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GYPSUM: GEOLOGY, QUARRYING, MINING AND GEOLOGICAL HAZARDS IN THE CHELLASTON AND ASTON-ON-TRENT AREAS

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SUMMARY

This report describes the occurrence, extraction and natural hazards related to Triassic gypsum in the Chellaston and Aston-on-Trent areas, south of Derby. A brief historical review of gypsum working from the Middle Ages onward is given. The stratigraphy of the gypsum and Cropwell Bishop Formation in the Mercia Mudstone Group is described. Details of the mines and quarries in the area are presented along with notes about their geology. Geological hazards, related to gypsum workings and natural gypsum dissolution, are noted. This work was undertaken as part of the BGS project to revise the Loughborough Geological Map (Sheet No. 141).

CONTENTS

FIGURES

1. INTRODUCTION

The Chellaston area has a long history of gypsum working dating back to the Middle Ages. Initially it was worked for monumental alabaster that was shipped throughout much of England and abroad. Later, in the 19th Century, both at Chellaston and Aston-on-Trent, it was worked in quarries and mines for ornamental alabaster and for plaster manufacture. Mining ceased in the early 20th Century leaving a legacy of disturbed ground at the surface and potentially unstable mineworkings at depth. Chellaston lies on the southern limits of Derby in an area largely designated for housing development. The presence of potential geological hazards is a consideration for developers.

2. HISTORY OF GYPSUM WORKING AT CHELLASTON

2.1 Middle Ages

A comprehensive account of the history of alabaster production, working and social history in the Chellaston area is given by Young (1990). The earliest examples of carved alabaster in England come from the Tutbury area, west of Chellaston. Here they are found in the carved doorway of the Tutbury Priory Church which dates from the latter half of the 12th Century. Further evidence of early alabaster working hereabouts comes from the monument to John de Hanbury (c1280-1300) in Hanbury (Edwards, 1966; Young, 1990). By the middle part of the 14th Century the working of alabaster had spread from Tutbury to Chellaston. The stone from both areas was extracted and worked by skilled *alabasterers, alabastermen, kervers* (carvers) and *imagemakers* mainly in Nottingham and Burton, but also more locally at Tutbury, Chellaston and Derby.

The Nottingham carvers relied on stone from Chellaston. Records show that in 1441 an agreement was made by a Nottingham middleman, with representatives of the Abbot of Fécamp in Normandy, for the export of alabaster slabs from Chellaston via Hull (Bilson, 1907; Sherlock, 1918; Firman, 1984; Young, 1990). There is also a contract for Ralph Green's tomb at Lowick, Northants, dated 1419, which implies that alabaster was quarried and worked locally at Chellaston (Firman,1984). Prior to 1580 many of the Chellaston monuments were supplied to local churches and the main concentration of alabaster monuments is within a 50 km radius of Chellaston; a similar distribution of pre-Reformation monuments is also suggested (Firman, 1984).

In the 14th and 15th Centuries only the purest white alabaster was used for monuments, consequently only the upper part of the Chellaston gypsum beds were initially exploited. It was only in the late 16th Century that coloured varieties of alabaster became acceptable, and it is probable that working began in the lower part of the Chellaston bed at this time (Firman, 1984 p.171).

2.2 19th Century

As far as Firman (1984) was aware no references to alabaster working at Chellaston exist for the 17th and 18th Centuries. In the 19th Century two mines worked the Chellaston gypsum; Chellaston and Chellaston Glebe. The map of the Chellaston area presented by Smith (1918) gives details of the locations of many of these workings. From Smith's map, and Fox-Strangways field maps, it would appear that Chellaston Covert and the area to the south-west of it are old workings for alabaster. The date of working is unknown, but the covert is shown as a wooded area on the geological field maps of around 1900 suggesting it may be an area of fairly ancient workings.

In 1850, during digging at Chellaston, some wedge-shaped picks 8-12 inches (0.2-0.3m) long, the remains of an oaken ladder and an unmoved slab of skilfully sawn alabaster, were uncovered some 16 feet (4.9m) below ground. Around 1900 a portion of an iron pick was also unearthed. These finds attest to the extensive earlier working in the vicinity.

2.3 20th Century

The early 20th Century saw an explosion in the use of alabaster and plaster; an increase in demand reflected in the expansion of quarrying and mining throughout the district including Chellaston. Mining was undertaken at Aston Glebe Mine, with trials undertaken at Duddle Plantation. The Alabaster Quarry, opened in 1909, lasted little more than 10 years and was filled in by 1938 (details below). Smith (1918) noted that demand for alabaster was for ornaments and monuments with the best rock, both from the quarries and mines, being shipped out via the railway. Much of it was taken to Derby where it was used for statuary work and the production of electric light bowls. Local production of ornamental columns, vases, etc was also undertaken at Chellaston. The bulk of the gypsum was used for plaster manufacture, mineral white, plaster of Paris, agricultural use and in cements. Some was also used as "brewers' gypsum" to "burtonise" water for beer making. The gypsum industry in Chellaston lasted only until 1937 when the Aston Glebe Mine closed.

A limited amount of gypsum continued to be produced as a by-product of quarrying for brick-making clay, up to at least 1965 (Sarjeant, 1965) when it was still worked at Woodlands Clay Pit.

3. GEOLOGY

3.1. General geological sequence in the area

The gypsiferous strata of the Chellaston and Aston-on-Trent areas belong to the Cropwell Bishop Formation which occurs in the upper part of the Triassic Mercia Mudstone Group. The Group varies in thickness; it is around 180 to 250m thick in the Nottingham district, to the east of the study area. In a westerly direction it thickens into the Burton area reaching 340m in the Bagot's Park Borehole, where halite deposits also occur (Stevenson and Mitchell, 1955). In the Chellaston/Aston area the development of the Group is probably between these thicknesses.

In the Nottingham area, the Mercia Mudstone Group has been subdivided into six formations (Table 1). The lowest subdivision, the Sneinton Formation, comprises up to 50m of fine- and medium-grained sandstones formerly called the 'Keuper Waterstones'. The succeeding succession of the Radcliffe Formation, Gunthorpe Formation and Edwalton Formation comprise a sequence of mainly red-brown and grey-green siltstones and mudstones with subordinate sandstone beds. Above these the Cropwell Bishop Formation, of similar lithology, includes thick units of commercially-exploited gypsum including the Newark and Tutbury gypsum beds. It is mainly the Tutbury Gypsum that has been mined and quarried in the Chellaston and Aston-on-Trent areas. The top of the Mercia Mudstone Group, both in Nottinghamshire and the Cheshire Basin, is marked by a change towards marine conditions. This resulted in the deposition of the Blue Anchor Formation (formerly called the Tea Green Marl) and the succeeding Penarth Group, both calcareous formations, that lie just beyond the southern and south-eastern limits of the region.

The nomenclature of the Mercia Mudstone Group (formerly Keuper Marl and locally Keuper Waterstones) has evolved considerably from the early subdivisions of the primary survey. Elliot (1961) subdivided the upper part of the sequence into the Trent and Parva Formations. Warrington *et al.* (1980), however, recognised three formations: the Trent, Glen Parva and Blue Anchor Formations, with the Blue Anchor Formation at the top recognisable throughout England. Taylor (1983) subdivided the Trent Formation into two members, the Fauld and the Hawton members, but these have not proved to be sustainable units. The Cropwell Bishop Formation was defined by Charsley *et al*. (1990) to supersede the Trent and Glen Parva formations which did not constitute readily mappable units. It is likely that the classification, used in Nottinghamshire (Charsley *et al*., 1990) (Table 1), will be fully applicable to the Loughborough District and the Chellaston/Aston area.

Group	Formations	Members and gypsum beds
Mercia Mudstone Group	Blue Anchor Formation	
	Cropwell Bishop Formation	Newark Gypsum Tutbury Gypsum
	Edwalton Formation	Hollygate Sandstone Member
		Cotgrave Sandstone Member
	Gunthorpe Formation	
	Radcliffe Formation	
	Sneinton Formation	

Table 1. Formations in the Mercia Mudstone Group (after Charsley *et al*., 1990)

3.2 The Cropwell Bishop Formation and Tutbury Gypsum

The Cropwell Bishop Formation in the Nottingham District, to the east, comprises between 37 and 54m of mainly red-brown siltstone with sporadic thin fine-grained sandstone beds. To the west of the district in the Burton-on-Trent area the equivalent sequence may be three times the thickness (Taylor, 1983). In the Chellaston/Aston area there are no boreholes that prove the full thickness of the formation. The thickness is derived from an amalgamation of borehole and mining information. The formation divides into three lithological entities, the lower part of the sequence is mainly siltstone with subordinate gypsum nodules. The middle unit comprises the Tutbury Gypsum and the upper part of the formation is composed of siltstone with sporadic subordinate layers of gypsum nodules representing an attenuated facies of the Newark Gypsum beds.

The basal part of the Cropwell Bishop Formation around Chellaston/Aston is penetrated by numerous boreholes (Brandon, 1996), but because the Tutbury Gypsum is largely dissolved the thickness of this part of the sequence is difficult to identify and calculate. However, the level of the top of the Hollygate Sandstone Member is given to be about 20m below the Tutbury Gypsum (Brandon, 1996, p.15), the intervening sequence (borehole SK33SE/28) being recorded as brown marl.

The main gypsum bed present in the Chellaston/Aston area is the Tutbury Gypsum. This ranges in thickness between a few metres and a maximum of 8.38m. Some of the variation in the thickness of the seam is due its large-scale nodular nature. However, severe local dissolution of the gypsum can also account for much of the variation. The characteristics of the gypsum can be derived from the descriptions of Sherlock & Smith (1918), Smith (1918), Sherlock & Hollingworth (1938) and Sarjeant (1962, 1965), details for which are given in the descriptions of the individual mines and quarries. In general the gypsum sequence appeared to comprise a lower unit (possibly 2-4.5m thick) of breccia or nodular gypsum with a red-brown muddy alabastrine matrix overlain by a unit of large, massive, mainly white, gypsum nodules that in places are amalgamated into a more continuous bed, generally up to a metre or so thick, but possibly up to 2.75m thick. This is overlain by a "cap" of up to 1m of green sandy mudstone and siltstone and green gypsiferous mudstone and siltstone (Smith, 1918).

Within the Chellaston/Aston area the upper part of the Cropwell Bishop Formation comprises mainly siltstone with subordinate nodular gypsum layers. These were formerly well seen in the Woodlands Brickpit [SK 384 303] and the Aston Brickyard [SK 414 306] both described below. East of the area in the Nottingham District the upper part of the formation includes substantial layers of nodular and bedded gypsum which comprise the Newark Gypsum Beds. On the Nottingham Sheet, at Cropwell Bishop, the Newark Gypsum sequence reaches a thickness of 18m. Here the Tutbury Gypsum is attenuated or missing (Charsley *et al*., 1990) though Firman (1964 p. 192) commented that the lower part of the Newark Gypsum may in fact be equivalent to part of the Tutbury gypsum. In the Chellaston/Aston area the upper part of the Cropwell Bishop Formation between the top of the Tutbury Gypsum and the overlying Blue Anchor Formation is estimated to be between 35 and 40m thick (Brandon, 1996).

Combining the thicknesses of the individual lithological units described above gives a local composite thickness for the Cropwell Bishop Formation of between 58 and 68 metres.

4. DEVELOPMENT OF QUARRIES

4.1. Alabaster Quarries, Chellaston [SK 3840 3045].

The Alabaster Quarries at Chellaston (Figures 1 & 2) were the main suppliers of high quality monumental and ornamental alabaster at the beginning of the 20th Century. Old workings and ancient quarry tools found in the modern workings suggested that the alabaster had been worked in a piecemeal fashion from medieval times. The quarry was owned by H. Forman & Son, Chellaston. A full history of the quarry and the involvement of the Forman family is presented by Young (1990), who also gives some geological details.

The quarry opened in 1908 and ceased production in 1915; by 1938 it had been filled in (Sherlock and Hollingworth, 1938) and now it is the site of housing. Sherlock and Smith (1918) reported that green and white alabaster from the quarry was used in the reredos of the Church of the English Martyrs, Alexandra Park, Manchester; the lounge of the Windsor Hotel, Victoria Street, Westminster, and the entrance to the new baths at Buxton. Note is also made of the alabaster reredos of Ely Cathedral. Much alabaster was also exported abroad. Young (1990) gives a fuller list of monuments and architectural works ascribed to Chellaston Alabaster. One of the finest examples of the stone and the carvers work being the lectern at All Saints Church, Mackworth (Young, 1990, p.11).

Smith's map of 1918 shows that the quarry extended for about 200m east from near the road junction [SK 3832 3043] parallel to the road to opposite the western corner [SK 3846 3046] of Chellaston Covert. In 1918 the quarry extended only 50 or so metres north from the road, a figure also suggested by recent site investigations in the area.

Although there are no longer any surface traces of this quarry, the descriptions of it by Smith (1918) and Sherlock and Smith (1918) plus the photographs in Young (1990, p.20) give precise details that can be interpreted in the light of modern understanding. The gypsum was present as one unit, but this was broken into "pillars". The main gypsum reached 8 to 9 feet thick (2.44-2.74m) and dipped to the south-south-east. The description of the gypsum unit indicates that the lower part of the gypsum was composed of gypsum breccia, or nodular gypsum with an alabastrine matrix of coloured gypsum containing small amounts of mudstone. The upper part of the gypsum, up to 3 feet (0.91m) thick comprised white alabastrine gypsum with fine subvertical pale green veining. The "pillars" of gypsum are shown with a roughly bowl-shape section; the outer part of the bowl comprising "coarsestone" (probably nodular and brecciated gypsum with a marl matrix). The bowls are shown resting in "foulstone" (disturbed marl with subordinate gypsum) and separated by swallow holes (Smith, 1918, fig. 2).

From the descriptions it is suggested that the "pillars" of gypsum are of probable depositional origin and may be large developments of an essentially nodular facies. However, many of the features described indicate that they must, in part, have been formed by dissolution and the formation of gypsum karst features, similar to those seen in gypsum quarries in the Vale of Eden (Ryder and Cooper, 1993). Smith (1918) records that:

"The gypsum occurs as a series of "pillars" sometimes almost or quite in contact, but usually separated by "coarsestone" and "foulstone", the former consisting of more gypsum than marl, the latter of more marl than gypsum. These pillars are nearly circular in plan, except when they abut one against the other, when they may be roughly polygonal."

He then gives more details of the bowl-shaped nature of the pillars and their domed tops. He notes that the upper surfaces of the gypsum is rough and pinnacled and that frequent swallow holes occur at the junctions of the "pillars". He also records that glacial drift overlies the gypsum and fills up parts of the swallow holes between the "pillars". The description he presents could be interpreted as the isolation of "pillars" of gypsum caused by dissolution, initially along joints, or between large nodules, followed by more severe dissolution and the collapse of the overlying marl sequence or glacial sequence into the dissolution fissures. The photographs presented by Young (1990) also suggest the presence of wedges of overburden collapsed between "pillars" of monumental quality alabaster. Dissolution upwards from the base of the gypsum, as suggested by Firman and Dickson (1968) may also help to explain the shape of the "pillars", though some of the bowl shape is probably of depositional origin.

A further clue to the conclusion that much of the Chellaston gypsum had suffered dissolution comes from the mines that occur down dip. Although they are recorded as having "pillars" with "foulstone" between them, the "pillars" are noted as being much larger than those seen at the surface in the quarries (Sherlock and Smith, 1918). The inference from this is that the gypsum underground has undergone less dissolution than that at outcrop.

The Chellaston Gypsum was worked as a quarry. After removal of the overburden the rock was sawn vertically into 3-feet (0.9m) strips by machine-driven wire saws. The rock between the saw cuts was removed by a hydraulic jack exploiting the more or less horizontal divisional planes called "vents" and presumably corresponding approximately with the bedding. Bored holes, into which wedges and feathers were inserted, were also used to separate the gypsum blocks. The resultant blocks were approximately 3 feet (0.9m) thick, and up to 10-11 feet (3-3.4m) long with an average weight of around 2-3 tons. These were taken to Chellaston railway station for shipping, or were worked on the spot, with the broken stone being used for plaster (Sarjeant, 1962).

4.2. Woodlands Clay Pit [SK 384 303]

The east side of the Woodlands Clay Pit (also called Woodland Brickpits) was originally worked by monks for alabaster (Sherlock and Hollingworth, 1938) In more recent times, the main pit (Figures 1 & 2) was chiefly excavated for marl used in the manufacture of bricks. Initially it was worked by J. Stapleford of Woodlands, Chellaston, but later it was owned by Chellaston Minerals Ltd also of Chellaston. Gypsum was a by-product sold for plaster manufacture. It was obtained both from the floor of the workings and from the nodular gypsum beds in the marl sequence. The quarry was in existence in 1918 (Sherlock and Smith, 1918), was still working in 1938 (Sherlock and Hollingworth, 1938) and in 1965 (Sarjeant, 1965). Sherlock and Smith (1918) noted that at the southern end of the pit, part of the workings of the old Chellaston Plaster Mine were exposed, with the gypsiferous green marl forming the roof of the workings; the abandonment plans for the mines suggest that these workings belonged to Chellaston Mine mentioned above. The quarry is now overgrown (Oral Communication, Dr A Brandon), but lithological details are given by Sherlock and Smith (1918), Sherlock and Hollingworth (1938) and Sarjeant (1965). By combining their descriptions the following composite sequence is derived:

Glacial till (boulder clay) 6-14 feet	1.8-4.4m
Red marl with gypsum nodules and lenses at four horizons, with isolated masses scattered throughout the sequence which was 30 ft (9.14m) thick. The horizon 20 feet (6.09m) below the top was almost continuous and varied between 6 inches and 1 ft (0.15-0.3m) thick. The masses of gypsum extended along the bedding planes for up to 10 feet (3.04m) and balls or large gypsum nodules up to 2ft 6ins (0.86m) of relatively pure gypsum were also present.	9.14m
Red and green marl, gypsiferous green marl and cakes of gypsum (nodular gypsum) 3 ft. (forming the roof in the mine exposed at the southern end of the workings).	0.91m
Gypsum, with patches of red and green marl. (This is the main seam, but few details are given).	2.74-3.05m

It is also noted by Sherlock and Hollingworth (1938) that anhydrite was present in the centres of some of the gypsum nodules.

4.3. Aston Brickyard, Aston-on-Trent [SK 414 306]

Aston Brickyard (Figure 3) was commenced in about 1931 and worked by the Derby Brick Company, Rowdich, Derby, for clay to make bricks; gypsum was largely a by-product. Sherlock and Hollingworth (1938), Sherlock (unpublished field notebook 3, p.143) and Sarjeant (1962) gave descriptions for the quarry. Sherlock and Hollingworth (1938) gave the following description:

"The working face at the time of our visit was about 30ft. [9.1m] deep to the main floor. The section shows red marl with thin bands of green marl. Thse show puckerings as if small faults were about to develop, but actual faults do not occur. There is a very slight easterly dip on the whole, but the puckered green beds which are about 12ft. [3.66m] apart, form a syncline in the middle of the face, two green bands being continuous round the quarry while a third, and uppermost, band appears in the synclinal part only.

Cakes of gypsum with hummocky surfaces appear about 3ft. [0.9m] above, and another layer of cakes immediately above the floor. It is expected that these two layers will be found to unite into one thick seam when the face has been worked back a short distance. Some of the gypsum shows a green banding.

A large hole in the floor, about 7 ft. [2.1m] deep has yielded a large `self' lump of gypsum"

In addition to these observations Sarjeant (1962) noted that a 4-5 foot (1.22-1.52m) seam of gypsum was reported some 25 to 30 feet (7.6-9.1m) below the quarry. However, the gypsum here was of indifferent quality, with frequent pockets of "foulstone"; it did not prove economic and was abandoned. In the late 1930's gypsum was mined on this site and when Sarjeant visited it in 1964/5 two adits were visible in the workings. Both the adits entered the ground at an angle of about 35 degrees. One had collapsed, and the other was open for a distance of about 9m. No indication of position or orientation is given for the openings (Sarjeant, 1965), however, the abandonment plan (record 4656) for Aston Holme Mine shows one adit located in about the middle of the brick pit [SK 4138 3040] with an entrance direction to the south-west (Figure 3), but it is not clear which of Sarjeant's adits this is. Sarjeant's description of Aston Brickyard quarry does not give any details of the section that was exposed, but some details can be gleaned from the plates that accompany the paper. Plate 8 shows the "cauliflower-like" shape of a gypsum nodule 0.6m in diameter and Plates 7 and 11 show lenticular nodules of gypsum up to 3 metres or so in length. Plate 9 shows a section through much of the quarry; four principal gypsum nodule horizons/discontinuous beds can be seen and other nodules are also present. No accurate scale or measurements are presented, but the gypsum layers appear to be about one metre apart, and the face about 7-8m high.

5. DEVELOPMENT OF MINES

The history of gypsum working in the Chellaston area indicates that mining was carried on there for a considerable period of time. Abandonment plans of the mines were only required by statutory obligation after 1872 so many of the old workings remain uncharted. Furthermore, some of the abandonment plans show areas of sketchy information suggesting collapse of the workings before they could be surveyed. It must be stressed that mine workings are almost certainly more extensive than indicated on figures 2 & 3.

Because much of the Chellaston and Aston gypsum forms large nodular clusters, or pillars of gypsum separated by "foulstone" or collapsed material, the pattern of working which followed the good stone is essentially random. Consequently, the plans of the mines show no regular pattern, with the unworked areas left in the poor quality rock. An illustration of the type of mining pattern found in the area is shown in Figure 4, which is an extract from the plan for the Aston No 1 Mine showing the area around "The Duddles".

5.1. Chellaston Mine [SK 387 300].

Abandonment plans for Chellaston Mine were deposited on 27th December, 1878 (Abandoned Mine Plan 923, currently held by Derbyshire County Council Archives in Matlock). Apart from these plans there appears to be no documentary evidence about the geology of the mine.

The mine worked the gypsum from near the western outcrop of the stone, eastwards for about 300m with an extension to the north-east for about 150m along the northern side of Aston Lane [SK 3885 3013 to 3897 3020]. The western side of the mine was entered from four adits, but two shafts are also shown on the abandonment plan [SK 3872 3006] and [SK 3882 3009]. Another shaft to the south of the site [SK 3865 2980], and two further shafts close together at the north of the workings [SK 3861 3020] are shown (Figure 1) on the plan published by Smith (1918). On this the south-western limit of the workings is marked by a note "Sand Fault No Gypsum" suggesting that the workable gypsum finished at an area of dissolution or glacial deposits. This "fault" continues to the east-south-east on to the area of the Weston-on-Trent mine where it divides two sets of workings and is labelled "Dirt Fault".

5.2. Chellaston Glebe Mine [SK 3883 3022].

Chellaston Glebe Mine is listed as Abandoned Mine Plan 143 (currently held by Derbyshire County Council Archives in Matlock) deposited with the Ministry on 13th September 1874. No details of this mine are published.

The mine is situated to the north of Aston Lane and extends for about 180m from west to east [SK 3873 3022 to 3890 3021]. The plan also shows a shaft labelled "Parsons Pit" [SK 3882 3025], which is also indicated by Smith (1918) (reproduced here as Figure 1), but is shown as a depression suggesting that the shaft may have collapsed by the time of Smiths visit. In addition to the workings of Glebe Mine the plan indicates that the area lying immediately to the west of the mine and abutting Aston Lane contained old workings.

5.3 Aston Glebe, Aston No1, or California Mine [SK 390 300].

This mine has three names in the various records. In the abandoned mine records, and on the abandonment plan, it is listed as Aston No1; California (Abandoned Mine Plan 12751) Aston upon Trent; Chellaston, abandoned 8th January, 1937. The plan itself is labelled Aston No 1 Mine, Chellaston Gypsum Workings. Smith (1918) and Sherlock and Smith (1918) call it Aston Glebe or California Mine, Chellaston. In 1918 the mine was reported to be about 80 years old suggesting it was opened in about 1840 (Sherlock and Smith, 1918). However, note is also made of the fact that the mine was supposedly worked out in about 1870 suggesting an association with Chellaston or Chellaston Glebe mines which were abandoned at around that time. Firman (1984) recorded an opening date of 1835 for Aston Glebe Mine, a date that accords with Sherlock and Smith (1918). These records suggest that the mine probably produced both alabaster and gypsum for plaster manufacture.

The plan of the mine shows that it was extensive, covering an area that was about 650m from south to north [SK 3902 2967 to 3897 3033] and 700m from west to east [SK 3884 2986 to 3953 3012]. The eastern part of the mine called "The Duddles", is shown in Figure 4 and described separately below. In addition to the main workings a small separate area of extraction with its own shaft [SK 3917 3035] is indicated to the north-east of the main mine workings; the plan shows the workings here with the title "Crevy" on the areas of extraction. The main buildings and winding shaft for the mine were situated centrally at the western side of the workings [SK 3896 3001]. Five other shafts are also shown on various plans and maps relating to the mine (Figure 2). The plan also shows that there was a considerable belt of unworkable ground extending from The Duddles to the south-west limits of the mine.

The earliest description of the mine was made on October 10th 1889 by C. Fox-Stangways (unpublished field notebook 6, p.9). He described:

"Pegg's Mine 90 ft deep [27.4m]. Here and there are strong indications of a wash from the surface of clay and flints and rounded pebbles, ?a few of them from the Rhaetic. The washed clay contains cast matter of vegetable? Underground watercourse 9yds (8.3m) across filled with soft clay. At the works half a mile from here the gypsum is worn and rounded. Each mass near the outcrop is encased in a layer of plastic bluish clay 1½ in to 2 in [3.8-5cm] thick. The clay in contact with the gypsum is greyish white shading off to ordinary blue clay. The inner layer is fairly pure $CaCO_3$, but becomes more argillaceous outside. The blue and red marls contain much $CaCO_3$ and the grey part of the gypsum also contains it in an impure state. The clay is probably the insoluble part of the gypsum." In the same notebook [page 92] Fox-Strangways noted the "California Mine (Pegg & Co) information from the foreman. Shaft nearly 100 feet [30.5m] may be two or three feet less [0.6-0.9m less]. Gypsum varies from 7 ft to 12 ft [2.13-3.65m] thick never as much as 18 ft [5.49m- the thickness noted on one of the mine plans that he saw], several washouts, but no faults. At the adit near Aston gypsum about 6 ft [1.83m] thick. Was thickest at Parson's Pit"

In the description of the geology of the mine Sherlock and Smith (1918) drew comparison with the geology of the Chellaston Alabaster Quarry. They noted that the gypsum ranged in thickness from 4 to 10 feet (1.22-3.05m) and exceptionally reached 18 feet (5.49m). The best rock was chiefly near the top of the seam and formed masses up to 100 tons (6343kg) or more. It is described as being white, fairly translucent and of fine saccharoidal texture, with fibrous veins giving a watered appearance; pink and pinkish white varieties are also recorded. The best areas corresponded roughly to the pillars in the Chellaston Quarry. It is noted that the gypsum sometimes formed posts (beds) 6 inches (0.15m) to 2-3 feet (0.6-0.91m) thick separated by marl or stratified loam (sandy marl?). The mine was worked on a pillar and stall system with the inferior marly rock being left as the pillars. The floor of the mine was composed of hard marl with veins of gypsum (foulstone) which commonly rose up between the gypsum pillars. The roof of the mine comprised 1.5-2 feet (0.46-0.61m) of gypsiferous rock.

Smith (1918) noted that from Chellaston Quarry "in the direction of Woodlands and Aston Glebe the pillars occur closer and closer together, and increase in size and irregularity, until they form with the coarsestone a fairly continuous seam with a nearly unbroken cap". This description suggests that the gypsum seam at depth may be fairly continuous, but that dissolution of the gypsum, presumably along the joints, has caused it to be broken into isolated masses or pillars.

Towards the east of the workings about 20 chains (201m) east of the winding shaft, a slight break in the rocks, trending in a NNW direction was named the "Crevvy". This admitted water into the workings which had a solvent action on the smashed rock and gave trouble in the Duddle Workings. Consequently, a water gallery was cut through the main mine to drain it and a pump installed. No indication of any throw across the "Crevvy" is given and it may have been a fissure with dissolution along it, or a fault.

The mine was worked from a winding shaft near the crushing mills. Extraction was undertaken by the pillar and stall method, the floor was foulstone (hard marl with veins of gypsum) and the roof of 1-2ft (0.3-0.61m) of gypsiferous rock. It was supported by the pillars which as far as possible were the poor quality rock occurring between the masses of alabastrine gypsum.

5.4. Duddle Plantation [SK 3944 3011]

Only passing reference is made to Duddle Plantation by Sherlock and Smith (1918) in their description of Aston Glebe or California Mine. They note that "For a period gypsum was mined separately at the Duddle Plantation" and the "outlying workings were approached by an incline". This indicates it was part of the same concern and it is included in the abandonment plan for Aston No 1 Mine. The description notes that a NNW trending break in the rocks known as the "Crevvy" gave trouble in the Duddle Workings and admitted water (see description of Aston Glebe Mine).

The plan for Aston No 1 Mine Chellaston (described above) includes "The Duddles" at the eastern end of the workings; a detail of this plan is shown in Figure 4. The eastern part of the mine was at one time entered by an adit in "The Duddles" [SK 3940 3013], but this is shown as disused on the plan and a shaft is also indicated [SK 3944 3008]. The pattern of working illustrated on the plan shows how the gypsum miners followed the best stone picking out a network of randomly orientated tunnels.

5.5. Weston-on-Trent [SK 3888 2968]

No details of this mine are published. It was abandoned in September 1877 and Abandoned Mine Plan 763 (currently held by Derbyshire County Council Archives in Matlock) was deposited on November 13th, 1877. The plan labels the mine as "Weston on Trent" and it has a note that it is situated in the Parish of Weston on Trent. The mine is situated at the northern edge of the Weston on Trent parish and forms part of the Chellaston area of mining abutting Aston No 1 Mine to the north-east and Chellaston Mine to the north-west (Figure 2). The mine access was via an adit [SK 3890 2952] heading a little east of north into a long tunnel for 150m curving to the north-west, then north; presumably this cut was an exploratory tunnel hoping to intersect the gypsum. The first workings spread out over an area about 100m long [SK 3884 2969 to 3892 2967] and 25m wide. They are separated from further workings to the north by the "Dirt Fault" about 30m across and extending from west to east through the workings and into the "Sand Fault" at the southern side of the Chellaston Mine workings. This "fault" appears to be an area of dissolution and collapse, not a true fault. To the north of this belt the mineworkings have a note that they were 32 yards (29m) deep. The plan also records that the land to the west and north of the workings was owned by the Chellaston Mining Company.

5.6. Aston, Aston-upon-Trent [SK 4118 3019]

No description of this mine has been published; Abandoned Mine Plan 983 (Currently held by Derbyshire County Council Archives in Matlock) was deposited in May 1879. Apart from the plan there appears to be no documentary evidence about the geology of the mine.

The abandonment plan shows the mine to be a small working covering an irregular area about 50m across (Figure 3). It was approached by a tramway from the south-east corner of the field and entered by an adit heading in a north-west direction [SK 4121 3016]. The abandonment plan dated 6th April 1879 has a note that the mine was worked by John Stevens & Son.

5.7 Aston Holme, Aston-upon-Trent [SK 409 301]

No description of this mine has been published; the mine was abandoned in March, 1904 and Abandoned Mine Plan 4656 (currently held by Derbyshire County Council Archives in Matlock) was deposited on September 16th 1904. Apart from the plan there appears to be no documentary evidence for the geology of the mine.

This was the largest of the mines in the Aston-upon-Trent area and has undermined most of the higher parts of Aston Hill, it measured about 800m in a SW-NE direction and 400m from NW to SE. The mine was reached by an adit [SK 4138 3040], subsequently revealed in Aston Brickyard (Sarjeant, 1965, who noted there were two adits). Other access to the mine was via two adits on the south-eastern side of Aston Hill and five shafts distributed around the workings (Figure 3).

It was abandoned in 1904 because it was exhausted. The seam dips to the north-north-east at about 4 degrees, and it might have been expected that it would carry on down-dip, in which case water might have been expected as the limit to the workings. Grouting works for the Derby Spur interchange yielded information that suggests that the gypsum largely failed, probably due to dissolution, in a northerly direction to be replaced with collapsed material. If this is so it would explain why the workings were terminated where they were. It could also explain why pinnacles of partially dissolved gypsum and subsidence crown holes were encountered on the line of the Derby Southern By-Pass just to the north of Aston Hill.

On the north-west side of Aston Hill there is an elongate cut in the hill side [SK 4105 3046] labelled as an adit on the Primary Survey; there are also notes suggesting workings along the side of the hill. It was through these features that the primary surveyors drew the crop of the gypsum beds. From the mine and borehole information for the Derby By-Pass, the probable attitude of the gypsum sequence is sub-parallel to the hill-side with a north-north-east dip of about 4 degrees. The grouting boreholes proved that the seam is up to 7m thick and is generally present at a depth of around 12 to 15m in the vicinity of the interchange [SK 4095 3040]. The abandonment plans for the mine do not show any entrances on the north-west side of the hill, and the mineworkings are shown stoping before that area is reached. Several possible explanations occur for the excavations; they may be marl pits, they may relate to another gypsum mine, or some could possibly be natural collapse after gypsum dissolution.

5.8 Bellington Hill [SK 425 316]

Gypsum has been worked in a small outlier at Bellington Hill, 2km NNE of Aston-upon-Trent. Sherlock and Smith (1915) record that the outlier covered about 1.5 acres (0.6 hectares) and was formerly worked by quarrying and from an adit. Brandon (1996) noted that "Numerous degraded pits occur around the hill and at least one adit [SK 4246 3150] is known. The only exposure seen was in a cutting [SK 4246 3149] on the south-east side of the hill dug for the Tarmac aggregate sorting plant. Red mudstone contained numerous massive gypsum nodules up to c. 1m in size. A south-easterly facing dip slope [SK 4259 3091] in the floor of the Tarmac aggregate quarry was in red silty mudstone, with pale green mottling, containing abundant gypsum nodules up to 0.4m in size."

6. GEOLOGICAL HAZARDS ASSOCIATED WITH GYPSUM AND ABANDONED GYPSUM MINES

6.1. Abandoned quarries

No abandoned alabaster quarries are currently open, but the disused brickpits that remain may pose problems related to the stability of the quarry faces, especially as they weather and degrade. In this way, quarries may considerably enlarge in area and consideration should be given to maintaining a safe distance for development away from such faces.

Abandoned quarries, such as the old Chellaston Alabaster Quarry, that have been filled in can pose serious problems for development. Very few accurate records of quarries exist and very detailed site investigation should be undertaken to determine the positions of the abandoned quarries. The uncovering of a probably medieval tool in the 19th Century workings also suggests that many local small diggings for alabaster have been undertaken over a long period, and unrecorded cavities may be present throughout the area where gypsum is present near-surface.

6.2. Abandoned Mines

All the gypsum mine workings in the Chellaston and Aston-upon-Trent areas are shallow and could pose stability problems in two ways. If the workings have not completely collapsed, voids at shallow depths could exist. If the workings have collapsed, the foundered material may be of a much lower load-bearing strength than the unaffected areas remaining over the pillars. Consequently, differential settlement may occur and provision for such eventualities should be made. A further possibility related to old mine workings is that natural gypsum dissolution could continue within the workings thus destabilising areas in the future (Cooper. 1988).

The abandoned mine workings for Aston Holme Mine caused difficult ground conditions in the vicinity of the Derby Spur/Derby By-Pass interchange [SK 4095 3040]. The recorded mine workings for Aston Holme Mine just enter the area of the roadwork excavations, but other older workings were also a necessary consideration. After the excavations were commenced it became apparent that *natural* dissolution cavities were also a problem hereabouts. To stabilise the ground, a large grouting operation was undertaken involving more than 1600 boreholes and approximately 6000 tons of grout. A perimeter grout curtain was installed and the enclosed area drilled at approximately 3m centres. Approximately half of the grout volume went to grouting up the drill holes, the remainder to grouting cavities and mineworkings. Soft and voided ground was encountered at the level of the gypsum seam, at a depth of around 15m, but breccia pipe propagation was also suggested by the presence of cavities generally at depths of 5-7m, but in one instance as shallow as 2m. The grout used was a PFA/Sulphate-resistant cement mix; many of the holes took 4-5 tons of mix.

6.3. Caves and natural dissolution

The natural dissolution of gypsum can be rapid if sufficient water flow is present (James, Cooper & Holliday, 1981). The result is caves that can enlarge at a significant rate, become unstable and collapse (Cooper, 1986, 1995, Ryder & Cooper, 1993). Gypsum naturally forms a buried gypsum karst with caves, and examples of caves in the local sequence have been described from Fauld Mine about 20km to the west of Chellaston. Here Wynne (1906) described a "wash hole" 16 feet (4.9m) in diameter (Figure 4m plate X). He also gave the following description: "They are circular holes, varying in size, which run up through the stone and often up through the roof marl, into the softer overlying marl. Some of these holes are large and circular in form, and appear to have been formed by the "swirling" action of water. The cavities of wash-holes are usually empty. Other holes are found, consisting of long, narrow fissures filled with soft earth which lies above the marl-roof. These fissures are found when approaching any surface-depression, and require to be timbered." This description is identical to the gypsum cave features seen in the Permian gypsum of the Vale of Eden (Ryder and Cooper, 1993). Features indicating partially clay-filled caves and collapsed drift material from breccia pipes are also noted by C. Fox-Strangways (unpublished field notebook 6) for the mines at Chellaston described above. Subsidence features filled with collapsed drift material (till and sand and gravel) were also recorded at Aston Hill in the cuttings for the Derby Southern By-Pass.

The fact that gypsum dissolves rapidly in sufficient water flow means that its presence should be treated with caution in any engineering works. Along the line of the new Derby Southern By-Pass three cavities, up to 2m across and 2m deep, were broken into. These cavities appeared to have propagated from the main Tutbury Gypsum Bed which was proved at a depth of around 5m beneath mudstone and siltstone. The location of these cavities, down-dip of gypsum outcrops and mineworkings and on the side of the Trent Valley was in a position where water flow down-dip or fluctuations in the main water table may be postulated to have caused natural dissolution and generation of the cavities.

The presence of thin fibrous gypsum veins, beds and nodules throughout much of the Mercia Mudstone Group can also cause problems. The veins, beds and nodules may dissolve producing cavities, or promoting water flow. The associated Mercia Mudstone may become brecciated, collapse and produce ground conditions of low bearing-strength. Such conditions were encountered in the ground adjacent to the Ratcliffe-on-Soar Power Station, where the dissolution of gypsum layers was responsible for cavities up to 10cm which formed the escape route for water leaking from the cooling ponds (Seedhouse and Sanders, 1993).

6.4. Building in gypsiferous areas

Development in areas underlain by gypsum calls for careful site investigation and conservative foundation design to avoid problems associated with gypsum dissolution and collapse. If cavities are detected and it can be proved that there is a negligible groundwater flow through them, it might be feasible to grout them up with a sulphate-resistant grout. If water flow through the cavities is suspected it may be unwise to grout them since blocking the water flow may induce enhanced flow and accelerated gypsum dissolution around the sides of the grouted areas (Cooper, 1995). The chance of this happening can only be determined by careful site investigation and hydrogeological modelling.

Where gypsum is present in the bedrock, either as massive beds or as veins, it can be associated with sulphate-rich groundwater. This groundwater may remain local, or can migrate into adjacent drift deposits from which it may emanate as sulphate-rich springwater. Wherever sulphates and sulphate-rich groundwater are present they have the capability of harming concrete in contact with them. Precautions to prevent such damage must be considered (Forster *et al.*, 1995). This situation applies to much of the Mercia Mudstone Group, especially the more gypsiferous sequences.

The Mercia Mudstone Group has a reputation for being deeply weathered, having a low bearing-strength and requiring careful site investigation (Chandler, 1969; Bacciarelli, 1993). Much of this lack of strength and weathering may be attributed to the dissolution of gypsum in the near-surface strata, possibly to a depth of 30m (Elliot, 1961; Reeves, *et al.*, 1993). In these rocks caution should be exercised because engineering works, such as piling, may open channels for water ingress into the gypsiferous strata. If this happens, and there is a throughput of water, dissolution such as that detailed above for Ratcliffe-on-Soar Power Station (Seedhouse and Sanders, 1993) may occur.

Over both mined and unmined areas underlain by gypsum, ingress of water from leaking services or from surface water disposal can have an exacerbating effect on both the natural dissolution of the gypsum and the collapse of the overlying strata. Care should be taken to ensure that soakaways are not constructed in the area and that all surface water is piped away.

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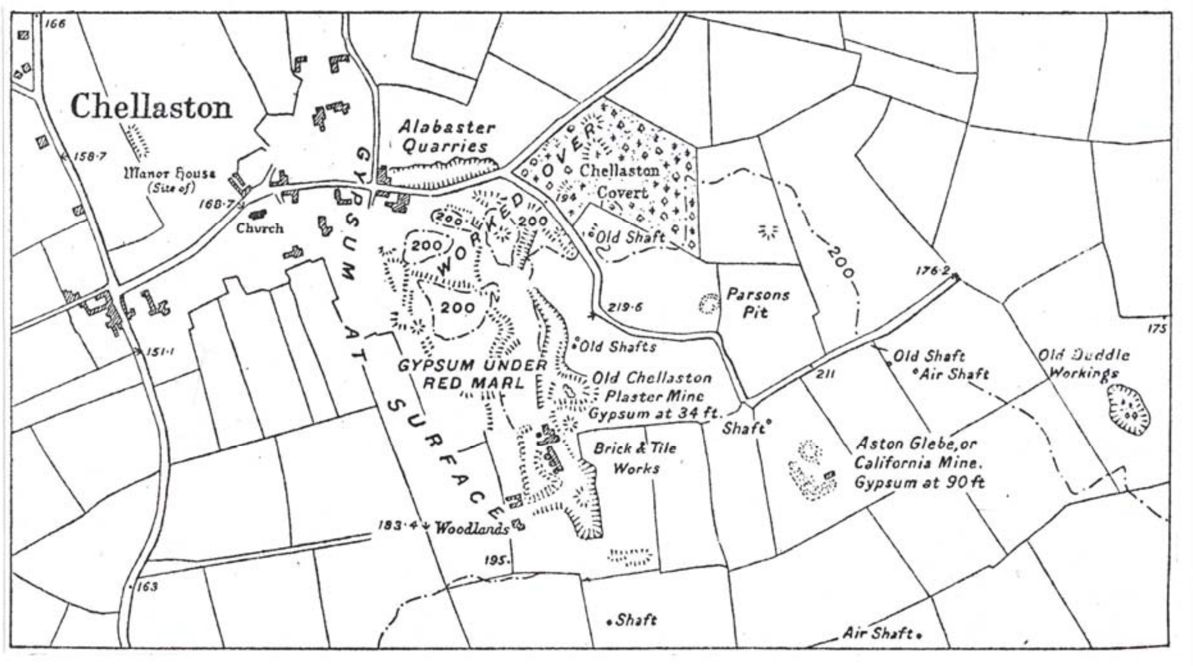

Figure 1. Topograpical map of the Chellaston area showing the localities of alabaster and gypsum workings (from Smith, 1918), enlarged to 1:10,000 scale.

Figure 2. Distribution of mine workings in the Chellaston area derived from abandonment plans; scale 1:10,000. Additional unrecorded mine workings, that pre-date 1872 when statutory recording of abandoned mines was introduced, are also present in the area.

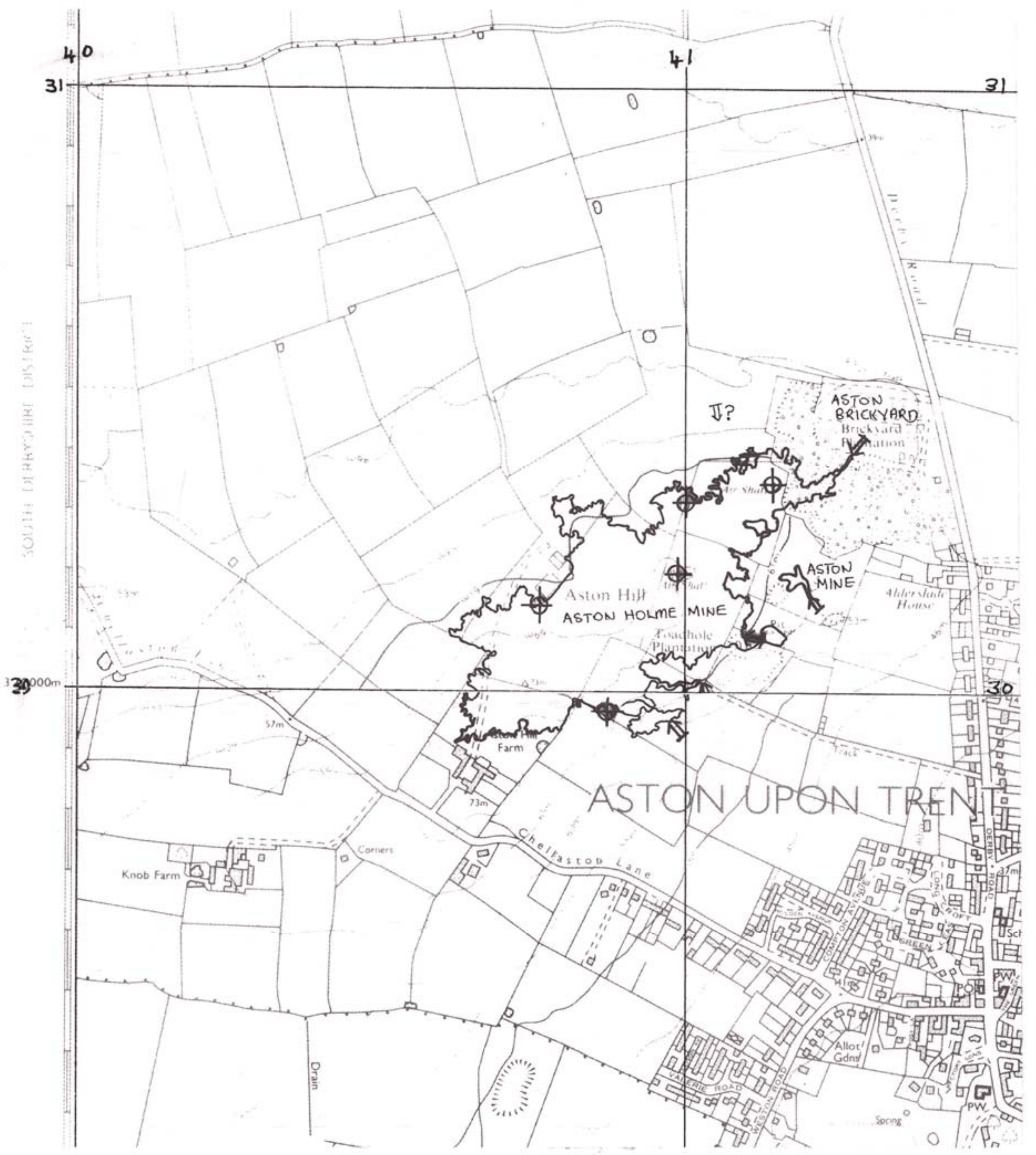

Figure 3. Distribution of mine workings in the Aston-on-Trent area derived from abandonment plans; scale 1:10,000. Additional unrecorded mine workings, that pre-date 1872 when statutory recording of abandoned mines was introduced, may also be present in the area.

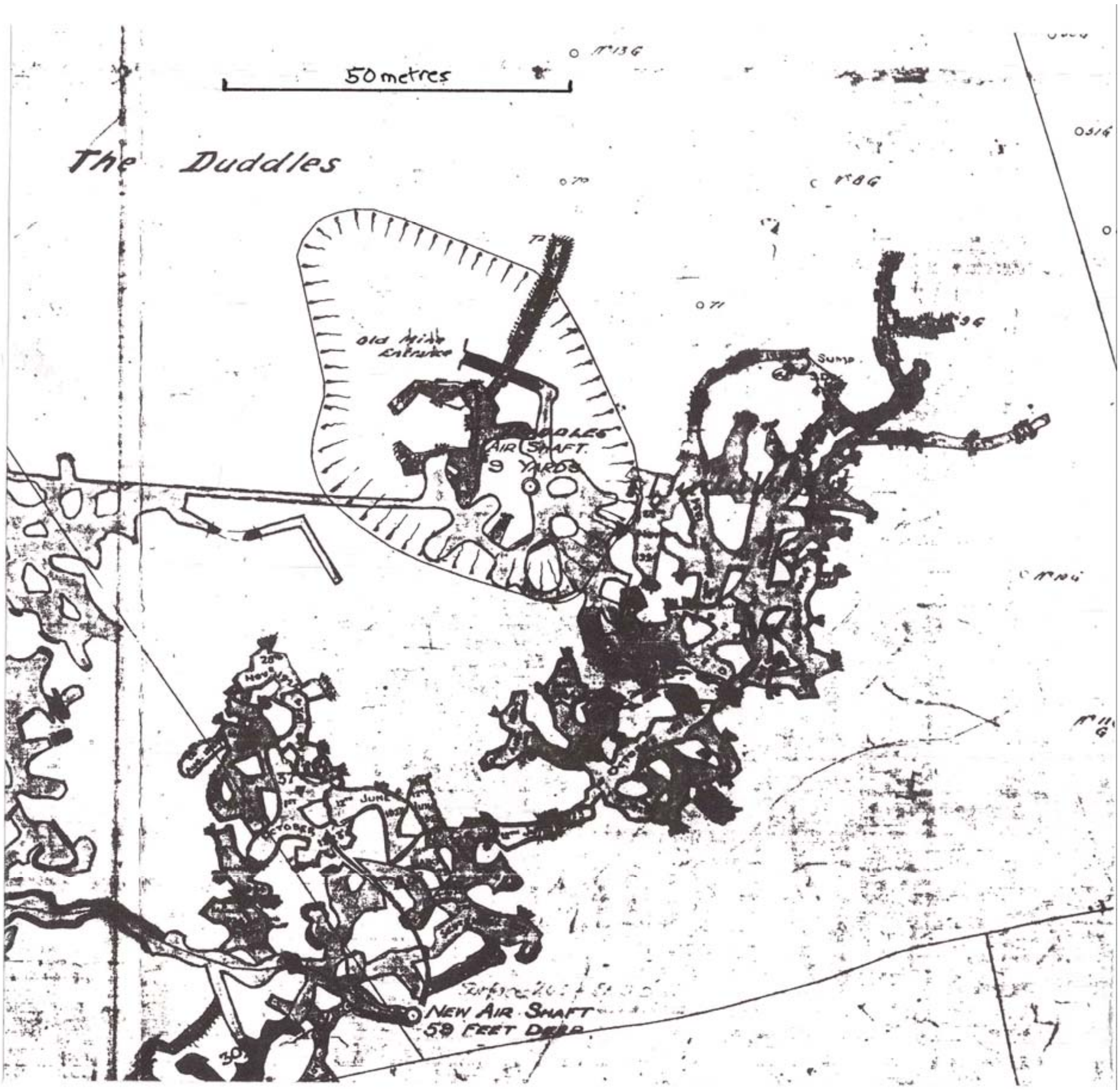

Figure 4. Detail of mine workings at "The Duddles" situated at the eastern limit of the Aston No 1 Mine; grid reference for shaft: [SK 3944 3009]. The plan illustrates the complex, near random, distribution of the workings as the miners chased the best stone and avoided the inferior material.