by Dalmarnock Colliery, from subsurface voids reported in boreholes. This area (depicted in Fig. 7(b) of Monaghan et al., 2017) extends to the depth of the Splint Coal for distances of ~500-1200 m west, northwest and north of the area known from reported mine plans to have been mined at this colliery.

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